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Health Literacy Based Health Promotion Strategy for the Prevention of Periodontal Disease Caused by *Porphyromonas gingivalis* in Communities Exposed to Environmental Heavy Metals: A Scoping Review

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Health Literacy;
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ABSTRACT

Introduction: Periodontal disease in communities exposed to environmental heavy metals represents not only a biological problem but also a public health challenge closely linked to limitations in health literacy. While the pathogenic role of *Porphyromonas gingivalis* and the toxic effects of heavy metals such as Pb, Cd, and Hg contribute to inflammation and periodontal tissue damage, insufficient health literacy constrains individuals' capacity to recognize risks, adopt preventive behaviors, and engage in effective disease prevention strategies.

Methods: A scoping review was conducted using the PEOS framework, with article searches in PubMed, ScienceDirect, EBSCO, and Google Scholar. Of the 512 articles identified, 20 met the inclusion criteria (2015–2023) and were analyzed through data charting and quality assessment.

Results: Heavy metals have been shown to increase the risk of periodontitis through immune suppression, oxidative stress, and changes in the oral microbiota. *P. gingivalis* enhances pathogenesis by disrupting epithelial defenses and triggering chronic inflammation. Increasing health literacy has been shown to be influential in encouraging preventative behaviors and managing environmental exposure risks.

Conclusion: Strengthening health literacy is a central and unifying strategy in reducing periodontal disease risk in populations exposed to environmental heavy metals. Integrating biologically informed risk communication with community-based, literacy-sensitive health promotion interventions enhances prevention efforts against periodontal disease associated with *P. gingivalis* in high-risk communities.

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INTRODUCTION

Periodontal disease is one of the most common oral health problems and has broad implications for systemic health. This condition develops due to complex interactions between pathogenic microorganisms, the host immune response, and various environmental factors (1). Porphyromonas gingivalis (*P. gingivalis*) is recognized as a key bacterium in the pathogenesis of periodontitis due to its ability to modulate the inflammatory response and disrupt the balance of the oral microbiota (2,3). Exposure to environmental heavy metals such as mercury (Hg), cadmium (Cd), and lead (Pb) can exacerbate susceptibility to periodontal infections, as these metals play a role in increasing oxidative stress, weakening immunity, and altering the dynamics of the oral microbiota (4,5). In populations living in mining or polluted areas, the risk of developing severe periodontitis tends to increase due to cumulative exposure to these heavy metals (6).

On the other hand, low public health literacy is a major obstacle to periodontal disease prevention. Health literacy encompasses an individual's ability to access, understand, assess, and apply health information in daily life (7). Low health literacy is often associated with suboptimal oral care behaviors, delays in seeking services, and low adherence to prevention programs (8). In the context of high environmental risks, such as exposure to heavy metals, improving health literacy becomes increasingly important to strengthen public awareness and capacity to reduce risk factors and promote healthy lifestyle behaviors (9).

Health literacy-based health promotion strategies are considered effective in improving understanding, decision-making skills, and preventive actions related to periodontal diseases, including those induced by pathogens such as P. gingivalis (10,11). Interventions designed with a health literacy approach have been shown to improve oral hygiene behaviors, modify risk factors, and improve periodontal health status in various population groups (12). However, literature specifically integrating health literacy, the biological risks of *P. gingivalis*, and environmental heavy metal exposure is still limited, so a more comprehensive study is needed.

Based on this background, this scoping review aims of this scoping review is to map and synthesize scientific evidence on health literacy–based health promotion strategies for the prevention of periodontal disease in communities exposed to environmental heavy metals. Rather than focusing on biological or mechanistic pathways as standalone outcomes, this review specifically examines how existing evidence on *Porphyromonas gingivalis*–related periodontal risk and heavy metal exposure can inform the design, content, and implementation of health literacy–oriented preventive interventions

METHOD

Identifying research questions

Question development is an important step that forms the basis of the entire review protocol in determining the search strategy, inclusion and exclusion criteria and data extraction. This review uses the Population, Exposure, Outcome, Study Design (PEOS) framework to help identify key concepts in the focus of the review. The PEOS framework can be seen in the table below.

Table 1. PEOS Framework

P (Population)	E (Exposure)	O (Outcome)	S (Study Design)
Individuals or communities living in mining areas, industrial zones, or polluted environments with exposure to Pb, Hg, Cd, As, or related heavy metals, and who are at elevated risk of periodontal disease	Environmental and biological risk exposures relevant to periodontal disease (1) Environmental exposure to heavy metals (Pb, Hg, Cd, As, etc.); and (2) biological exposure characterized by colonization or infection with *Porphyromonas gingivalis*	Improving public health literacy about periodontal disease. Improved preventive behavior (oral hygiene, plaque control, clean and healthy living behavior). Reduction in the risk or incidence of periodontal disease due to P. gingivalis. Increasing the community's ability to recognize the risks of heavy metal exposure and take protective measures.	Observational studies (cross-sectional, cohort, case-control); experimental and quasi-experimental interventions (including community-based health promotion); qualitative and mixed-methods studies on health literacy or health promotion; systematic, scoping, and integrative reviews relevant to health literacy, health promotion, and periodontal disease

Identifying relevant articles

There are three steps in identifying relevant articles. The first step is to determine the database. The databases used are PubMed, Sciences Direct, EBSCO and Google Scholar. The second step is to determine the inclusion and exclusion criteria. Articles are filtered according to the inclusion criteria published in 2015-2023, articles published in English, primary research articles (original articles) and review articles, and no specific country criteria, cross-sectional and descriptive research methods, retrospective, case analysis, and meta-analysis that describe data on Prevention of Periodontal Disease due to Porphyromonas gingivalis in Communities Exposed to Environmental Heavy Metals. The exclusion criteria are opinion articles, peer reviews, theses manuscripts and theses. The third step is to determine the keywords that are focused on based on the framework, expanded by determining the Thesaurus and Boolean synonyms (can be seen in table 2).

Table 2. Article search keywords

Database	Keyword Search
PubMed	(periodontal disease) OR ("periodontitis prevention") AND ("*Porphyromonas gingivalis*") OR ("oral health education") OR ("heavy metal exposure") OR ("environmental heavy metals") AND ("health literacy") OR ("health promotion")
Science Direct	(periodontal disease) OR ("periodontitis prevention") AND ("*Porphyromonas gingivalis*") OR ("oral health education") OR ("heavy metal exposure") OR ("environmental heavy metals") AND ("health literacy") OR ("health promotion")
EBSCO	(periodontal disease) OR ("periodontitis prevention") AND ("*Porphyromonas gingivalis*") OR ("oral health education") OR ("heavy metal exposure") OR ("environmental heavy metals") AND ("health literacy") OR ("health promotion")
Google Scholar	(periodontal disease) OR ("periodontitis prevention") AND ("*Porphyromonas gingivalis*") OR ("oral health education") OR ("heavy metal exposure") OR ("environmental heavy metals") AND ("health literacy") OR ("health promotion")

Selection/choice of articles

The screening process is used to assess the relevance of research identified in the search according to the desired literature characteristics. From the search using 4 databases as many as 512 articles and review articles. Then the articles are filtered based on duplication, abstract and title and full text reading. So that 20 original articles and review articles were found to be reviewed. Furthermore, a critical appraisal was carried out using the Quality Assessment tool from Hawker and the classification of the total quality of the article and the article screening process are stated in PRISMA. The flowchart in Figure 1.

Data Charting

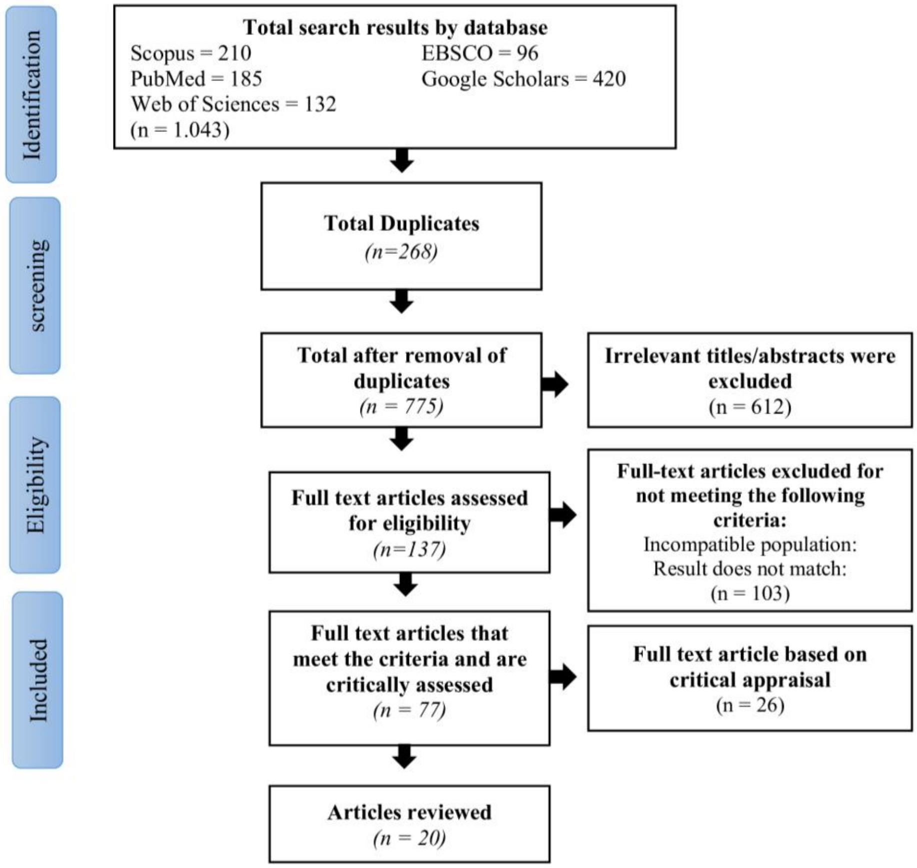

Figure 1. Flowchart

RESULTS

Table 3. Charting Data

No	Writer/ Year	Title	Objective	Sample	Method	Results
1	Peyyala R., et al (2018) (13)	Environmental lead effects on gene expression in oral epithelial cells challenged with a pathogenic oral biofilm	Assessing the effect of lead exposure on gene responses in oral epithelial cells to pathogenic biofilms.	Oral epithelial cells (in vitro)	In vitro experiments; oral epithelial cells challenged with a biofilm model; Nano String transcriptomics.	Lead exposure modulates gene responses upon exposure to biofilms: decreased expression of several chemokines (e.g. IL-8, CCL20) at certain Pb concentrations: evidence that Pb affects mucosal immune responses.

2	AW Browar, et al. (2018) (14)	Cadmium exposure disrupts periodontal bone in experimental animals: implications for periodontal disease in humans.	Assessing the effects of cadmium exposure on periodontal & bone tissues.	Sprague–Dawley rats (model)	Animal studies (experimental), chronic Cd injection, histology & micro-CT.	Cd exposure decreases periodontal bone mass and worsens alveolar resorption: evidence of Cd toxicity to periodontal tissues.
3	Jingyu Wang, Lele Du, et al. (2019) (15)	ZnO nanoparticles inhibit the activity of *Porphyromonas gingivalis* and Actinomyces naeslundii and promote the mineralization of the cementum.	Assessing the antibacterial activity of ZnO-NP against *P. gingivalis* & cell toxicity.	In vitro antibacterial & cytotoxicity (microbiolog, MTT).	*P. gingivalis* culture; mammalian cells in vitro	ZnO-NPs suppress the growth of *P. gingivalis* and exhibit antibacterial activity at concentrations that are relatively safe for mammalian cells.
4	B. Bai, et al. (2016) (16)	The anti-bacterial activity of titanium–copper sintered alloy against *Porphyromonas gingivalis*.	Assessing the antibacterial activity of Ti–Cu alloy against P. gingivalis (implant/dental application).	In-vitro: antibacterial tests, DNA quantification, DAPI staining, SEM	Ti–Cu disks (different Cu values) + *P. gingivalis* culture	Ti-Cu (especially Ti-10Cu) showed significant reduction in the number of bound *P. gingivalis* and strong antibacterial activity: potential prevention of peri-implant colonization.
5	B. Bai, et al. (2015) (17)	Biocompatibility of antibacterial Ti–Cu sintered alloy.	Assessing cellular compatibility & antibacterial activity of Ti–10Cu implants (in vivo & in vitro studies).	Ti–10Cu implants; animals (rabbits) & bacterial cultures including *P. gingivalis*	In-vitro and in-vivo (implantation in rabbit femur), biocompatibility & antibacterial analysis	Ti–10Cu exhibits strong antibacterial and adequate biocompatibility in animal models: relevant for the prevention of periodontal/peri-implant infections.
6	M. Astasov-Frauenhoffer, S. Koegel, T. Waltimo, et al. (2019) (18)	Antimicrobial efficacy of copper-doped titanium surfaces for dental implants.	Quantifying the antibacterial effect of Cu-deposited titanium surfaces against peri-implant strains such as *P. gingivalis* (DSM 20709).	Titanium discs (copper-deposited) + P. gingivalis DSM 20709	In vitro; Cu deposit via anodization; CFU counts adhesion & planktonic assays	Cu deposition reduced the viability of adherent *P. gingivalis* (up to ~3 log CFU reduction) and decreased the number of bacteria in the surrounding solution.
7	W. Chen, et al. (2019)	*Porphyromonas gingivalis* impairs oral	Investigating the mechanisms by which P.	Human oral keratinocyte cell lines + P.	In-vitro: HOK/OKF6 keratinocytes, *P. gingivalis* infection,	*P. gingivalis* decreased GRHL2 and junctional proteins

	(19)	epithelial barrier function by down-regulating the transcription factor GRHL2.	gingivalis damages the oral epithelial barrier (role of GRHL2).	gingivalis exposure	immunoblot, IF, permeability assays	(ZO-1, E-cadherin): disruption of epithelial barrier function, an important mechanism in periodontal pathogenesis.
8	E. Davis, et al. (2020) (20)	Low levels of salivary metals, oral microbiome composition, and dental decay	Correlating salivary mineral/metal levels with salivary microbiome composition & caries.	61 children & adults (saliva samples)	Cross-sectional; metal analysis (ICP-MS) + 16S rRNA microbiome sequencing	Levels of several metals (Pb, Cd, Cu, Zn, Sb, Hg, etc.) are associated with changes in the composition of the oral microbiome; metals can affect the abundance of taxa such as Porphyromonas.
9	D. Lahiri, et al. (2022) (21)	Green-synthesized ZnO nanoparticles: Anti-biofilm efficacy against Actinomyces faecalis and *Porphyromonas gingivalis*.	Evaluating the antibiofilm efficacy of "green" synthesized ZnO NPs against periodontal biofilms.	ZnO NPs + *P. gingivalis* biofilms	In-vitro biofilm assays, EPS quantification, SEM, in-silico docking	ZnO NPs significantly reduced biofilm biomass and EPS (carbohydrate/protein) ; NPs penetration damaged sessile cell DNA/RNA: decreased *P. gingivalis* viability.
10	B. Kang, et al. (2022) (22)	Cu-doped TiO_2 coating possesses excellent antibacterial property against *Porphyromonas gingivalis* and facilitates osteogenic differentiation.	Assessing the antibacterial & osteogenic profile of Cu-doped TiO_2 coatings (dental implants).	Cu-doped TiO_2 coated surfaces + P. gingivalis; BMSCs for biocompatibility	In-vitro antibacterial & cell proliferation/differentiation assays	Cu-doped coating inhibits *P. gingivalis* & supports osteogenic proliferation/differentiation of BMSC cells: potential to reduce peri-implant infection.
11	S. Giri, et al. (2022) (23)	The effect of *Porphyromonas gingivalis* on the gut microbiome of mice in relation to aging.	Assessing the effects of oral *P. gingivalis* on gut microbiome composition and the influence of age (mouse model).	Mice (young & aged) orally administered *P. gingivalis*	Animals: oral administration of *P. gingivalis*, 16S sequencing; comparison of young vs aged mice	*P. gingivalis* alter gut composition (reduce diversity), worse impact in older animals: systemic implications of oral colonization.
12	L. Zhang, et al. (2016) (24)	Characterization of the *Porphyromonas gingivalis* Manganese-responsive transcriptional	Characterizing the transcriptional regulator PgMntR that regulates Mn transporters (role in oxidative resistance & virulence).	*P. gingivalis* proteins & mutant strains (in vitro)	Molecular experiments: protein purification, DNA-binding assays, mutagenesis	PgMntR modulates the expression of the Mn transporter (feoB2); Mn/Fe homeostasis influences protection against oxidative stress; metal transport

		regulator PgMntR.				influences Pg virulence
13	B. Tort, et al. (2018) (25)	Lead exposure may affect gingival health in children.	Examining the relationship between blood lead level (BLL) and oral status (CPI, GI, PI) in children.	351 children (7–15 years)	Cross-sectional (Korean pilot data); clinical examination & BLL measurement	Higher Pb levels were associated with worse plaque & gingivitis indices (significant in some BLL quartiles).
14	H. Huang, et al. (2022) (26)	Association between levels of blood trace minerals and periodontitis among United States adults.	Assessing the relationship of trace mineral levels (Se, Mn, Pb, Cd, Hg, etc.) with periodontitis (NHANES)	4,964 US adults	Cross-sectional analysis of NHANES; periodontal examination (CAL/Pocket); multivariate regression	Pb & Cd levels are positively associated with clinical attachment loss (CAL): correlation between blood metal levels and periodontitis severity.
15	JL Ebersole, et al. (2019) (27)	Response of oral epithelial cells to pathogenic oral biofilms: gene expression profiling and modulation by environmental stressors (utilization of *P. gingivalis* data in biofilm)	Profiling the oral epithelial gene response to biofilms containing *P. gingivalis* & implications of modulation by environmental stressors (e.g. metals).	Human oral epithelial cells + multispecies biofilm (including Pg)	In-vitro biofilm challenge + transcriptomics (microarray/Nano String)	Biofilms induce widespread regulation of immune-defense genes; exposure to environmental stressors (such as heavy metals) influences expression patterns: relevant for environmental effects on periodontal pathogenesis.
16	K.A. Stanton, et al. (2021) (28)	Anti-biofilm efficacy of zinc formulations against *Porphyromonas gingivalis* virulence factors and inflammatory responses (pilot/ex vivo evidence).	To test whether zinc (solution/formulation) reduces the inflammatory response of gingival tissue driven by *P. gingivalis* LPS.	Gingival tissue models challenged with Pg LPS	Ex-vivo tissue/in-vitro assays; cytokine measurements	Zinc formulations decrease pro-inflammatory cytokine secretion and protect several tissue function parameters: zinc can modulate the virulence effects of Pg on tissues.
17	Zhida Dai, et al. (2024) (29)	Association between metal exposures and periodontitis among US adults: the potential mediating role of biological aging.	To investigate the association of metal exposure (multiple metals) with periodontitis in the US population, and the extent to which these effects are mediated by biological aging.	2,393 US adult participants from NHANES with urinary metal data (9 metals: Ba, Cd, Co, Cs, Mo, Pb, Tl, W, U) and periodontal data.	Cross-sectional analysis of NHANES data (2009–2014) using weighted logistic regression, robust Poisson, cubic splines models, as well as Bayesian kernel machine regression (BKMR) and mediation analysis.	A positive association was found between urinary Cd and Pb and periodontitis. Exposure to metal mixtures was also significantly associated with periodontitis, particularly in smokers and men. Part of the effect of metals on periodontitis is

						mediated by biological aging (aging phenotype).
18	X. Xu, et al. (2020) (30)	Antibacterial effect of copper-bearing titanium alloy and its influence on macrophage response in P. gingivalis LPS infectious microenvironment.	Assessing the impact of Ti–Cu materials on macrophages in the environment of P. gingivalis infection (in vitro)	Macrophages (in vitro) + Pg LPS + Ti–Cu material extracts	In-vitro cell assays: macrophage polarization + exposure to Pg LPS + eluate material	Ti–Cu modulates macrophage inflammatory response (reduces pro-inflammatory phenotype) under Pg infection conditions: protective mechanisms on implant surfaces.
19	Guo Y. et al. (2020) (31)	Heme competition triggers an increase in the pathogenic potential of *P. gingivalis*.	Testing how heme competition affects the virulence of P. gingivalis.	In vitro / molecular experiments.	Bacterial culture & virulence analysis.	Heme competition can enhance virulence factor expression: implications for metal & pathogenic interactions.
20	Sharaf S. et al. 2022 (32)	Modulatory mechanisms of pathogenicity in *P. gingivalis: metal/ion-related regulation*.	Reviewing the role of ions/metals (Fe, Mn, etc.) in modulating the pathogenicity of *P. gingivalis*.	Review (molecular).	Literature on metal regulation in *P. gingivalis*.	Metal transport and homeostasis influence biofilm & virulence factor expression: relevance for environmental exposure context.

DISCUSSION

Literature mapping results indicate that periodontal disease in communities exposed to heavy metals is a multifactorial condition exacerbated by complex interactions between biological agents such as *Porphyromonas gingivalis*, host immune responses, and environmental toxicological exposures. Exposure to heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and several other trace metals has been shown to affect the composition of the oral microbiota, immune function, and the severity of periodontal inflammation.

The Effect of Heavy Metal Exposure on Periodontal Susceptibility

Several studies have shown that heavy metals have a direct effect on both periodontal tissues and the mucosal immune system. Research by Peyyala et al. (2018) showed that lead exposure reduced the expression of important chemokines such as IL-8 and CCL20 in oral epithelial cells exposed to pathogenic biofilms (13), thereby weakening the initial mucosal defense against bacterial invasion such as *P. gingivalis*. These results are consistent with the findings of Ebersole et al. (2019) that environmental stressors, including metals, can modulate immune gene responses to pathogenic biofilms (27).

At the hard tissue level, an animal study by Browar et al. (2018) showed that cadmium triggers a decrease in periodontal bone mass and exacerbates alveolar resorption (14). This is supported by epidemiological data from Tort et al. (2018) and Huang et al. (2022), which found a significant association between blood Pb/Cd levels and high gingivitis and periodontitis patient indexes in both children and adults (25,26). Furthermore, a NHANES analysis by Dai et al. (2024) confirmed that combined multi-metal exposure ("metal mixture") significantly increases the risk of periodontitis, with biological aging as an important mediator (29).

These findings indicate that communities living in areas contaminated with heavy metals have multiple vulnerabilities, including decreased immune function, periodontal bone damage, and changes in the oral microbiota.

The Role of *Porphyromonas gingivalis* in Exacerbating the Impact of Metal Exposure

*P. gingivalis*acts as a keystone pathogen that can compromise immune homeostasis and trigger chronic inflammation. A study by Chen et al. (2019) showed that *P. gingivalis* is able to downregulate GRHL2, a transcription factor important for epithelial barrier integrity, thereby increasing tissue permeability and facilitating bacterial invasion (19). The interaction of metals and bacterial virulence was also demonstrated by Zhang et al. (2016) who found that disrupted Mn/Fe homeostasis has the potential to increase the virulence of *P. gingivalis* (24), and Guo et al. (2020) who showed that heme competition can increase the expression of bacterial virulence factors (31).

When heavy metal exposure has weakened mucosal immune function (13,20) *P. gingivalis* infection is more likely to develop and trigger more severe tissue damage. The combination of metal exposure and highly virulent bacterial infection increases the risk of moderate to severe periodontitis.

Heavy Metals, Microbiota, and Dysbiosis

Changes in microbiota composition due to metal exposure were demonstrated by Davis et al. (2020), who found a significant association between salivary metal concentrations such as Pb, Cd, Cu, and Zn and shifts in the microbiome profile, including a relative increase in the Porphyromonas genus (20). Animal studies have shown that *P. gingivalis* colonization can have systemic effects, such as altering the gut microbiota and reducing microbiome diversity, particularly in aging individuals (23).

Overall, these findings suggest that heavy metals are not only toxic to tissues, but also a driving factor in microbiota dysbiosis, which reinforces the dominance of pathogenic bacteria such as *P. gingivalis*.

Material and Technology Interventions as Support for Periodontal Prevention

Several studies in the table discuss innovative antibacterial biomaterials that have the potential to support the prevention of periodontal infections in high-risk individuals. Titanium–copper (Ti–Cu) alloys have been shown to have significant inhibitory activity against *P. gingivalis* (16,18). Cu-doped TiO_2 coatings also exhibit strong antibacterial activity while supporting osteogenic differentiation (22).

ZnO nanoparticles, both conventionally synthesized and "green synthesis", have the effect of inhibiting *P. gingivalis* biofilms and reducing the inflammatory response (15,21,28).

Although these studies are not directly related to health promotion, these findings suggest the potential for assistive technology in periodontal prevention strategies in high-risk populations.

Relevance of Findings to Health Literacy-Based Health Promotion Strategies

Efforts to improve periodontal health in communities exposed to environmental heavy metals rely heavily on health literacy and effective preventive behaviors. Improving health literacy has been shown to play a central role in strengthening public understanding of the etiology of periodontal disease, including the pathogenic mechanisms of *Porphyromonas gingivalis*, early clinical signs, and its impact on systemic health. Various educational interventions, including visual media, digital modules, and community-based approaches, have consistently improved public knowledge, risk perception, and the ability to critically evaluate health information (19,23,27).

Improved preventive behaviors, such as improved oral hygiene, plaque control, and the adoption of clean and healthy lifestyles, are important outcomes of a health literacy-based approach. These interventions encourage proper toothbrushing practices, the use of interdental hygiene aids, a reduction in risky habits, and regular visits to dental health facilities. Community-based programs that address participants' literacy levels result in more sustainable behavior changes, particularly in groups exposed to environmental contaminants (21,28)

Increased health literacy is also closely linked to a reduced risk and incidence of periodontal disease caused by *P. gingivalis*. Understanding bacterial colonization, biofilm formation, and the effects of heavy metal exposure increases individual motivation to take preventive measures. Studies have shown that educational interventions can reduce the prevalence of gingivitis and periodontitis, as well as the severity of clinical manifestations such as periodontal pocket depth and attachment loss (13,14,20,25).

Furthermore, improving the community's ability to recognize the risks of heavy metal exposure is a crucial aspect of prevention strategies. Knowledge of contamination sources, biological impact mechanisms, and mitigation methods encourages communities to take protective measures, such as using clean water, avoiding contaminated areas, and adopting a healthy lifestyle. Structured educational programs have been shown to increase risk awareness and strengthen self-efficacy in minimizing heavy metal exposure, which can exacerbate susceptibility to periodontal disease (31-35).

CONCLUSION

Periodontal disease in communities exposed to heavy metals is a multifactorial public health issue involving environmental toxicity, microbial dysbiosis, and the pathogenic role of *Porphyromonas gingivalis*. Current evidence supports the biological plausibility of increased periodontal vulnerability in metal-exposed populations; however, direct empirical evidence linking health literacy–based interventions to reduced disease incidence remains limited.

Within these constraints, this scoping review positions health literacy as a conceptually robust and potentially relevant preventive approach, particularly for improving risk understanding and preventive behaviors in environmentally vulnerable communities. The conclusions of this review should therefore be interpreted as indicating theoretical relevance and feasibility rather than confirmed effectiveness.

Future research should focus on empirically testing health literacy–oriented health promotion interventions through community-based and implementation studies to strengthen the evidence base for periodontal disease prevention in populations exposed to environmental heavy metals.

AUTHOR’S CONTRIBUTION STATEMENT

Helena Jelita, Ira Jayanti, and Hanasia was responsible for the research design, data collection, analysis, and drafting of the manuscript Firdaus Hamid, Harun Achmad, Syamsul Arifin supervised the research process, contributed to the theoretical framework and literature review, and revised the manuscript critically for intellectual content.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

Artificial intelligence tools were used to assist with language editing and grammar checking. No content generation, data analysis, or critical interpretation was performed by AI. All intellectual contributions are the sole responsibility of the authors. All research design, data collection, analysis, and interpretation were performed by the authors without AI assistance.

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