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EMERGING TECHNOLOGIES IN PERIODONTAL CARE: FROM MICROBIOME ANALYSIS TO LASER THERAPY IN THE CONTEXT OF PUBLIC HEALTH AND PERSONALIZED MEDICINE

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ABSTRACT

Periodontitis is a highly prevalent chronic inflammatory disease with a substantial global burden and significant links to systemic conditions such as diabetes and cardiovascular disease. It also represents a major public health challenge due to persistent inequalities in access to care.

This narrative review synthesizes current evidence on emerging technologies in periodontal care, including microbiome analysis, biomarker-based diagnostics, laser-assisted therapies, and artificial intelligence. Advances in sequencing technologies have reframed periodontitis as a dysbiosis-driven condition, while biomarker-based approaches and AI-driven models enable earlier diagnosis and individualized risk assessment. Laser-assisted therapies provide modest but clinically relevant improvements when used as adjuncts to conventional treatment.

Despite these advances, translation into routine clinical practice remains limited by issues of standardization, cost, and accessibility. Bridging this gap is essential to ensure that technological innovation translates into improved population-level oral health outcomes.

KEYWORDS

Periodontitis; Oral Microbiome; Personalized Medicine; Biomarkers; Laser Therapy; Public Health

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Introduction

Periodontitis is not merely a localized dental condition but a highly prevalent chronic inflammatory disease with a substantial and uneven global burden. According to Global Burden of Disease (GBD) estimates, approximately 1.1 billion cases of severe periodontitis were recorded worldwide in 2019, and subsequent analyses continue to identify periodontal diseases as a major public health challenge, with increasing incidence, prevalence, and disability-adjusted life years (DALYs) (Collaborators, 2020).

Its significance extends beyond oral health. A growing body of evidence supports associations between periodontitis and systemic conditions such as cardiovascular disease and diabetes, while acknowledging the complexity of causal relationships. In individuals with diabetes, periodontitis is associated with poorer glycemic control and an increased risk of both microvascular and macrovascular complications, including myocardial infarction and stroke (Chapple et al., 2013; Sanz et al., 2018). These findings position periodontal care within the broader framework of noncommunicable diseases rather than as an isolated clinical concern.

Importantly, the burden of periodontitis is socially patterned. Access to dental care is shaped by cost, insurance coverage, geographic disparities, workforce distribution, and oral health literacy. These structural barriers affect the availability of preventive services, early diagnosis, and effective treatment (Watt et al., 2019). At the population level, regions with lower sociodemographic index (SDI) bear a disproportionate burden, highlighting persistent inequalities in oral health outcomes (Peres et al., 2019).

In this context, emerging technologies are gaining attention as tools to address both clinical and public health challenges in periodontal care. Advances in microbiome analysis, including high-throughput sequencing and bioinformatics, enable a more precise characterization of dysbiosis and disease mechanisms. Concurrently, biomarker-based diagnostics and risk stratification models offer opportunities for earlier detection and individualized interventions. In the therapeutic domain, laser-based modalities are being investigated as adjunctive approaches that may improve clinical outcomes while reducing invasiveness.

Recent advances in artificial intelligence and digital health technologies further support the transition toward precision dentistry by enabling data-driven diagnostics, risk prediction, and personalized treatment strategies (Gao et al., 2025; Patel et al., 2025).

Taken together, these innovations align with the paradigm shift toward personalized medicine and may enhance the accessibility, efficiency, and scalability of periodontal care. This review aims to synthesize current evidence on emerging technologies in periodontology—particularly microbiome analysis, biomarker-based diagnostics, laser therapy, and artificial intelligence—and to evaluate their relevance within the frameworks of public health and personalized medicine.

Methods

This narrative review was conducted to synthesize current evidence on emerging technologies in periodontal care, with a particular focus on microbiome analysis, biomarker-based diagnostics, laser-assisted therapies, and artificial intelligence, in the context of public health and personalized medicine.

A structured literature search was performed using PubMed, Scopus, and Web of Science databases to identify relevant studies published between January 2010 and February 2026. The search strategy combined keywords and MeSH terms related to periodontitis, oral microbiome, dysbiosis, biomarkers, salivary diagnostics, laser therapy, artificial intelligence, machine learning, and precision medicine.

The initial search yielded approximately 612 records. After removal of duplicate records, 428 titles and abstracts were screened**,** and 24 articles were included in the final synthesis following full-text assessment.

Articles were included if they met the following criteria: (1) addressed emerging or technology-driven approaches in periodontal diagnostics or treatment, (2) provided clinical, translational, or mechanistic insights, and (3) were published in English in peer-reviewed journals. Eligible study types included original research articles, systematic reviews, meta-analyses, and consensus reports.

Studies were excluded if they focused exclusively on conventional periodontal therapies without a technological component, lacked clinical or translational relevance, or were non-peer-reviewed publications.

Titles and abstracts were screened for relevance, followed by full-text assessment. Given the narrative nature of the review, formal quality assessment or risk-of-bias analysis was not systematically performed. However, priority was given to high-quality evidence, including randomized controlled trials, systematic reviews, and widely cited consensus statements.

The selected literature was analyzed and synthesized narratively. Findings were organized into thematic domains reflecting key areas of technological development in periodontology: (1) microbiome analysis, (2) biomarker-based diagnostics, (3) laser-assisted therapies, and (4) artificial intelligence.

As a narrative review, this study is subject to potential selection bias and does not provide a quantitative synthesis of findings.

Results

Microbiome analysis and periodontal disease mechanisms

Advances in high-throughput sequencing technologies have significantly improved the understanding of periodontal disease as a dysbiosis-driven condition rather than a classical infection caused by specific pathogens. Studies consistently demonstrate that periodontitis is associated with a shift in microbial community structure, characterized by increased abundance of keystone pathogens and disruption of host–microbe homeostasis (Curtis et al., 2020; Dzidic et al., 2018; Hajishengallis, 2015; Lamont et al., 2018; Wade, 2013).

Metagenomic and metatranscriptomic approaches have enabled the identification of functional changes in microbial communities, highlighting alterations in virulence factors, metabolic pathways, and inflammatory signaling. These findings support the concept of personalized microbial profiling as a potential tool for risk assessment and targeted interventions. Recent studies further emphasize the role of the oral microbiome in personalized dentistry, highlighting its potential for individualized prevention, diagnosis, and treatment strategies (Rajasekaran et al., 2024).

Biomarkers and personalized diagnostics

Biomarker-based approaches, particularly in saliva and gingival crevicular fluid, have shown promise for early detection and disease monitoring. Inflammatory mediators (e.g., IL-1β, TNF-α), matrix metalloproteinases, and microbial-derived markers have been investigated as diagnostic and prognostic indicators (Bostanci & Belibasakis, 2018; Giannobile, 2012; Kinney et al., 2007).

Although no single biomarker has demonstrated sufficient sensitivity and specificity for routine clinical use, multimarker panels and integration with clinical parameters appear to improve diagnostic accuracy. These approaches are increasingly aligned with precision medicine frameworks.

Laser-assisted periodontal therapy

Laser technologies, including diode, Nd:YAG, and Er:YAG lasers, have been evaluated as adjuncts to conventional scaling and root planing. Evidence from systematic reviews and meta-analyses suggests that laser-assisted therapy may provide modest improvements in clinical parameters such as probing depth reduction and clinical attachment gain (Cobb, 2006; Sgolastra et al., 2014; Slot et al., 2014).

However, results remain heterogeneous, and the magnitude of benefit varies depending on laser type, protocol, and patient characteristics. Current evidence supports laser therapy as an adjunct rather than a replacement for conventional treatment.

Artificial intelligence and digital periodontology

Artificial intelligence (AI) is emerging as a promising tool in periodontal diagnostics and risk prediction. Machine learning and deep learning algorithms have demonstrated potential in detecting dental pathologies, analyzing radiographic images, and supporting clinical decision-making(Khanagar et al., 2021; Lee et al., 2018; Schwendicke et al., 2020).

Recent studies demonstrate that AI-based systems can achieve high diagnostic accuracy and support clinical decision-making, particularly in imaging analysis and disease classification (Gao et al., 2025). These technologies also enable risk prediction and personalized treatment planning. However, their clinical applicability remains limited by challenges related to data quality, standardization, and external validation (Mao et al., 2025; Patel et al., 2025).

Across domains, emerging technologies improve diagnostic precision and support individualized care; however, their clinical applicability remains constrained by limited standardization, heterogeneity of evidence, and challenges in integration into routine healthcare systems.

Discussion

This review highlights the growing role of emerging technologies in periodontal care, while underscoring the persistent gap between technological innovation and real-world clinical and public health implementation. Although advances in microbiome analysis, biomarker discovery, laser-assisted therapy, and artificial intelligence are reshaping the conceptual framework of periodontology, their translation into routine practice remains uneven and limited.

The shift from a pathogen-centered model to a dysbiosis-driven understanding of periodontitis represents a major paradigm change. Current evidence emphasizes ecological imbalance and host–microbiome interactions rather than specific pathogens (Curtis et al., 2020; Dzidic et al., 2018; Hajishengallis, 2015; Lamont et al., 2018; Wade, 2013). Despite these advances, clinical application of microbiome profiling remains constrained by high costs, lack of standardization, and absence of validated diagnostic thresholds.

Biomarker-based diagnostics similarly demonstrate promise but face important limitations. While inflammatory mediators and tissue degradation markers are consistently associated with disease activity, variability across populations and methodological heterogeneity limit their use as standalone diagnostic tools (Bostanci & Belibasakis, 2018; Giannobile, 2012; Kinney et al., 2007). Future approaches will likely require integration of biomarkers with clinical and microbiological data within multimodal predictive frameworks.

Laser-assisted therapies are among the most clinically implemented innovations. Evidence suggests modest but clinically relevant improvements when used as adjuncts to conventional treatment, but not as replacements (Cobb, 2006; Sgolastra et al., 2014; Slot et al., 2014). However, heterogeneity in study design, laser parameters, and outcome measures limits comparability across studies.

Artificial intelligence introduces a rapidly evolving dimension to periodontal care. AI-based models have demonstrated promising performance in imaging analysis, diagnosis, and risk prediction (Khanagar et al., 2021; Lee et al., 2018; Schwendicke et al., 2020). More recent evidence confirms high diagnostic accuracy and expanding applications in clinical decision support (Gao et al., 2025). However, several barriers must be addressed before widespread implementation, including lack of external validation, algorithmic bias, limited transparency (explainability), and challenges in integrating AI systems into clinical workflows (Mao et al., 2025; Patel et al., 2025).

From a public health perspective, emerging technologies present both opportunities and risks. While they may enhance early detection, efficiency, and personalization of care, they also risk exacerbating existing inequalities if access remains limited to high-resource settings. Recent evidence suggests that AI may support broader public health strategies, including teledentistry and population-level screening, as well as optimization of healthcare resources (Li et al., 2026; Schwendicke et al., 2020). However, these benefits depend on equitable implementation and robust data infrastructure.

The concept of precision public health provides a useful framework for aligning technological innovation with equity and accessibility. Future research should move beyond demonstrating efficacy toward evaluating real-world effectiveness, cost-efficiency, and scalability within diverse healthcare settings.

Conclusions

Emerging technologies are reshaping periodontal care by advancing the understanding of disease mechanisms and enabling more personalized diagnostic and therapeutic approaches. Microbiome analysis, biomarker-based diagnostics, laser-assisted therapies, and artificial intelligence collectively contribute to a more precise and data-driven model of care.

However, their clinical and public health impact remains constrained by limitations in standardization, cost, accessibility, and insufficient evidence for routine implementation. At present, most technologies function as adjuncts rather than replacements for conventional approaches.

Future progress will depend on integrating these innovations into scalable and equitable healthcare systems, as well as generating robust evidence through longitudinal and implementation-focused research. Aligning technological advancement with the principles of precision public health will be essential to ensure that benefits extend beyond individual patients to broader populations.

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