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Review Article

# Advancing dental implantology with phototherapy: A comparative review of photobiomodulation and photodynamic therapies

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ABSTRACT

This review examines the roles of phototherapy such as Photobiomodulation Therapy (PBMT) and Photodynamic Therapy (PDT) in the field of implantology, assessing their benefits, limitations, and clinical applications. PBMT has emerged as a promising adjunctive treatment, offering benefits such as enhanced tissue healing, improved implant stability, and reduced postoperative discomfort through stimulation of cellular processes. However, inconsistencies in treatment protocols and the need for more comprehensive long-term studies underscore the need for standardized approaches. PDT, on the other hand, shows efficacy in managing peri-implantitis by targeting bacterial infections with photosensitizers and light. Despite its potential, challenges such as incomplete bacterial eradication suggest a need for further refinement and integration with mechanical debridement. The review highlights the necessity for developing standardized treatment protocols, conducting extended research, and exploring combination therapies to optimize the application of PBMT and PDT in implantology. Future investigations should focus on these areas to enhance clinical outcomes and establish best practices in implant therapy.



## 1. Introduction

Light plays a crucial role in biological systems, influencing processes like sleep–wake cycles, circadian rhythms, and vitamin absorption. Building on this foundation, our research aims to explore the application of high-powered light at specific wavelengths in biology. This investigation opens up new perspectives on its use for healing, cell protection, and tissue engineering. Phototherapy refers to the therapeutic use of specific wavelengths of light to treat medical and dental conditions by stimulating cellular processes. In dentistry, phototherapy plays a crucial role across various specialties, including oral surgery, endodontics, periodontics, orthodontics, and implantology. By reducing inflammation, promoting tissue regeneration, and managing pain, it provides a non-invasive and effective treatment option. The branches of phototherapy in dentistry include Photobiomodulation therapy (PBMT) and photodynamic therapy (PDT). PBMT is widely used for pain relief and wound healing while PDT combines light with photosensitizers to eliminate harmful bacteria and cells, proving useful in periodontal and endodontic treatments. In prosthodontics, phototherapy is particularly valuable for managing mucosal lesions, alleviating pain from prosthetic fittings, and enhancing healing around dental implants. It supports better treatment outcomes by accelerating tissue repair and minimizing recovery time, making it a vital tool in modern dental care.[1]

## 2. Discussion

### 2.1. *Photobiomodulation therapy*

Photobiomodulation (PBM), also known as low-level laser therapy (LLLT), is a non-invasive treatment that utilizes low-intensity light to relieve pain, reduce inflammation, and

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promote tissue healing. This technique is widely employed in dentistry as an adjunct therapy for various hard and soft tissue procedures. PBM has gained attention for its potential in immune regulation, particularly during the COVID-19 pandemic, where it was explored for modulating cytokine storms through T cells and macrophages, affecting cytokines like IL-1b, IL-2, IL-6, IL-8, IL-10, IL-12, IFN-g, and TNF.[2]

One of the most intriguing aspects of PBM is its impact on stem cells and progenitor cells. By enhancing the differentiation and proliferation of these cells, PBM contributes significantly to tissue repair and regeneration. Research has shown that PBM can stimulate various types of stem cells, including gingival fibroblasts, dental pulp stem cells, and mesenchymal stem cells derived from bone marrow or adipose tissue. The therapy promotes increased collagen production, enhanced mitotic activity of epithelial cells, and fibroblast proliferation.

PBM's influence on cells extends to its anti-inflammatory actions, which are mediated by stimulating lymphocytes and mast cells. This stimulation leads to changes in capillary hydrostatic pressure, resulting in edema absorption and the elimination of intermediary metabolites. Additionally, PBM produces an analgesic effect by inhibiting nociceptive signals, which helps alleviate pain.

The mechanism behind PBM involves photochemical reactions within target cells. Mitochondria, which contain chromophores, absorb photons from the light, leading to increased production of molecules such as nitric oxide (NO), ATP, calcium ions, and reactive oxygen species (ROS). The regulation of ROS is crucial for maintaining signaling pathways that govern stem cell development and proliferation. PBM also enhances bone healing by accelerating the differentiation of stem cells into osteoblasts and improving calcium transport during bone formation.[3,4]

Photobiomodulation therapy (PBMT) is used in dentistry for pain relief, reducing inflammation, and promoting tissue healing. It enhances stem cell proliferation, collagen production, and accelerates bone regeneration. Additionally, PBMT supports immune modulation and is effective in treating peri-implantitis and enhancing post-surgical recovery.[5]

### 2.2. *Photodynamic therapy*

Photodynamic therapy (PDT) is a non-invasive treatment that leverages chemical agents called photosensitizers (PS), light of specific wavelengths, and oxygen to target and destroy unwanted cells, such as cancer cells in the oral cavity or pathogens in infections. The process involves exciting the photosensitizer with light, triggering photochemical reactions that produce reactive oxygen species (ROS), which are toxic to the targeted cells. Although the individual components (photosensitizer, light, and oxygen) are typically non-toxic on their own, their combination initiates a reaction that results in cell death.[6]

#### 2.2.1. *Photosensitizers (PS)*

Photosensitizers are special compounds activated by light to produce cytotoxic effects. Depending on the type of PS, they can be administered intravenously, orally, or applied topically to the treatment area. The PS requires activation by a specific wavelength of light to trigger the reaction needed to target unhealthy tissue. The structure of most PSs resembles chlorophyll or heme, and they can be classified into different generations based on their properties.

1. First-generation PSs: Developed in the 1970s and 1980s, these compounds include porphyrins and their derivatives. However, their limitations, such as poor solubility and phototoxicity, make them less suitable for current treatments. Photofrin® (hematoporphyrin) is the most extensively studied PS in this category, used for various cancers.
2. Second-generation PSs: These were developed to overcome the drawbacks of the first generation, offering better pharmacokinetic properties and lower toxicity. Compounds like verteporfin and talaporfin fall under this category. These PSs absorb light in the near-infrared range, enabling deeper tissue penetration and higher ROS production.
3. Third-generation PSs: The latest advancements in PS development involve conjugating second-generation PSs with biological molecules (e.g., antibodies, nanoparticles) to improve targeting and minimize side effects. These PSs are designed to be activated specifically at the disease site, ensuring precise treatment.

The ideal PS should be commercially available, cost-effective, easy to administer, selectively target unhealthy cells, have low toxicity, and be rapidly eliminated from the body. Although no PS meets all these criteria, ongoing research aims to develop improved compounds.

#### 2.2.2. *Light source*

The effectiveness of PDT relies on the proper choice of light, its delivery, and sufficient PS concentration in the presence of oxygen at the target site. Light in the 600-900 nm wavelength range is optimal for tissue penetration and activating the PS. Light sources used in PDT include:

1. Non-coherent light sources: These include sodium lamps and halogen lamps, which can cover large areas and are easy to use. However, their low intensity and poor dose control limit their use.
2. Lasers: These are more precise but complex, labor-intensive, and expensive. Various lasers like dye lasers and Nd/YAG lasers have been used.
3. LED-based systems: Emerging as a preferred option, LEDs are cost-effective, portable, and offer uniform

light distribution, making them a practical choice for PDT.

### 2.2.3. *Role of oxygen and reactive oxygen species (ROS)*

Oxygen plays a critical role in PDT, as the treatment's efficacy depends on generating ROS and singlet oxygen ($^1O_2$). The process begins with light activation of the PS, leading to photochemical reactions that produce these toxic species, which cause cell death. The specific molecular mechanisms involve transitions between excited and ground states of the PS, resulting in the formation of singlet or triplet oxygen.

PDT offers a promising therapeutic alternative with applications in oncology and infectious disease management, although challenges such as optimizing photosensitizers and light delivery methods remain. Ongoing research is essential to advance the field and enhance its clinical outcomes.[7–9] Table 1 highlights the key differences between Photobiomodulation (PBM) and Photodynamic Therapy (PDT), including their mechanisms, light sources, energy doses, and clinical applications.[2–9]

## 2.3. *Applications of photobiomodulation therapy (PBMT) in implantology*

Photobiomodulation therapy (PBMT) has become an essential adjunct in implantology due to its ability to enhance various aspects of the dental implant process. It accelerates osseointegration by stimulating osteoblast activity, promoting faster bone formation around the implant. PBMT also reduces post-surgical inflammation, minimizing swelling and discomfort, which contributes to a smoother recovery process. Additionally, its analgesic effects help manage post-operative pain, improving patient comfort. PBMT's ability to enhance wound healing accelerates soft tissue repair around the implant, contributing to better overall outcomes. It is also effective in treating peri-implantitis by reducing bacterial infections and promoting tissue regeneration without causing damage. By improving bone quality and decreasing the risk of post-operative complications, PBMT significantly reduces the chances of implant failure, making it a valuable tool in dental implantology.[10]

Mohajerani, Salehi, Tabeie, and Tabrizi investigated the impact of low-level light therapy (LLL) and light-emitting diode (LED) therapy on the implant stability quotient (ISQ).[11] Their study found that using both LLL and LED therapies concurrently led to improved implant stability at the 9-week follow-up compared to a control group that did not receive these therapies. They suggested that additional research is needed to validate the benefits of photobiomodulation therapy (PBMT) for implants.[11]

Reza and colleagues examined how PBMT influences wound healing and pain after implant surgery.[12] Their study involved placing 42 implants in 21 patients, and the findings indicated that PBMT accelerated wound healing and reduced postoperative pain following dental implant procedures.[12]

Matys and team performed a study where 40 implants were placed in the posterior mandible of 24 patients. Each implant received PBMT on the day before placement, immediately after placement, and at intervals of 2, 4, 7, and 14 days post-placement. The study reported that PBMT improved secondary implant stability and bone density. The authors noted the need for more controlled, long-term trials with larger sample sizes to confirm these findings.[13]

In contrast, a study by Kinalski, Agostini, Bergoli, and dos Santos assessed the effects of PBMT applied to the healed bone site before implant placement and after wound suturing. This study found no significant positive impact on implant stability from PBMT.[14]

The use of photobiomodulation therapy (PBMT) or low-level light therapy (LLL) in human clinical trials for improving dental implant success reveals a limited number of studies and a lack of long-term follow-up. Despite the small volume of research, the positive outcomes observed so far justify further in-depth investigation to firmly establish a correlation between PBMT and improved dental implant success.The variations in results are influenced by differing parameters and methodologies used in PBMT applications. To address this issue, it is essential to develop standardized PBMT operating protocols for its use as an adjunct in implant therapy.

## 2.4. *Application of photodynamic therapy (PDT) in implantology*

Peri-implantitis is a localized inflammatory condition affecting the bone and soft tissue surrounding dental implants, primarily caused by bacterial contamination and colonization on the implant surface. If left untreated, peri-implantitis can lead to implant failure and significant bone and tissue loss, adversely impacting patients' quality of life.[15] Traditional treatment methods focus on decontamination through physical, chemical, and mechanical means to remove bacteria from the infected area.[16] However, the precise amount of bacterial and non-bacterial residue that needs to be removed for stable, predictable outcomes post-treatment remains unclear.

Recent research by Dörtbudak et al. explored the efficacy of photodynamic therapy (PDT) in treating peri-implantitis caused by P. gingivalis, P. intermedia, and Aggregatibacter actinomycetemcomitans.[17] They utilized toluidine blue as a photosensitizer (PS) combined with diode laser irradiation on the implant surfaces of 15 patients with clinical and radiological signs of peri-implantitis. Microbiological samples were collected at baseline, post-treatment with toluidine blue alone, and following combined PDT with toluidine blue and laser irradiation at 690 nm. The study found significant reductions in P. intermedia and A.

**Table 1:** Highlighting the differences between Photobiomodulation (PBM) and Photodynamic Therapy (PDT)

| Aspect | Photobiomodulation (PBM) | Photodynamic Therapy (PDT) |
|---|---|---|
| **Mechanism** | Uses low-level laser or light to stimulate cellular processes, primarily interacting with mitochondria. | Combines light with a photosensitizing agent to generate reactive oxygen species (ROS), which destroy targeted cells. |
| **Primary Purpose** | Non-invasive, aimed at promoting tissue repair, reducing inflammation, and relieving pain. | Destructive, targeting and killing diseased cells or pathogens, such as in cancer therapy or infections. |
| **Photosensitizer Required** | No | Yes |
| **Cellular Effect** | Stimulates and enhances cell function, regeneration, and healing. | Destroys cells through oxidative damage. |
| **Thermal Damage** | No thermal damage; non-invasive and gentle. | May cause localized damage to targeted cells. |
| **Common Applications** | Wound healing, pain management, inflammation reduction, tissue regeneration. | Cancer treatment, bacterial infection treatment, periodontal therapy. |
| **Application in Dentistry** | Used for soft and hard tissue healing, pain relief, implant integration, and reducing inflammation. | Used for treating periodontal diseases, peri-implantitis, and bacterial infections. |
| **Type of Light Used** | Low-level laser or light therapy (LLLT), non-thermal wavelengths. | Light of specific wavelengths, typically in combination with a photosensitizer. |
| **Invasiveness** | Non-invasive | Minimally invasive, but can cause cell damage. |
| **Duration of Effect** | Long-term effects due to cellular stimulation. | Immediate destruction of targeted cells, followed by healing. |
| **Target** | Broad application, targeting healthy tissues to enhance function. | Specific targeting of diseased or abnormal cells for destruction. |

**Table 2:** Summarizes the key benefits and drawbacks of PBMT and PDT in implantology, highlighting their respective roles and limitations in clinical practice.

| Aspect | Photobiomodulation Therapy (PBMT) | Photodynamic Therapy (PDT) |
|---|---|---|
| Primary Function | Enhances tissue healing and reduces inflammation. | Targets and eliminates bacteria using a photosensitizer and light. |
| Mechanism of Action | Uses low-level laser or light to stimulate cellular activity and promote healing. | Combines a photosensitizer with light to produce reactive oxygen species that kill bacteria. |
| Effectiveness in Implant Success | Improves implant stability and bone density by enhancing soft tissue healing. | Reduces bacterial load and inflammation, which can help manage peri-implantitis. |
| Clinical Outcomes | Positive impact on tissue repair and implant stability, but results vary. | Effective in reducing bacterial load and inflammation, though complete bacterial eradication is challenging. |
| Standardization | Protocols are not yet fully standardized; results can vary based on parameters used. | Standardized protocols exist, but the efficacy can depend on the type of photosensitizer and light parameters. |
| Treatment Duration | Generally involves shorter sessions with multiple applications. | Treatment may involve longer sessions depending on the photosensitizer and light exposure. |
| Side Effects | Minimal side effects; generally well-tolerated. | Potential for local tissue irritation; sensitivity to light can occur. |
| Cost | Relatively low cost compared to PDT; equipment is less expensive. | Higher cost due to the need for photosensitizers and specialized equipment. |
| Applicability | Can be used as an adjunct to various implant procedures for improving outcomes. | Primarily used for managing peri-implantitis and related infections. |
| Research Evidence | Shows promising results but requires more long-term, well-controlled studies. | Evidence supports efficacy in reducing bacterial load but with mixed long-term outcomes. |
| Limitations | Effectiveness can be influenced by treatment parameters and patient variability. | Complete bacterial elimination is difficult; may need to be combined with mechanical debridement. |

actinomycetemcomitans with PS alone, though not for P. gingivalis. PDT using both the PS and laser light resulted in greater reductions in bacterial loads, including P. gingivalis, though complete bacterial eradication was not achieved.[17] The authors concluded that PDT showed promising results in treating peri-implantitis and suggested that combining PDT with mechanical debridement could be beneficial for managing peri-implantitis and peri-implant mucositis.[18]

However, these findings were recently contested by Esposito et al.[19] In their study involving 80 patients with peri-implantitis, 40 patients received conventional non-surgical or surgical treatment, while the remaining were treated with PDT. Over a 12-month period, success criteria included implant failures, recurrent peri-implantitis, implant complications, changes in peri-implant marginal bone levels (RAD), probing depth (PD) changes, and the number of retreatments. Results showed one implant failure in the PDT group compared to none in the control group, with complications arising in four PDT patients. Peri-implantitis recurrence occurred in six patients (three from each group), with 29 implants in the PDT group and 33 in the control group requiring retreatment. Despite stable peri-implant marginal bone levels and significant PD reduction in both groups, no significant differences were observed between the PDT and control groups.[19] Therefore, the authors concluded that PDT, when used alongside conventional mechanical cleaning, did not significantly enhance clinical outcomes. Table 2 provides a detailed comparison of the benefits and drawbacks of Photobiomodulation Therapy (PBMT) and Photodynamic Therapy (PDT) in implantology, highlighting their respective roles in clinical practice.[10–19]

## 3. Conclusion

This review underscores the growing interest in Photobiomodulation Therapy (PBMT) and Photodynamic Therapy (PDT) within implantology, revealing their respective benefits and limitations. PBMT has demonstrated potential in enhancing tissue healing and improving implant stability by stimulating cellular activity, though the variability in treatment protocols and the need for more long-term data highlight the necessity for standardized guidelines and further research. PDT has proven effective in reducing bacterial loads and managing peri-implantitis through the use of photosensitizers and light, yet challenges such as incomplete bacterial eradication suggest a need for additional refinement and integration with mechanical debridement. The future of these therapies lies in developing standardized protocols, conducting long-term studies, exploring combination therapies, and tailoring treatments to individual patient factors. This review provides a critical synthesis of current evidence and identifies key areas for future investigation, emphasizing the importance of continued research to optimize the application of PBMT and PDT in implantology and ultimately improve clinical outcomes.

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None.

## 5. Conflict of Interest

None.

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