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LITERATURE REVIEW:

Applications of Photodynamic Therapy in Pediatric Dentistry: A Narrative Review

Aplicaciones de la terapia fotodinámica en odontología pediátrica: una revisión narrativa

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ABSTRACT: Various non-invasive techniques and therapeutic methods have been researched in order to improve the patients' overall clinical experience and overcome the drawbacks of traditional dental treatments. One such treatment is photodynamic therapy which relies on generation of a reactive species of partially reduced oxygen by activation of a chemical agent under the influence of photons. The aim of this review was to evaluate the literature concerning the use of photodynamic therapy as a treatment modality in dentistry for children. The databases searched include MEDLINE/PubMed, Cochrane and ScienceDirect. The search strategy was based on the keywords such as photodynamic therapy, biofilms, oral mucositis and pediatric dentistry. The articles written in the English language were included in full text. The search yielded 259 articles out of which 25 were included based on free access, timeline from 2016 to 2024.The review sheds a light on the insufficiency of in vivo studies and literature on the use of appropriate dosage and concentration of photosensitizing agents and light source related factors such as type of source, wavelength and duration of light exposure. Further research is needed to better define and standardize the clinical protocols for use of photodynamic therapy in pediatric dentistry.

KEYWORDS: Photodynamic therapy; Biofilms; Oral mucositis; Pediatric dentistry; Antimicrobial agents; Nanotechnology.

RESUMEN: Diversas técnicas no invasivas y métodos terapéuticos han sido investigados con el fin de mejorar la experiencia clínica general de los pacientes y superar las limitaciones de los tratamientos dentales tradicionales. Uno de estos tratamientos es la terapia fotodinámica, la cual se basa en la generación de especies reactivas de oxígeno parcialmente reducido mediante la activación de un agente químico bajo la influencia de fotones. El objetivo de esta revisión fue evaluar la literatura relacionada con el uso de la terapia fotodinámica como modalidad terapéutica en odontología pediátrica. Se realizaron búsquedas en las bases de datos MEDLINE/PubMed, Cochrane y ScienceDirect. La estrategia de búsqueda se basó en palabras clave como terapia fotodinámica, biopelículas, mucositis oral y odontología pediátrica. Se incluyeron artículos escritos en inglés con disponibilidad de texto completo. La búsqueda identificó 259 artículos, de los cuales 25 fueron incluidos según criterios de acceso libre y periodo de publicación comprendido entre 2016 y 2024. La revisión pone de manifiesto la insuficiencia de estudios in vivo y de literatura relacionada con el uso de dosis y concentraciones apropiadas de agentes fotosensibilizantes, así como de factores vinculados a la fuente de luz, tales como el tipo de fuente, la longitud de onda y la duración de la exposición lumínica. Se requiere investigación adicional para profundizar en estos aspectos.

PALABRAS CLAVE: Terapia fotodinámica; Biofilms; Mucositis oral; Odontopediatría; Agentes antimicrobianos; Nanotecnología.

INTRODUCTION

Photodynamic therapy (PDT) has been researched extensively in the medical field in the past, which has led to its subsequent exploration in dentistry in the 20th century. Wilson *et al*. (1) was one of the first researchers to demonstrate the antimicrobial property of PDT in managing oral pathogens. This was followed by further research by various authors such as Soukos *et al*. (2) as well as Meisel & Kocher (3) who confirmed the effectiveness of PDT in reducing microbial load in root canals as well as periodontal tissues. Since the 2010s until recently, scope of PDT in dental therapy has broadened to encompass management of carious lesions, hypomineralized teeth, disinfection in endodontics, biofilm-related infections and oral soft tissue lesions. It has been used individually and as a combination with conventional therapy in order to treat a variety of oral hard and soft tissue conditions. This treatment modality is based on the principle of cell death by the generation of reactive oxygen species (ROS) and singlet oxygen (1O2) which damage the cellular DNA and affect the metabolic activity of the target cells. It utilizes photon energy to activate various chemical agents to bring about oxidative damage in the cells. The aim of this review was to evaluate the literature concerning the use of photodynamic therapy as a treatment modality in dentistry for children.

HISTORY

The foundation of PDT can be traced back to the early 20th century. Niels Finsen (4), a Danish physicist, pioneered phototherapy research, laying the groundwork for modern light-based treatments. Oscar Raab & Hermann von Tappeiner (5) further advanced the field by discovering the photodynamic effect, where light-activated dyes could kill microorganisms. In the mid-20th century, hematoporphyrin was identified as a potential photosensitizer, leading to increased interest in PDT. The establishment of the International Photodynamic Association in 1986 marked a significant milestone, promoting research and clinical applications of PDT. The FDA's approval of PDT for treating precancerous skin lesions in 1999 further solidified its position as a valuable therapeutic modality (6). As research progressed, scientists explored the mechanisms of PDT, identifying the role of reactive oxygen species in cell damage. The concept of the "bystander effect" was introduced, highlighting the ability of PDT to induce cell death in neighboring cells, even those not directly exposed to light (7).

MATERIALS AND METHODS

STUDY SELECTION

To identify the relevant studies for this review, A thorough and detailed search was conducted utilizing electronic databases, including MEDLINE/PubMed, Cochrane, Scopus, Web of Science, and ScienceDirect. The search timeline was 8 years including articles from 2016 to 2024. The search strategy was based on the keywords such as “photodynamic therapy”, “biofilms”, “oral mucositis”, “pediatric dentistry”, “oral health”, “antimicrobial agents”, “anti-inflammatory agents”, “dental caries”, “molar incisor hypomineralization” and “nanotechnology”.

A manual search was also performed, encompassing a review of reference lists from initial articles and an exploration of relevant journal websites.

SEARCH STRATEGY

The following search strategy was established: TITLE-ABS-KEY ("photodynamic therapy*" OR "photo-therapy" OR "minimally invasive therapy") AND TITLE-ABS-KEY ("oral health" OR "oral mucositis" OR "biofilms" OR "dental caries" OR "pediatric dentistry").

INCLUSION CRITERIA

The databases were searched for systematic reviews, review articles, and original research. The articles chosen for the current review were related to the mechanism of photodynamic therapy and its effectiveness as a minimally invasive dental therapy. The articles written in the English language only were included in full text.

EXCLUSION CRITERIA

Articles focusing on management of head and neck cancer in pediatric patients were excluded. The articles written in a language other than the English language were excluded in full text.

RESULTS

The search yielded 259 articles out of which 25 were included based on free access, timeline from 2016 to 2024. The included studies have primarily focused on applications of Photodynamic therapy in pediatric dentistry such as in root canal disinfection, management of oral biofilms and revascularization procedure by stimulating the apical papilla cells (APCs) and the endothelial cells (Table 1).

Table 1.

Sr no	Author, year	Objectives	Key findings	Conclusion
1	Fekrazad *et al.*, 2013 (13)	To investigate the efficacy of photoelimination of *Streptococcus mutans* using photodynamic and photothermal therapy as an alternative to conventional antibacterial agents.	Standard suspensions of *S. mutans* were treated using photodynamic therapy (Toluidine blue O and Rhadachlorin®) and photothermal therapy (EmunDo®), along with their respective light sources.Both photodynamic and photothermal therapy demonstrated similar efficacy, with no significant priority of one over the other.	Photoelimination using photodynamic and photothermal therapy can be considered a potential future modality for eradicating S. mutans colonies, offering an alternative to conventional antibacterial treatments.
2	Panhóca *et al.*, 2016 (14)	Evaluate the effect of antimicrobial photodynamic therapy using Photogem® and curcumin on in situ *Streptococcus mutans* biofilm.	aPDT using Photogem® showed significant antibacterial performance against S. mutans biofilm by reducing bacterial count.	aPDT could be a promising alternative for reducing bacterial activity in the oral environment.
3	Beytollahi *et al.*, 2017 (15)	To assess the antimicrobial and anti-biofilm effects of photodynamic therapy (PDT) with toluidine blue O (TBO) and photo thermal therapy (PTT) with indocyanine green (ICG) on *Streptococcus mutans*.	PDT (TBO) and PTT (ICG) significantly reduced *S. mutans* colony-forming units (CFU/mL) by bacterial inactivation. 0.1 mg/mL TBO-PDT and 1 mg/mL ICG-PTT showed the strongest inhibitory effects on biofilm formation, reducing it by 63.87% and 67.3%, respectively.	High concentrations of TBO-PDT and ICG-PTT demonstrated strong antibacterial and anti-biofilm effects on S. mutans, highlighting their potential as alternative antibacterial treatments.
4	Batool *et al.*, 2024 (18)	To compare the effectiveness of Photodynamic Therapy (PDT) and Sodium Hypochlorite (NaOCl) in root canal disinfection.	PDT showed potential in reducing bacterial counts, especially in complex areas and resistant biofilms. NaOCl remained highly effective for microbial reduction and tissue dissolution but had limitations such as tissue damage and incomplete disinfection in complex systems. Variability in PDT's effectiveness due to differences in photosensitizers and light parameters.	PDT has potential as an alternative or adjunct to NaOCl, particularly for resistant biofilms and tissue preservation.
5	Li *et al.*, 2022 (19)	Evaluate the *in vitro* antibacterial efficacy of PDT on planktonic *E. faecalis* and its biofilm in the root canal of infected deciduous teeth.	PDT significantly reduced bacterial counts in the root canal compared to the saline group ($p < 0.05$). The lowest CFU counts were observed in the 1% NaClO and 1% NaClO + PDT groups ($p < 0.05$). The bacterial death rate on the biofilm surface was significantly increased in the PDT group ($p < 0.05$). The highest bacterial death rates were found in the 1% NaClO and 1% NaClO + PDT groups ($p < 0.05$).	PDT exhibits antibacterial activity against *E. faecalis* in the root canals of deciduous teeth. Its effect on planktonic E. faecalis is stronger than on biofilm. PDT is less effective than 1% NaClO in reducing *E. faecalis* in root canals of deciduous teeth. Hence may be used as an adjunct to NaClO.
6	Kattan HF *et al.*, 2023 (21)	To critically appraise and synthesize evidence on the antimicrobial efficacy of aPDT as an adjunct to conventional root canal therapy in primary teeth.	Majority of included studies concluded that adjunct aPDT improves the antimicrobial efficacy of conventional root canal therapy, but studies had several sources of bias.	aPDT is a suitable adjunct to improve disinfection in conventional root canal treatment, but future studies with clinical outcomes are needed.
7	Gaikwad, A. A, 2022 (22)	To compare the effectiveness of conventional root canal therapy alone vs. conventional root canal therapy combined with antimicrobial PDT for endodontic treatment of primary teeth with pulp necrosis.	Both groups showed a significant reduction in Colony-Forming Units (CFU/mL) after treatment. Group I (conventional alone) showed CFU reduction from high initial counts to near or complete elimination in some samples. Group II (conventional + PDT) also showed CFU reduction, but with some residual bacteria in most samples. Both groups had similar overall effectiveness.	Conventional treatment combined with antimicrobial PDT was found to be equally effective as conventional treatment alone in primary teeth.

Sr no	Author, year	Objectives	Key findings	Conclusion
8	Fernandes, *et al*., 2020 (23)	To evaluate the effectiveness of aPDT in root canal decontamination of infected deciduous teeth by quantifying viable bacteria.	aPDT significantly reduced bacteria at baseline (T1) compared to after aPDT (T2), mechanical/chemical manipulation (T3), and a second aPDT application (T4), but not significantly between T2, T3, and T4.	aPDT can be a useful adjunct in primary teeth root canal treatment, significantly reducing bacteria, especially with initial application.
9	Deluca *et al*., 2021 (24)	To evaluate the effects of photodynamic therapy (PDT) and photobiomodulation therapy (PBM) as adjuncts to pulp revascularization using cultures of apical papilla cells (APCs) and endothelial cells (HUVECs).	PDT and PBM increased APC viability compared to their controls.	PBM and PDT appear to be effective adjuncts for revascularization in nonvital immature teeth.
10	da Mota *et al*., 2016 (25)	To evaluate the effectiveness of PapacárieMblue with PDT in the treatment of deep carious lesions while maintaining pulp integrity.	The approach minimized the removal of dental tissue, improving the prognosis. After 3 months, the treated tooth was asymptomatic, and radiographic examination showed no furcation lesions.	PDT with PapacárieMblue was effective in treating deep carious lesions while preserving pulp integrity and reducing tissue removal.
11	Ferreira *et al*., 2022 (26)	Evaluate the effects of adjunctive therapies (Phosphate Buffer Saline (PBS), Chlorhexidine (CHX), Papacárie® (Papain gel), Ozone (O3), and antimicrobial Photodynamic Therapy (aPDT)) on carious lesions and the dentin-pulp complex without interfering with restoration survival.	CHX and aPDT reduced bacterial load by ~1 log. PBS, CHX, and aPDT showed MMP-2 and MMP-9 expression. Cell viability decreased by <30% after 120 h in all groups. CHX, O3, and aPDT promoted ~20% higher odontodifferentiation.	Adjunctive therapies had minimal biological impact on bacterial reduction in artificial carious lesions. Stimulation of hard tissue formation was noted with use of aPDT, CHX, and O3 treatments.
12	Vieira *et al*., 2024 (27)	To describe the treatment of MIH-affected teeth with atypical carious lesions using a minimal intervention protocol combining aPDT and selective chemical-mechanical caries removal.	Effective decontamination of carious tissue, control of hypersensitivity in MIH-affected teeth and successful treatment of atypical carious lesions with PDT.	This protocol is promising for the decontamination and control of hypersensitivity in teeth with MIH.
13	Al Nazeh *et al*., 2020 (28)	To evaluate the effectiveness of PDT as an adjunct to ultrasonic scaling (US) in reducing gingival inflammatory parameters and periodontal pathogens in adolescent patients undergoing fixed orthodontic treatment.	Both US and PDT significantly reduced plaque scores (PS) and bleeding on probing (BOP). PDT showed a significantly greater effect on bacterial reduction (*P. gingivalis* and *T. forsythia*) compared to US.	PDT was effective in significantly reducing periodontal pathogens in established gingivitis lesions in adolescent patients undergoing fixed orthodontic treatment in the short term.
14	Baeshen *et al*., 2020 (29)	To evaluate the effectiveness of PDT on clinical gingival inflammatory parameters, bacterial load, proinflammatory cytokine status, and pain scores in adolescent patients undergoing fixed orthodontic treatment with gingivitis.	PDT significantly reduced plaque scores (PS), bleeding on probing (BOP), IL-6 and TNF-α levels.	PDT effectively reduces the periodontal microbial load in adolescent patients with established gingivitis undergoing fixed orthodontic treatment.
15	Pessoa *et al*., 2015 (30)	To propose an alternative therapy PDT for removal of black pigmentation caused by black-pigmented bacteria (BPB).	BPB levels significantly reduced after photodynamic therapy (PDT), with clinical absence of black pigmentation and reduced gingival bleeding. No recurrence of black pigmentation during a 7-month follow-up period, though plaque index remained unchanged.	PDT offers a promising alternative treatment for BPB-induced pigmentation in periodontal cases.
16	Medeiros-Filho *et al*., 2017 (31)	To evaluate the effect of low-level laser therapy (LLLT) combined with photochemotherapy (PCT) on chemotherapy-induced oral mucositis in young patients.	A statistically significant difference was found between therapies for lesion area on Days 6-8 (p=0.020, 0.011, 0.005). Lesions treated with PCT+LLLT showed a smaller area at the end of the evaluation.	PCT+LLLT had a greater therapeutic effect than LLLT alone in reducing the severity of chemotherapy-induced oral mucositis.

Sr no	Author, year	Objectives	Key findings	Conclusion
17	Vichitrananda V. *et al.*, 2024 (34)	To investigate the anti-migration effect of 5-Aminolevulinic acid (5-ALA) Photodynamic Therapy (PDT) on palatal fibroblast cells, specifically in the context of reducing scar formation after palatoplasty	5-ALA PDT at 0.1 and 0.2 mM inhibited palatal fibroblast cell migration. 0.2 mM 5-ALA PDT caused abnormal cell morphology. The optimal condition for suppressing palatal fibroblast migration without causing cell damage was 0.1 mM 5-ALA PDT with 635-nm red LED at 50 mW/cm^2, $10J/cm^2$.	5-ALA PDT effectively suppressed palatal fibroblast migration, with 0.1 mM being the optimal concentration to minimize cell damage thereby reducing scar formation.
18	Dantas Lopes dos Santos *et al.*, 2021 (40)	Study aimed at evaluating the efficacy of aPDT using Curcumin (Cur)-loaded Pluronic® F-127 micelles against *Streptococcus mutans* and *Candida albicans* biofilms.	Cur-loaded Pluronic® F-127 demonstrated antibacterial/antifungal effect by reduction of *S. mutans* and *C. albicans* in the oral biofilm.	Cur-loaded Pluronic® F-127 micelles demonstrate good photo-chemical properties and could be a promising alternative for Cur delivery to enhance the efficacy of aPDT in treating dental caries.
19	Shitomi *et al.*, 2020 (42)	To evaluate the effectiveness of silver nanoclusters/rose bengal nanocomposite (AgNCs/RB) as a novel photosensitizer for antimicrobial photodynamic therapy (a-PDT) in targeting dental diseases.	AgNCs/RB generates singlet oxygen (1O2) upon irradiation, reducing bacterial turbidity of *Streptococcus mutans*, *Porphyromonas gingivalis*, and *Aggregatibacter actinomycetemcomitans* , thus reducing bacterial colonization by membrane destruction and cell death.	AgNCs/RB is an effective photosensitizer for dental antimicrobial photodynamic therapy with a synergistic antibacterial effect via 1O2 generation and Ag+ ion release. The approach offers low cytotoxicity and a long-term antibacterial effect, making it a promising candidate for clinical use in dental treatments.
20	de Araújo *et al.*, 2022 (46)	Study investigated publication metrics and research trends related to PDT in endodontics.	342 studies retrieved from 84 journals across 33 countries. 85% of studies published in the last decade. 74.5% of studies are laboratory-based. Main clinical outcomes evaluated were microbiological load reduction and postoperative pain.	This bibliometric analysis suggests that future research should focus on discovering new photosensitizer agents, standardizing photoactivation protocols, and emphasizing more clinical-oriented studies.
21	Romano *et al.*, 2020 (47)	To evaluate the usefulness of topical PDT for treating benign oral soft tissue lesions.	Topical PDT is easy to perform, well-tolerated, and appears effective for benign oral lesions	Topical PDT shows promise in treating benign oral soft tissue lesions but requires further studies to expand current knowledge and improve its application.
22	Perin *et al.*, 2024 (48)	To identify, describe, and synthesize data on the effectiveness of aPDT in primary teeth pulpectomies	15 studies were included, published between 2014 and 2022, comprising 6 *in vitro* studies, 5 clinical trials, and 4 case reports. Most studies used diode lasers, methylene blue, and optical fibers.	aPDT is effective in reducing microorganisms and shows promise as an adjunct treatment in primary teeth pulpectomies

Abbreviations - aPDT: antimicrobial photodynamic therapy, PDT: photodynamic therapy, Curcumin: Cur.

DISCUSSION

MECHANISM OF ACTION

PDT involves external application of a natural or artificially synthesized photosensitizing (PS) agent and an appropriate light source. Under the influence of photon energy this PS gets converted to an excited molecular state which reacts with the substrate such as the cell membrane or another molecule to generate reactive oxygen species (ROS). As stated by Dixon *et at.* (8), "ROS is a blanket term for a collection of partially reduced oxygen containing molecules, including superoxide (O2•–), peroxides (H_2O_2 and ROOH) and free radicals (HO• and RO•)". These ROS are highly reactive and hence are short lived. Thus, a more localized effect of PDT is seen. Half-life of $^1O_2$ has been reported to be approximately 40 nanoseconds with a minute radius of 20nm (9). The chemical reaction in PDT has been noted to be of 2 types. Type I chemical reaction is the Fenton reaction which causes generation of highly reactive hydroxyl radical (HO•) from superoxide anion. HO• damages cell membranes by penetrating them. The type II chemical reaction leads to formation of a singlet oxygen species ($^1O_2$) which directly reacts with amino acids such as cysteine, methionine, tyrosine, histidine, and tryptophan, hampering cellular metabolism (10). For the desired effect of PDT, the selection of a suitable PS agent and light source is extremely crucial. The most commonly used PS are derived from phthalocyanine (e.g., toluidine blue O (TBO)and methylene blue (MB)), phenothiazinium and porphyrin. Literature reports that the appropriate wavelength for maximum light absorption for TBO is 625nm and that for MB is 656nm (11).

APPLICATION OF PDT IN PEDIATRIC DENTISTRY

ROLE IN DENTAL CARIES

Numerous studies have explored the anti-cariogenic potential of photodynamic therapy (PDT) by targeting *Streptococcus mutans*, a key bacterium implicated in dental caries (12-14). A diverse range of light sources and photosensitizing agents have been employed in these investigations. For instance, researchers have utilized a gallium-arsenide diode laser (600 nm, 11 mW output power) in conjunction with aluminum de-sulphonated phthalocyanine, as well as light-emitting diodes (LEDs) (630 nm, 2-4 mW/cm² output power) with toluidine blue O (TBO) (12). Additionally, laser-based PDT has been explored with Radachlorin photosensitizer (662 nm, 24 J/cm² energy density), and a combination of LED and diode laser with curcumin has also been investigated (450 nm LED, 764 mW/cm² and 630 nm diode, 381 mW/cm² power density). These studies collectively provide valuable insights into the efficacy of PDT in mitigating dental caries (13-14). Beytollahi *et al.* (15) investigated the impact TBO as a photosensitizer on *Streptococcus mutans* biofilms, demonstrating that TBO, when activated by light, significantly inhibited the formation of these biofilms, highlighting its potential as a valuable tool in preventing dental caries. Furthermore, antimicrobial photodynamic therapy (aPDT) appears to reduce the *S. mutans* counts in saliva thereby helping control the caries activity especially in children with severe early childhood caries. It was found that reduced levels of *S. mutans* proved to be beneficial in long term to bring down the incidence of secondary caries and minimized extensive excavation of the affected dentin while restoring carious teeth (16).

ROLE IN PULP THERAPY

In endodontic therapy, traditional irrigants such as sodium hypochlorite (NaClO), chlorhexidine (CHX), and ethylenediaminetetraacetic acid (EDTA) have demonstrated excellent efficacy. Nonetheless, these irrigants possess some disadvantages, such as an unpleasant taste and odor, an inability to fully neutralize endotoxins, and antagonistic interactions with other irrigants (17). To overcome these drawbacks, newer techniques such as PDT have been studied. PDT, a more contemporary method, has been examined as a possible remedy for these drawbacks. Compared to the efficacy of NaClO, PDT has shown the capability of efficiently eliminating persistent biofilm bacteria. Moreover, it has exhibited promising antibacterial properties, particularly against gram-positive pathogens (18-20). PDT and photo biomodulation therapy (PMBT) have both been tested as supplementary treatment strategies for pulp revascularization procedures. These light-based therapies have been shown to stimulate the proliferation and differentiation of apical papilla cells (APCs) and endothelial cells, which are crucial for the formation of new blood vessels and pulp tissue regeneration (21).

ROLE IN MOLAR INCISOR HYPOMINERALIZATION

Dentin hypersensitivity and increased friability of the enamel pose difficulty in managing the MIH affected teeth. While restoring these teeth, selective caries removal is, at times, chosen in order to preserve the tooth structure. In such cases, PapaMblue gel as photosensitizing agent in aPDT has been used to disinfect the dentin prior to restoring the tooth in order to reduce the microbial load (22). This also aids in improving the longevity of the restoration by inhibiting or minimizing the secondary caries incidence. Additionally, laser when used as the light source in aPDT, offers additional benefits beyond antimicrobial activity. Laser irradiation has been shown to possess anti-inflammatory properties, which can help mitigate post-operative sensitivity and accelerate tissue healing. Laser irradiation has also been linked to the stimulation of tertiary dentin formation, a natural reparative process that can help preserve tooth vitality and structural integrity (23).

ROLE OF PDT IN GINGIVITIS

Al Nazeh *et al*. (24) used a protocol for PDT as an adjunct to conventional ultrasonic scaling in adolescent with gingivitis. They used MB as a PS agent activated by a diode laser with wavelength of 670nm and 22J/cm² of fluence rate and 150mW power output. The gingival sulcus was exposed to the PS agent for approximately 3 minutes followed by light application for 1 minute. The results showed successful treatment with PDT as an adjunct to the traditional treatment with a reduction in inflammatory mediators (IL-6 and TNF-alpha) and count of *P. Gingivitis* and *T. forsythia* in the gingival sulcus (24-25).

ROLE IN REMOVAL OF EXTRINSIC STAINS

Photodynamic therapy (PDT) has shown promise in managing dental esthetics, specifically in addressing black pigmentation caused by black-pigmented bacteria (BPB). These anaerobes are predominantly proteolytic gram negative including Porphyromonas gingivalis and Prevotella intermedia, contribute to periodontal disease and can cause unsightly black stains on teeth. A case report demonstrated the effectiveness of PDT in eliminating black pigmentation on 10-year-old's teeth, resulting in improved aesthetics and reduced gingival inflammation (26). By targeting and killing BPB, PDT can effectively remove extrinsic stains without causing significant damage to tooth structure. This approach offers a potential alternative to traditional mechanical cleaning methods, especially in cases of stubborn pigmentation. Further research is needed to fully explore the potential of PDT in managing various types of extrinsic tooth stains and to optimize treatment protocols.

ROLE IN ORAL MUCOSITIS

A study investigated the effectiveness of photodynamic therapy (PDT) combined with low-level laser therapy (LLLT) in reducing the severity and duration of oral mucositis (OM) in pediatric cancer patients undergoing chemotherapy. The results demonstrated that the combination of PDT and LLLT significantly reduced the lesion area and accelerated healing compared to LLLT alone. This suggests that PDT can enhance the therapeutic efficacy of LLLT in managing OM, improving patient quality of life and potentially reducing the risk of complications associated with severe mucositis (27).

ROLE OF PDT IN SPECIAL HEALTHCARE NEEDS CHILDREN

Photodynamic therapy (PDT) has been investigated as a complementary treatment to traditional ultrasonic scaling in pediatric patients with Down syndrome. Studies have shown that PDT can effectively reduce bleeding on probing without causing any systemic side effects, thereby minimizing discomfort and potential complications (28). This is especially effective in children with compromised immune system (29). Additionally, in cleft palate children who have undergone palatoplasty usually present with a palatal scar as a common complication. 5-aminolevulinic acid (5-ALA PDT) (0.1 mM with red LED (635nm) at 50 mW/cm², 10J/cm²) as a PS agent has been evidenced to suppress the migration of palatal fibroblasts in the wound area without causing damage to these cells. PDT has shown to morphologically alter the structure of the fibroblastic cells, thus preventing scar tissue formation (30-31).

PDT WITH NANOTECHNOLOGY

Although, PDT has shown to be promising in oral and dental applications, it has several drawbacks including repulsion between PS agents and biofilm bacteria, due to similar electrical charge, superficial action and requirement of oxygen (32-33). In order to overcome these disadvantages, nanotechnology has been incorporated along with PDT. Graphene based nano-carrier system was developed to carry indocyanine green (ICG), which improved the stability of the PS agent and synergistically decreased the *S. mutans* counts in the biofilm (34). Similarly, Poly (lactic-co-glycolic acid) (PLGA) and Pluronic ®F-127 (PF-127) as carriers for curcumin and curcumin doped Zinc oxide nanoparticles (ZnONPs) were developed to prolong the bioavailability of water insoluble curcumin (35-37). Cerium oxide nanoparticle and silver nanoparticles (AgNP) mediated PDT have been shown to have a strong inhibitory effect on *Streptococcus gordonii*, *F. nucleatum* and *P gingivalis*, and *S. mutans*, *Aggregatibacter actinomycetemcomitans* (*A. actinomycetemcomitans*), and *Porphyromonas gingivalis* (*P. gingivalis*) respectively (11)(38). Furthermore, cerium oxide and silver nanoparticles have been observed to downregulate the expression of virulence genes in biofilms, including those associated with adhesion, invasion, and biofilm formation (39). Thus, conjugation of nanoparticles with PDT has been used to greatly enhance its effect.

CONCLUSION

Evidence based clinical practice and newer advancements in oral and dental therapy aid in improving overall dental health and psychological well-being of patients. Based on current analysis of the relevant literate, Photodynamic therapy being minimally invasive appears to be a promising technique for improving the clinicians' ease of operation and overall patient experience in the dental operatory. PDT offers multiple benefits over traditional therapy such as single session efficacy and reduced chairside time, as well as minimizing chances of development of antibiotic-resistant microbes. Hence, PDT seems to be a promising treatment modality for children incorporating the concepts and principles of minimal intervention dentistry. However, it presents with several limitations, including cost ineffectiveness, the necessity for sophisticated equipment, potential allergic reactions to photosensitizing agents and photosensitivity. The current evidence is considered inconclusive to formulate standardized clinical protocols for the application of PDT in dentistry, highlighting the need for additional high-quality research to enhance the understanding of PDT.

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LIST OF ABBREVIATIONS: PDT: Photodynamic therapy; aPDT: antimicrobial photodynamic therapy; LLLT: low-light laser therapy; ROS: Reactive oxygen species; $^1O_2$ –: singlet oxygen; O2•–: superoxide; H_2O_2: hydrogen peroxide; HO•: hydroxyl ions; TBO: toluidine blue O; MB: methylene blue; NaClO: sodium hypochlorite; CHX: chlorhexidine; EDTA: ethylenediaminetetraacetic acid; PMBT: photobiomodulation therapy; APCs: apical papilla cells; ICG: indocyanine green; PLGA: Poly lactic-co-glycolic acid; PF-127: Pluronic ®F-127; ZnONPs: Zinc oxide nanoparticles; AgNPs: Silver nanoparticles; 5-ALA: 5-amino levulinic acid.

AUTHOR CONTRIBUTION STATEMENT: Conceptualization, drafting of the manuscript, literature review: I.G and V.S. Formal analysis, writing-original draft, editing: I.G, L.Z and V.S. Final approval of the manuscript: I.G, V.S. and L.Z. Supervision and project administration: V.S. All authors contributed to the conduct of this study.

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