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THE ROLE OF SALIVARY BIOMARKERS IN THE EARLY DIAGNOSIS OF ORAL DISEASES: MODERN PERSPECTIVES IN CLINICAL DENTISTRY

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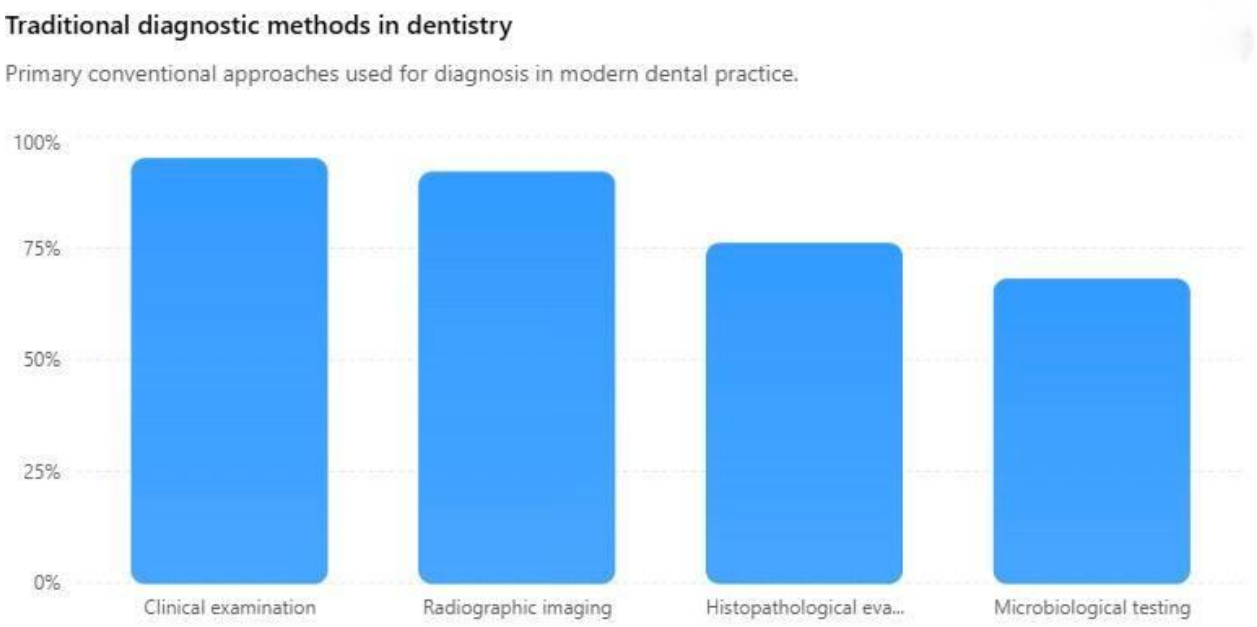
Abstract: Saliva has recently attracted significant attention as a promising diagnostic biological fluid in modern dentistry and medicine. Unlike traditional blood-based diagnostic methods, saliva collection is noninvasive, painless, safe, and easily repeatable. Advances in molecular biology, proteomics, genomics, and biosensor technologies have considerably expanded the diagnostic potential of salivary biomarkers. Today, salivary diagnostics are actively investigated for the early detection of oral cancer, periodontal diseases, dental caries, systemic diseases, and inflammatory conditions. Saliva contains numerous biologically active components, including proteins, enzymes, antibodies, cytokines, nucleic acids, metabolites, and microbiological markers that reflect both local and systemic pathological processes. The development of rapid chairside diagnostic systems and artificial intelligence-based analytical technologies may transform salivary diagnostics into an integral component of personalized dental care. This article provides a comprehensive analysis of salivary biomarkers, their clinical significance, diagnostic applications, limitations, and future perspectives in modern dentistry.

Keywords: saliva, salivary biomarkers, oral cancer, periodontal disease, diagnostics, proteomics, personalized dentistry, inflammatory markers, biosensors, oral medicine.

Introduction

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Modern dentistry increasingly focuses not only on treatment but also on early diagnosis and prevention of oral diseases. The success of dental treatment largely depends on the ability to identify pathological processes at their earliest stages before irreversible tissue destruction develops.



Although these methods remain highly important, many pathological changes become clinically detectable only after substantial disease progression has occurred.

In recent years, saliva has emerged as an important diagnostic medium due to its complex biochemical composition and easy accessibility. Saliva contains a wide range of biological molecules that may reflect inflammatory, infectious, neoplastic, metabolic, and immunological processes occurring in the body.

Advantages of Saliva Collection Compared with Blood Sampling	**Clinical Significance**
Noninvasive procedure	Eliminates tissue trauma and improves patient acceptance during diagnostic procedures.
Does not require needles	Reduces fear and anxiety, especially in pediatric and anxious patients.
Minimizes patient discomfort	Provides a painless method for repeated diagnostic evaluation and monitoring.
Reduces infection risk	Decreases the possibility of cross-contamination and accidental needle-stick injuries.
Allows repeated monitoring	Enables continuous assessment of disease progression and treatment response over time.

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These advances have significantly improved the sensitivity and specificity of salivary analysis.

Technological Fields Supporting the Development of Salivary Biomarkers	Role in Modern Dentistry and Diagnostics
Molecular diagnostics	Allows identification of specific biological and genetic disease markers in saliva.
Proteomics	Studies salivary proteins associated with inflammation, cancer, and tissue destruction.
Genomics	Analyzes genetic material and mutations related to oral and systemic diseases.
Nanotechnology	Improves sensitivity and precision of salivary biomarker detection systems.
Biosensor engineering	Enables rapid chairside detection of salivary biomarkers using portable devices.
Artificial intelligence	Assists in interpretation of complex biomarker data and improves diagnostic accuracy.

Salivary diagnostics may become especially important in dentistry because oral fluids are directly associated with the local pathological environment. Therefore, saliva may provide valuable information regarding both oral and systemic diseases.

The aim of this article is to evaluate the clinical significance of salivary biomarkers and analyze their role in modern dental diagnostics.

Saliva is a highly complex biological fluid secreted primarily by the parotid, submandibular, sublingual, and minor salivary glands. In a healthy adult, the average daily production of saliva ranges from approximately 0.5 to 1.5 liters, depending on physiological conditions, hydration status, age, and functional activity of the salivary glands. Although saliva is often underestimated in clinical practice, it plays a fundamental role in maintaining oral and systemic health.

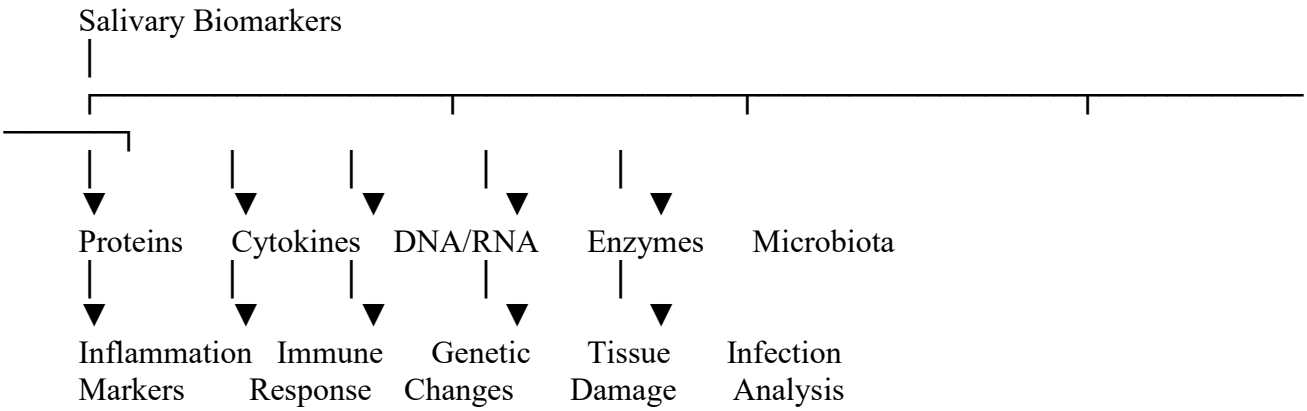
One of the primary functions of saliva is lubrication of the oral tissues, which facilitates speech, mastication, and swallowing. Saliva also contributes significantly to the initial stages of digestion through the action of digestive enzymes. In addition, it provides important antimicrobial protection by inhibiting the growth of pathogenic microorganisms and supporting the balance of the oral microbiome. Another essential function of saliva is buffering activity, which helps maintain stable oral pH and protects dental hard tissues from acidic damage. Saliva is also involved in the remineralization of enamel through the supply of calcium, phosphate, and other minerals necessary for maintaining tooth integrity. Furthermore, it plays a central role in preserving oral homeostasis and regulating the physiological environment of the oral cavity.

The biochemical composition of saliva is highly diverse and includes water, electrolytes, proteins, enzymes, antibodies, cytokines, hormones, nucleic acids, metabolites, and numerous microorganisms. These biological components reflect both local and systemic physiological processes occurring within the body. Because of this complex molecular composition, saliva has become an

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important subject of interest in modern diagnostic medicine and dentistry. Alterations in salivary composition may indicate the presence of inflammatory, infectious, metabolic, autoimmune, or neoplastic diseases. Consequently, salivary analysis is increasingly considered a promising noninvasive diagnostic approach for early disease detection, monitoring of pathological progression, and evaluation of treatment outcomes.

Main Components of Salivary Biomarkers



Periodontal diseases are chronic inflammatory conditions that affect the supporting structures of the teeth, including the gingiva, periodontal ligament, cementum, and alveolar bone. The progression of periodontitis is closely associated with connective tissue destruction, alveolar bone resorption, immune dysregulation, and the activity of pathogenic bacterial biofilms. In recent years, saliva has become an important diagnostic medium for the evaluation of periodontal disease because it contains numerous biological molecules that reflect inflammatory activity within periodontal tissues. Among the most clinically significant salivary biomarkers are inflammatory cytokines such as interleukin-1β (IL-1β), interleukin-6 (IL-6), and tumor necrosis factor-α (TNF-α). Elevated concentrations of these mediators are strongly associated with periodontal tissue destruction and disease severity.

In addition to cytokines, matrix metalloproteinases, particularly MMP-8 and MMP-9, play a crucial role in collagen degradation and periodontal breakdown. Increased salivary levels of these enzymes may indicate active periodontal destruction, assist in monitoring treatment response, and help predict future disease progression. Because of these characteristics, salivary diagnostics are increasingly considered a promising tool for noninvasive periodontal assessment and long-term disease monitoring.

Salivary biomarkers also demonstrate significant potential in the early detection of oral cancer. Oral squamous cell carcinoma remains one of the most aggressive diseases in oral medicine, mainly due to delayed diagnosis and poor survival rates in advanced stages. Early identification of malignant transformation greatly improves prognosis and treatment outcomes. Research has identified multiple salivary biomarkers associated with oral cancer, including p53 mutations, interleukin-8, microRNAs, epidermal growth factor receptor, and cytokeratin fragments. The presence of these molecular alterations in saliva suggests that salivary analysis may become an effective noninvasive screening approach for the early detection of oral malignancies.

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The diagnostic potential of salivary biomarkers extends beyond oncology and periodontology. Modern salivary analysis allows identification of disease-associated biomarkers, supports disease screening, contributes to early diagnosis, enables continuous treatment monitoring, and facilitates personalized therapeutic approaches. As a result, saliva is increasingly viewed as an important component of precision and preventive dentistry.

Salivary diagnostics are also highly relevant in dental caries research. Dental caries is a multifactorial disease influenced by bacterial activity, salivary composition, dietary habits, and host immune response. Saliva plays a critical protective role against demineralization through buffering activity and mineral supply. Various salivary biomarkers may help evaluate individual caries risk, including Streptococcus mutans levels, Lactobacillus counts, salivary pH, buffering capacity, and calcium and phosphate concentrations. Patients with reduced buffering capacity and altered oral microbiological composition frequently demonstrate increased susceptibility to carious lesions.

In addition to oral diseases, saliva may reflect numerous systemic pathological conditions. Current research demonstrates the potential application of salivary diagnostics in diseases such as diabetes mellitus, cardiovascular disorders, autoimmune diseases, viral infections, and hormonal imbalances. For example, elevated glucose concentrations in saliva may correlate with poorly controlled diabetes mellitus. Similarly, inflammatory biomarkers associated with cardiovascular pathology may also be identified in oral fluids. These findings support the concept that saliva may serve as a valuable diagnostic medium not only in dentistry but also in general medicine, contributing to the development of noninvasive and personalized healthcare approaches.

Comparison of Diagnostic Applications of Salivary Biomarkers

Disease Category	Main Biomarkers	Clinical Importance
Periodontal disease	IL-1β, TNF-α, MMP-8	Evaluation of inflammation and tissue destruction
Oral cancer	p53, IL-8, microRNAs	Early cancer detection
Dental caries	Streptococcus mutans, salivary pH	Caries risk assessment
Diabetes mellitus	Salivary glucose	Metabolic monitoring
Viral infections	Viral RNA, antibodies	Rapid infection detection

Artificial intelligence has significantly improved the analysis and interpretation of salivary biomarker data in modern dentistry and medical diagnostics. Traditional laboratory analysis of saliva often requires extensive manual processing and complex statistical interpretation, whereas AI-based systems are capable of rapidly identifying hidden molecular patterns and clinically significant correlations within large biological datasets. Machine learning algorithms can predict disease risk, classify patients according to specific biomarker profiles, and improve overall diagnostic sensitivity and accuracy. These technologies are particularly valuable when analyzing complex inflammatory, genetic, and proteomic changes associated with oral and systemic diseases. In addition, artificial intelligence can process enormous molecular datasets considerably faster than conventional analytical methods, allowing clinicians to obtain more precise diagnostic information within shorter periods of time. The integration of AI technologies with biosensor systems may eventually enable real-time

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chairside diagnostics, making salivary testing more accessible and clinically practical during routine dental examinations.

Recent technological advances have substantially expanded the clinical applicability of salivary diagnostics. One of the most important developments is the introduction of biosensors capable of rapidly detecting specific biological molecules within saliva. These devices demonstrate several significant advantages, including rapid analysis, minimal sample volume requirements, high sensitivity, and portability. As a result, biosensor technologies may simplify diagnostic procedures and facilitate early disease detection in both clinical and remote settings.

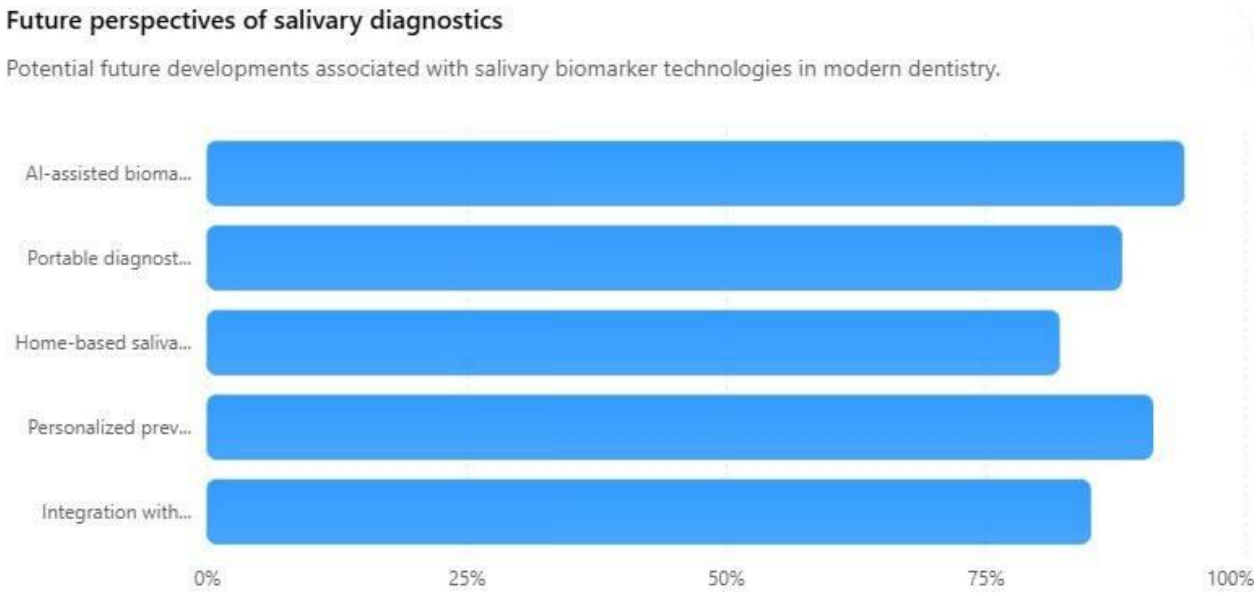
Another important innovation is lab-on-a-chip technology. These microfluidic systems enable simultaneous analysis of multiple salivary biomarkers using extremely small saliva samples. Such technologies combine miniaturized laboratory functions within compact devices and may become essential tools in personalized and preventive dentistry. Their ability to provide rapid and highly sensitive analysis supports the transition toward individualized patient care and minimally invasive diagnostics.

Salivary diagnostics also offer numerous clinical advantages compared with traditional diagnostic methods. One of the most important benefits is the noninvasive nature of saliva collection, which eliminates the discomfort and psychological stress commonly associated with blood sampling. In addition, saliva collection allows repeated monitoring of patients over time, making it possible to dynamically assess disease progression and treatment effectiveness. Noninvasive sampling also reduces the risk of cross-contamination and accidental infection transmission. Furthermore, salivary testing may lower laboratory and procedural costs, improving the accessibility of diagnostic services.

Despite significant progress in this field, salivary diagnostics continue to face several important limitations and challenges. One of the major difficulties is biological variability, since salivary composition may change depending on age, hydration status, circadian rhythm, medication use, dietary habits, and smoking. These factors may influence biomarker concentrations and complicate result interpretation. Another important challenge is the lack of standardized collection and analytical protocols, which limits comparison between different clinical studies and diagnostic systems. Additionally, some salivary biomarkers are present in extremely low concentrations and therefore require highly sensitive and technologically advanced detection methods. Consequently, further research and technological development remain necessary to improve the reliability, standardization, and clinical implementation of salivary diagnostics in modern dentistry.

The future of salivary diagnostics appears highly promising.

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The combination of genomics, proteomics, nanotechnology, and artificial intelligence may revolutionize noninvasive diagnostics in dentistry.

Salivary diagnostics may eventually become a routine part of preventive dental examinations.

Future Expansion of Salivary Diagnostics

Conventional Diagnostics
↓
Molecular Salivary Analysis
↓
AI-Based Interpretation
↓
Chairside Diagnostics
↓
Personalized Dentistry
↓
Predictive Healthcare

Conclusion

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Salivary biomarkers represent one of the most promising directions in modern dental diagnostics. The noninvasive nature of saliva collection, combined with advances in molecular biology and artificial intelligence, has significantly expanded the clinical potential of salivary analysis. Salivary biomarkers demonstrate considerable diagnostic value in periodontal disease, oral cancer, dental caries, and systemic conditions. Modern biosensor technologies and AI-assisted analysis may further improve the sensitivity, specificity, and accessibility of salivary diagnostics.

Despite existing limitations related to biological variability and standardization, ongoing technological developments continue to enhance the reliability of salivary biomarker analysis.

The integration of salivary diagnostics into routine dental practice may contribute to earlier disease detection, personalized treatment planning, and improved preventive care.

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