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Precision and Personalized Periodontics: Transforming Periodontal Care in the Era of Precision Medicine

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ABSTRACT

Periodontitis is a multifactorial chronic inflammatory disease characterized by complex interactions among microbial dysbiosis, host immune response, genetic predisposition, environmental factors, and systemic conditions. Conventional periodontal therapy largely follows a standardized approach despite substantial inter-individual variation in disease susceptibility, progression, and treatment response. Precision periodontics has emerged as a paradigm shift that integrates genomic, proteomic, metabolomic, microbiomic, biomarker, clinical, and digital data to tailor preventive and therapeutic interventions for individual patients. Recent advances in salivary diagnostics, artificial intelligence (AI), multi-omics technologies, and personalized regenerative therapies are enabling risk prediction, early diagnosis, and customized treatment planning. This review discusses the biological basis, diagnostic tools, therapeutic applications, current challenges, and future directions of precision and personalized periodontics.

Keywords: Precision periodontics; Personalized medicine; Biomarkers; Artificial Intelligence

INTRODUCTION

Periodontitis is a chronic multifactorial inflammatory disease initiated by microbial dysbiosis and influenced by a complex interplay of genetic, environmental, behavioral, and systemic factors.[1] Despite remarkable advances in periodontal diagnosis and treatment, conventional periodontal therapy continues to rely primarily on clinical signs such as probing pocket depth, clinical attachment loss, bleeding on probing, and radiographic bone loss.[2,3] These parameters reflect past tissue destruction rather than current disease activity or future risk. Consequently, patients exhibiting similar clinical presentations often demonstrate markedly different disease progression patterns and treatment outcomes. Such variability has highlighted the limitations of traditional population-based therapeutic approaches and emphasized the need for more individualized patient management strategies.[4,5]

The concept of precision medicine emerged from the recognition that biological variability among individuals significantly influences disease susceptibility, progression, and therapeutic response. Precision medicine seeks to provide the right treatment to the right patient at the right time by integrating genetic, molecular, environmental, and lifestyle factors into clinical decision-making. When applied to periodontology, this concept has given rise to precision and personalized periodontics, an evolving discipline that aims to tailor preventive, diagnostic, and therapeutic interventions according to the unique characteristics of each patient. Rather than treating all patients with similar clinical findings in the same manner, precision periodontics recognizes that periodontal disease manifests differently in different individuals and therefore requires customized treatment approaches **(Table1)**.[6-8]

Table 1. Conventional Periodontics versus Precision Periodontics

Parameter	Conventional Periodontics	Precision Periodontics
Approach	Disease-centered	Patient-centered
Diagnosis	Clinical and radiographic findings	Clinical, radiographic, molecular, and genetic data
Risk Assessment	Population-based	Individualized risk profiling
Treatment Planning	Standardized protocols	Personalized therapeutic strategies
Monitoring	Periodic clinical examination	Biomarker-guided and predictive monitoring
Prognosis	Generalized prediction	Individualized prediction
Recall Interval	Fixed schedule	Risk-based schedule
Therapeutic Goal	Control of disease	Prevention, prediction, and personalized management

Concept of Precision and Personalized Periodontics: Precision periodontics represents a paradigm shift from disease-centered care to patient-centered care. The traditional periodontal model focuses primarily on eliminating bacterial biofilm and controlling inflammation through standardized protocols. While these approaches have proven effective for many patients, they often fail to account for individual variations in host immune response, genetic susceptibility, microbial composition, and environmental influences. Precision periodontics integrates multiple sources of patient-specific information, including genomic data, molecular biomarkers, microbiological profiles, clinical characteristics, and digital imaging findings, to develop individualized risk assessments and treatment strategies.

Personalized periodontics and precision periodontics are often used interchangeably, although subtle differences exist. Personalized medicine focuses on tailoring treatment according to an individual's characteristics, whereas precision medicine utilizes advanced technologies and molecular information to classify patients into subgroups that are more likely to respond to specific interventions. Together, these concepts aim to improve diagnostic accuracy, enhance treatment effectiveness, reduce unnecessary interventions, and optimize long-term periodontal outcomes **(Table 2)**.[9,10]

Table 2. Components of Precision Periodontics

Component	Description	Clinical Application
Genomics	Study of genetic variations	Identification of susceptible individuals
Epigenomics	Study of gene regulation mechanisms	Understanding environmental influences
Transcriptomics	Analysis of gene expression	Assessment of active disease pathways
Proteomics	Study of proteins	Identification of inflammatory biomarkers
Metabolomics	Analysis of metabolites	Evaluation of disease activity
Microbiomics	Characterization of oral microbial communities	Personalized antimicrobial therapy
Artificial Intelligence	Data-driven predictive analysis	Diagnosis, prognosis, and treatment planning
Digital Dentistry	Digital imaging and workflow integration	Precision diagnosis and monitoring

Biological Basis of Precision Periodontics: The scientific foundation of precision periodontics lies in understanding the biological heterogeneity of periodontal disease. Although dental plaque serves as the primary etiological factor, the severity and progression of periodontal destruction are largely determined by the host's immune-inflammatory response. Genetic factors play a significant role in influencing susceptibility to periodontal disease. Variations in genes encoding inflammatory mediators, such as interleukin-1 (IL-1), tumor necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), and toll-like receptors, have been associated with altered immune responses and increased risk of tissue destruction. Individuals carrying specific genetic polymorphisms may exhibit exaggerated inflammatory reactions to microbial challenges, predisposing them to more severe periodontal breakdown.

In addition to genetic influences, epigenetic mechanisms contribute significantly to periodontal disease susceptibility and progression. Epigenetics refers to heritable modifications in gene expression that occur without alterations in DNA sequence. Environmental

factors such as smoking, diabetes, stress, nutrition, and microbial exposure can induce epigenetic changes including DNA methylation, histone modifications, and microRNA regulation. These alterations may influence inflammatory pathways and tissue responses, thereby affecting disease outcomes. Understanding these mechanisms provides valuable insights into why individuals with similar genetic backgrounds may experience different clinical manifestations of periodontitis.

The host immune response represents another critical component of precision periodontics. Periodontal tissue destruction results primarily from an excessive inflammatory response rather than direct bacterial action. Cytokines such as IL-1β, IL-6, TNF-α, prostaglandin E2, and matrix metalloproteinases play pivotal roles in mediating connective tissue degradation and alveolar bone resorption. Significant inter-individual variations exist in the production and regulation of these mediators, contributing to differences in disease severity and treatment response. Precision approaches seek to identify these variations and utilize them for individualized therapeutic planning.[11,12]

Multi-Omics Technologies in Precision Periodontics: Multi-omics technologies have significantly advanced precision periodontics by enabling comprehensive analysis of the biological factors involved in periodontal disease. Genomics identifies genetic variations associated with disease susceptibility and treatment response. Transcriptomics evaluates gene expression patterns, providing insights into active inflammatory processes. Proteomics analyzes proteins involved in tissue destruction and inflammation, helping identify potential biomarkers and therapeutic targets. Metabolomics examines cellular metabolites that reflect current disease activity and treatment outcomes. Microbiomics characterizes the oral microbial ecosystem, allowing detailed assessment of microbial dysbiosis associated with periodontitis. Together, these technologies facilitate personalized diagnosis, risk assessment, and treatment planning.[13,14]

Biomarkers in Precision Periodontics: Biomarkers have emerged as one of the most promising tools in precision periodontics. A biomarker is a measurable biological indicator that reflects normal physiological processes, pathological conditions, or therapeutic responses. Unlike conventional clinical measurements that assess historical tissue destruction, biomarkers can provide real-time information regarding disease activity and future progression.

Saliva has gained considerable attention as a diagnostic fluid because of its non-invasive collection, ease of storage, and rich molecular content. Numerous salivary biomarkers have been investigated for periodontal diagnosis, including interleukin-1β, interleukin-6, tumor necrosis factor-alpha, C-reactive protein, matrix metalloproteinase-8, and matrix metalloproteinase-9. Elevated concentrations of these biomarkers have been associated with increased disease severity and active periodontal breakdown. Salivary diagnostics may therefore facilitate early disease detection and personalized treatment planning.

Gingival crevicular fluid (GCF) provides another valuable source of biomarkers. As an inflammatory exudate originating from periodontal tissues, GCF contains numerous molecules reflecting local disease processes. Biomarkers such as receptor activator of nuclear factor kappa-B ligand (RANKL), osteoprotegerin, osteocalcin, and various matrix metalloproteinases can provide insights into ongoing tissue destruction and bone metabolism. The development of point-of-care diagnostic technologies, including biosensors and microfluidic devices, has further enhanced the clinical applicability of biomarker-based diagnostics.[15-17]

Oral Microbiome and Personalized Therapy: The understanding of periodontal microbiology has evolved substantially over recent decades. Traditional models focused primarily on identifying specific periodontal pathogens responsible for disease initiation. However, contemporary research recognizes periodontitis as a consequence of microbial dysbiosis, characterized by disruption of the ecological balance within the oral microbiome. Rather than being caused by individual pathogens alone, periodontal disease results from complex interactions among diverse microbial communities and host immune responses.

Advanced sequencing technologies have enabled comprehensive characterization of the oral microbiome and revealed substantial inter-individual variability in microbial composition. These findings support the concept of personalized microbiome-based therapy. Microbial profiling may help identify patients who are likely to benefit from specific antimicrobial interventions, probiotics, prebiotics, or microbiome-modulating strategies. Such approaches have the potential to improve treatment effectiveness while minimizing unnecessary antibiotic use and reducing the risk of antimicrobial resistance.[18,19]

Artificial Intelligence in Precision Periodontics: Artificial intelligence has emerged as a transformative technology in modern periodontology. AI systems utilize machine learning and deep learning algorithms to analyze large datasets and identify complex patterns that may not be readily apparent to clinicians. In periodontal diagnosis,

AI algorithms have demonstrated remarkable accuracy in detecting alveolar bone loss, classifying disease severity, and assessing peri-implant conditions from radiographic images.

Beyond diagnostic applications, AI has significant potential in predictive analytics and clinical decision support. By integrating clinical parameters, biomarker data, genetic information, and microbiological profiles, AI systems can generate individualized risk assessments and predict disease progression. Such predictive models may enable clinicians to identify high-risk patients, optimize recall intervals, and implement targeted preventive strategies. As digital dentistry continues to evolve, AI is expected to become an integral component of precision periodontal care.[20,21]

Personalized Therapeutic Approaches: The ultimate goal of precision periodontics is the development of individualized therapeutic strategies that address each patient's unique biological characteristics. Personalized treatment begins with comprehensive risk assessment incorporating genetic, molecular, microbial, systemic, and behavioral factors. Based on this information, clinicians can customize treatment plans and maintenance protocols according to individual risk profiles.

Host modulation therapy represents an important aspect of personalized periodontal treatment. Unlike conventional therapies that focus primarily on bacterial reduction, host modulation aims to regulate the inflammatory response responsible for tissue destruction. Agents such as subantimicrobial-dose doxycycline, specialized pro-resolving mediators, and cytokine-targeted therapies have shown promise in modifying disease progression among susceptible individuals.

Precision regenerative periodontics is another rapidly expanding field. Advances in tissue engineering, stem cell biology, growth factor delivery, and platelet concentrates have created opportunities for individualized regenerative therapies. Platelet-rich fibrin, injectable platelet-rich fibrin, recombinant growth factors, mesenchymal stem cells, and biomimetic scaffolds can be selected according to specific patient characteristics and defect morphology, thereby enhancing regenerative outcomes.[7,8,15,16]

Table 3. Advantages and Limitations of Precision Periodontics

Advantages	Limitations
Early disease detection	High cost of technology
Improved diagnostic accuracy	Limited clinical availability
Personalized treatment planning	Lack of standardization
Better treatment outcomes	Need for specialized training
Reduced overtreatment	Data integration challenges
Enhanced patient compliance	Ethical and privacy concerns
Predictive disease management	Limited long-term evidence

Challenges and Future Perspectives: Although precision periodontics offers significant potential, its clinical implementation is limited by the lack of standardized biomarkers, validated diagnostic protocols, high costs, and the need for specialized expertise. Ethical concerns related to genetic data privacy, security, and informed consent also require careful consideration. Future advancements are expected to integrate multi-omics technologies, artificial intelligence, digital dentistry, and regenerative medicine into personalized care models. Emerging innovations such as digital twins and wearable biosensors may enable real-time disease monitoring, predictive diagnostics, and more effective individualized periodontal treatment.

CONCLUSION

Precision and personalized periodontics represent the future of periodontal healthcare. By integrating genetic susceptibility, epigenetic influences, molecular biomarkers, microbiome analysis, artificial intelligence, and regenerative technologies, clinicians can move beyond traditional reactive treatment approaches toward predictive, preventive, and individualized care. Although significant challenges remain, ongoing advances in molecular biology, bioinformatics, and digital technologies are rapidly transforming this vision into reality. The successful implementation of precision periodontics has the potential to improve diagnostic accuracy, enhance therapeutic outcomes, reduce healthcare costs, and ultimately provide more effective patient-centered periodontal care.

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