

Point-of-Care Biosensing: Innovation for Global Health

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Introduction

The development and application of point-of-care (POC) biosensing technologies for disease diagnosis represent a significant advancement in modern healthcare, offering the promise of rapid, accurate, and accessible diagnostic tools across diverse healthcare settings, particularly in regions with limited resources. The underlying principles of various biosensing platforms, including electrochemical, optical, and microfluidic devices, are being explored to enhance sensitivity, specificity, and portability, addressing critical challenges in sample preparation, signal transduction, and data processing at the POC [1]. Novel electrochemical biosensors are being designed for the rapid detection of infectious disease biomarkers, with ongoing research focusing on the fabrication of electrode materials and functionalization strategies to achieve high sensitivity and selectivity for POC applications, aiming to improve patient outcomes through early diagnosis and management [2]. The integration of microfluidics with biosensing is crucial for developing advanced POC diagnostics, enabling miniaturization, automation, and multiplexing for more efficient and cost-effective systems. Microfluidic devices are instrumental in sample handling, manipulation, and reaction, synergizing with various sensing modalities to revolutionize diagnostics for conditions like cancer and cardiovascular diseases [3]. Surface plasmon resonance (SPR) biosensor platforms are emerging as a potent tool for the rapid POC detection of viral antigens, employing antibody-functionalized surfaces for real-time monitoring of antigen binding. These sensors demonstrate excellent sensitivity and rapid response times, offering a promising avenue for the timely diagnosis of viral infections and adaptation to detect a broad spectrum of infectious agents [4]. The role of nanomaterials in enhancing POC biosensing performance is a rapidly evolving area, with materials such as nanoparticles, nanotubes, and nanowires significantly improving sensitivity, specificity, and speed through increased surface area and signal amplification. These advancements are being applied to target various disease biomarkers for cancer and metabolic disorders, showcasing the versatility of nanomaterials in electrochemical, optical, and piezoelectric sensing platforms [5]. Portable multiplexed biosensing systems are being developed for the simultaneous detection of multiple cardiac biomarkers, integrating microfluidics with electrochemical detection for rapid, quantitative analysis from minimal blood samples. Such systems offer high diagnostic accuracy and a significant advantage in time-sensitive cardiac emergencies, making them ideal for POC use [6]. Paper-based analytical devices (PADs) are gaining prominence for POC diagnostics due to their low cost, ease of use, and portability, making them particularly suitable for resource-limited settings. Various detection strategies, including colorimetric, electrochemical, and fluorescent methods, are employed in PADs for detecting infectious diseases and chronic conditions, highlighting their substantial potential in global health initiatives [7]. Aptasensors based on advanced materials like graphene oxide are being developed for sensitive electrochemical detection of key disease biomarkers such as prostate-specific antigen (PSA). These aptasensors leverage the unique

electrochemical properties of graphene oxide and the high specificity of aptamers, enabling rapid and sensitive detection at clinically relevant concentrations for POC screening and early diagnosis of prostate cancer [8]. Wearable biosensors represent a frontier in continuous health monitoring and disease diagnosis, integrating diverse sensing modalities into wearable devices for real-time detection of physiological parameters and biomarkers in biofluids. These sensors hold immense potential for early disease detection, personalized medicine, and remote patient monitoring, especially for chronic condition management [9]. Microfluidic-based immunoassays are being introduced for the rapid detection of critical disease antigens, such as those for malaria, in endemic regions. These devices employ antibody-functionalized microchannels for efficient capture and detection, requiring minimal sample volume and processing time, thus presenting an excellent option for POC diagnosis in resource-limited settings [10].

Description

Point-of-care (POC) biosensing technologies are revolutionizing disease diagnosis by enabling rapid, accurate, and accessible testing outside traditional laboratory settings. This field encompasses a diverse range of platforms, including electrochemical, optical, and microfluidic devices, each offering unique advantages in terms of sensitivity, specificity, and portability. Addressing challenges such as sample preparation, signal transduction, and data processing at the POC is paramount for the successful implementation of these technologies, with ongoing research exploring emerging trends like nanomaterials and advanced microfluidics to enhance device performance and enable multiplexed detection of various biomarkers [1]. Novel electrochemical biosensors are at the forefront of this revolution, designed for the rapid detection of infectious disease biomarkers. The meticulous fabrication of electrode materials and sophisticated functionalization strategies are key to achieving the high sensitivity and selectivity required for effective POC applications, ultimately contributing to improved patient outcomes through early diagnosis and management of diseases [2]. Microfluidics plays a pivotal role in advancing POC diagnostics by facilitating miniaturization, automation, and multiplexing capabilities, leading to more efficient and cost-effective diagnostic systems. The design principles of microfluidic devices for sample handling, manipulation, and reaction are being harmonized with various sensing modalities to create integrated systems capable of revolutionizing the diagnosis of conditions such as cancer and cardiovascular diseases [3]. Surface Plasmon Resonance (SPR) biosensor platforms are being developed for rapid POC detection of viral antigens, a critical need in managing infectious outbreaks. By modifying sensor surfaces with specific antibodies, these systems enable real-time monitoring of antigen binding, demonstrating excellent sensitivity and rapid response times that are crucial for timely diagnosis and adaptation to detect a wide array of infectious agents [4]. The integration of nanomaterials is a significant factor in enhancing the performance of POC biosensors. Materials like nanoparticles, nanotubes, and

nanowires offer substantial improvements in sensitivity, specificity, and speed by increasing surface area and facilitating signal amplification. These nanomaterial-enhanced sensors are being applied to detect a variety of disease biomarkers, including those for cancer and metabolic disorders, showcasing their adaptability across different sensing platforms such as electrochemical and optical systems [5]. The development of portable multiplexed biosensing systems addresses the need for simultaneous detection of multiple biomarkers. For instance, systems integrating microfluidics with electrochemical detection are being engineered for the rapid and quantitative analysis of cardiac biomarkers from small blood samples, offering high diagnostic accuracy and a critical time advantage in managing acute myocardial infarction at the POC [6]. Paper-based analytical devices (PADs) represent a cost-effective and user-friendly approach to POC diagnostics, particularly valuable in resource-limited settings. Utilizing various detection strategies like colorimetric, electrochemical, and fluorescent methods, PADs are being designed for the detection of infectious diseases and chronic conditions, demonstrating their significant potential to improve global health outcomes [7]. Aptasensors, utilizing the specificity of aptamers and the unique properties of materials like graphene oxide, are emerging for sensitive electrochemical detection of key disease biomarkers such as prostate-specific antigen (PSA). These systems offer rapid and sensitive detection at clinically relevant concentrations, making them ideal for POC screening and early diagnosis of diseases like prostate cancer [8]. Wearable biosensors are paving the way for continuous health monitoring and disease diagnosis by integrating diverse sensing modalities into wearable devices. These sensors can detect physiological parameters and biomarkers in biofluids, offering significant potential for early disease detection, personalized medicine, and remote patient monitoring, especially for chronic conditions [9]. Microfluidic-based immunoassays are specifically being developed for rapid POC detection of critical disease antigens, such as those associated with malaria, a significant public health challenge in endemic regions. These assays utilize antibody-functionalized microchannels for efficient capture and detection, requiring minimal sample volume and processing time, thus providing an excellent solution for POC diagnosis in resource-constrained environments [10].

Conclusion

Point-of-care (POC) biosensing technologies are crucial for rapid and accurate disease diagnosis, especially in resource-limited areas. Research focuses on developing diverse biosensing platforms, including electrochemical, optical, and microfluidic devices, to enhance sensitivity, specificity, and portability. Key advancements include the use of nanomaterials to improve sensor performance and the integration of microfluidics for miniaturization and multiplexed detection. Emerging technologies like paper-based analytical devices (PADs) and wearable biosensors offer cost-effective and continuous monitoring solutions. These innovations are critical for early detection, personalized medicine, and managing infectious diseases and chronic conditions.

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Conflict of Interest

None.

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