REVIEW

OPEN ACCESS

MEDICA

(International Medical Scientific Journal)
Vol.8, No.10, October 2026, pp. 1145 – 1156
ISSN 2622-660X (Online), ISSN 2622-6596 (Print)
https://doi.org/10.53770/medica.v8i10.1329



Antimicrobial Photodynamic Therapy Targeting Streptococcus mutans Biofilm for Caries Prevention in Pediatric Dentistry: A Scoping Review

Etika Ayu Sondang Tera Wati[1], Arifah Ratna Dewi[1], Indra Bramanti[1], Putri Kusuma Wardani Mahendra[1]✉

[1] Specialist Program in Pediatric Dentistry, Faculty of Dentistry, Universitas Gadjah Mada, Yogyakarta, Indonesia

Article Info

Article History:
Received:
29 July 2026
Revised:
08 October 2026
Accepted:
15 October 2026
Published:
31 October 2026

Keywords:
Antimicrobial Photodynamic Therapy
Streptococcus Mutans
Dental Caries
Pediatric Dentistry

Citation:
Wati, E.A.S.T., Dewi, A.R., Bramanti, I., & Mahendra, P.K.W. (2026). Antimicrobial Photodynamic Therapy Targeting Streptococcus mutans Biofilm for Caries Prevention in Pediatric Dentistry: A Scoping Review. *MEDICA (International Medical Scientific Journal)*, 8(10), 1145–1156. https://doi.org/10.53770/medica.v8i10.1329

Abstract

Dental caries in children is largely associated with Streptococcus mutans biofilms, which may be controlled using minimally invasive antimicrobial photodynamic therapy (aPDT). This scoping review aimed to map the current evidence regarding the application of aPDT against Streptococcus mutans biofilms for pediatric caries prevention. The review was conducted in accordance with the PRISMA-ScR guidelines using ScienceDirect, PubMed, ProQuest, and SpringerLink. The literature search covered studies published between January 2021 and July 2026, with eligibility restricted to original, English-language, full-text research articles investigating aPDT against Streptococcus mutans or cariogenic biofilms. A total of 2,365 records were identified from the four databases. After duplicate removal and exclusion of studies available only as abstracts, 429 articles underwent title and abstract screening. Eligible studies were subsequently assessed in full text according to the predefined selection criteria, resulting in the inclusion of eight original studies in the qualitative synthesis. The included studies generally reported reductions in Streptococcus mutans viability and biofilm formation following aPDT. Individual studies also reported reductions in bacterial virulence factors, enhanced enamel remineralization when aPDT was combined with titanium tetrafluoride, and improved antimicrobial performance using nanotechnology-based delivery systems. The available evidence suggests that aPDT may have potential as an adjunctive minimally invasive approach for controlling cariogenic biofilms in pediatric dentistry. However, because the evidence is predominantly laboratory-based, well-designed clinical studies are needed to establish its long-term efficacy, safety, and clinical applicability in children.

COPYRIGHT & LICENSING
Copyright © 2026 MEDICA (International Medical Scientific Journal). Published by Borneo Scientific Publishing.
This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

Corresponding Author:
✉ Putri Kusuma Wardani Mahendra
Specialist Program in Pediatric Dentistry, Faculty of Dentistry, Universitas Gadjah Mada, Yogyakarta, Indonesia
Email: putrikusuma_64@ugm.ac.id

1. INTRODUCTION

Dental caries is among the most common chronic diseases worldwide and continues to impose a substantial public health burden despite advances in preventive dentistry (Giacaman et al., 2022; Pitts et al., 2021). Global epidemiological evidence shows that untreated caries in primary teeth affects approximately 9% of the world's child population and ranks among the ten most prevalent health conditions globally, while untreated caries in permanent teeth affects more than 2.4 billion people worldwide (Barranca-Enríquez & Romo-González, 2022). The prevalence of Early Childhood Caries (ECC) increases markedly with age, ranging from 12-27% among children aged 2-3 years and reaching 27-48% in those aged 4-6 years (Ribeiro & Paster, 2023). Besides causing pain and infection, dental caries negatively affects nutrition, speech development, school attendance, and quality of life, while creating considerable economic burdens for families and healthcare systems. These findings show that dental caries remains a persistent global health challenge, particularly during early childhood when prevention is most critical. Given the high burden of childhood caries, preventing disease progression has become a central focus of pediatric dentistry (Han et al., 2025).

The development of dental caries is strongly associated with the establishment of cariogenic biofilms, in which Streptococcus mutans recognized as an important cariogenic microorganism (Spatafora et al., 2024). This bacterium adheres efficiently to tooth surfaces, synthesizes extracellular polysaccharides that facilitate biofilm maturation, produces organic acids through carbohydrate metabolism, and survives in acidic environments, thereby contributing to enamel demineralization and lesion progression. Molecular studies have consistently shown that Streptococcus mutans is strongly associated with severe early childhood caries (S-ECC), particularly among children younger than 36 months of age (Lu et al., 2023). Interactions between Streptococcus mutans and other microorganisms, especially Candida albicans, may further enhance biofilm pathogenicity and increase caries severity (Li et al., 2023). Because primary teeth possess thinner enamel and dentin than permanent teeth, biofilm-mediated demineralization can progress rapidly in children.

Conventional caries prevention relies primarily on mechanical plaque removal, fluoride therapy, and antimicrobial agents such as chlorhexidine (Katrak et al., 2026). Although these approaches have shown clinical effectiveness, their success often depends on patient compliance, which may be difficult to achieve in young children. Moreover, prolonged use of chemical antimicrobials may be associated with undesirable effects, including tooth staining, taste alteration, mucosal irritation, and concerns regarding bacterial adaptation. These limitations have encouraged the development of minimally invasive antimicrobial strategies capable of disrupting cariogenic biofilms while potentially reducing reliance on conventional antimicrobial agents. Among these approaches, antimicrobial photodynamic therapy (aPDT) has attracted increasing attention because it combines a photosensitizer with light of an appropriate wavelength to generate reactive oxygen species that inactivate microorganisms through multiple cellular targets (Polat & Kang, 2021). Experimental evidence suggests that the localized action of aPDT may reduce bacterial viability with limited effects on surrounding tissues. However, its safety and clinical effectiveness in pediatric patients require further investigation.

In recent years, growing research has investigated various photosensitizers, light sources, and nanotechnology-based delivery systems to improve the antimicrobial performance of aPDT against Streptococcus mutans (Panda et al., 2024). Natural compounds such as curcumin, phycocyanin, emodin, and Brazilian green propolis, as well as conventional photosensitizers including toluidine blue O, have shown encouraging antibacterial activity in experimental studies (Afrasiabi et al., 2022; Fiegler-Rudol et al.,

2025). In addition, nanoparticle formulations and combination therapies have been developed to enhance photosensitizer stability, improve penetration into mature biofilms, and increase treatment efficacy. Nevertheless, the available evidence remains scattered across different experimental models, treatment protocols, irradiation parameters, and outcome measurements. Moreover, the available evidence is predominantly derived from in vitro and ex vivo studies, with limited evidence directly involving pediatric clinical populations. To date, no comprehensive scoping review has specifically mapped the recent evidence regarding the application of antimicrobial photodynamic therapy against Streptococcus mutans biofilms with particular emphasis on its potential role in pediatric dentistry.

Therefore, this scoping review aims to map and synthesize evidence on the use of antimicrobial photodynamic therapy against Streptococcus mutans biofilms relevant to pediatric dentistry, focusing on photosensitizers, treatment protocols, antimicrobial outcomes, and technological approaches such as nanotechnology-based delivery systems and combination therapies. The review also identifies evidence gaps, particularly the limited pediatric clinical evidence, to inform future research on the potential application of aPDT in pediatric caries prevention.

2. METHODS

This scoping review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines (Peters et al., 2020). The review process followed the stages of identifying the research question, identifying relevant studies, selecting eligible studies, charting the data, and collating, summarizing, and reporting the findings. The eligibility criteria and review scope were structured using the Population, Concept, and Context (PCC) framework. The population comprised *Streptococcus mutans* biofilms or cariogenic biofilms, the concept focused on antimicrobial photodynamic therapy (aPDT), and the context was pediatric dentistry and caries prevention.

A literature search was conducted in four electronic databases: ScienceDirect, PubMed, ProQuest, and SpringerLink. The search was conducted in July 2026 and covered studies published from January 2021 to July 2026. The search strategy was adapted to the indexing and search functions of each database using combinations of keywords related to antimicrobial photodynamic therapy, *Streptococcus mutans*, biofilm, caries, and pediatric dentistry.

Studies were included if they were original research articles published in English between January 2021 and July 2026, available in full text, and investigated the use of aPDT against *Streptococcus mutans* or cariogenic biofilms relevant to caries prevention in pediatric dentistry. Studies were excluded if they were review articles, unrelated to aPDT, did not involve *Streptococcus mutans* or cariogenic biofilms, were published before 2021, were not written in English, did not provide full-text access, or were not original research.

A total of 2,365 records were identified from the four databases, comprising 456 records from ScienceDirect, 23 from PubMed, 1,682 from ProQuest, and 204 from SpringerLink. After the removal of duplicate records and studies available only as abstracts, 429 records remained for eligibility assessment. The study selection process was conducted by all authors in accordance with the predetermined eligibility criteria. Following full-text assessment, 421 articles were excluded based on the eligibility criteria, resulting in 8 studies being included in the final review.

The screening and study selection procedures were conducted by all authors, and all decisions regarding study eligibility were discussed and agreed upon collectively. Data

charting was performed according to the established review procedures to ensure that relevant information from each included study was consistently recorded and synthesized. The review protocol was developed for the purposes of this scoping review but was not registered in a public review registry. Figure 1 shows the identification and selection process of studies through the databases.

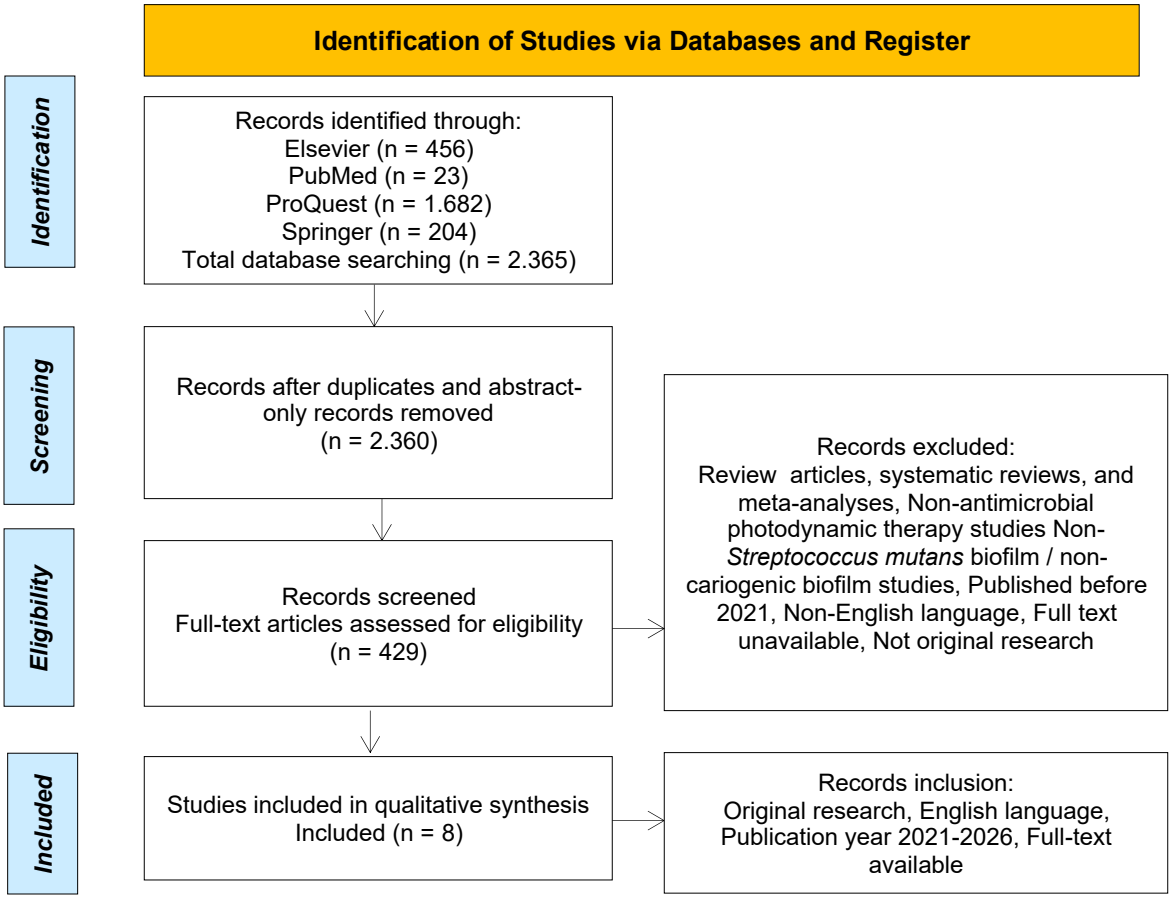


Figure 1. PRISMA Flow Diagram.

3. RESULTS AND DISCUSSION

This scoping review included eight original research studies investigating the use of antimicrobial photodynamic therapy (aPDT) against *Streptococcus mutans* and cariogenic biofilms in experimental models relevant to caries prevention in pediatric dentistry. The selected studies were conducted in three countries, including Iran (n = 5), Brazil (n = 2), and India (n = 1). Based on study design, seven studies were conducted in vitro and one study was conducted ex vivo. The experimental models included bacterial suspensions, single and dual-species biofilms, primary tooth dentin, and enamel surfaces. No randomized clinical trials or in vivo human studies meeting the eligibility criteria were identified.

The included studies evaluated a wide range of photosensitizers and delivery systems for aPDT. Conventional photosensitizers included toluidine blue O (TBO), phycocyanin, curcumin, nano-curcumin, erythrosine, Brazilian green propolis, and emodin, whereas several studies investigated advanced formulations, including curcumin-loaded nanocapsules, nanoliposome-loaded improved toluidine blue O (NLITBO), and emodin-

chitosan nanoparticles. The light sources included red LEDs, blue LEDs, and diode lasers, with reported wavelengths ranging from 450 to 650 nm.

The primary outcomes evaluated across the included studies consisted of bacterial viability measured by colony-forming units (CFU), biofilm biomass, reactive oxygen species (ROS) generation, minimum inhibitory concentration (MIC), zone of inhibition (ZOI), extracellular DNA (eDNA), lactic acid production, expression of virulence-associated genes such as *gtfB*, and enamel remineralization. Across the included studies, aPDT generally reduced *Streptococcus mutans* viability, biofilm-related outcomes, or bacterial metabolic activity under the respective experimental conditions. The magnitude of the observed effects varied according to the photosensitizer, concentration, light source, irradiation parameters, comparator, and outcome measure. Several investigations also reported changes in virulence-related outcomes, including reductions in eDNA, lactic acid production, and *gtfB* expression, while the study combining TBO-mediated aPDT with TiF4 reported increased enamel Ca/P ratios.

The evidence was predominantly generated using laboratory-based experimental models. One study evaluated *S. mutans* on primary tooth dentin, while other studies used human enamel disks or enamel slabs, bacterial suspensions, or laboratory biofilms. These findings suggest that aPDT may have potential relevance to pediatric dentistry, particularly for controlling *S. mutans* and cariogenic biofilms, although the observed effects were obtained under experimental conditions and require further validation in clinical pediatric populations. Accordingly, the available evidence suggests potential applicability of aPDT as an adjunctive approach in pediatric caries prevention, but its clinical effectiveness in children cannot yet be established based on the predominantly in vitro and ex vivo evidence. The characteristics and principal findings of the included studies are shown in Table 1.

Table 1. Characteristics and principal findings of studies evaluating antimicrobial photodynamic therapy (aPDT) against *Streptococcus mutans* and cariogenic biofilms.

Authors	Study Setting	Photosensitizer	Light source and wavelength	Comparator
Alkidsawy et al. (2026)	In vitro; mature S. mutans biofilm	TBO with naringenin (NAR)	Red LED, 630 nm, 60 J/cm²	Untreated control, TBO alone, NAR alone, LED alone, TBO + LED, and 0.2% CHX
Abbasianfar et al. (2024)	In vitro; S. mutans bacterial model	Phycocyanin (2.5, 5, and 10 mg/mL)	Diode laser, 635 nm; 400 and 500 mW	Untreated control and phycocyanin without laser
Moradi et al. (2024)	In vitro; S. mutans and Lactobacillus acidophilus dual-species biofilm on human enamel disks	Phycocyanin (PC) or TBO combined with sodium fluoride varnish (FV) or TiF4	Diode laser, 635 nm	Saline control, PC alone, TBO alone, FV alone, and TiF4 alone

Authors	Study Setting	Photosensitizer	Light source and wavelength	Comparator
Erckmann et al. (2025)	In vitro; S. mutans-contaminated primary tooth dentin	Curcumin-loaded zein nanocapsules (nano-curcumin)	Diode laser; wavelength not specified in the provided article text	Untreated control, nano-curcumin alone, and diode laser alone
de Oliveira et al. (2023)	In vitro; single- and dual-species biofilms of S. mutans and Candida albicans	Brazilian green propolis extracts (BGP-AF and BGP-AG)	Light irradiation parameters not specified in the provided article text	Extracts/fractions without aPDT and control groups
Ahrari et al. (2024)	In vitro; planktonic and S. mutans biofilm cultures	Curcumin, nano-curcumin, and erythrosine	Blue LED, 450 nm	0.12% CHX positive control and PS/light-free negative control
Panda et al. (2024)	In vitro; S. mutans suspension	Nanoliposome-loaded improved TBO (NLITBO)	Red light, 650 nm, 0.1 W/cm², 9-9.1 J/cm², 90 s	2% chlorhexidine gluconate and untreated/control conditions
Pourhajibagher et al. (2022)	Ex vivo; S. mutans biofilm on enamel slabs	Emodin-chitosan nanoparticles (Emo-CS-NPs)	Blue laser, wavelength not specified in the provided article text	Untreated/control biofilm

Table 2. Main outcomes and principal findings.

Authors	Main Outcomes	Principal Findings
Alkidsawy et al. (2026)	CFU, crystal violet biofilm biomass	NAR showed a synergistic interaction with low-concentration TBO (FICI = 0.375). NAR + TBO-mediated aPDT significantly reduced viable counts and biofilm compared with the control and enhanced the effect of low-concentration TBO.
Abbasianfar et al. (2024)	CFU/mL	The greatest bacterial reduction was observed with 2.5 mg/mL phycocyanin combined with a 500 mW diode laser. Higher laser power was associated with greater bacterial reduction, while the effect of aPDT decreased with increasing phycocyanin concentration.
Moradi et al. (2024)	Biofilm reduction, Ca/P ratio, FESEM	TBO-mediated aPDT combined with TiF4 showed superior antibiofilm activity among the combined treatments and produced the highest Ca/P ratio.

Authors	Main Outcomes	Principal Findings
Erckmann et al. (2025)	CFU, cytotoxicity, physicochemical properties	Nano-curcumin and PDT-treated nano-curcumin significantly reduced *S. mutans* CFU compared with controls. The PDT-enhanced formulation produced the greatest reduction, although the difference from non-photosensitized nano-curcumin was not statistically significant.
de Oliveira et al. (2023)	CFU, ROS, cytotoxicity, regrowth, color stability	BGP-mediated aPDT produced reductions greater than 3 log10 CFU/mL in single- and dual-species biofilms, generated singlet oxygen, and delayed microbial regrowth after 24 h. BGP-AF showed 72.41% oral keratinocyte viability.
Ahrari et al. (2024)	CFU/mL	PDT with curcumin and erythrosine significantly reduced *S. mutans* viability in planktonic and biofilm forms. The highest cell killing was observed with curcumin 3 g/L and erythrosine 250 µmol/L, whereas nano-curcumin showed lower antibacterial activity.
Panda et al. (2024)	ZOI, MIC, physicochemical characteristics	NLITBO showed antibacterial activity without light based on ZOI and demonstrated a MIC of 0.6 µg/mL under the reported photodynamic conditions. Its ZOI was comparable to that of 2% chlorhexidine gluconate.
Pourhajibagher et al. (2022)	ROS, cell viability, metabolic activity, eDNA, lactic acid, *gtfB* expression	Emo-CS-NPs-mediated aPDT generated ROS and significantly reduced *S. mutans* viability and metabolic activity. It also reduced eDNA levels by 48%, lactic acid production by 72.4%, and downregulated *gtfB* expression by 7.8-fold compared with the control.

One of the most consistent observations emerging from this review is that the antimicrobial efficacy of aPDT depends greatly on the selection of the photosensitizer and the method used to deliver it. Alkidsawy et al. (2026) reported that combining naringenin with toluidine blue O (TBO) enhanced antibacterial activity, allowing lower concentrations of TBO to produce antimicrobial effects comparable with higher doses while reducing *Streptococcus mutans* biofilm ($p<0.0001$). This finding suggests that photosensitizer combinations may improve treatment efficiency without increasing chemical exposure, although the relevance of this approach to pediatric treatment requires further clinical evaluation (Silva et al., 2023). Similarly, Panda et al. (2024) reported that nanoliposome-loaded improved toluidine blue O (NLITBO) exhibited physicochemical stability together with antibacterial activity comparable to chlorhexidine, indicating that nanocarrier systems may influence photosensitizer performance under experimental conditions. The potential for improved penetration into mature biofilms should be interpreted cautiously because direct evidence of deeper biofilm penetration was not established across the included studies. Collectively, these studies suggest that optimizing the chemical composition and

delivery system of photosensitizers may influence the antimicrobial performance of aPDT, although its clinical effectiveness remains to be established (Raphaelle et al., 2021).

The findings further indicate that naturally derived photosensitizers may represent an area for further investigation in pediatric caries prevention. Abbasianfar et al. (2024) reported that phycocyanin-mediated aPDT reduced *Streptococcus mutans*, with the greatest antibacterial effect achieved using 2.5 mg/mL phycocyanin activated by a 500 mW diode laser, indicating that irradiation parameters and photosensitizer concentration may both influence antimicrobial activity under the tested conditions. Likewise, Ahrari *et al*. (2024) found that both curcumin- and erythrosine-mediated aPDT reduced bacterial viability in planktonic and biofilm forms, whereas nano-curcumin showed comparatively lower antibacterial activity under the tested conditions. In addition, de Oliveira et al. (2023) reported that Brazilian green propolis-mediated aPDT reduced *Streptococcus mutans* biofilms by more than 3 log10 CFU/mL while generating singlet oxygen and maintaining the reported level of oral keratinocyte viability. Together, these findings suggest that naturally derived photosensitizers warrant further investigation as potential alternatives to conventional antimicrobial agents, but their suitability for repeated pediatric use and long-term caries prevention cannot yet be established from the available laboratory evidence (Doğru & Akgün, 2026).

The application of nanotechnology has also provided experimental evidence for alternative photosensitizer delivery systems in antimicrobial photodynamic therapy. Erckmann et al. (2025) evaluated curcumin-loaded nanocapsules on primary tooth dentin contaminated with *Streptococcus mutans* and reported cytocompatibility together with antibacterial activity. Importantly, this was the only study included in the review that directly used primary tooth substrates, making its findings particularly relevant when considering pediatric dentistry, although they do not constitute direct evidence of clinical effectiveness in children. Photodynamic activation further enhanced bacterial reduction, although the difference from non-photosensitized nano-curcumin was not statistically significant. Similar findings were reported by Panda et al. (2024), where nanoliposome-loaded TBO demonstrated antibacterial activity and physicochemical stability under the tested conditions. These findings indicate that nanotechnology may offer alternative approaches to photosensitizer delivery, but evidence regarding superior delivery, long-term safety, or clinical benefit remains limited.

Combination therapy emerged as an important theme identified in this review because several studies indicated that aPDT may have additional effects when combined with other preventive agents. Moradi et al. (2024) reported that TBO-mediated aPDT combined with titanium tetrafluoride (TiF_4) produced antibiofilm activity and the highest enamel Ca/P ratio among the evaluated combined treatments. This finding suggests that combining antimicrobial treatment with fluoride-based interventions may simultaneously influence biofilm control and enamel mineral characteristics under experimental conditions. However, the observed Ca/P changes should not be interpreted as evidence that aPDT directly restores carious lesions or provides superior clinical remineralization in children. The integration of antimicrobial and remineralization-related effects may warrant further investigation in pediatric caries prevention, particularly in early enamel lesions, but clinical studies are needed to determine whether such combinations provide additional benefits over established preventive treatments.

Beyond reducing bacterial viability, several studies reported effects of aPDT on virulence-related outcomes associated with cariogenic biofilms. Pourhajibagher et al. (2022) reported that emodin-chitosan nanoparticle-mediated aPDT reduced biofilm-associated activity while simultaneously decreasing extracellular DNA production,

reducing lactic acid synthesis, and downregulating the *gtfB* virulence gene. Because extracellular DNA contributes to biofilm structural stability and *gtfB* is responsible for glucan production that facilitates bacterial adhesion, suppression of these virulence factors may contribute to reduced biofilm development under experimental conditions. In addition, lower lactic acid production may reduce acidogenic activity relevant to enamel demineralization. These observations suggest that the effects of aPDT may extend beyond direct bacterial viability to several measurable biofilm-associated characteristics. However, whether these laboratory findings translate into reduced caries development or broader clinical protection remains uncertain, particularly in the absence of pediatric clinical or in vivo evidence.

The studies included in this review also provide preliminary laboratory evidence regarding the biological compatibility of selected aPDT formulations. Erckmann et al. (2025) reported favorable cytocompatibility of curcumin-loaded nanocapsules together with antibacterial activity on primary tooth dentin, while de Oliveira et al. (2023) reported oral keratinocyte viability following exposure to Brazilian green propolis-mediated aPDT. These findings are relevant because preventive interventions in children should minimize tissue damage while preserving oral tissues. Unlike systemic antibiotics, aPDT acts locally through photoactivation-dependent generation of reactive oxygen species, which may limit antimicrobial activity to the treated area under controlled conditions. Nevertheless, the available cytocompatibility findings were obtained from limited experimental models and short-term assessments, so they cannot establish long-term biocompatibility or suitability for repeated preventive use in children.

Despite the generally favorable laboratory findings, several limitations of the available evidence should be acknowledged. Seven of the eight included studies were conducted using in vitro experimental models, whereas only Pourhajibagher et al. (2022) employed an ex vivo design, and no eligible in vivo investigations or randomized clinical trials involving pediatric patients were identified. Furthermore, substantial heterogeneity was observed in the evaluated photosensitizers, laser wavelengths, irradiation power, exposure duration, delivery systems, and outcome measurements, making direct comparison between studies difficult. Differences in experimental protocols may also influence antimicrobial performance, thereby limiting the generalizability of individual findings to clinical settings. Laboratory conditions cannot fully reproduce the complexity of the oral environment, where saliva, host responses, dietary factors, and multispecies biofilms may influence treatment outcomes. Therefore, standardized experimental protocols together with well-designed clinical trials involving children are required before the clinical effectiveness and routine use of aPDT in pediatric dentistry can be determined.

4. CONCLUSION

Antimicrobial photodynamic therapy (aPDT) may represent a potential minimally invasive approach for controlling Streptococcus mutans and cariogenic biofilms relevant to pediatric dental caries. Across the eight included studies, various photosensitizers, including toluidine blue O, phycocyanin, curcumin, Brazilian green propolis, emodin, and nanotechnology-based formulations, generally demonstrated antimicrobial or antibiofilm activity under the respective experimental conditions, with some studies also reporting changes in bacterial virulence-related outcomes and enamel mineral characteristics. These findings suggest that optimization of photosensitizer formulations, irradiation parameters, and delivery systems may improve the performance of aPDT, although its effectiveness for pediatric caries prevention has not yet been established. However, the available evidence was predominantly derived from in vitro and ex vivo studies, with no eligible pediatric clinical or in vivo human studies identified. Therefore, conclusions

regarding routine clinical use, long-term efficacy, safety, or clinical caries-preventive benefits in children cannot yet be drawn. Standardized protocols and well-designed clinical studies involving pediatric populations are needed to determine the clinical effectiveness and applicability of aPDT before its implementation in routine pediatric dental practice.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHICAL CONSIDERATIONS

Not applicable.

AUTHOR CONTRIBUTIONS

Etika Ayu Sondang Tera Wati conceived and designed the study, developed the research methodology, conducted the literature search and screening, performed data extraction and analysis, and drafted the original manuscript. Arifah Ratna Dewi contributed to the study design, literature screening, data extraction, interpretation of findings, and critical revision of the manuscript. Indra Bramanti contributed to the research methodology, data analysis and interpretation, and critically reviewed and revised the manuscript. Putri Kusuma Wardani Mahendra contributed to literature screening, data management, interpretation of findings, and manuscript revision. All authors read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the Specialist Program in Pediatric Dentistry, Faculty of Dentistry, Universitas Gadjah Mada, Indonesia, for providing support and facilities that contributed to the completion of this study.

FUNDING

This research received no external funding.

DECLARATION OF ARTIFICIAL INTELLIGENCE USE

The authors declare that no generative artificial intelligence (AI) or AI-assisted technologies were used in the preparation, writing, analysis, or revision of this manuscript.

REFERENCES

Abbasianfar, Z., Seraj, B., Afrasiabi, S., Fard, M. J. K., Ghadimi, S., & Chiniforush, N. (2024). The effect of antimicrobial photodynamic therapy using different concentrations of phycocyanin against Streptococcus mutans. *Photodiagnosis and Photodynamic Therapy*, 50, 104384. https://doi.org/10.1016/j.pdpdt.2024.104384

Afrasiabi, S., Partoazar, A., Chiniforush, N., & Goudarzi, R. (2022). The potential application of natural photosensitizers used in antimicrobial photodynamic therapy against oral infections. *Pharmaceuticals*, 15(6), 1–11. https://doi.org/10.3390/ph15060767

Ahrari, F., Nazifi, M., Mazhari, F., Ghazvini, K., Menbari, S., Fekrazad, R., Babaei, K., & Banihashemrad, A. (2024). Photoinactivation effects of curcumin, nano-curcumin, and erythrosine on planktonic and biofilm cultures of Streptococcus mutans. *Journal of Lasers in Medical Sciences*, 15(1), e7. https://doi.org/10.34172/JLMS.2024.07

Alkidsawy, A., Younespour, S., & Afrasiabi, S. (2026). Toluidine blue O-mediated antimicrobial photodynamic inactivation reinforced with naringenin against Streptococcus mutans biofilms. *Photodiagnosis and Photodynamic Therapy*, 59, 105465. https://doi.org/10.1016/j.pdpdt.2026.105465

Barranca-Enríquez, A., & Romo-González, T. (2022). Your health is in your mouth: A comprehensive view to promote general wellness. *Frontiers in Oral Health*, 3, 1–14. https://doi.org/10.3389/froh.2022.971223

de Oliveira, A. B., Ferrisse, T. M., França, G. G., de Annunzio, S. R., Kopp, W., Fontana, C. R., & Brighenti, F. L. (2023). Potential Use of Brazilian Green Propolis Extracts as New Photosensitizers for Antimicrobial Photodynamic Therapy against Cariogenic Microorganisms. *Pathogens*, 12(2), 155. https://doi.org/10.3390/pathogens12020155

Doğru, P., & Akgün, Ö. M. (2026). Applications of photodynamic therapy in pediatric dentistry. *HRU International Journal of Dentistry and Oral Research*, 6(1), 67–72. https://doi.org/10.61139/ijdor.1809455

Erckmann, M. C., Almeida, A., Dominguini, D., Becker, D., Rutz, J. K., Hotza, D., Parolia, A., Dos Santos, V. V., Nunes, M. R., Da Rosa, C. G., & Masiero, A. V. (2025). Curcumin-photosensitized nanocapsules: biocompatibility and antimicrobial evaluation in primary tooth dentin contaminated with Streptococcus mutans. *Frontiers in Cellular and Infection Microbiology*, 15, 1–12. https://doi.org/10.3389/fcimb.2025.1614363

Fiegler-Rudol, J., Skaba, D., Truchel, D., Misiołek, M., & Wiench, R. (2025). Effectiveness of natural photosensitizers in antimicrobial photodynamic therapy within dentistry: a systematic review of RCTs. *Journal of Clinical Medicine*, 14(24), 1–15. https://doi.org/10.3390/jcm14248894

Giacaman, R., Constanza, F., Cecilia Muñoz, S., & Soraya, L. (2022). Understanding dental caries as a non-communicable and behavioral disease: Management implications. *Frontiers in Oral Health*, *3*(764479), 1–10.

Han, S. Y., Chang, C. L., Wang, Y. L., Wang, C. S., Lee, W. J., Vo, T. T. T., Chen, Y. L., Cheng, C. Y., & Lee, I. T. (2025). A narrative review on advancing pediatric oral health: comprehensive strategies for the prevention and management of dental challenges in children. *Children*, 12(3), 1–17. https://doi.org/10.3390/children12030286

Katrak, C., Reed, S., Carter, M., Khatib, M., Peterson, A., Martin, K., Kajfasz, J. K., & Abranches, J. (2026). Oral hygiene agents at work: effects on Streptococcus mutans and caries risk. *Frontiers in Cellular and Infection Microbiology*, 16, 1–9. https://doi.org/10.3389/fcimb.2026.1768512

Li, Y., Huang, S., Du, J., Wu, M., & Huang, X. (2023). Current and prospective therapeutic strategies: tackling Candida albicans and Streptococcus mutans cross-kingdom biofilm. *Frontiers in Cellular and Infection Microbiology*, 13, 1–16. https://doi.org/10.3389/fcimb.2023.1106231

Lu, Y., Lin, Y., Li, M., & He, J. (2023). Roles of Streptococcus mutans-Candida albicans interaction in early childhood caries: a literature review. *Frontiers in Cellular and Infection Microbiology*, 13, 1–7. https://doi.org/10.3389/fcimb.2023.1151532

Moradi, Z., Baghbani, F., Kermanshah, H., Chiniforush, N., & Afrasiabi, S. (2024). Destruction of cariogenic biofilms by antimicrobial photodynamic therapy mediated by phycocyanin and toluidine blue along with sodium fluoride varnish or titanium tetrafluoride. *Photodiagnosis and Photodynamic Therapy*, 49, 104296. https://doi.org/10.1016/j.pdpdt.2024.104296

Panda, S., Rout, L., Mohanty, N., Satpathy, A., Satapathy, B. S., Rath, S., & Gopinath, D. (2024). Exploring the photosensitizing potential of nanoliposome loaded improved toluidine blue O (NLITBO) against Streptococcus mutans: An in-vitro feasibility study. *PLoS ONE*, 19 (10), 1–14. https://doi.org/10.1371/journal.pone.0312521

Peters, M. D. J., Marnie, C., Tricco, A. C., Pollock, D., Munn, Z., Alexander, L., McInerney, P., Godfrey, C. M., & Khalil, H. (2020). Updated methodological guidance for the conduct of scoping reviews. *JBI Evidence Synthesis*, 18(10), 2119–2126. https://doi.org/10.11124/JBIES-20-00167

Pitts, N. B., Twetman, S., Fisher, J., & Marsh, P. D. (2021). Understanding dental caries as a non-communicable disease. *British Dental Journal*, 231(12), 749–753. https://doi.org/10.1038/s41415-021-3775-4

Polat, E., & Kang, K. (2021). Natural photosensitizers in antimicrobial photodynamic therapy. *Biomedicines*, 9(6), 1–30. https://doi.org/10.3390/biomedicines9060584

Pourhajibagher, M., Keshavarz Valian, N., & Bahador, A. (2022). Theranostic nanoplatforms of emodin-chitosan with blue laser light on enhancing the anti-biofilm activity of photodynamic therapy against Streptococcus mutans biofilms on the enamel surface. *BMC Microbiology*, 22(1), 1–16. https://doi.org/10.1186/s12866-022-02481-6

Raphaelle, Y., Muller, M., Balasini, A., Thetiot, F., & Marekie, M. (2021). Antimicrobial photodynamic therapy: latest developments with a focus on combinatory strategies. *Pharmaceutics*, 13(12), 1–56. https://doi.org/10.3390/pharmaceutics13121995

Ribeiro, A. A., & Paster, B. J. (2023). Dental caries and their microbiomes in children: what do we do now? *Journal of Oral Microbiology*, 15(1), 2198433. https://doi.org/10.1080/20002297.2023.2198433

Silva, T., Lunardi, A. J. L., Barros, A. C. S. M., Mandetta, A. R. H., Grudzien, E., San-Martín, M., Horliana, A. C. R. T., Bussadori, S. K., & Motta, L. J. (2023). Application of photodynamic therapy in pediatric dentistry: literature review. *Pharmaceutics*, 15(9), 1–14. https://doi.org/10.3390/pharmaceutics15092335

Spatafora, G., Li, Y., He, X., Cowan, A., & Tanner, A. C. R. (2024). The evolving microbiome of dental caries. *Microorganisms*, 12(1), 121. https://doi.org/10.3390/microorganisms12010121