

Nanomaterial-ai electrochemical biosensors: Transforming diagnostics.

Maria Silva*

Department of Bioengineering, University of São Paulo, São Paulo, Brazil

Introduction

Electrochemical biosensors represent a rapidly evolving field with significant implications for diverse applications, from clinical diagnostics to environmental monitoring and food safety. The recent progress in this area highlights the integration of nanomaterials and Artificial Intelligence (AI) for enhanced sensitivity and multiplexing capabilities [1].

This development is crucial for detecting a wide range of biomarkers associated with cancer, infectious diseases, and neurological disorders, while addressing challenges in clinical translation. A major focus has been on the role of nanomaterials in advancing these biosensors, especially for glucose detection. Various nanoparticles, carbon-based materials, and Metal-Organic Frameworks have been explored to improve sensitivity, selectivity, and response time, proving vital for both enzymatic and non-enzymatic glucose sensing in diabetes management [2].

Beyond health, electrochemical biosensors are crucial for detecting heavy metal ions in environmental samples. Here, sensing mechanisms and electrode modifications using nanomaterials like graphene and metal nanoparticles, along with biological recognition elements, achieve enhanced specificity and lower detection limits to address pressing environmental concerns [3].

In the realm of food safety, aptamer-based electrochemical biosensors have emerged as powerful tools. They are applied in detecting pathogens, toxins, and drug residues, leveraging aptamers for their stable and specific recognition properties. Discussions also involve signal amplification and miniaturization strategies, indicating their potential for rapid, on-site quality control [4].

Personalized medicine benefits significantly from wearable electrochemical biosensors designed for continuous, real-time health monitoring. Innovations in flexible materials and miniaturized electronics allow for non-invasive detection of biomarkers in sweat, tears, and interstitial fluid, including glucose, lactate, and ions, thereby supporting early disease detection [5].

The capacity of electrochemical biosensors for rapid and accurate detection extends to public health crises, as evidenced by their

development for SARS-CoV-2 and its emerging variants. These sensors employ diverse nucleic acid-based and antigen-based approaches, utilizing various electrode materials and signal transduction mechanisms, making them ideal for point-of-care diagnostics critical in pandemic management [6].

Graphene and its derivatives are particularly important in enhancing biosensor performance. Their unique electrical, mechanical, and surface properties facilitate improved electron transfer and offer higher surface area for biomolecule immobilization, thereby increasing overall sensor sensitivity, although challenges in their large-scale synthesis and functionalization remain [7].

These advancements also extend to neurological applications, with ongoing developments in electrochemical biosensors for detecting neurotransmitters. Such sensors are vital for understanding brain function and diagnosing neurological disorders, employing platforms like enzyme-based and non-enzymatic designs to enhance selectivity and sensitivity for real-time monitoring of substances such as dopamine, serotonin, and acetylcholine [8].

Point-of-care electrochemical biosensors, characterized by their portability, rapidity, and cost-effectiveness, are transforming decentralized disease diagnosis. They are particularly impactful in resource-limited settings, detailing design principles, fabrication techniques, and applications for various biomarkers [9].

Furthermore, electrochemical DNA biosensors specifically designed for detecting pathogenic microorganisms offer significant advantages. They utilize various strategies for nucleic acid recognition and signal amplification, providing sensitive, fast, and cost-effective alternatives for infectious disease diagnostics and food safety monitoring compared to traditional methods [10].

This collective body of work underscores the transformative potential of electrochemical biosensors across a spectrum of analytical challenges.

Conclusion

Electrochemical biosensors have seen significant progress, integrat-

*Correspondence to: Maria Silva, Department of Bioengineering, University of São Paulo, São Paulo, Brazil. E-mail: maria.silva@usp.br

Received: 01-Apr-2025, Manuscript No. aacbc-210; Editor assigned: 03-Apr-2025, Pre QC No. aacbc-210 (PQ); Reviewed: 23-Apr-2025, QC No. aacbc-210; Revised: 02-May-2025, Manuscript No. aacbc-210 (R); Published: 13-May-2025, DOI: 10.35841/aacbc-9.2.210

ing nanomaterials and Artificial Intelligence for enhanced sensitivity and multiplexing capabilities across various diagnostic applications. This includes detecting biomarkers for cancer, infectious diseases, and neurological disorders, with a focus on improving clinical translation. Nanomaterials like graphene, nanoparticles, carbon-based materials, and Metal-Organic Frameworks are crucial for boosting sensitivity, selectivity, and response time, particularly in glucose sensing for diabetes management. These sensors are also being developed for environmental monitoring, specifically for heavy metal ions, and for ensuring food safety by detecting pathogens, toxins, and drug residues using aptamer-based designs. Furthermore, innovations extend to wearable biosensors for continuous, real-time health monitoring, utilizing flexible materials for non-invasive detection of sweat, tears, and interstitial fluid biomarkers like glucose, lactate, and ions. The technology has proven vital for rapid detection of pathogens, including SARS-CoV-2 and its variants, supporting point-of-care diagnostics and pandemic management. Advancements also target neurotransmitter detection for brain function insights and DNA biosensors for pathogenic microorganisms, providing rapid, cost-effective alternatives to traditional methods. Overall, electrochemical biosensors are transforming diagnostics and monitoring across health, environmental, and food safety sectors.

References

1. Xiaohui W, Meng S, Xiaoming L. Recent advances in electrochemical biosensors for disease diagnosis: *A comprehensive review*. *Anal Chim Acta*. 2023;1243:341498.
2. Mengting C, Lu L, Qiangqiang S. Nanomaterial-enhanced electrochemical biosensors for glucose detection: *A review*. *Biosens Bioelectron*. 2022;196:113645.
3. Jingjing L, Yaohui L, Zhiqiang Y. *Recent advances in electrochemical biosensors for heavy metal detection*. *Crit Rev Anal Chem*. 2021;51(6):588-608.
4. Xiaofei W, Peng G, Li Z. Aptamer-based electrochemical biosensors for food safety. *Trac Trends Anal Chem*. 2020;133:116035.
5. Samira S, K. Sanjana L, V. N. *Wearable electrochemical biosensors for continuous health monitoring*. *Acc Chem Res*. 2020;53(12):3505-3518.
6. Xiaomeng C, Feng Z, Qingqing W. Electrochemical biosensors for rapid detection of SARS-CoV-2 and its variants. *Mater Today Bio*. 2023;20:100612.
7. Jiaqi F, Xiaoli W, Yang L. Graphene and its derivatives in electrochemical biosensors: *Recent progress and challenges*. *Trac Trends Anal Chem*. 2022;153:116773.
8. Yifan W, Zhen Z, Yichun H. Electrochemical biosensors for neurotransmitter detection: *Recent advances and future perspectives*. *Biosens Bioelectron*. 2021;188:113426.
9. Bo L, Zhaoyin H, Weiwei C. Point-of-care electrochemical biosensors for disease diagnosis. *Adv Healthc Mater*. 2020;9(14):2000287.
10. Xiaoli W, Xue B, Ying C. *Electrochemical DNA biosensors for pathogenic microorganisms*. *Trac Trends Anal Chem*. 2019;119:115620.