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Continuous Wearable Salivary Biosensors for Real-time Periodontal Inflammation Monitoring

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ABSTRACT

Periodontal inflammation remains one of the most prevalent oral health conditions, often progressing silently until significant tissue destruction has occurred. Conventional diagnostic methods rely on periodic clinical examinations, limiting the ability to detect dynamic changes in disease activity. Continuous wearable salivary biosensors represent an emerging approach that enables real-time, non-invasive monitoring of inflammatory biomarkers directly from saliva. These wearable devices integrate advanced biosensing technologies with miniaturized electronics to continuously measure biochemical indicators associated with periodontal disease, providing immediate insights into disease progression and treatment response. The incorporation of flexible materials, wireless communication, and portable analytical platforms allows seamless data acquisition and transmission, supporting personalized oral healthcare and remote patient monitoring. Continuous assessment of salivary biomarkers may facilitate earlier intervention, improve treatment planning, enhance patient compliance, and reduce the long-term burden of periodontal disease. Furthermore, integration with digital health systems and artificial intelligence-based analytical tools has the potential to improve diagnostic accuracy and support predictive disease management. Although technical challenges such as sensor stability, biomarker variability, and regulatory considerations remain, ongoing advances in wearable biosensor design continue to improve clinical feasibility. Continuous wearable salivary biosensors therefore represent a promising innovation for precision periodontology, offering a practical strategy for early detection, continuous disease surveillance, and individualized management of periodontal inflammation.

INTRODUCTION

Periodontal inflammation is a chronic inflammatory condition initiated by microbial biofilms and characterized by progressive destruction of the supporting structures of the teeth. Early diagnosis and continuous monitoring are essential for preventing disease progression, minimizing irreversible tissue damage, and improving long-term treatment outcomes. Conventional periodontal assessment relies primarily on clinical parameters such as probing depth, clinical attachment loss, bleeding on probing, and radiographic evaluation. While these methods provide valuable diagnostic information, they are largely episodic and may not accurately reflect real-time inflammatory activity occurring between clinical visits (Steigmann et al., 2020).

Saliva has emerged as an attractive diagnostic medium because it contains numerous biomarkers associated with periodontal inflammation, including cytokines, enzymes, metabolites, and microbial products. Its non-invasive collection, rapid accessibility, and close association with oral tissues make saliva particularly suitable for continuous disease surveillance. Advances in salivary biosensor technology have enabled sensitive detection of these biomarkers, supporting earlier diagnosis and more personalized management of periodontal diseases (Malon et al., 2014; Steigmann et al., 2020).

Recent developments in wearable biosensors, lab-on-a-chip platforms, and intraoral sensing devices have expanded the possibilities for continuous monitoring of periodontal health. These systems integrate miniaturized biosensors with wireless communication technologies to provide real-time biochemical analysis while improving patient convenience and facilitating remote clinical monitoring (Pataranutaporn et al., 2019; Moonla et al., 2022). The incorporation of molecularly imprinted polymers and advanced point-of-care biosensing platforms has further enhanced analytical sensitivity, specificity, and portability for intraoral applications (Park et al., 2022).

The growing integration of biosensor technology with digital dentistry complements broader advances in minimally invasive dental care, regenerative procedures, and precision treatment strategies that emphasize biological monitoring and individualized patient management (Singh, 2020; Singh, 2019). Continuous wearable salivary biosensors therefore represent a promising innovation for real-time periodontal inflammation monitoring, supporting earlier intervention, improved therapeutic decision-making, and the advancement of precision oral healthcare.

Continuous Wearable Salivary Biosensors for Periodontal Inflammation Monitoring

Continuous wearable salivary biosensors have emerged as a promising innovation for monitoring periodontal inflammation through non-invasive, real-time analysis of salivary biomarkers. Unlike conventional periodontal assessments that rely on intermittent clinical examinations, these wearable systems continuously detect biochemical changes in saliva, allowing earlier identification of inflammatory activity and improved monitoring of disease progression. Salivary biomarkers such as interleukin-1β (IL-1β), matrix metalloproteinase-8 (MMP-8), tumor necrosis factor-α (TNF-α), and C-reactive protein provide valuable information regarding periodontal tissue destruction and host immune response, making saliva an ideal diagnostic medium (Malon et al., 2014; Steigmann et al., 2020).

Modern wearable platforms combine electrochemical sensing, lab-on-a-chip technology, flexible electronics, and wireless communication to provide continuous biomarker measurement with minimal patient discomfort. Wearable "lab-on-body" concepts further integrate biochemical sensing with digital physiological monitoring, enabling comprehensive assessment of oral health and supporting personalized disease management (Pataranutaporn et al., 2019). Recent developments in molecularly imprinted polymer (MIP)-based biosensors have enhanced the selectivity, sensitivity, and stability of point-of-care devices designed for intraoral fluid analysis, improving their potential for clinical application (Park et al., 2022).

Advances in "lab-in-a-mouth" systems have further expanded the capabilities of wearable salivary diagnostics by integrating miniaturized sensing platforms into oral appliances capable of continuous biomarker detection and wireless data transmission (Moonla et al., 2022). Such technologies may facilitate early diagnosis, evaluate treatment response, and support preventive periodontal care through personalized monitoring. These developments complement broader advances in regenerative and minimally invasive dental therapies, where accurate biological assessment contributes to optimized clinical decision-making (Singh, 2020; Singh, 2019). Collectively, continuous wearable salivary biosensors represent a significant step toward precision periodontology by enabling real-time, patient-centered monitoring of periodontal inflammation (Steigmann et al., 2020).

Challenges, Clinical Translation, and Future Perspectives

Despite remarkable progress in wearable salivary biosensor technology, several challenges must be addressed before routine clinical implementation. One major limitation is maintaining sensor stability and analytical accuracy within the complex oral environment, where fluctuations in salivary flow, pH, temperature, microbial activity, and food intake can influence biomarker measurements. Long-term biocompatibility, resistance to biofouling, and reliable calibration remain critical engineering priorities for continuous monitoring systems (Malon et al., 2014; Steigmann et al., 2020).

Clinical translation also requires standardized protocols for biomarker selection, validation, and interpretation. Variability in inflammatory biomarkers among individuals and across different stages of periodontal disease may affect diagnostic consistency. In addition, device affordability, patient comfort, wireless data security, regulatory approval, and integration into routine dental practice are important considerations for widespread adoption. Advances in point-of-care platforms, molecularly imprinted polymer-based biosensors, and miniaturized lab-on-a-chip technologies are improving sensitivity, specificity, and portability, thereby enhancing their clinical potential (Park et al., 2022; Moonla et al., 2022).

Future developments are expected to focus on multiplex biosensors capable of simultaneously detecting multiple salivary biomarkers, providing a more comprehensive assessment of periodontal inflammation. Integration with artificial intelligence, cloud-based analytics, and smartphone applications may enable predictive monitoring, personalized treatment recommendations, and remote patient management (Pataranutaporn et al., 2019; Moonla et al., 2022). Furthermore, combining continuous biosensing with regenerative and minimally invasive dental therapies may strengthen precision oral healthcare, complementing advances in endodontic treatment strategies and biomaterial-based tissue preservation (Singh, 2020; Singh, 2019). Continued interdisciplinary collaboration among clinicians, engineers, and material scientists will be essential to translate wearable salivary biosensors into reliable tools for precision periodontal diagnostics and long-term disease management (Steigmann et al., 2020).

CONCLUSION

Continuous wearable salivary biosensors represent a promising advancement in periodontal diagnostics by enabling real-time, non-invasive monitoring of inflammatory biomarkers associated with disease onset, progression, and therapeutic response. Compared with conventional chairside assessments, these technologies offer continuous surveillance, supporting earlier detection of periodontal inflammation and more personalized clinical decision-making. Innovations in lab-on-a-chip systems, wearable sensing platforms, and point-of-care diagnostic devices have significantly improved the feasibility of integrating saliva-based biomarker analysis into routine oral healthcare (Malon et al., 2014; Steigmann et al., 2020; Park et al., 2022).

Although challenges related to sensor stability, biomarker variability, clinical validation, and regulatory approval remain, ongoing developments in biosensor engineering, wireless communication, and digital health technologies continue to enhance their translational potential. The incorporation of wearable monitoring systems with artificial intelligence and mobile health platforms is expected to further improve diagnostic precision, patient engagement, and remote periodontal care (Pataranutaporn et al., 2019; Moonla et al., 2022). Moreover, these innovations complement broader advances in minimally invasive and biologically guided dental therapies, supporting a shift toward precision dentistry and preventive oral healthcare (Singh, 2020; Singh, 2019). Continued interdisciplinary research and well-designed clinical studies will be essential to establish continuous wearable salivary biosensors as reliable tools for routine periodontal inflammation monitoring and individualized disease management.

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