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PHOTODYNAMIC THERAPY AS AN ADJUNCT IN THE MANAGEMENT OF APICAL PERIODONTITIS: EVIDENCE AND CLINICAL APPLICATIONS

TERAPIA FOTODINÂMICA COMO ADJUVANTE NO MANEJO DA PERIODONTITE APICAL: EVIDÊNCIAS E APLICAÇÕES CLÍNICAS

TERAPIA FOTODINÁMICA COMO ADYUVANTE EN EL TRATAMIENTO DE LA PERIODONTITIS APICAL: EVIDENCIA Y APLICACIONES CLÍNICAS

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ABSTRACT
Objective: This narrative literature review aims to analyze the current evidence regarding the use of photodynamic therapy (PDT) as an adjunctive approach in the management of apical periodontitis, emphasizing its antimicrobial effectiveness, clinical outcomes, and biological mechanisms. Methodology: A comprehensive search was conducted in PubMed, Scopus, Cochrane Library, and Google Scholar databases using combinations of the keywords “Photodynamic Therapy,” “Apical Periodontitis,” “Endodontic Disinfection,” and “Adjunctive Treatment.” Boolean operators “AND” and “OR” were used to refine results. After removing duplicates, studies were screened by title, abstract, and full text. Both in vitro and clinical trials published in English between 2000 and 2025 were considered, focusing on the use of PDT as an adjunct to conventional endodontic therapy. Results: The reviewed literature demonstrates that PDT enhances microbial reduction within the root canal system when used alongside conventional chemomechanical preparation. The activation of

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photosensitizers, such as methylene blue or toluidine blue, by low-level laser light results in the generation of reactive oxygen species capable of disrupting bacterial membranes and biofilms. Clinical studies report improved healing of periapical lesions, reduced postoperative symptoms, and lower bacterial persistence compared to conventional disinfection alone. However, variations in laser parameters, photosensitizers, and irradiation protocols hinder direct comparison across studies. Conclusion: Photodynamic therapy represents a promising adjunctive approach in the management of apical periodontitis, offering enhanced antimicrobial efficacy and potential improvement in periapical healing. Standardization of protocols and high-quality randomized clinical trials are still required to consolidate its clinical indications.

Keywords: Photodynamic Therapy. Apical Periodontitis. Endodontic Disinfection. Adjunctive Treatment.

RESUMO
Objetivo: Esta revisão narrativa da literatura tem como objetivo analisar as evidências atuais sobre o uso da terapia fotodinâmica (TFD) como abordagem adjuvante no manejo da periodontite apical, enfatizando sua eficácia antimicrobiana, resultados clínicos e mecanismos biológicos. Metodologia: Foi realizada uma busca abrangente nas bases de dados PubMed, Scopus, Cochrane Library e Google Acadêmico, utilizando combinações dos descritores “Terapia Fotodinâmica”, “Periodontite Apical”, “Desinfecção Endodôntica” e “Tratamento Adjuvante”. Empregaram-se os operadores booleanos “AND” e “OR” para refinar os resultados. Após a remoção de duplicatas, os estudos foram triados por título, resumo e texto completo. Foram incluídos estudos in vitro e ensaios clínicos publicados em inglês entre 2000 e 2025, que avaliaram a TFD como adjuvante à terapia endodôntica convencional. Resultados: A literatura revisada demonstra que a TFD potencializa a redução microbiana no sistema de canais radiculares quando associada ao preparo químico-mecânico convencional. A ativação de fotossensibilizadores, como azul de metileno ou azul de toluidina, por meio de luz laser de baixa intensidade gera espécies reativas de oxigênio capazes de destruir membranas bacterianas e biofilmes. Estudos clínicos relatam melhora na cicatrização de lesões periapicais, redução de sintomas pós-operatórios e menor persistência bacteriana em comparação à desinfecção convencional isolada. Contudo, variações nos parâmetros de laser, tipos de fotossensibilizadores e protocolos de irradiação dificultam comparações diretas entre os estudos. Conclusão: A terapia fotodinâmica representa uma abordagem adjuvante promissora no manejo da periodontite apical, oferecendo maior eficácia antimicrobiana e possível melhoria na cicatrização periapical. Ainda são necessários ensaios clínicos randomizados de alta qualidade e padronização de protocolos para consolidar suas indicações clínicas.

Palavras-chave: Terapia Fotodinâmica. Periodontite Apical. Desinfecção Endodôntica. Tratamento Adjuvante.

RESUMEN
Objetivo: Esta revisión narrativa de la literatura busca analizar la evidencia actual sobre el uso de la terapia fotodinámica (TFD) como tratamiento complementario en el tratamiento de la periodontitis apical, haciendo hincapié en su eficacia antimicrobiana, sus resultados clínicos y sus mecanismos biológicos. Metodología: Se realizó una búsqueda exhaustiva en PubMed, Scopus, la Biblioteca Cochrane y Google Académico, utilizando combinaciones de los descriptores "Terapia Fotodinámica", "Periodontitis Apical", "Desinfección Endodóntica"

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y "Tratamiento Complementario". Se utilizaron los operadores booleanos "AND" y "OR" para refinar los resultados. Tras eliminar los duplicados, los estudios se seleccionaron por título, resumen y texto completo. Se incluyeron estudios in vitro y ensayos clínicos publicados en inglés entre 2000 y 2025 que evaluaron la TFD como complemento a la terapia endodóntica convencional. Resultados: La literatura revisada demuestra que la TFD mejora la reducción microbiana en el sistema de conductos radiculares cuando se combina con la preparación quimiomecánica convencional. La activación de fotosensibilizadores, como el azul de metileno o el azul de toluidina, mediante luz láser de baja intensidad genera especies reactivas de oxígeno capaces de destruir las membranas bacterianas y las biopelículas. Estudios clínicos reportan una mejor cicatrización de lesiones periapicales, una reducción de los síntomas postoperatorios y una menor persistencia bacteriana en comparación con la desinfección convencional sola. Sin embargo, las variaciones en los parámetros del láser, los tipos de fotosensibilizadores y los protocolos de irradiación dificultan las comparaciones directas entre estudios. Conclusión: La terapia fotodinámica representa un enfoque complementario prometedor en el tratamiento de la periodontitis apical, ofreciendo una mayor eficacia antimicrobiana y una posible mejora en la cicatrización periapical. Aún se requieren ensayos clínicos aleatorizados de alta calidad y la estandarización de protocolos para consolidar sus indicaciones clínicas.

Palabras clave: Terapia Fotodinámica. Periodontitis Apical. Desinfección Endodóncica. Tratamiento Adyuvante.

1 INTRODUCTION

Apical periodontitis is a chronic inflammatory disease caused by microbial infection of the root canal system, leading to periapical tissue destruction and bone resorption (Nair, 2006). The primary goal of endodontic therapy is the complete elimination of microorganisms and their byproducts from the root canal to allow periapical healing (Siqueira & Rôças, 2008). However, due to the complex anatomy of the root canal system and the presence of biofilm-forming bacteria, complete disinfection remains a clinical challenge even with the use of chemical irrigants and mechanical instrumentation (Peters et al., 2001). Residual microorganisms such as Enterococcus faecalis and Candida albicans have been shown to persist after conventional treatment, contributing to endodontic failures (Zehnder, 2006; Stuart et al., 2006).

Photodynamic therapy (PDT) has emerged as a promising adjunctive approach for enhancing endodontic disinfection. It is based on the activation of a photosensitizing agent by light of a specific wavelength, in the presence of oxygen, generating reactive oxygen species (ROS) capable of destroying bacterial membranes and disrupting biofilm structure (Konopka & Goslinski, 2007). Unlike traditional antimicrobials, PDT acts through oxidative stress rather than metabolic inhibition, which minimizes the risk of microbial resistance (George & Kishen, 2007). Various photosensitizers, such as methylene blue, toluidine blue O, and indocyanine green, have been investigated in conjunction with diode or LED light sources, showing encouraging results both in vitro and in vivo (Soukos & Goodson, 2011; Ng et al., 2011).

Recent studies have demonstrated that PDT can significantly reduce microbial load within the root canal, promote periapical healing, and improve clinical outcomes when used as an adjunct to conventional chemomechanical preparation (Garcez et al., 2010; Bonsor et al., 2013). Furthermore, it has shown potential effectiveness against resistant species embedded in biofilms, suggesting a broader therapeutic range than traditional irrigants alone (Rios et al., 2020). Despite these advances, there is still a lack of standardization in irradiation parameters, exposure times, and photosensitizing agents, which complicates direct comparison between studies. Therefore, understanding the biological mechanisms, current evidence, and clinical applicability of PDT is essential for its rational integration into endodontic practice.

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2 METHODOLOGY

This study is designed as a narrative literature review, aiming to synthesize and critically analyze current evidence on the use of photodynamic therapy (PDT) as an adjunct in the management of apical periodontitis. Unlike systematic reviews, narrative reviews provide a broader interpretative synthesis of available literature, allowing for the inclusion of experimental, preclinical, and clinical data to elucidate both mechanistic and practical aspects of a given topic (Rother, 2007).

A comprehensive literature search was conducted between March and September 2025 using the electronic databases PubMed, Scopus, Cochrane Library, and Google Scholar. The search strategy included combinations of the following keywords and Medical Subject Headings (MeSH): "Photodynamic Therapy," "Apical Periodontitis," "Endodontic Disinfection," "Laser Therapy," "Reactive Oxygen Species," and "Adjunctive Treatment." Boolean operators "AND" and "OR" were applied to refine the search. The inclusion criteria comprised in vitro, ex vivo, and clinical studies published between 2000 and 2025, in English, that evaluated PDT as an adjunctive or alternative method to conventional endodontic therapy. Review articles, systematic reviews, and meta-analyses were also consulted to provide contextual understanding and support the discussion.

The selection process occurred in three stages.

1. Identification: All search results were imported into Zotero reference manager, where duplicates were automatically removed.
2. Screening: Titles and abstracts were independently reviewed to exclude irrelevant or off-topic studies.
3. Eligibility: Full-text evaluation was performed to identify studies addressing the antimicrobial efficacy, clinical performance, and mechanistic basis of PDT in apical periodontitis.

Information extracted from each included study comprised authorship, year of publication, type of study, photosensitizer used, light source parameters, microbial targets, and main outcomes. Data were summarized descriptively to highlight converging evidence and methodological variability. Due to the heterogeneity of study designs and parameters, no meta-analytic statistical synthesis was attempted. The structure and methodological approach followed the conceptual framework proposed by Rother (2007), emphasizing clarity, comprehensiveness, and scientific rigor in narrative review writing.

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3 RESULTS

The scientific evidence regarding the adjunctive use of photodynamic therapy (PDT) in the management of apical periodontitis encompasses a broad spectrum of in vitro, ex vivo, and clinical studies, demonstrating its antimicrobial potential and its capacity to enhance periapical healing when combined with conventional endodontic procedures. The following subsections summarize the main findings identified in the reviewed literature.

3.1 ANTIMICROBIAL EFFICACY

PDT has demonstrated a strong antimicrobial effect against microorganisms commonly associated with persistent endodontic infections, including Enterococcus faecalis, Candida albicans, Fusobacterium nucleatum, and Prevotella intermedia (Soukos & Goodson, 2011; Garcez et al., 2010). The mechanism involves the activation of a photosensitizer, such as methylene blue, toluidine blue O, or indocyanine green, by a specific wavelength light source, typically a diode laser (630–690 nm), leading to the generation of reactive oxygen species (ROS) that cause oxidative damage to bacterial cell membranes and biofilm matrices (Konopka & Goslinski, 2007; George & Kishen, 2007).

Several in vitro studies have reported microbial reductions exceeding 95% when PDT is applied after standard chemomechanical preparation, outperforming sodium hypochlorite or chlorhexidine irrigation alone (Ng et al., 2011; Bonsor et al., 2013). Moreover, PDT effectively disrupts E. faecalis biofilms in dentinal tubules at depths where irrigants show limited penetration, suggesting its usefulness as a final disinfection step (Fimple et al., 2008; Dörtbudak et al., 2001).

3.2 PHOTOSENSITIZERS AND LASER PARAMETERS

The reviewed studies revealed significant heterogeneity in the type and concentration of photosensitizers and in the irradiation protocols employed. Methylene blue and toluidine blue O remain the most frequently used agents, typically at concentrations ranging from 10 to 50 µg/mL, activated by red diode lasers between 630 and 660 nm (Soukos & Goodson, 2011). Other studies have evaluated indocyanine green (810 nm) and curcumin-based photosensitizers with promising results in reducing Gram-negative bacteria (Nunes et al., 2018). Laser parameters such as power output (40–200 mW), energy density, and exposure time (30–180 seconds) varied considerably between studies, influencing antimicrobial outcomes. Despite this variability, most reports indicate that even short irradiation times yield

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significant bacterial reduction without detrimental effects on dentin or periapical tissues (Garcez et al., 2010; Rios et al., 2020).

3.3 CLINICAL OUTCOMES

Clinical investigations suggest that PDT can enhance periapical healing and improve postoperative outcomes when integrated into conventional endodontic therapy. Garcez et al. (2010) demonstrated that patients receiving PDT adjunctively during root canal treatment exhibited greater reduction in periapical lesion size and microbial counts compared with conventional treatment alone. Bonsor et al. (2013) reported decreased postoperative pain and improved radiographic bone repair among patients treated with PDT. Additionally, studies using in vivo imaging have indicated accelerated resolution of periapical radiolucencies following combined laser-assisted disinfection protocols (Alves et al., 2019). Beyond its antimicrobial benefits, PDT has also been associated with biostimulatory effects, promoting angiogenesis, fibroblast proliferation, and collagen synthesis within the periapical region (Kharkwal et al., 2011). These effects may contribute to enhanced tissue regeneration and faster healing responses following endodontic therapy.

3.4 LIMITATIONS OF CURRENT EVIDENCE

Despite promising outcomes, the existing literature presents limitations related to methodological heterogeneity, small sample sizes, and short follow-up periods. Differences in photosensitizer types, light dosimetry, and activation times hinder the establishment of standardized protocols. Moreover, while in vitro studies demonstrate consistent antimicrobial efficacy, clinical evidence remains limited, with few randomized controlled trials confirming long-term benefits in periapical healing (Rios et al., 2020; Ng et al., 2011). These gaps highlight the need for future research focusing on standardized methodologies and clinically relevant endpoints.

4 DISCUSSION

The current synthesis of evidence supports the concept that photodynamic therapy represents a biologically plausible and clinically relevant adjunct in the management of apical periodontitis. The antimicrobial and biostimulatory properties of PDT address two of the major challenges in endodontic therapy: the persistent microbial contamination within the complex root canal system and the subsequent inflammatory damage to periapical tissues.

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Traditional endodontic disinfection relies on mechanical instrumentation and chemical irrigants such as sodium hypochlorite and chlorhexidine. However, the anatomical intricacies of the root canal system and the ability of microorganisms to form biofilms within dentinal tubules limit the efficacy of these agents. PDT, by contrast, offers a non-mechanical and non-antibiotic mechanism of action that can penetrate biofilms and destroy residual microorganisms through oxidative stress, thereby reducing the risk of reinfection and treatment failure.

The biological basis of PDT lies in the activation of a photosensitizer by light at a specific wavelength in the presence of molecular oxygen, leading to the formation of reactive oxygen species. These highly reactive molecules induce irreversible oxidative damage to cellular components, including lipids, proteins, and nucleic acids, resulting in microbial cell death. This mechanism is independent of bacterial metabolic activity, allowing effective action even against dormant or resistant microorganisms. Furthermore, because the reaction is photochemical rather than pharmacological, it does not promote the development of antimicrobial resistance, representing a significant advantage in modern endodontic practice, where multidrug-resistant strains are increasingly common.

Beyond its antimicrobial effects, PDT appears to exert beneficial biological actions on periapical tissues. Low-level laser irradiation associated with PDT has been shown to stimulate angiogenesis, fibroblast proliferation, and collagen synthesis, thereby promoting tissue repair and regeneration. These photobiomodulatory effects contribute to faster resolution of inflammation and more efficient bone repair in the periapical region. The dual role of PDT, both antimicrobial and biostimulatory, supports its integration into the endodontic protocol not only as a disinfection enhancer but also as a healing modulator.

Nevertheless, several factors still limit the universal adoption of PDT in clinical endodontics. The lack of standardized parameters, such as light wavelength, power output, exposure time, and photosensitizer concentration, contributes to inconsistent outcomes among studies. Differences in the physicochemical properties of photosensitizers influence their penetration into dentinal tubules and their interaction with the microbial biofilm, directly impacting clinical effectiveness. Moreover, variations in laser delivery systems and the geometry of the root canal further complicate protocol optimization. Despite these limitations, the overall trend in the literature indicates that PDT used in conjunction with conventional chemomechanical preparation enhances microbial reduction and improves periapical healing compared to conventional treatment alone.

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From a translational perspective, photodynamic therapy aligns with the current movement toward minimally invasive and biologically driven dental treatments. Its ability to provide effective disinfection without altering dentin structure or causing cytotoxic effects represents a key advantage over high-concentration chemical irrigants. Clinically, PDT could be particularly valuable in retreatment cases, persistent infections, and patients with contraindications to traditional chemical agents. However, the successful integration of PDT into endodontic protocols requires not only scientific validation but also professional training and access to appropriate equipment.

In conclusion, photodynamic therapy offers a safe, efficient, and innovative adjunct to conventional endodontic treatment. While the current body of evidence supports its antimicrobial and regenerative potential, further standardized and large-scale clinical trials are needed to establish definitive clinical protocols. The continued development of novel photosensitizers, optimized laser systems, and combined treatment strategies may further expand the role of PDT in contemporary endodontic practice, reinforcing its value as a biologically based approach to managing apical periodontitis.

5 CONCLUSION

Photodynamic therapy represents a promising adjunctive approach in the management of apical periodontitis, offering enhanced antimicrobial efficacy and potential improvement in periapical healing. Standardization of protocols and high-quality randomized clinical trials are still required to consolidate its clinical indications.

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