Review Article

Peri-implant Diseases: Enhanced Antibacterial Photodynamic Therapy

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Abstract The extensive adoption of dental implants has greatly enhanced the functional and aesthetic rehabilitation of patients who are partially or completely edentulous. Nevertheless, the rising incidence of peri-implant diseases has become a significant clinical issue in the field of implant dentistry. Peri-implant mucositis and peri-implantitis are inflammatory disorders triggered by the accumulation of biofilm around dental implants, characterized by the progressive destruction of peri-implant tissues if not addressed. Traditional treatment methods, including mechanical debridement, antiseptic agents, and supplementary antibiotic therapy, frequently exhibit limited effectiveness due to the intricate surface morphology of implants and the resilience of dysbiotic biofilms. Antibacterial photodynamic therapy (aPDT) has been introduced as a non-invasive adjunctive treatment option that employs a photosensitizer activated by light of a specific wavelength to produce reactive oxygen species capable of selectively eliminating pathogenic microorganisms. Recent developments, particularly dual-light antibacterial photodynamic therapy that combines blue light and near-infrared light, have shown improved antimicrobial effectiveness and a notable decrease in inflammatory biomarkers. This review discusses the pathogenesis of peri-implant diseases, the limitations of conventional treatment approaches, the biological principles underlying aPDT, and the clinical evidence that supports the use of dual-light photodynamic therapy in the management and preservation of peri-implant health.

Keywords: Antibacterial photodynamic therapy, dental implants, Dual-light therapy, Peri-implantitis, Peri-implant mucositis

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INTRODUCTION

Dental implants are regarded as a highly reliable and effective solution for replacing lost teeth, boasting long-term survival rates that surpass 90%. However, despite these positive results, biological complications impacting peri-implant tissues have become more common due to the rising number of implants being placed globally. Peri-implant diseases are inflammatory disorders that affect the soft and hard tissues surrounding osseointegrated implants, posing a significant risk to the longevity of these implants.[1] Peri-implant mucositis is marked by inflammation limited to the soft tissues around the implant and is

deemed reversible with proper plaque management. Conversely, peri-implantitis is characterized by inflammation that leads to the progressive loss of supporting alveolar bone and is often irreversible if not addressed promptly. Both conditions are primarily caused by biofilm, and their development is influenced by the interplay between microbial factors and the host's immune response.[2] While peri-implant diseases share some causes with periodontal diseases, there are notable anatomical and histological distinctions. Peri-implant tissues do not contain periodontal ligament fibers and have a lower blood supply, which results in weakened host defense mechanisms. These factors contribute to a quicker and more aggressive inflammatory response around implants compared to natural teeth. Therefore, early detection and effective biofilm management are essential to prevent disease progression. This has sparked greater interest in supplementary treatment options such as antibacterial photodynamic therapy.[3]

Etiopathogenesis of Peri-Implant Diseases

The initiation and progression of peri-implant diseases are closely linked to the accumulation of pathogenic biofilms on implant surfaces. Once biofilm formation occurs, bacterial endotoxins and metabolic by-products stimulate an inflammatory response in the peri-implant tissues. The inflammatory infiltrate consists predominantly of neutrophils, macrophages, and lymphocytes, which release a wide range of cytokines, chemokines, and proteolytic enzymes.[4] A key feature of peri-implant disease progression is the increased expression of matrix metalloproteinases, particularly matrix metalloproteinase-8 (MMP-8), which plays a major role in collagen degradation. The active form of this enzyme (aMMP-8) is considered a reliable biomarker for ongoing connective tissue destruction and disease activity. Elevated levels of aMMP-8 in peri-implant sulcus fluid have been consistently associated with peri-implant inflammation and bone loss.[5] Unlike periodontal tissues, peri-implant tissues exhibit a weaker barrier against inflammatory spread due to the absence of periodontal ligament fibers and reduced vascularity. This anatomical vulnerability allows inflammation to spread apically more rapidly, leading to early involvement of the supporting bone. As a result, effective control of microbial biofilms is essential to halt disease progression at an early stage.

Limitations of Conventional Peri-Implant Therapy

Mechanical debridement remains the cornerstone of peri-implant disease management and includes the use of hand instruments, ultrasonic scalers, and air-abrasive devices. However, the complex geometry of implant surfaces, including threads, roughened surfaces, and micro-irregularities, limits the effectiveness of these approaches. Complete elimination of biofilm from implant surfaces is often difficult to achieve, even with meticulous instrumentation.[6] Chemical plaque control agents such as chlorhexidine are frequently used as adjuncts but provide only short-term benefits and may be associated with adverse effects such as staining and taste alteration. Systemic and local antibiotic therapy has also been employed; however, concerns regarding antimicrobial resistance, disruption of the oral microbiome, and limited long-term efficacy restrict their routine use.[7] Given these limitations, there is a growing demand for alternative non-antibiotic treatment modalities that can effectively target peri-implant biofilms while minimizing adverse effects. Antibacterial photodynamic therapy has emerged as one such promising approach.[8]

Principles of Antibacterial Photodynamic Therapy

Antibacterial photodynamic therapy is based on a photochemical reaction involving three essential components: a photosensitizing agent, light of a specific wavelength, and molecular oxygen. Upon activation by light, the photosensitizer undergoes a transition to an excited state, resulting in the generation of reactive oxygen species such as singlet oxygen and free radicals. These reactive oxygen species exert cytotoxic effects on bacterial cells by damaging cell membranes, proteins, and nucleic acids, ultimately leading to bacterial cell death. Importantly, this mechanism does not rely on specific bacterial metabolic pathways, thereby reducing the risk of microbial resistance. aPDT has demonstrated efficacy against a wide range of periodontal and peri-implant pathogens, including those organized within mature biofilms.[9] Another advantage of aPDT is its selective action. Photosensitizers preferentially bind to microbial cells rather than host tissues, allowing targeted antimicrobial activity with minimal collateral damage. This safety profile makes aPDT suitable for repeated clinical use and long-term maintenance therapy.

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Dual-Light Antibacterial Photodynamic Therapy

Recent technological advancements have led to the development of dual-light antibacterial photodynamic therapy systems, which combine antibacterial blue light (405 nm) with near-infrared light (810 nm). Blue light exerts a direct bactericidal effect by activating endogenous bacterial chromophores, while near-infrared light activates exogenous photosensitizers such as indocyanine green to produce reactive oxygen species.[10] This dual mechanism allows for enhanced penetration and more effective disruption of biofilms compared to conventional single-wavelength photodynamic systems. The combination of two complementary light sources increases antimicrobial efficacy and improves treatment outcomes. The randomized controlled trial conducted by Lähteenmäki and colleagues evaluated the effectiveness of dual-light aPDT in patients with newly diagnosed peri-implant disease. In this study, patients in the treatment group used a home-based dual-light aPDT device in conjunction with indocyanine green mouth rinsing for a period of four weeks, while the control group followed enhanced self-care measures alone. Clinical parameters and inflammatory biomarkers were assessed at baseline, two weeks, and four weeks.[11]

Clinical Outcomes of Dual-Light aPDT

The study demonstrated a significant reduction in bleeding on probing in the dual-light aPDT group, indicating effective resolution of peri-implant inflammation. In contrast, no statistically significant improvement was observed in the control group. These findings highlight the adjunctive benefit of dual-light aPDT beyond conventional plaque control measures.[11] Visible plaque index showed improvement in both groups, emphasizing the importance of oral hygiene. However, the superior reduction in inflammatory parameters in the aPDT group suggests that photodynamic therapy provides additional benefits by directly targeting pathogenic biofilms rather than relying solely on mechanical plaque removal.

Biomarker-Based Assessment of Treatment Efficacy

In addition to clinical parameters, the study incorporated biomarker-based evaluation using levels of aMMP-8 in peri-implant sulcus fluid. Biomarkers offer valuable insight into the biological activity of disease and allow for objective assessment of treatment response. The treatment group exhibited a statistically significant reduction in aMMP-8 levels following dual-light aPDT, whereas no significant change was observed in the control group. This reduction indicates decreased collagen degradation and suppression of destructive inflammatory processes. The use of aMMP-8 as a biomarker strengthens the evidence supporting the biological efficacy of dual-light aPDT in peri-implant disease management.[12]

Significance of Home-Based aPDT

One of the most notable advantages of the dual-light aPDT system evaluated in the study is its suitability for home use. Regular application by patients enhances long-term plaque control and reduces inflammatory burden, potentially preventing disease recurrence. Home-based aPDT empowers patients to actively participate in peri-implant maintenance and may reduce the frequency of professional interventions. This approach is particularly beneficial in the management of peri-implant mucositis, where early intervention can prevent progression to peri-implantitis. The simplicity, safety, and non-invasive nature of the device contribute to improved patient compliance and acceptance.[13]

Limitations and Future Directions

Despite encouraging results, certain limitations must be acknowledged. The relatively short follow-up period restricts evaluation of long-term clinical stability and bone level changes. Additionally, variations in implant systems, surface characteristics, and patient-related factors may influence treatment outcomes.[14] Kajorn Kungsadalpipob 2020 found that absence of the keratinized mucosa around the dental implant was associated with more plaque accumulation, recession ≥1mm, interproximal bone level ≥3mm and peri-implantitis.[15] Future studies should focus on long-term randomized controlled trials with larger sample sizes to establish standardized treatment protocols. Integration of biomarker-based diagnostics with photodynamic therapy may further enhance personalized peri-implant disease management. Continued research is required to validate long-term outcomes and establish its position in routine clinical practice.[16]

CONCLUSION

Antibacterial photodynamic therapy is a promising supplementary approach in treating peri-implant diseases. The dual-light aPDT method, which integrates antibacterial blue light with near-infrared photodynamic activation, provides improved antimicrobial effectiveness and a notable decrease in inflammatory biomarkers like aMMP-8. Recent clinical trial evidence endorses its safety, non-invasiveness, and effectiveness as an adjunct to traditional peri-implant therapy. Moreover, the introduction of home-based aPDT systems enhances its potential as a maintenance solution for sustaining long-term peri-implant health.

REFERENCE

1. Berglundh T, Armitage G, Araujo MG, Avila-Ortiz G, Blanco J, Camargo PM, et al. Peri-implant diseases and conditions: Consensus report of workgroup 4 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. *J Clin Periodontol*. 2018;45(Suppl 20):S286-S291. doi: 10.1111/jcpe.12957.
2. Renvert S, Persson GR, Pirih FQ, Camargo PM. Peri-implant health, peri-implant mucositis, and peri-implantitis: Case definitions and diagnostic considerations. *J Clin Periodontol*. 2018; 89 Suppl 1:S304-S312. doi: 10.1002/JPER.17-0588.
3. Heitz-Mayfield LJA, Salvi GE. Peri-implant mucositis. *J Clin Periodontol*. 2018;45(Suppl 20):S237-S245. doi: 10.1111/jcpe.12953.
4. Schwarz F, Derks J, Monje A, Wang HL. Peri-implantitis. *J Clin Periodontol*. 2018;45(Suppl 20):S246-S266. doi: 10.1111/jcpe.12954.
5. Konopka K, Goslinski T. Photodynamic therapy in dentistry. *J Dent Res*. 2007;86(8):694-707. doi: 10.1177/154405910708600803.
6. Zhang Z, Zhang Z, Wang P, Zheng Y, Wang Z, Wang Z. The relationship between adequate keratinized mucosa and peri-implant disease: A systematic review and meta-analysis. *BMC Oral Health*. 2025;25(1):345. doi: 10.1186/s12903-025-05680-5.
7. Kamalakannan K, Rajasekar A. Evaluation of peri-implant clinical and radiographic parameters in relation to keratinized mucosa width. *Ann Dent Spec.* 2025;13(3):38-42. doi:10.51847/kJd4UlHxDj.
8. Lahteenmaki H, Patila T, Raisanen IT, Kalliala R, Sorsa T. Peri-implant diseases: Enhanced antibacterial photodynamic therapy. *Clin Exp Dent Res*. 2025;11:e70146. doi: 10.1002/cre2.70146.
9. Sorsa T, Gursoy UK, Nwhator S, Hernández M, Tervahartiala T, Leppilahti J, et al. Analysis of matrix metalloproteinases, especially MMP-8, in gingival creviclular fluid, mouthrinse and saliva for monitoring periodontal diseases. *Periodontol 2000*. 2016;70(1):142-163. doi: 10.1111/prd.12101.
10. Bevilacqua L, Biasi MD, Lorenzon MG, Frattini C, Angerame D. Volumetric analysis of gingival crevicular fluid and peri-implant sulcus fluid in healthy and diseased sites: A cross-sectional split- mouth pilot study. *Open Dent J*. 2016;10:131-138. doi: 10.2174/1874210601610010131.
11. Sakamoto E, Kido R, Tomotake Y, Naitou Y, Ishida Y, Kido JI. Calprotectin and cross-linked N-telopeptides of type I collagen levels in crevicular fluid from implant sites with peri-implant diseases: A pilot study. *Int J Implant Dent*. 2018 Sep 13;4(1):26. doi: 10.1186/s40729-018-0138-2.
12. Kido R, Kido JI, Nishikawa Y, Sakamoto E, Tomotake Y, Yumoto H. Diagnosis of inflammatory peri-implant diseases using an immunochromatographic assay for calprotectin

in peri-implant crevicular fluid. *Int J Implant Dent*. 2021;7(1):106. doi: 10.1186/s40729-021-00386-z.
13. Vakaki C, Fragkioudakis I, Pätilä T, Sakellari D. Regular home use of dual-light photodynamic therapy as an adjunct to non-surgical periodontal treatment in smokers: a single-center randomized controlled clinical trial. Clin Oral Investig. 2025 Nov 6;29(12):553. doi: 10.1007/s00784-025-06600-1.
14. Alterman M, Jensen OT, Glick PL, Mazor D, Casap N. Dental implant risk factors for peri-implant disease: A narrative review. *Front Oral Maxillofac Med*. 2023;5.
15. Kungsadalpipob K, Supanimitkul K, Manopattanasoontorn S, Sophon N, Tangsathian T, Arunyanak SP. The lack of keratinized mucosa is associated with poor peri-implant tissue health: A cross-sectional study. *Int J Implant Dent*. 2020;6(1):28. doi: 10.1186/s40729-020-00227-5.
16. Ramanauskaite A, Schwarz F, Sader R. Influence of width of keratinized tissue on the prevalence of peri-implant diseases: A systematic review and meta-analysis. *Clin Oral Implants Res*. 2022;33:8-31. doi: 10.1111/clr.13766.