Precision periodontics: A new era of data-driven periodontal care (Review)

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Abstract. Precision periodontics represents a paradigm shift in periodontal care by embracing personalized, data-driven strategies to manage periodontal diseases. Moving beyond traditional diagnostic methods, this approach integrates genomic, proteomic, microbiomic and environmental data to tailor prevention and treatment to individual patient profiles. The present review discusses precision periodontics and its role in data-driven periodontal care. With periodontitis affecting almost half the global adult population, the urgency for more effective, personalized interventions is evident. Innovations in omics technologies have enabled the identification of genetic markers, microbial dysbiosis patterns and inflammatory biomarkers, enhancing diagnostic accuracy and risk stratification. Salivary diagnostics and next-generation sequencing provide non-invasive tools for real-time assessment, while point-of-care technologies provide rapid, chairside evaluations. Digital advancements, such as electronic health records, wearable devices, teledentistry and artificial intelligence-driven analytics, further support personalized care by improving data integration, monitoring and patient engagement. Treatment modalities, including microbiome-guided antimicrobials, pharmacogenomics-based drug regimens, minimally invasive procedures and biomaterial-guided regeneration, demonstrate how precision periodontics optimizes outcomes and reduces overtreatment. The clinical benefits include early detection, the better management of complex cases, and enhanced patient adherence to care plans. Despite challenges, such as cost and accessibility, precision periodontics holds transformative potential to reduce global oral health disparities. Its successful implementation will require collaboration among clinicians, researchers, and educators to advance innovation and ensure equitable access. Ultimately, precision periodontics promises to redefine the future of periodontal therapy by providing more effective, personalized and inclusive therapeutics.

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1. Introduction to precision periodontics

Precision periodontics represents a transformative shift in the management of periodontal diseases, leveraging individualized approaches that integrate genetic, microbial and environmental data to optimize diagnosis and treatment (1,2). Unlike traditional methods, which rely heavily on clinical measures, such as pocket depth and radiographs, precision periodontics tailors interventions to the unique biological and lifestyle profiles of patients (3,4). This approach addresses the limitations of conventional diagnostics, which often fail to capture the complex, multifactorial nature of periodontal disease (1,3).

Periodontitis, a chronic inflammatory condition affecting the supporting structures of teeth, affects ~50% of adults worldwide, rendering it a significant global health burden (1). Its prevalence underscores the urgent need for more effective strategies to prevent, diagnose and treat the disease. Traditional diagnostics, while valuable, lack the granularity to account for individual variability in disease susceptibility and progression, often leading to suboptimal outcomes (3).

The present review discusses the foundations of precision periodontics, focusing on the role of omics technologies, e.g., genomics, proteomics, microbiomics, digital tools and their clinical applications (1,3). By harnessing these advancements, precision periodontics aims to revolutionize periodontal care, providing personalized solutions that improve patient outcomes and reduce the global impact of periodontal disease (5).

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2. Foundations of precision periodontics

Precision periodontics adapts the principles of precision medicine to dentistry, integrating patient-specific data to tailor prevention, diagnosis and treatment strategies for periodontal diseases (6). This approach leverages advances in omics technologies, including genomics, microbiomics and proteomics to understand the complex interplay of biological and environmental factors driving disease progression (6,7). By focusing on individualized data, precision periodontics moves beyond one-size-fits-all approaches, providing targeted interventions that address the unique characteristics of the condition of each patient (6,7).

The oral microbiome and dysbiosis. The oral microbiome plays a central role in periodontal health and disease. Dysbiosis, an imbalance in microbial communities, is a hallmark of periodontitis, characterized by the proliferation of pathogenic species, such as *Porphyromonas gingivalis* and *Tannerella forsythia* (8). Advances in metataxonomics and metagenomics have enabled detailed profiling of the periodontal microbiome, revealing microbial signatures associated with disease severity and progression (8). These insights allow clinicians to identify specific microbial patterns in patients, paving the way for targeted therapies, such as personalized antimicrobial treatments or probiotics, to restore microbial balance (7,8).

Genetic predispositions. Genetic factors significantly influence susceptibility to periodontal diseases. Variants in genes, such as IL-1, which regulate inflammatory responses, have been associated with an increased risk and severity of periodontitis (7). For example, IL-1 gene polymorphisms can amplify inflammatory cascades in response to microbial challenges, exacerbating tissue destruction (7). Genomic profiling enables the identification of such predispositions, allowing clinicians to stratify patients by risk and tailor preventive measures or early interventions accordingly (7).

Environmental influences. Environmental and lifestyle factors, including smoking and diet, are critical drivers of periodontal disease (7). Smoking, a well-established risk factor, exacerbates inflammation and impairs immune responses, accelerating disease progression (7). Similarly, diets high in refined sugars or low in micronutrients can promote dysbiosis and inflammation, worsening periodontal outcomes. Precision periodontics incorporates these factors into patient assessments, using data on lifestyle and environmental exposures to design personalized treatment plans, such as smoking cessation programs or dietary counseling (7).

By integrating insights from the oral microbiome, genetics and environmental factors, precision periodontics provides a comprehensive framework for understanding and managing periodontal diseases. These scientific foundations enable the development of innovative diagnostics and therapies, setting the stage for more effective, patient-centered care (7).

3. Omics technologies: Revolutionizing diagnostics

Omics technologies, namely genomics, proteomics and metabolomics, are transforming periodontal diagnostics by enabling the identification of biomarkers that reflect disease susceptibility, progression, and response to treatment (9-11). These advanced tools provide a comprehensive view of the molecular and microbial underpinnings of periodontal diseases, moving beyond traditional clinical assessments to deliver precise, patient-specific insight (9). By integrating omics data with innovative diagnostic platforms, such as salivary diagnostics and point-of-care devices, precision periodontics is poised to revolutionize clinical practice (10).

Genomic profiling for disease susceptibility. Genomic profiling identifies genetic variants associated with the risk of developing periodontal disease, enabling the early detection of susceptible individuals (9). For instance, polymorphisms in genes such as IL-1, which regulate inflammatory pathways, are linked to increased periodontitis severity (9). Next-generation sequencing (NGS) enhances the ability to map these genetic markers with high precision, allowing clinicians to stratify patients by risk and tailor preventive strategies (11). By identifying genetic predispositions, genomics supports proactive interventions before clinical symptoms manifest (9,11).

Proteomics for inflammatory markers. Proteomics focuses on analyzing proteins in biological fluids, such as gingival crevicular fluid (GCF) and saliva, to detect inflammatory markers of periodontal disease (10). Proteins such as matrix metalloproteinases (MMPs) and cytokines (e.g., IL-6, TNF-α) are elevated in periodontitis, serving as reliable indicators of tissue inflammation and destruction (10). Advanced proteomic techniques, such as mass spectrometry, enable the high-throughput identification of these biomarkers, providing insight into disease activity and treatment response (9,10). Salivary diagnostics, in particular, provide a non-invasive method for routine proteomic screening, enhancing accessibility in clinical settings (10,11).

Metabolomics for bone destruction byproducts. Metabolomics examines small-molecule metabolites to uncover byproducts of periodontal tissue breakdown, such as those associated with alveolar bone destruction (9). For example, elevated levels of amino acids and lipid degradation products in saliva or GCF can signal active bone resorption (11). Metabolomic profiling, supported by technologies, such as nuclear magnetic resonance and liquid chromatography, provides a metabolic snapshot of disease states, aiding in the early detection of progressive periodontitis (9,11). These insights enable clinicians to monitor disease progression and dynamically adjust treatment strategies (9).

Salivary diagnostics and NGS. Salivary diagnostics, powered by omics technologies, represent a cornerstone of precision periodontics due to their non-invasive nature and rich biomarker content (10,11). Saliva contains DNA, proteins and metabolites that reflect the oral and systemic health of patients, making it an ideal medium for diagnostic testing (10). NGS enhances salivary diagnostics by enabling rapid sequencing of microbial DNA and host genetic material, identifying pathogenic microbial profiles and genetic risk factors in real time (9,11). This technology supports the development of personalized treatment strategies by

linking specific microbial dysbiosis patterns to disease phenotypes (9).

Point-of-care (POC) applications. POC diagnostics translate omics discoveries into practical, chairside tools for rapid periodontal assessment (11,12). Devices leveraging microfluidic technology and biosensors can detect biomarkers such as MMPs or IL-1 polymorphisms within minutes, enabling immediate clinical decision-making (10,11). These POC systems integrate genomic, proteomic and metabolomic data to provide actionable insight, such as identifying patients who are at risk of rapid disease progression or those likely to respond to specific therapies (9,11). By bringing omics-based diagnostics to the dental office, POC applications bridge the gap between research and clinical practice (11).

Omics technologies are redefining periodontal diagnostics by providing a deeper understanding of disease mechanisms and enabling personalized care (9-11). Through genomic profiling, proteomic analysis, metabolomic insights, salivary diagnostics and POC applications, these tools empower clinicians to detect and manage periodontal diseases with unprecedented precision, ultimately improving patient outcomes (11).

4. Digital innovations in periodontal care

Digital innovations are reshaping periodontal care by enhancing data integration, patient monitoring and treatment personalization (13-15). Tools such as electronic health records (EHRs), wearable devices, teledentistry and artificial intelligence (AI)-driven risk assessment platforms enable clinicians to deliver precision periodontics with improved efficiency and patient engagement (14,15). These technologies facilitate the aggregation of clinical, genetic and lifestyle data, support remote care, and optimize treatment outcomes through data-driven insights (13).

EHRs for data integration. EHRs serve as a cornerstone for precision periodontics by aggregating diverse patient data, including clinical records, genetic profiles, microbial analyses, and lifestyle factors (14,16). By centralizing this information, EHRs enable clinicians to create comprehensive patient profiles that inform personalized treatment plans (16). For example, integrating genomic data on IL-1 polymorphisms with clinical findings allows for tailored interventions based on disease susceptibility. Advanced EHR systems also incorporate multi-omics data, enhancing the ability to identify patterns and predict disease progression, thus supporting proactive periodontal care (13,16).

Wearable devices and patient monitoring. Wearable devices, such as smart toothbrushes and intraoral sensors, are revolutionizing patient monitoring by providing real-time data on oral hygiene practices and periodontal health (12). Smart toothbrushes equipped with pressure sensors and connectivity features track brushing habits, providing feedback to patients and clinicians to improve compliance with oral care regimens (12). These devices also collect patient-reported outcome measures (PROMs), such as discomfort or bleeding during brushing, which can be integrated into EHRs for longitudinal

monitoring (17). By empowering patients to actively participate in their care, wearables enhance adherence to preventive strategies and early intervention protocols (12,15).

Teledentistry for remote care. Teledentistry expands access to periodontal care by enabling remote consultations, diagnostics, and follow-ups (15). Through video conferencing and digital imaging, clinicians can assess periodontal status, review PROMs, and provide guidance on oral hygiene without requiring in-person visits (15). Teledentistry is particularly valuable for patients in underserved areas or those with mobility constraints, ensuring continuity of care (15). Additionally, it facilitates the integration of digital tools, such as mobile apps for tracking oral health metrics, further supporting patient engagement and remote monitoring (15).

AI-driven risk assessment tools. AI-driven tools are transforming periodontal care by analyzing complex datasets to predict disease risk and optimize treatment strategies (13,18). Machine learning algorithms can process EHR data, omics profiles and lifestyle factors to identify patients at high risk of periodontitis progression (19). For instance, AI models can predict the likelihood of treatment success based on microbial dysbiosis patterns or genetic predispositions, enabling clinicians to prioritize interventions (18). These tools also support real-time decision-making by generating risk scores and treatment recommendations, enhancing the precision and efficiency of clinical workflows (18).

Digital innovations, from EHRs to AI-driven analytics, are unlocking new possibilities in periodontal care by enabling seamless data integration, remote monitoring, and personalized risk assessment (18). By leveraging these technologies, clinicians can deliver more effective, patient-centered care, ultimately reducing the burden of periodontal diseases (15).

5. Personalized treatment strategies

Precision periodontics revolutionizes clinical practice by delivering tailored interventions that address the unique biological, microbial, and environmental profiles of patients (1,20). By leveraging data from omics technologies, electronic health records and digital tools, clinicians can design personalized treatment strategies that enhance efficacy and minimize invasiveness. These strategies include microbiome-guided antimicrobials, pharmacogenomics for drug optimization and regenerative therapies using customized biomaterials, providing targeted solutions to improve periodontal outcomes (1,20).

Microbiome-guided antimicrobials. Microbiome profiling enables the identification of specific pathogenic bacteria driving periodontal disease, allowing for targeted antimicrobial therapies (1). For example, NGS can detect dysbiotic microbial signatures, such as elevated levels of *Porphyromonas gingivalis*, guiding the selection of narrow-spectrum antibiotics or adjunctive agents like chlorhexidine. This approach minimizes disruption to beneficial oral flora and reduces the risk of antibiotic resistance, ensuring more effective and sustainable treatment outcomes (1). Microbiome-guided therapies also support the use of probiotics to restore microbial balance, further personalizing care (1).

Pharmacogenomics for drug optimization. Pharmacogenomics tailors medication regimens based on the genetic profile of a patient, optimizing drug efficacy and minimizing adverse effects. In periodontics, genetic variants affecting drug metabolism, such as those in cytochrome P450 enzymes, can influence responses to analgesics, anti-inflammatory drugs, or antimicrobials used in periodontal therapy (1). For instance, pharmacogenomic testing can identify patients likely to benefit from specific nonsteroidal anti-inflammatory drugs or those at risk of poor response, enabling clinicians to adjust dosages or select alternative medications (1). This personalized approach enhances treatment safety and effectiveness, particularly for patients with complex medical histories (1).

Minimally invasive procedures. Precision periodontics emphasizes minimally invasive procedures tailored to individual disease profiles, reducing patient discomfort and recovery time. Techniques such as laser-assisted periodontal therapy or guided tissue regeneration can be customized based on microbial, genetic and clinical data. For example, patients with specific inflammatory markers identified through proteomics analysis may benefit from targeted laser therapy to reduce pocket depth without extensive surgery. These procedures are informed by real-time diagnostic tools, ensuring interventions are precise and aligned with the patient's unique disease characteristics (1).

Regenerative therapies with customized biomaterials. Regenerative therapies in periodontics leverage biomaterials tailored to patient-specific needs to promote bone and tissue regeneration (20,21). Omics technologies, such as proteomics and transcriptomics, identify biomarkers associated with bone regeneration potential, guiding the selection of biomaterials like growth factor-enriched scaffolds or bioactive membranes (20). For instance, patients with specific protein expression profiles may respond better to platelet-derived growth factor-enhanced grafts, which stimulate osteogenesis (20). These customized regenerative approaches enhance the success of periodontal regeneration, particularly in cases of severe bone loss, by aligning interventions with the biological capacity of the patient for healing (1,20).

Personalized treatment strategies in precision periodontics integrate microbiome-guided therapies, pharmacogenomics, minimally invasive techniques and regenerative biomaterials to deliver highly effective, patient-centered care (1,20). By addressing the unique needs of each patient, these approaches improve clinical outcomes, reduce treatment risks and pave the way for a new era of periodontal therapy (1).

Personalized/precise oxidative stress therapy (POST). Emerging evidence positions oxidative stress as a central driver of periodontitis; yet, conventional antioxidant-based adjuncts have shown limited benefit due to patient variability. To address this issue, Bullon *et al* (22) proposed POST, a framework that aligns with precision periodontics by tailoring interventions to the oxidative profile of each patient. POST considers three domains, namely environmental factors (e.g., smoking, diet and stress), individual characteristics (age, systemic health, microbiome and lifestyle) and intracellular oxidative physiology (mitochondria,

endoplasmic reticulum stress, autophagy and aging). Rather than indiscriminate antioxidant use, POST advocates biomarker-guided, patient-specific strategies to restore redox balance without disrupting essential physiological signaling. This paradigm provides a roadmap for integrating oxidative profiling into diagnosis, risk assessment and treatment planning, moving periodontics closer to true precision care (22).

6. Clinical benefits of precision periodontics

Precision periodontics provides significant clinical advantages by leveraging individualized data to enhance diagnostic accuracy, optimize treatment, and improve patient outcomes (3,6). By integrating omics technologies, digital tools and patient-specific insights, this approach enables early detection, reduces overtreatment and improves the management of complex periodontal cases (3,6). Additionally, digital innovations foster greater patient engagement, empowering individuals to actively participate in their care (6). These benefits collectively advocate for the widespread adoption of precision periodontics in clinical practice.

Early detection and prevention. Precision periodontics facilitates the early detection of periodontal disease through advanced diagnostics, such as genomic profiling and salivary biomarker analysis (6). For example, identifying IL-1 gene variants or elevated levels of inflammatory markers, such as MMPs allows clinicians to detect disease susceptibility before clinical symptoms emerge (3,6). Early intervention based on these insights can prevent disease progression, preserving periodontal health and reducing the need for invasive treatments (3). This proactive approach is particularly valuable for high-risk patients, such as those with genetic predispositions or systemic conditions such as diabetes (6).

Reduced overtreatment. By tailoring interventions to the specific needs of each patient, precision periodontics minimizes overtreatment and its associated risks (3). Traditional approaches often rely on standardized protocols, which may lead to unnecessary procedures or prolonged antibiotic use (3). By contrast, microbiome-guided antimicrobials and pharmacogenomic insights ensure that treatments are targeted and effective, reducing the likelihood of adverse effects or resistance (3,6). For instance, precise microbial profiling can guide the use of narrow-spectrum antibiotics, avoiding disruption of the healthy oral microbiome (6).

Better management of complex cases. Precision periodontics excels in managing complex periodontal cases, particularly those involving comorbidities or refractory disease (3,6). By integrating multi-omics data with electronic health records, clinicians can develop comprehensive treatment plans that account for genetic, microbial and environmental factors (6). For example, patients with aggressive periodontitis and systemic inflammation may benefit from customized regenerative therapies or AI-driven risk assessments to prioritize interventions (3,6). This holistic approach improves treatment success rates and enhances long-term disease control in challenging cases (3).

Enhanced patient engagement. Digital tools, such as teledentistry and PROMs significantly boost patient engagement in precision periodontics (6). Teledentistry enables remote consultations and monitoring, allowing patients to receive timely guidance on oral hygiene practices without frequent office visits (6). Mobile apps and wearable devices, such as smart toothbrushes collect PROMs, such as bleeding or discomfort, empowering patients to track their periodontal health and adhere to personalized care plans (6). These tools foster a collaborative relationship between patients and clinicians, improving compliance and overall treatment outcomes (3,6).

The clinical benefits of precision periodontics, namely early detection, reduced overtreatment, effective management of complex cases and enhanced patient engagement, demonstrate its potential to transform periodontal care (3,6). By delivering personalized, data-driven solutions, this approach not only improves clinical outcomes, but also empowers patients, rendering it a compelling model for modern dentistry (6).

7. Conclusion and future perspectives

Precision periodontics is redefining periodontal care by integrating omics technologies, digital tools and personalized therapies to address the global burden of periodontal diseases, which affect ~50% of adults (22). This transformative approach leverages genetic, microbial and environmental data to deliver tailored diagnostics and treatments, improving outcomes and patient engagement (22). By overcoming challenges such as high costs and limited access, precision periodontics holds the potential to reduce oral health disparities worldwide. The present review summarizes key insights and issues a call to action for clinicians, researchers and educators to adopt, advance, and equitably implement these innovations (1,22).

Precision periodontics represents a paradigm shift in periodontal care, providing personalized, data-driven solutions to improve outcomes and reduce the global burden of periodontal diseases (1,23). By leveraging omics, digital tools and personalized therapies, this approach addresses the limitations of traditional methods and enhances patient engagement (22). However, realizing its full potential requires overcoming barriers through adoption, research, training, and global access initiatives. Clinicians, researchers, educators and advocates need to collaborate to advance precision periodontics, ensuring that its benefits reach all populations equitably. Together, these efforts will shape a future where periodontal care is precise, accessible, and transformative (22,24).

Economic feasibility and reimbursement remain major hurdles in advancing precision periodontics. The integration of multi-omics, advanced imaging and AI diagnostics, while clinically transformative, is associated with high costs for sequencing, proteomics platforms and cone-beam computed tomography (CBCT)/magnetic resonance imaging (MRI) infrastructure, which limits accessibility particularly in low-resource settings. Current reimbursement models rarely cover these technologies, as they are classified as adjunctive or investigational rather than standard-of-care procedures, leaving patients to shoulder the expense. This creates inequities, where only well-resourced populations benefit from innovations. The present review stresses the importance of developing cost-effective diagnostic kits and imaging tools, which could broaden

accessibility by lowering upfront expenses (25). Strategies to improve feasibility include standardizing AI-omics toolkits for wider applicability, leveraging cloud-based registries to reduce redundant testing, and implementing tiered use of omics testing restricted to high-risk patients to optimize the cost-benefit. Policy-level interventions such as expanding insurance coding for biomarker-based risk assessment and AI-assisted imaging, along with pilot reimbursement programs, are critical for accelerating adoption. Moreover, international initiatives such as the Global Oral Health Initiative (2023), which promotes standardized integration protocols and open-access databases, are expected to reduce economic barriers and foster equitable access across diverse populations (25).

Despite promising results, several barriers hinder the adoption of precision periodontics. Data remain disconnected, with omics and imaging outputs fragmented across institutions. This limits predictive modeling and cross-validation, but could be addressed through shared, cloud-based registries. High costs of sequencing, proteomics and advanced imaging pose accessibility challenges, although AI-driven automation and the selective use of omics testing in high-risk patients provide feasible cost-saving strategies. Ethical concerns are another barrier, with genetic and microbiome data raising privacy risks (25).

The evidence base, while growing, is not yet definitive. A number of studies are observational, proof-of-concept trials, or limited randomized clinical studies (26-28). To validate precision approaches, large-scale, multicenter randomized controlled trials are warranted to determine whether biomarker-guided therapy consistently improves outcomes, such as pocket depth reduction, clinical attachment gain and long-term tooth retention. Equally important are meta-analyses to synthesize effect sizes, harmonize outcome measures and reduce heterogeneity across studies (25,29).

Quantitative outcome comparisons highlight the added value of precision over conventional care. Multi-omics combined with imaging have improved early disease detection by 25%. CBCT lowered diagnostic errors by 35%, and MRI enhanced soft tissue diagnostic accuracy by 25%. AI-driven imaging analysis accelerated workflows by 40%, directly benefiting clinical efficiency and treatment planning (25). In therapy, adjunctive ozone with scaling and root planing achieved improved periodontal healing than scaling alone, illustrating how tailored interventions outperform traditional approaches (29). Saliva-based proteomic and DNA assays further demonstrated superiority over conventional probing in predicting disease progression risk, reinforcing the diagnostic and prognostic potential of precision methods (30,31).

Precision periodontics represents a paradigm shift in periodontal care, providing personalized, data-driven solutions to improve outcomes and reduce the global burden of periodontal diseases (1,23). By leveraging omics, digital tools and personalized therapies, this approach addresses the limitations of traditional methods and enhances patient engagement (24). However, realizing its full potential requires overcoming barriers through adoption, research, training, and global access initiatives. Clinicians, researchers, educators and advocates need to collaborate to advance precision periodontics, ensuring that its benefits reach all populations equitably. Together, these efforts will shape a future where periodontal care is precise, accessible, and transformative (23,32).

Availability of data and materials

Not applicable.

Authors' contributions

SS was involved in designing the concept of the review followed by conducting the literature search and drafting the initial manuscript. SS and NS were involved in revising and editing the manuscript. Data authentication is not applicable. Both the authors reviewed, and have read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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