

# Illuminating oral health: a comprehensive Review of photodynamic therapy in dentistry

## Abstract:

Photodynamic therapy (PDT) is a promising non-invasive treatment in dentistry for managing microbial infections, oral malignancies, and periodontal diseases. It uses photosensitizers to generate reactive oxygen species, targeting and killing pathogenic microorganisms. Recent advancements in photosensitizing agents and light-delivery systems for dental applications evaluate their efficacy and limitations. PDT has clinical applications in endodontics, periodontics, and caries prevention, with comparative effectiveness with traditional treatments. However, limitations such as tissue penetration depth and photosensitizer specificity remain for further research. The article suggests potential advancements in light technology and photosensitizer formulations to enhance PDT's scope and effectiveness.

**Key-words:** Photodynamic Therapy, antimicrobial photodynamic therapy, oral pathogens, photosensitizers in dentistry, dental biofilm control, periodontal therapy

## Introduction:

### Definition and basic principles of photodynamic therapy:

Photodynamic therapy (PDT) is a non-invasive treatment that uses a photosensitizing agent, light, and molecular oxygen to produce reactive oxygen species (ROS). These ROS have potent antimicrobial and tissue-destructive effects, targeting cell death in pathogenic microorganisms or diseased tissues while minimizing damage to healthy structures. PDT's versatility, targeted action, and minimal adverse effects have led to increased interest in medical fields, including dentistry, for managing infections and enhancing tissue health.[1,2]

### History and development of photodynamic therapy in medical and dental fields:

PDT was first introduced in the early 20th century by Hermann von Tappeiner and Oscar Raab.[3] Its widespread application in medicine, particularly in dentistry, was driven by cancer therapy and dermatological treatments.[4] PDT targets microbial biofilms, a key factor in oral diseases like caries and periodontitis. With the discovery of more effective

photosensitizers and advanced light-delivery systems, PDT is now a growing adjunctive tool in dental care, offering innovative solutions for microbial management and tissue preservation.[5]

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### **Mechanism of action: interaction of photosensitizer, light, and oxygen:**

PDT is a method of treating pathogens in the body using a photosensitizer, light source, and oxygen.<sup>1</sup>It works by localizing the photosensitizer to target tissue or pathogenic microorganisms, absorbing energy from light and converting it into an excited state. This energy, when absorbed by oxygen, generates ROS and free radicals, damaging cellular components. This mechanism is particularly effective against resistant bacteria in dental applications, enhancing its therapeutic potential.[6]

### **Photosensitizers used in dentistry:**

Choosing the right photosensitizer is essential for PDT to produce the optimal attainable therapeutic results, especially in challenging oral environments where tissue structure and biofilms may restrict treatment penetration and efficacy.<sup>1</sup>ROS are chemicals known as photosensitizers that, when triggered by a certain wavelength of light, can cause cytotoxicity in pathogenic bacteria or abnormal tissues.[6] Methylene blue (MB), curcumin, and toluidine blue O (TBO) are some of the most widely used photosensitizers in dentistry, which have been evaluated for their effectiveness, safety, and compatibility with oral tissues.[7,8]

### **Types of photosensitizers:**

**Methylene Blue:** Because of its remarkable efficacy against a wide range of oral infections, especially in periodontal and endodontic applications, MB is a photosensitizer that has been extensively researched in dentistry.<sup>9</sup> Red light in the 630–660 nm range activates it, enabling improved tissue penetration and efficient ROS formation even in root canals and biofilms.[10]

### **Curcumin:**

Turmeric is the source of curcumin, a natural photosensitizer with anti-inflammatory and antibacterial qualities that make it particularly ideal for dental applications where low toxicity is of paramount importance.<sup>11</sup> It has demonstrated encouraging benefits in lowering bacterial counts in dental caries and periodontitis, and is usually triggered by blue light (400–450 nm).[12]

### **Toluidine Blue O:**

Similar to MB, TBO is a cationic dye that is activated by red light (630–660 nm). Because of its potent antibacterial properties, TBO has been utilized widely. It responds efficiently to break up biofilms and is frequently used in oral

surgery and periodontics to minimize infection in difficult to access areas.[13]

### **Properties of an ideal photosensitizer for dental applications:**

An ideal photosensitizer for dental PDT should exhibit selective uptake, minimal toxicity in the dark, generate high singlet oxygen or other ROS upon light activation, be water-soluble, and have high tissue penetration capabilities when activated by wavelengths suitable for oral tissues. This ensures the photosensitizer's efficacy in the oral cavity, where complex biofilms and deeper structures may impact its efficacy.[14]

### **Activation wavelengths and modes of delivery:**

The activation wavelength of a photosensitizer is crucial for its efficiency and depth of penetration. Red light is preferred for MB and TBO in dentistry due to superior tissue penetration, while blue light is effective for curcumin activation but has limited penetration depth.[15,16]

Photosensitizers can be delivered as topical gels or solutions, allowing precise localization in the oral cavity. In periodontal or endodontic treatments, irrigation systems or applicator tips can reach confined spaces.<sup>17</sup>Newer techniques explore nanocarrier systems to enhance photodetection efficacy in challenging areas.[18]

### **Mechanism of action in dental applications:**

PDT generates ROS, which are potent antimicrobial agents with cytotoxic effects on microbial cells and pathologically altered host tissues.<sup>6</sup> This makes PDT useful in managing dental diseases like periodontitis, caries, and root canal infections, as ROS can break down microbial cell walls, damage intracellular structures, and interfere with essential biochemical processes.[19]

### **Cellular targets in oral microorganisms and tissues:**

PDT targets bacterial cell walls, membranes, and intracellular components in the oral cavity. In gram-positive bacteria, photosensitizers can penetrate the thick peptidoglycan layer and reach the inner membrane, where ROS cause oxidative damage that disrupts cellular function. Gram-negative bacteria have resistance to photosensitizer penetration due to thinner peptidoglycan layers and outer lipopolysaccharide membrane.[20] However, various delivery strategies and photosensitizer modifications have improved their effectiveness in these bacteria.[21]

PDT is effective in biofilms, which are resistant to conventional antimicrobial therapies. It targets bacteria within protective structures and can target host tissues, making it beneficial for selective treatment of inflamed or diseased tissue while minimizing harm to healthy tissue. [22]

#### **Specific biochemical and microbiological effects:**

By inducing oxidative stress, which damages vital biomolecules in microbial cells and pathologically altered tissues, the ROS produced during PDT disrupt cellular function. Increased permeability and ultimately cell wall rupture, which can be toxic for bacteria, are caused by oxidation of membrane lipids. While oxidative DNA damage can stop microbial reproduction and cause some bacteria to undergo programmed cell death, damage to proteins affects vital enzyme processes.[2,6]

#### **Applications of photodynamic therapy in dentistry:**

##### **1. Periodontics:**

Periodontal disease, including gingivitis and periodontitis, is an inflammatory disorder caused by pathogenic microorganisms in subgingival biofilms. Traditional treatments include scaling and root planing, along with antimicrobial therapies.[23] However, challenges like bacterial resistance, complex biofilm structures, and limited access to deep periodontal pockets have led to interest in alternative therapies. PDT has emerged as an effective adjunctive treatment, offering a minimally invasive and targeted approach to manage microbial etiologies and inflammatory processes.[24]

PDT is a method used to reduce the microbial load in periodontal pockets by applying a photosensitizer, typically MB or TBO, to the area. This process, when activated by specific light wavelengths, produces ROS, which disrupt bacterial cell walls, damage components, and induce cell death, thus reducing the microbial load. PDT's antimicrobial effects also disrupt the biofilm matrix, protecting periodontal pathogens from host immune defenses and antibiotics.[25]

#### **PDT as an adjunct to scaling and root planing:**

PDT is a promising addition to scaling and root planning (SRP) to target residual bacteria that are not mechanically removed. Studies show that PDT can significantly reduce bacterial counts when used with SRP, leading to better clinical outcomes like reduced pocket depth, decreased bleeding on probing, and improved attachment levels.[26,27] Additionally, PDT's antimicrobial effects can reduce

inflammation by decreasing bacterial endotoxins that stimulate pro-inflammatory cytokines, which are key mediators of tissue destruction in periodontal disease.[25]

#### **Minimizing antibiotic use and addressing antibiotic resistance:**

PDT in periodontics offers a solution to antibiotic resistance by generating ROS through a photochemical mechanism. This non-specific effect destroys bacteria without relying on conventional antibiotics, making it effective against both antibiotic-sensitive and resistant strains. PDT is a sustainable approach to periodontal disease management, reducing the risk of resistance and providing a viable solution in an era where antibiotic stewardship is increasingly prioritized.[28]

#### **Host modulation and wound healing in periodontics:**

PDT, a type of antimicrobial, has shown positive effects on wound healing and tissue modulation in periodontics. It selectively damages inflamed or infected tissue, sparing healthy cells and promoting a controlled healing response. This selective cytotoxicity reduces inflammation and promotes tissue regeneration, improving treatment outcomes in severe periodontitis cases.<sup>29</sup> PDT also helps modulate the expression of pro-inflammatory cytokines and enzymes, such as matrix metalloproteinases (MMPs), thereby targeting infection and creating a more favorable environment for tissue repair and regeneration.[30]

PDT, a minimally invasive treatment for periodontitis, has shown promising results in terms of pocket depth reduction, attachment gain, and reduced bleeding.<sup>31</sup> Its minimally invasive nature and single-visit completion make it a popular choice. As technology advances, research is focused on optimizing PDT protocols and combining it with other therapies like lasers and biomodulatory agents.[32]

## **2**

### **2. Endodontics:**

Endodontic infections, caused by polymicrobial communities in root canal systems, are challenging due to the complexity of root canal anatomy, presence of biofilms, and limitations of conventional chemomechanical debridement methods. Traditional endodontic therapy uses mechanical instrumentation and chemical irrigation, but may not completely eradicate bacteria from hard-to-reach canal spaces, especially in apical and lateral canal areas.[33] PDT offers an efficient, minimally invasive approach for microbial control and enhanced disinfection within the root canal

system.[34]

Endodontic Photodisinfection involves introducing a photosensitizer like MB or TBO into the root canal system. This activates the canal's intricacies, generating ROS that can penetrate biofilms, disrupt microbial cell membranes, and damage intracellular structures.[35] PDT's antimicrobial action targets endodontic pathogens, including *Enterococcus faecalis* (*E. faecalis*), which is resistant to conventional disinfection methods and often causes persistent root canal infections.[36]

### **PDT as an adjunct to conventional root canal therapy:**

PDT is a promising adjunct to traditional root canal treatment (RCT) to reduce bacterial load and disrupt biofilms. Despite advancements in endodontics and irrigation solutions, residual bacteria may remain in the canal system. PDT can improve the success rate of root canal disinfection, reducing the risk of reinfection and post-treatment complications.[34]

### **Elimination of antibiotic resistance and bacterial persistence:**

PDT is a promising method in endodontics for combating antibiotic-resistant microorganisms without relying on traditional antimicrobial agents. Antibiotic-resistant strains, such as *E. faecalis*, are known to survive within the protected biofilm matrix in root canal systems, rendering conventional antimicrobial approaches less effective.<sup>35</sup> PDT produces ROS which bypasses bacterial resistance pathways, making it effective against both antibiotic-sensitive and resistant strains. PDT's non-specific oxidative mechanism reduces bacterial regrowth and persistence, improving long-term endodontic treatment outcomes without contributing to antibiotic resistance.[36]

### **Enhanced efficacy against endodontic biofilms:**

Endodontic biofilms are challenging to eradicate due to their dense extracellular matrix and resistance to disinfectants.<sup>37</sup> PDT has shown success in breaking down biofilm structures and killing bacteria, even in challenging root canal anatomies. The generated ROS allow deeper penetration of antimicrobial agents, especially in lateral canals and isthmuses. Integrating PDT enhances root canal treatment success.[38]

### **Impact on periapical healing and post-treatment success:**

PDT, when used in conjunction with RCT, can enhance periapical healing by reducing bacterial endotoxins and inflammatory mediators associated with persistent infections.

This results in improved tissue regeneration, decreased pain and inflammation, and higher patient satisfaction, ultimately leading to long-term treatment success.[35]

PDT in endodontics is expected to improve clinical outcomes by optimizing protocols, refining photosensitizer formulations, enhancing light-delivery systems, and determining optimal dosages and exposure times.[39]

### **3. Oral surgery and oncology:**

PDT is a promising treatment for oral surgery and oncology due to its targeted cytotoxic effects, minimal invasiveness, and reduced systemic side effects. It can manage infections, promote wound healing, and reduce complications in oral surgery.[40] In oncology, PDT targets diseased cells and infected tissues through ROS production through light-activated photosensitizers.[41]

### **PDT in oral surgery for infection control and enhanced healing:**

Postoperative infections in oral surgery can significantly affect patient recovery. PDT can reduce bacterial load in surgical sites by producing ROS, which destroy pathogenic microorganisms.[22] PDT can improve wound healing in oral surgery by modulating inflammation and reducing bacterial endotoxins. It stimulates tissue repair by reducing inflammatory cytokines and supporting regeneration, making it a viable option for procedures like implant placements and bone graft surgeries.[42]

### **PDT in oral oncology: treatment of premalignant and malignant lesions:**

PDT is a promising treatment for oral squamous cell carcinoma (OSCC), a common form of oral cancer. Traditional treatments like surgery, radiation, and chemotherapy can be invasive and cause damage to healthy tissues.[43] PDT uses photosensitizers that accumulate in cancerous tissues to generate ROS that damage cancer cells through cell membrane disruption, protein oxidation, and DNA fragmentation.[44]

PDT is effective in controlling premalignant lesions like leukoplakia and erythroplakia, preventing malignancy progression. It targets abnormal cells while preserving normal tissues, controlling dysplastic changes with fewer side effects and reducing lesion recurrence.[45,46] PDT is used as a primary treatment in early-stage OSCC, or as an adjunctive therapy to reduce tumor mass before surgery or improve chemotherapy and radiation efficacy.[43]

PDT in oral surgery and oncology lies in improving precision and efficacy through improved photosensitizers and light-delivery systems. Researchers are exploring nanoparticles for targeted drug delivery and combining PDT with immunotherapy and chemotherapy for better outcomes in aggressive oral cancer treatment.[47]

#### **4. Restorative dentistry:**

PDT is a valuable tool in restorative dentistry, helping manage bacterial contamination, enhance caries treatment, and improve bonding protocols. Its targeted antimicrobial action reduces microbial load in cavity preparations and dental restorations, enhancing treatment success and preserving the longevity of restorations.[48,49]

#### **PDT in caries treatment and cavity disinfection:**

PDT is a key tool in restorative dentistry for treating dental caries.[48] Traditional methods, like mechanical excavation, can leave residual bacteria in dentinal tubules and inaccessible areas, causing recurrent decay and compromising restoration success.[50] PDT uses activated photosensitizers to generate reactive ROS that penetrate deep into dentinal tubules, killing bacteria not accessible through traditional methods.[51]

Photosensitizers like MB and TBO can be used to treat cavities before restorations, reducing bacterial load and enhancing restoration longevity. PDT's selectivity allows it to target carious dentin while preserving healthy tissue, making it useful in minimally invasive dentistry.[52]

#### **Enhancement of bonding in restorative procedures:**

The bond between tooth structure and restorative material is crucial in restorative dentistry. Bacterial contamination can compromise bonding strength, leading to leakage and restoration failure. PDT can enhance bonding efficacy by providing antimicrobial action before adhesive application, reducing secondary caries risk and restoration failure.[49]

PDT is a valuable tool in adhesive dentistry, especially in deep or subgingival restorations where traditional methods struggle to control moisture and microbial contamination. It improves bonding performance by maintaining a stable interface, extending the lifespan of resin-based composites and dental sealants, enhancing patient outcomes.[53]

#### **Application in managing crown margin disinfection:**

PDT is a valuable adjunct in restorative procedures for disinfecting crown margins, especially in cases of gingival

inflammation or biofilm accumulation. It helps control bacterial load, contributes to healthier tissue, and minimizes periodontal complications, making it a valuable tool for restoration success.[54]

The future of PDT in restorative dentistry involves refining photosensitizer formulations and improving light-delivery systems for complex cavities and deep restorations. Research on photosensitizers targeting specific pathogens and innovations like fiber-optic light delivery systems and lasers will expand PDT's versatility and efficacy.[55]

#### **5. Prosthodontics:**

Prosthodontics, a dental specialty focusing on tooth restoration, faces challenges in microbial control, tissue health, and prosthetic complications. PDT, with its minimally invasive, targeted antimicrobial properties, has shown potential in improving patient outcomes by managing infections, enhancing tissue health, and preventing prosthetic complications.[4]

#### **PDT in peri-implantitis management:**

PDT is a significant treatment for peri-implantitis, an inflammatory condition affecting dental implants. Traditional treatments like mechanical debridement and chemical disinfectants are ineffective due to implant anatomy and biofilms. PDT uses photosensitizers like MB or TBO to target pathogens, producing ROS that disrupt microbial cell walls and biofilm structures around the implant surface.[56]

PDT significantly reduces microbial load around implants, including bacteria like *Porphyromonas gingivalis* (P gingivalis) and *Fusobacterium nucleatum* (F nucleatum) which can penetrate and disrupt biofilms, controlling infection without damaging healthy tissues. It also reduces inflammation, modulates immune responses, and supports implant stability, making it an essential treatment adjunct.[57]

#### **Denture-related infections and stomatitis management:**

Denture stomatitis, a common inflammatory condition, is often linked to *Candida* species colonizing the denture surface and mucosa. Traditional treatments, like antifungal medications, can lead to microbial resistance and have limited biofilm eradication.[58] PDT offers an alternative method to disinfect denture surfaces, using light-activated photosensitizers to kill fungi and microorganisms within biofilms.

Periodic Denture Disinfection by PDT not only treats active infections but also serves as a preventive measure by regularly disinfecting dentures, enhancing oral health and reducing stomatitis recurrence. This method offers improved mucosal health, comfort, and fewer complications for immunocompromised patients and those susceptible to infections.[59]

#### **PDT in pre-prosthetic and mucosal tissue health:**

Prosthetic treatment relies on optimal tissue health, especially in soft tissue requiring conditioning before prosthetic placement. PDT can reduce bacterial load and modulate inflammation in areas requiring pre-prosthetic surgery or preparation, such as gingival tissues around abutments, creating a more favorable environment for prosthetic devices. PDT effectively treats inflamed or infected residual ridges and mucosal tissues before denture fabrication, enhancing mucosal health and improving fit and comfort. Its minimally invasive nature makes it ideal for patients unable to tolerate extensive surgical procedures, offering a conservative alternative for managing tissue health.[60]

#### **6. Orthodontics:**

PDT is a promising tool in orthodontics due to its antimicrobial and anti-inflammatory properties. It helps prevent demineralization, manage gingival inflammation, and prevent bacterial biofilm formation on appliances. Orthodontic treatment often involves long-term placement of brackets, wires, and other appliances, which can lead to plaque buildup, biofilm formation, and complications like white spot lesions and gingivitis.[61]

#### **Prevention of white spot lesions:**

White spot lesions in orthodontic treatment are a major issue due to plaque accumulation and demineralization around brackets and bands. Traditional methods like fluoride applications require patient compliance and may not fully prevent lesions. PDT offers an alternative approach by selectively targeting cariogenic bacteria, such as *Streptococcus mutans*, to manage bacterial buildup and prevent lesions.[62]

Photosensitizers like MB or TBO can be applied to teeth around orthodontic appliances, generating ROS that kill bacteria responsible for demineralization. This method reduces bacterial count without harming surrounding tissues, preserving enamel integrity. Integrating PDT into orthodontic

care protocols is a promising preventive measure against white spot lesions.[63]

#### **Control of gingival inflammation and gingivitis:**

Orthodontic appliances can cause plaque accumulation, leading to gingivitis and periodontal inflammation. PDT's anti-inflammatory properties can reduce inflammation and manage gingivitis. Photosensitizers can activate inflammation-prone areas, killing pathogens like *P. gingivalis* and *Aggregatibacter actinomycetemcomitans* (*A. actinomycetemcomitans*).[64,65]

PDT can be used as an adjunctive therapy for patients with persistent gingivitis or plaque control issues, especially those not tolerant of frequent mechanical cleaning or those with extensive orthodontic appliances.[62]

Research shows PDT can accelerate orthodontic tooth movement by modulating inflammation and promoting tissue remodeling. However, further studies are needed to establish standardized protocols and verify long-term effects. PDT offers a minimally invasive solution for caries prevention, gingivitis control, and biofilm management.[66]

#### **Clinical protocols for PDT in dentistry Typical procedures, dosages, and irradiation protocols:**

PDT is a standard dental procedure that involves applying a photosensitizer to the target tissue or biofilm, followed by exposure to a light source, typically lasers or LEDs, at wavelengths matching the photosensitizer's absorption spectrum. Dosages vary based on the clinical indication, with irradiance ranging between 50-150 mW/cm<sup>2</sup> and energy density between 5-200 J/cm<sup>2</sup>. Treatment time ranges from 30 seconds to 2 minutes per site, with multiple sessions often required for optimal results. Light can be delivered using fiber optics, hand-held LED devices, or laser probes, with care to ensure even exposure.[4]

#### **Considerations for patient safety and comfort**

PDT is a safe and non-invasive procedure that requires local anesthesia for deep tissue procedures like root canal therapy. To prevent excessive tissue heating, it's crucial to monitor the light source's power output and exposure time. Protective eyewear is also necessary for both patients and clinicians to prevent accidental exposure to laser beams.

Clear communication about treatment steps, potential side effects, and expected outcomes is crucial for patient

compliance. Informed consent is essential to avoid allergic reactions to the photosensitizer. Clinical settings should offer appropriate follow-up to monitor treatment outcomes and address post-procedure discomfort. These individualized protocols optimize therapeutic outcomes while minimizing risks. Further research is ongoing to refine treatment parameters and explore new photosensitizers.[67]

#### **Efficacy and limitations of PDT in dentistry:**

Clinical trials show PDT reduces bacterial load, enhances tissue healing, and decreases inflammation without the drawbacks of systemic antibiotics or invasive surgery. However, its effectiveness depends on photosensitizer concentration, irradiation parameters, and the specific dental condition being treated. Further research is needed to standardize protocols and validate long-term outcomes.[5]

#### **Evidence from clinical trials and comparison with traditional treatments:**

PDT has been shown to be effective in periodontal therapy, reducing inflammation and bacterial colonies, and achieving comparable bacterial reduction to sodium hypochlorite irrigation in endodontic treatments.[68] However, traditional antimicrobial agents like chlorhexidine are still widely used due to their cost-effectiveness and ease of application. PDT also offers tissue preservation and reduced postoperative complications in surgical interventions, but its antibacterial efficacy may not always be as consistent as mechanical debridement, especially in cases of deep infections or complex anatomical sites. Traditional antimicrobial agents like chlorhexidine remain widely used due to their cost-effectiveness and ease of application.[69]

#### **Limitations, challenges, and side effects:**

PDT, a non-invasive method with minimal side effects, faces challenges in widespread adoption. These include the need for protocol optimization, variations in photosensitizer type, light dose, and tissue absorption, and its ineffectiveness against highly resistant bacterial biofilms. Additionally, light penetration is a constraint for deep infections, necessitating precise light delivery techniques.

#### **Challenges and future perspectives of PDT in dentistry**

PDT has several advantages but faces limitations due to shallow light penetration, making it difficult to treat deep infections or complex anatomical structures.[1] The use of visible light, particularly in red and blue wavelengths, can

only penetrate a few millimeters into soft tissues. Selecting the right photosensitizer for different dental conditions is also challenging due to varying absorption spectrum, tissue affinity, and antimicrobial activity. Additionally, the variability in protocols across studies makes it difficult to establish standardized treatment guidelines.[70]

#### **Innovations in photosensitizer technology and light delivery systems:**

Recent advancements in photosensitizer technology aim to enhance the effectiveness and versatility of PDT. Nanoparticle-based photosensitizers are being developed to improve tissue penetration and staining, while second-generation photosensitizers with higher singlet oxygen yield and photostability are being explored. Targeted delivery systems, like liposomes or biopolymer-based carriers, offer increased specificity and controlled release at the treatment site.[71]

New intraoral devices with fiber-optic or LED arrays are improving the precision and accessibility of PDT, enabling efficient light delivery to hard-to-reach areas like periodontal pockets or root canals. Wireless LED devices are also being developed for patient comfort and simplifying the application process. Research into infrared lasers and upconversion nanoparticles is ongoing to explore deeper tissue penetration.[4,55]

#### **Future potential in targeted and personalized dental care:**

PDT in dentistry can be improved by integrating it with personalized and targeted care. As dental diagnostics advance, PDT can be tailored to individual patients based on microbial profiles, tissue characteristics, and treatment needs. Personalized photosensitizers targeting specific bacterial strains or inflammatory markers can enhance PDT's precision.[72] Combining PDT with other modalities like low level laser therapy (LLT) or probiotics can optimize patient outcomes and provide holistic care.[73]

#### **Conclusion:**

PDT is a promising tool in dentistry, offering a minimally invasive, effective, and patient-friendly approach to managing oral diseases. It selectively targets pathogenic microorganisms and diseased tissues while preserving healthy structures, making it an appealing adjunct to traditional therapies. PDT addresses challenges like tissue trauma, postoperative complications, and antimicrobial

resistance. It is effective across various dental applications, including periodontal disease, peri-implantitis, endodontic infections, and oral mucosal conditions. PDT's benefits extend beyond microbial eradication, contributing to improved patient outcomes and recovery. Faster healing times, reduced reliance on antibiotics, and lower risks of adverse effects make it suitable for chronic conditions and patients with systemic health concerns. Innovations in photosensitizer technology and light delivery systems are enhancing PDT's potential, while personalized applications and preventive care strategies are likely to increase its relevance in future dental practice. PDT represents a significant advancement in modern dentistry, aligning with the broader movement towards minimally invasive and patient-centered care.

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