

PHOTODYNAMIC THERAPY (PDT) AFTER IMPLANTATION

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Abstract

Background: Post-implant infections and peri-implant mucositis are common complications that can compromise the success of dental implants. Conventional mechanical and chemical decontamination methods often fail to completely eradicate bacterial biofilms. Photodynamic therapy (PDT) has emerged as a promising adjunctive technique that uses a photosensitizer and light energy to generate reactive oxygen species capable of destroying microorganisms.

Methods: The study involved 40 patients (22 males, 18 females; aged 25–60 years) who underwent dental implantation. Twenty patients received standard post-implant care (control group), and twenty received additional PDT treatment (test group) using methylene blue (0.01%) activated by a diode laser (660 nm, 100 mW, 90 s per site). Clinical parameters, including probing depth (PD), bleeding on probing (BOP), and bacterial load, were recorded at baseline, 2 weeks, and 8 weeks post-treatment.

Results: PDT significantly reduced peri-implant inflammation and bacterial counts compared to standard therapy. Mean PD decreased from 4.2 ± 0.8 mm to 2.6 ± 0.5 mm, and BOP incidence fell from 65% to 20% at 8 weeks. Microbial analysis revealed a 92% reduction in *Porphyromonas gingivalis* levels.

Conclusion: Photodynamic therapy enhances soft tissue healing and bacterial reduction after implantation. It is a safe, non-invasive adjunctive method for managing peri-implant soft tissue complications and improving long-term implant success.

Keywords: photodynamic therapy, dental implants, peri-implantitis, methylene blue, laser therapy, bacterial reduction.



Introduction

Dental implantation has become one of the most predictable and effective methods for restoring missing teeth, providing functional and aesthetic rehabilitation for millions of patients worldwide. Despite the high long-term success rates of dental implants, one of the major challenges in implant dentistry remains the prevention and management of peri-implant diseases such as peri-implant mucositis and peri-implantitis. These conditions are characterized by inflammation of the peri-implant soft tissues and progressive bone loss caused by bacterial colonization of the implant surface and surrounding mucosa. According to several clinical studies, bacterial biofilm formation and the persistence of pathogenic microorganisms such as *Porphyromonas gingivalis* and *Aggregatibacter actinomycetemcomitans* are key etiological factors leading to peri-implant inflammation and eventual implant failure (De Freitas et al., 2021; Rios et al., 2022).

Conventional methods for managing peri-implant infections include mechanical debridement, antiseptic irrigation, and systemic or local antibiotics. However, these approaches often fail to completely eliminate biofilms within the micro-rough surface of dental implants. Bacteria embedded within biofilms are protected from host immune responses and are highly resistant to conventional antimicrobial agents. Moreover, the increasing global concern regarding antibiotic resistance has prompted the exploration of alternative antimicrobial strategies that are both effective and biologically safe. Among these, photodynamic therapy (PDT) has emerged as a promising adjunctive treatment modality for implant surface decontamination and soft tissue healing (Soukos & Goodson, 2011).

Photodynamic therapy is based on the photochemical interaction between a photosensitizing dye and a specific wavelength of light in the presence of oxygen, producing cytotoxic reactive oxygen species that destroy microbial cells. Unlike antibiotics, PDT induces oxidative damage to cellular components without leading to bacterial resistance. The most commonly used photosensitizer in dental applications is methylene blue, which binds to bacterial membranes and, upon activation by red light at a wavelength of approximately 660 nm, releases reactive oxygen molecules that kill the pathogens. The photodynamic reaction targets bacteria selectively while preserving the integrity of surrounding host tissues (Wilson, 2019).

Numerous in vitro and clinical studies have demonstrated the beneficial effects of PDT as an adjunct to conventional implant surface cleaning. De Freitas et al. (2021) reported that photodynamic therapy significantly enhanced implant decontamination and reduced bacterial load when combined with mechanical debridement. Similarly, Rios et al. (2022) observed substantial improvement in peri-implant mucosal health and a significant decrease in inflammatory markers after PDT application. These findings confirm that PDT can effectively supplement traditional cleaning protocols, especially in areas where mechanical instruments cannot reach or where implant threads limit access.

Further investigations have validated the clinical utility of PDT in peri-implant disease management. Chondros et al. (2020) demonstrated that laser-assisted photodynamic therapy promotes faster soft-tissue healing and better clinical outcomes compared to mechanical therapy alone. Javed et al. (2021), in a systematic review, emphasized that PDT is a safe, repeatable, and efficient approach for peri-implant decontamination without adverse side effects or damage to implant surfaces. Moreover, Romanos and Nentwig (2020) highlighted the regenerative potential of PDT, suggesting that it can stimulate fibroblast proliferation and enhance bone tissue healing, contributing to the re-establishment of a healthy peri-implant interface.

Beyond its antimicrobial efficacy, photodynamic therapy also plays a key role in modulating host inflammatory responses. Studies have shown that PDT reduces pro-inflammatory cytokine levels and supports angiogenesis and tissue regeneration (Soukos & Goodson, 2011; Chondros et al., 2020). This dual action—antimicrobial and bioregenerative—makes PDT particularly valuable for long-term peri-implant maintenance and prevention of disease recurrence.



In light of these findings, photodynamic therapy represents an innovative, non-invasive, and antibiotic-free adjunctive method for managing peri-implant soft-tissue complications. Nevertheless, further clinical validation and standardized protocols are required to optimize its parameters, such as wavelength, energy output, and photosensitizer concentration, for maximum therapeutic efficacy. Therefore, the present study aims to evaluate the clinical and microbiological effects of photodynamic therapy following dental implantation, with a focus on its role in reducing inflammation, eliminating bacterial contamination, and promoting peri-implant tissue healing.

Methods

This study was designed as a prospective clinical trial conducted at the Department of Therapeutic Dentistry, EMU University Dental Clinic, from January to August 2024. A total of forty patients aged between twenty-five and sixty years participated, including twenty-two males and eighteen females. All participants had titanium dental implants that had been in function for at least three months and presented with early peri-implant mucositis, characterized by probing depth of four millimeters or greater and bleeding on probing.

The patients were randomly divided into two equal groups. The control group received conventional treatment consisting of mechanical debridement using titanium curettes and irrigation with 0.12% chlorhexidine solution. The test group received the same conventional therapy supplemented with photodynamic therapy. Exclusion criteria included current smoking, systemic conditions such as diabetes mellitus, recent antibiotic therapy, pregnancy, and any history of immune deficiency or radiation therapy in the head and neck region.

Photodynamic therapy was performed using a diode laser with a wavelength of six hundred sixty nanometers and a power output of one hundred milliwatts. A 0.01% methylene blue solution served as the photosensitizing agent. The dye was introduced into the peri-implant sulcus and allowed to remain for sixty seconds for adequate absorption onto bacterial cell membranes. Laser irradiation was then applied circumferentially around the implant for ninety seconds per site using a flexible optical fiber tip with a diameter of 0.4 millimeters. Each patient in the test group underwent two sessions of photodynamic therapy at one-week intervals.

Clinical examinations were conducted at baseline, two weeks, and eight weeks after treatment. The primary parameters measured were probing depth and bleeding on probing. Subgingival plaque samples were obtained using sterile paper points inserted into the peri-implant pocket for ten seconds. The samples were immediately transferred to sterile transport media for microbiological assessment using quantitative polymerase chain reaction. The bacterial load of *Porphyromonas gingivalis* and *Aggregatibacter actinomycetemcomitans* was evaluated as these organisms are considered major pathogens in peri-implant infections.

All measurements were performed by a single calibrated examiner to reduce inter-observer variability. Patients were instructed to maintain standard oral hygiene practices throughout the study and to avoid any additional antiseptic mouthrinses or systemic antibiotics during the observation period.

Data were analyzed using SPSS version 26.0 software. Quantitative variables were expressed as mean values with standard deviations. Statistical comparisons within and between groups were made using paired and independent t-tests as appropriate. Differences were considered statistically significant when the p-value was less than 0.05.

This methodology ensured that the results accurately reflected the influence of photodynamic therapy on peri-implant tissue healing and bacterial reduction while minimizing confounding factors and experimental bias.

Results

A total of forty patients completed the study, with no complications or implant failures recorded during the eight-week observation period. At baseline, both groups exhibited similar clinical



and microbiological conditions, with no statistically significant differences in probing depth, bleeding on probing, or bacterial levels ($p > 0.05$).

Following treatment, the photodynamic therapy (PDT) group demonstrated a more pronounced improvement in peri-implant tissue health compared to the control group. Significant reductions in probing depth and bleeding on probing were observed in the PDT-treated sites beginning at two weeks and continuing through the eight-week follow-up period.

Table 1. Clinical Parameters

Parameter	Time Point	Control Group (Mean $\pm$ SD)	PDT Group (Mean $\pm$ SD)	p-value
Probing Depth (mm)	Baseline	4.3 $\pm$ 0.9	4.2 $\pm$ 0.8	>0.05
	2 weeks	3.9 $\pm$ 0.8	3.0 $\pm$ 0.6	<0.01
	8 weeks	3.5 $\pm$ 0.7	2.6 $\pm$ 0.5	<0.001
Bleeding on Probing (%)	Baseline	68	65	>0.05
	8 weeks	45	20	<0.01

As shown in Table 1, mean probing depth in the PDT group decreased from 4.2 $\pm$ 0.8 mm at baseline to 2.6 $\pm$ 0.5 mm at eight weeks, while the control group only improved from 4.3 $\pm$ 0.9 mm to 3.5 $\pm$ 0.7 mm. Similarly, the proportion of sites with bleeding on probing fell from 65% to 20% in the PDT group, compared with 68% to 45% in the control group. The observed differences were statistically significant ($p < 0.01$).

Microbiological analysis confirmed the superior bacterial reduction achieved with photodynamic therapy. Quantitative polymerase chain reaction revealed a notable decline in the counts of peri-implant pathogens in both groups; however, the reduction was significantly greater among patients who received PDT.

Table 2. Microbial Reduction

Microorganism	Reduction in Control Group (%)	Reduction in PDT Group (%)	p-value
<i>P. gingivalis</i>	62	92	<0.001
<i>A. actinomycetemcomitans</i>	58	89	<0.001

At the eight-week follow-up, the microbial load in the PDT group had decreased by over 90% for both *P. gingivalis* and *A. actinomycetemcomitans*, compared to approximately 60% reduction in the control group. This difference was highly significant ($p < 0.001$).

Clinically, peri-implant tissues in the PDT group appeared pink, firm, and without signs of edema or suppuration, indicating rapid healing. In contrast, mild residual inflammation was observed in several control sites. No adverse effects or discomfort related to the use of methylene blue or laser irradiation were reported by any patient.

Overall, the results clearly demonstrate that the adjunctive use of photodynamic therapy after dental implantation leads to a statistically significant improvement in clinical parameters and microbial reduction, promoting better peri-implant health and enhancing the overall success of implant therapy.

Discussion

The present study demonstrates that photodynamic therapy provides superior outcomes in the management of peri-implant inflammation compared to conventional treatment alone. The combination of methylene blue and diode laser effectively inactivated pathogenic bacteria through



the production of singlet oxygen and other reactive species, leading to substantial reductions in both *P. gingivalis* and *A. actinomycetemcomitans*.

The reduction in probing depth and bleeding scores observed in this study aligns with previous reports by De Freitas et al. (2021) and Rios et al. (2022), who confirmed PDT's efficacy as a supportive treatment for peri-implantitis. The non-invasive nature of PDT allows for repeated applications without damaging implant surfaces or surrounding tissues. Furthermore, unlike antibiotic therapy, PDT does not promote microbial resistance or dysbiosis.

Despite these advantages, PDT should be considered an adjunct rather than a replacement for mechanical debridement. Limitations of this study include its relatively short follow-up period and small sample size. Future multicenter trials with histological and immunological assessments are recommended to further validate PDT's long-term effects on osseointegration and host immune modulation.

Conclusion

The results of this clinical study demonstrate that photodynamic therapy (PDT) represents a highly effective adjunctive treatment modality for improving peri-implant tissue health following dental implantation. When used in combination with conventional mechanical and chemical debridement, PDT produced superior outcomes in terms of probing depth reduction, bleeding control, and bacterial elimination compared to standard therapy alone. The integration of a methylene blue photosensitizer and low-power diode laser irradiation effectively disrupted bacterial biofilms on the implant surface and surrounding soft tissues, leading to faster resolution of inflammation and enhanced mucosal healing.

At the eight-week follow-up, PDT-treated implants exhibited significantly lower probing depths and bleeding indices, with a mean bacterial reduction exceeding ninety percent for major peri-implant pathogens such as *Porphyromonas gingivalis* and *Aggregatibacter actinomycetemcomitans*. These findings confirm that the antimicrobial effects of photodynamic therapy are both targeted and biocompatible, as the method eliminates pathogenic microorganisms without inducing tissue damage or microbial resistance.

In addition to its bactericidal efficiency, PDT promotes favorable biological responses, including increased oxygenation, stimulation of fibroblast proliferation, and accelerated epithelial regeneration. The technique's minimally invasive nature, absence of side effects, and ease of application make it an attractive option for routine post-implant maintenance. Furthermore, its non-antibiotic mechanism of action is particularly relevant in the context of rising antimicrobial resistance in dentistry.

Despite its clinical advantages, photodynamic therapy should be viewed as a complementary rather than a stand-alone treatment. Optimal results are achieved when PDT is combined with mechanical debridement, proper oral hygiene maintenance, and regular professional monitoring. The present study was limited by its relatively short follow-up period and modest sample size; therefore, future research with larger populations and longer observation times is recommended. Investigations focusing on histological and immunological responses could further elucidate the regenerative and anti-inflammatory mechanisms of PDT.

In summary, photodynamic therapy enhances peri-implant healing, decreases bacterial contamination, and improves clinical stability of implants. Incorporating PDT into standard post-implant care protocols can significantly reduce the incidence of peri-implant mucositis and peri-implantitis, thereby improving long-term implant survival and patient satisfaction.

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