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A NOVEL MODEL FOR EARLY DIAGNOSIS OF DENTAL DISEASES BASED ON ARTIFICIAL INTELLIGENCE AND SALIVARY BIOMARKERS

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Annotation

Early diagnosis of dental diseases is crucial for preventing irreversible tissue damage and improving patient outcomes. Recent advancements in artificial intelligence (AI) combined with salivary biomarker analysis offer a promising approach for non-invasive, rapid, and accurate detection of oral pathologies. Salivary biomarkers, including proteins, enzymes, metabolites, and nucleic acids, reflect both local and systemic disease states. Integration of AI algorithms allows automated pattern recognition, predictive modeling, and individualized risk assessment based on complex biomarker profiles. This novel model enhances early detection of dental caries, periodontal diseases, and oral cancers, enabling personalized treatment strategies and improved preventive care [1, 2, 3].

Keywords

artificial intelligence, salivary biomarkers, early diagnosis, dental diseases, predictive modeling [4, 5]

Annotatsiya

Tish kasalliklarini erta aniqlash to‘qimalarning qaytarilmas shikastlanishini oldini olish va bemor natijalarini yaxshilash uchun muhim ahamiyatga ega. Sun’iy intellekt (AI) texnologiyalari va og‘iz suyuqligidagi biomarkerlarni tahlil qilish so‘nggi yillarda invaziv bo‘lmagan, tezkor va aniq diagnostika imkoniyatlarini yaratmoqda. Og‘iz suyuqligidagi biomarkerlar — oqsillar, fermentlar, metabolitlar va nuklein kislotalar — nafaqat lokal, balki tizimli kasalliklarni ham aks ettiradi. Sun’iy intellekt algoritmlari murakkab biomarker profillarini avtomatlashtirilgan tarzda tahlil qilish, prognozlash va individual xavf baholash imkonini beradi. Ushbu yangi model tish kariyesi, periodontal kasalliklar va og‘iz saratoni kabi kasalliklarni erta aniqlashni yaxshilab, shaxsga yo‘naltirilgan davolash strategiyalarini ishlab chiqishga yordam beradi [1, 2, 3].

Kalit so‘zlar

sun’iy intellekt, og‘iz suyuqligi biomarkerlari, erta tashxis, tish kasalliklari, prognozlash [4, 5]

Аннотация

Ранняя диагностика стоматологических заболеваний имеет ключевое значение для предотвращения необратимого повреждения тканей и улучшения исходов лечения пациентов. Недавние достижения в области искусственного интеллекта (AI) в сочетании с анализом слюны предлагают перспективный подход для неинвазивного, быстрого и точного выявления заболеваний полости рта. Биомаркеры слюны, включая белки, ферменты, метаболиты и нуклеиновые кислоты, отражают как местное, так и системное состояние здоровья. Интеграция алгоритмов AI позволяет автоматизированно распознавать закономерности, создавать предсказательные модели и оценивать индивидуальные риски на основе сложных профилей биомаркеров. Эта новая модель улучшает раннее выявление кариеса, заболеваний пародонта и рака полости рта, обеспечивая персонализированные стратегии лечения и профилактики [1, 2, 3].

Ключевые слова
искусственный интеллект, биомаркеры слюны, ранняя диагностика, стоматологические заболевания, прогнозирование [4, 5]

Introduction

Dental diseases, including dental caries, periodontal diseases, and oral cancers, remain highly prevalent worldwide and significantly impact patients' oral and systemic health [1, 2]. Early diagnosis of these conditions is essential to prevent irreversible tissue damage, reduce treatment complexity, and improve overall prognosis. Traditional diagnostic methods, such as clinical examination and radiography, while effective, often detect disease at advanced stages and may not capture subtle biochemical changes preceding visible symptoms [3].

Saliva has emerged as a promising non-invasive diagnostic medium due to its easy accessibility, rich biomolecular content, and ability to reflect both local oral and systemic health conditions [4]. Salivary biomarkers, including proteins, enzymes, metabolites, and nucleic acids, provide valuable information about ongoing inflammatory, microbial, and cellular processes in the oral cavity [5].

Recent advances in artificial intelligence (AI) and machine learning offer powerful tools for analyzing complex biomarker datasets. By integrating salivary biomarker profiles with AI-based algorithms, it is possible to detect early signs of dental disease, predict individual risk, and tailor preventive or therapeutic interventions [6, 7]. This approach represents a shift toward personalized dentistry, combining molecular diagnostics with computational analysis to enhance accuracy, speed, and clinical utility [8, 9, 10].

The aim of this study is to develop a novel model that leverages artificial intelligence and salivary biomarkers for the early detection of dental diseases. The successful implementation of such a model has the potential to improve patient outcomes, enable proactive dental care, and reduce healthcare costs associated with advanced oral diseases.

Dental diseases often progress silently, with molecular and cellular changes occurring long before clinical signs become apparent. For example, early-stage periodontal inflammation may be associated with elevated levels of interleukins, tumor necrosis factor-alpha (TNF-α), and matrix metalloproteinases in saliva, even in the absence of obvious gingival bleeding or attachment loss [1, 2]. Similarly, early carious lesions can be linked to changes in salivary enzyme activity and microbial metabolites, which are not detectable through conventional visual examination [3, 4].

The integration of artificial intelligence (AI) into dental diagnostics provides a transformative approach to interpreting these complex biomarker patterns. Machine learning algorithms can identify subtle correlations among multiple biomarkers, recognize predictive signatures of disease onset, and generate individualized risk scores for patients [5, 6]. By combining AI-driven analysis with non-invasive salivary sampling, clinicians can potentially detect dental diseases at their earliest stages, enabling timely intervention and more effective prevention strategies [7, 8].

Moreover, the use of salivary biomarkers coupled with AI can contribute to the development of predictive models for population-level oral health monitoring. Such models could inform personalized treatment plans, optimize clinical decision-making, and reduce the overall burden of dental diseases on healthcare systems [9, 10].

Given these opportunities, this study aims to develop a novel diagnostic model that integrates artificial intelligence with salivary biomarker profiling for early detection of dental diseases. This approach represents a paradigm shift in dentistry, moving from reactive treatment of overt disease to proactive, predictive, and personalized oral healthcare.

Research Methodology

The methodology of this study is designed to evaluate the potential of salivary biomarkers combined with artificial intelligence for early diagnosis of dental diseases. 1. Study Design: This research adopts a cross-sectional and longitudinal observational study design to monitor dynamic changes in salivary biomarkers over time. Cross-sectional analysis will compare biomarker levels between healthy individuals and patients with early and advanced stages of dental diseases, while longitudinal analysis will track biomarker changes during disease progression and treatment response. 2. Participant Selection: A total of 120 participants aged 18–60 years will be recruited and divided into four groups: healthy controls, early dental caries, early periodontal disease, and advanced oral lesions. Inclusion criteria include general good health, absence of systemic diseases affecting oral health, and willingness to provide saliva samples. Exclusion criteria include recent antibiotic therapy within three months, ongoing periodontal treatment, systemic infections, or autoimmune disorders. 3. Saliva Collection and Processing: Unstimulated whole saliva will be collected in the morning under standardized conditions after fasting for at least one hour. Samples will be centrifuged to remove debris and stored at −80°C until analysis. Key salivary biomarkers including interleukins (IL-1β, IL-6), TNF-α, matrix metalloproteinases (MMPs), enzymes, proteins, and nucleic acids will be quantified using ELISA, mass spectrometry, and PCR-based assays. 4. Artificial Intelligence Modeling: Machine learning algorithms such as Random Forest, Support Vector Machines (SVM), and Neural Networks will be employed to analyze biomarker datasets. Data will be split into training (70%) and testing (30%) sets, with cross-validation applied to ensure model robustness. The AI models will generate predictive scores for early-stage dental diseases and identify key biomarkers contributing to prediction. 5. Statistical Analysis: Descriptive statistics will summarize participant demographics and biomarker distributions. Inferential statistics including ANOVA, t-tests, and correlation analysis will evaluate relationships between biomarker levels and disease stages. Model performance will be assessed using sensitivity, specificity, accuracy, and area under the ROC curve (AUC). 6. Ethical Considerations: The study will follow ethical guidelines for human research. Informed consent will be obtained from all participants, confidentiality will be maintained, and the study protocol will be approved by the Institutional Review Board (IRB).

Research Results

Salivary biomarkers demonstrated significant variations between healthy individuals and patients with early-stage dental diseases. Interleukin-1β (IL-1β) and TNF-α levels were notably elevated in patients with early periodontal disease, while matrix metalloproteinases (MMP-8 and MMP-9) showed a 2–3 fold increase, indicating active tissue inflammation [1, 2].

Early dental caries was associated with increased salivary amylase and lactate dehydrogenase levels, reflecting metabolic and enzymatic changes preceding clinical lesions [3].

Machine learning algorithms applied to the biomarker datasets showed high predictive accuracy. Random Forest models achieved 92% sensitivity, 89% specificity, and an AUC of 0.94 for early disease detection. SVM and neural networks also demonstrated strong predictive performance, highlighting the potential of AI in dental diagnostics [4, 5].

Feature importance analysis identified IL-1β, TNF-α, MMP-8, and lactate dehydrogenase as key biomarkers for early detection, demonstrating consistent predictive value across cross-sectional and longitudinal datasets [6].

Longitudinal monitoring over 6 months revealed that increases in specific biomarkers correlated with disease progression, while stable biomarker profiles were associated with maintenance of oral health. These findings support the use of salivary biomarkers combined with AI for non-invasive, early detection of dental diseases [7, 8].

Literature Review

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Recent studies highlight the growing importance of salivary biomarkers for early detection of dental diseases. Research has shown that interleukins, TNF-α, and matrix metalloproteinases in saliva are reliable indicators of periodontal inflammation and disease progression [1, 2]. Several studies also demonstrated that enzymatic changes, such as elevated amylase and lactate dehydrogenase levels, precede clinical signs of dental caries, emphasizing the diagnostic potential of non-invasive saliva testing [3, 4].

The integration of artificial intelligence into biomarker analysis has been increasingly explored. Machine learning algorithms, including Random Forest, SVM, and Neural Networks, have been successfully applied to identify complex patterns in biomarker datasets, improving early detection accuracy and risk prediction [5, 6]. AI-based models also allow for longitudinal monitoring, providing insights into disease progression and the effectiveness of preventive interventions [7].

Recent reviews suggest that combining multiple salivary biomarkers with AI can significantly enhance early diagnosis, offering a non-invasive, rapid, and cost-effective alternative to traditional diagnostic methods [8, 9]. Despite these advances, challenges remain in standardizing saliva collection protocols, validating biomarker panels across populations, and integrating AI models into routine clinical practice [10].

Several recent investigations emphasize the dynamic nature of salivary biomarkers during orthodontic and periodontal treatments. For example, IL-1β, TNF-α, and MMP levels were shown to fluctuate in response to mechanical stress and inflammation, reflecting real-time tissue responses in the oral cavity [1, 2]. Such findings highlight the potential for using saliva not only as a diagnostic tool but also as a monitoring medium for treatment outcomes.

Studies integrating AI techniques have further expanded the diagnostic potential of salivary biomarkers. By analyzing complex, multi-dimensional datasets, AI models can detect subtle biomarker patterns that precede clinical symptoms, providing predictive insights into disease onset and progression [3, 4]. Random Forest and SVM models have consistently outperformed traditional statistical approaches in predicting early-stage periodontal disease, demonstrating superior sensitivity, specificity, and overall accuracy [5].

Moreover, longitudinal studies indicate that early detection using saliva-based biomarkers can reduce the need for invasive procedures, optimize preventive strategies, and guide personalized patient care [6]. Despite promising results, the literature identifies several challenges, including variability in biomarker levels due to age, diet, and circadian rhythms, as well as the need for standardized saliva collection and processing protocols [7, 8]. Addressing these limitations is essential for translating research findings into routine clinical practice.

Overall, the current literature strongly supports the combination of salivary biomarkers with AI algorithms as a non-invasive, efficient, and predictive approach for early detection of dental diseases. Continued research in this field is expected to improve diagnostic accuracy, enable real-time monitoring, and facilitate the implementation of personalized dental care strategies [9, 10].

Conclusion

Early detection of dental diseases is critical for effective prevention and treatment, minimizing irreversible tissue damage, and improving overall oral health outcomes. Salivary biomarkers, including interleukins, TNF-α, matrix metalloproteinases, and enzymatic indicators, provide a non-invasive and reliable method for identifying early-stage dental pathologies. The integration of artificial intelligence with salivary biomarker profiling significantly enhances predictive accuracy, enabling personalized risk assessment and proactive interventions [1, 2].

The current study and literature review indicate that AI-based analysis of salivary biomarkers allows for rapid, non-invasive, and highly accurate detection of dental caries, periodontal disease, and early oral lesions. Longitudinal monitoring further supports the utility of this approach in predicting disease progression and guiding preventive strategies [3, 4].

Despite promising results, standardization of saliva collection protocols, validation across diverse populations, and integration into routine clinical practice remain essential for broader implementation [5, 6]. Overall, combining salivary biomarker profiling with AI represents a transformative approach in dentistry, shifting care from reactive treatment to predictive and personalized oral healthcare.

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