

Personalized caries prevention using AI-driven salivary microbiome analysis integrated with wearable dietary monitoring.

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Abstract

Dental caries remains one of the most prevalent chronic oral diseases worldwide despite significant advances in preventive dentistry. Conventional preventive approaches often rely on generalized risk assessments that may not adequately account for individual variations in oral microbiology, dietary habits, and host responses. The convergence of artificial intelligence (AI), salivary microbiome analysis, and wearable dietary monitoring offers a transformative strategy for personalized caries prevention. AI algorithms can process complex salivary microbiome profiles, salivary biomarkers, and behavioral data collected through wearable biosensors to identify individualized caries risk patterns with greater accuracy than traditional methods. Continuous monitoring of dietary sugar intake, eating frequency, and oral environmental changes enables real-time assessment of factors that influence cariogenic activity, facilitating timely preventive interventions and personalized clinical recommendations. Integrating these technologies supports precision dentistry by improving early risk prediction, enhancing patient engagement, promoting preventive behavioral modifications, and optimizing evidence-based decision-making. Furthermore, remote monitoring capabilities expand access to preventive oral healthcare while supporting long-term disease surveillance and individualized treatment planning. Although challenges related to data integration, standardization, privacy, clinical validation, and implementation remain, AI-driven salivary microbiome analysis combined with wearable dietary monitoring represents a promising framework for advancing personalized, preventive, and predictive dental care.

Keywords: Artificial intelligence, dental caries, salivary microbiome, salivary biomarkers, wearable biosensors, dietary monitoring, precision dentistry, personalized prevention, oral health monitoring, predictive analytics.

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INTRODUCTION

Dental caries remains one of the most prevalent chronic oral diseases worldwide, affecting individuals across all age groups and imposing substantial clinical, social, and economic burdens. Although conventional preventive measures such as fluoride therapy, dietary counseling, oral hygiene promotion, and periodic dental examinations have significantly reduced disease prevalence, these approaches are largely population-based and often fail to account for individual biological variability. The growing emphasis on precision dentistry has therefore shifted attention toward personalized preventive strategies that integrate patient-specific biological, behavioral, and environmental factors to improve risk prediction and clinical outcomes (Nayak et al., 2025).

Artificial intelligence (AI) has emerged as a powerful tool for transforming preventive dentistry by enabling the rapid analysis of complex datasets generated from salivary biomarkers, microbiome sequencing, wearable biosensors, and digital health platforms. Machine learning algorithms can identify hidden patterns associated with cariogenic microbial communities, dietary behaviors, salivary pH fluctuations, and host responses, thereby facilitating individualized caries risk assessment and evidence-based preventive recommendations (Falkner, 2025; Sgiea et al., 2025). Advances in salivary biomarker identification and high-throughput analytical technologies have further strengthened the

role of saliva as a non-invasive diagnostic medium for monitoring oral health and disease progression (Constantin et al., 2025).

The integration of wearable bioelectronics with AI has expanded opportunities for continuous monitoring of dietary habits, sugar exposure, and physiological parameters that influence the oral ecosystem. These wearable systems generate real-time data that can be combined with salivary microbiome profiles to support dynamic and personalized preventive interventions (Chen et al., 2025). Such precision-based approaches complement contemporary minimally invasive caries management strategies, including biomaterial-based restorative treatments and silver diamine fluoride applications aimed at preserving tooth structure and pulpal vitality (Singh, 2025; Singh et al., 2026). Collectively, AI-driven salivary microbiome analysis integrated with wearable dietary monitoring represents a promising paradigm for advancing predictive, preventive, and personalized caries management.

AI-DRIVEN SALIVARY MICROBIOME ANALYSIS

Artificial intelligence (AI)-driven salivary microbiome analysis represents a major advancement in precision dentistry by enabling individualized assessment of caries risk based on microbial composition, salivary biomarkers, and host-related factors. Unlike conventional diagnostic methods that primarily detect established lesions, AI integrates high-throughput sequencing data with clinical parameters to identify early microbial shifts associated with cariogenic biofilm formation and disease progression (Constantin et al., 2025; Nayak et al., 2025).

Saliva serves as a non-invasive diagnostic medium containing diverse microorganisms, metabolites, proteins, inflammatory mediators, and pH-related indicators that collectively reflect oral health status. Machine learning and deep learning algorithms analyze these multidimensional datasets to classify patients according to their personalized caries risk while identifying dominant cariogenic species and protective microbial profiles. Integration of salivary pH measurements with AI further improves early detection of acidogenic changes that precede enamel demineralization, particularly in pediatric and high-risk populations (Sgiea et al., 2025; Falkner, 2025).

The predictive capability of AI is strengthened by combining microbiome data with biomarker profiling, enabling clinicians to develop targeted preventive strategies rather than generalized recommendations. Emerging wearable bioelectronic platforms facilitate continuous collection of salivary information, allowing dynamic risk monitoring and adaptive preventive interventions (Chen et al., 2025). These advances complement minimally invasive caries management strategies and support preservation of pulpal health through timely preventive care (Singh et al., 2026). Furthermore, AI-generated risk profiles can guide the selection of preventive restorative materials and personalized treatment planning, contributing to improved long-term clinical outcomes (Singh, 2025).

Table 1. AI-Driven Salivary Microbiome Parameters for Personalized Caries Risk Assessment

Salivary Parameter	AI Analytical Approach	Clinical Significance
Microbial diversity	Machine learning classification	Individual caries risk stratification
Cariogenic bacterial abundance	Deep learning prediction models	Early identification of dysbiosis
Salivary pH	Real-time AI monitoring	Detection of acidogenic challenges
Salivary proteins and metabolites	Multi-biomarker pattern recognition	Early disease prediction
Inflammatory biomarkers	Predictive analytics	Monitoring disease activity and treatment response
Integrated microbiome profile	AI decision-support systems	Personalized preventive and clinical management

WEARABLE DIETARY MONITORING AND AI INTEGRATION

Wearable dietary monitoring has emerged as an important component of precision dentistry by enabling continuous assessment of dietary behaviors that influence dental caries risk. Smart wearables, including biosensor-enabled wristbands, smart oral appliances, and mobile health devices, can record sugar intake frequency, meal timing, hydration status, and behavioral patterns associated with cariogenic challenges. When integrated with artificial intelligence (AI), these data are analyzed alongside salivary microbiome profiles and salivary biomarkers to generate individualized caries risk predictions and preventive recommendations (Chen et al., 2025; Falkner, 2025).

AI algorithms combine real-time dietary information with salivary pH, microbial composition, and biomarker data to identify periods of elevated cariogenic activity. This integrated approach allows clinicians to deliver personalized interventions such as dietary counseling, fluoride recommendations, salivary stimulation strategies, and targeted recall schedules before irreversible demineralization occurs. The incorporation of AI-assisted salivary pH monitoring further improves early detection of acidogenic episodes, particularly in pediatric and high-risk populations (Sgiea et al., 2025; Constantin et al., 2025).

Wearable bioelectronics also facilitate remote patient monitoring and improve adherence by providing automated reminders and feedback regarding dietary choices and oral hygiene practices. Such continuous monitoring aligns with the goals of preventive and minimally invasive dentistry, complementing contemporary restorative strategies and individualized management of carious lesions (Singh, 2025; Singh et al., 2026). Furthermore, AI-supported wearable systems have demonstrated considerable potential in early childhood caries prevention by enabling personalized behavioral modifications and continuous risk assessment across diverse patient populations (Nayak et al., 2025).

Table 2. Integration of Wearable Dietary Monitoring with AI for Personalized Caries Prevention

Wearable Technology	Data Collected	AI Function	Clinical Benefit
Smart dietary trackers	Sugar intake frequency, meal timing	Dietary risk prediction	Personalized nutritional counseling
Salivary biosensors	Salivary pH and biomarkers	Early acidogenic event detection	Timely preventive intervention
Smart oral devices	Oral hygiene behaviors	Compliance monitoring	Improved patient adherence
Integrated AI platform	Dietary, microbiome, and salivary data	Individualized caries risk stratification	Precision preventive care and optimized recall scheduling

CLINICAL APPLICATIONS, CHALLENGES, AND FUTURE PERSPECTIVES

Clinical Applications

AI-driven salivary microbiome analysis integrated with wearable dietary monitoring represents a major advancement in personalized caries prevention by enabling continuous, patient-specific risk assessment. Salivary microbiome profiling combined with AI algorithms can identify cariogenic microbial patterns, metabolic changes, and biomarker signatures associated with early disease development. Advanced salivary diagnostic platforms incorporating pH monitoring and biomarker analysis may support early detection and preventive intervention before irreversible tooth damage occurs (Constantin et al., 2025; Sgiea et al., 2025).

Wearable bioelectronic devices can continuously capture dietary behaviors, sugar exposure frequency, and oral environmental fluctuations, allowing AI systems to generate real-time preventive recommendations. These technologies may enhance remote oral health monitoring, patient motivation, and individualized preventive strategies in both adults and children (Falkner, 2025; Chen et al., 2025). In pediatric dentistry, AI-assisted risk prediction models can improve early childhood caries management by identifying vulnerable individuals and guiding targeted preventive programs (Nayak et al., 2025). Integration with minimally invasive approaches, including preventive remineralization and caries arrest strategies, may further optimize personalized treatment planning (Singh et al., 2026).

Challenges

Despite promising clinical potential, several challenges remain, including variability in salivary microbiome composition, lack of standardized diagnostic protocols, and difficulties in integrating multi-dimensional biological and behavioral datasets. Data privacy, cybersecurity, cost limitations, and accessibility of wearable technologies must also be addressed before widespread clinical implementation (Chen et al., 2025). Additionally, AI models require extensive clinical validation to ensure reliability, transparency, and applicability across diverse populations.

Future Perspectives

Future developments will focus on combining microbiomics, metabolomics, wearable biosensors, and explainable AI to create comprehensive digital oral health platforms. Predictive AI systems may enable continuous caries surveillance, personalized dietary coaching, and adaptive preventive interventions. These innovations are expected to strengthen precision dentistry by shifting caries management from reactive treatment toward proactive, individualized prevention (Falkner, 2025; Constantin et al., 2025).

CONCLUSION

Personalized caries prevention using AI-driven salivary microbiome analysis integrated with wearable dietary monitoring represents a significant advancement toward precision dentistry. By combining microbiological, biochemical, behavioral, and real-time physiological data, this approach enables more accurate identification of individual caries susceptibility and supports proactive preventive interventions. AI-based interpretation of salivary microbiome profiles and biomarkers provides opportunities for early detection of cariogenic changes before clinical disease progression, improving the effectiveness of preventive strategies (Constantin et al., 2025; Sgiea et al., 2025).

The integration of wearable biosensors and intelligent monitoring platforms further enhances continuous oral health assessment by tracking dietary behaviors, salivary changes, and risk-related factors in real time. These technologies can facilitate personalized dietary guidance, patient engagement, and remote oral healthcare delivery while supporting data-driven clinical decision-making (Falkner, 2025; Chen et al., 2025). AI-driven approaches are particularly valuable in high-risk populations, including children susceptible to early childhood caries, where individualized prediction and preventive management can contribute to improved global oral health outcomes (Nayak et al., 2025).

Although challenges related to technological accessibility, data privacy, clinical validation, and integration into routine dental workflows remain, continued development of AI algorithms, wearable bioelectronics, and biomarker-based diagnostics is expected to improve the reliability and applicability of personalized caries prevention. Furthermore, combining preventive technologies with minimally invasive caries management approaches may enhance long-term tooth preservation and patient outcomes (Singh, 2025; Singh et al., 2026). Overall, AI-enabled salivary microbiome analysis with wearable dietary monitoring provides a promising pathway toward predictive, preventive, and patient-centered dental care.

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