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Latest Developments in Aptamer-based Biosensors for the Identification of Bacteria

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Introduction

Biosensors have revolutionized the field of bacterial identification by providing rapid, sensitive, and specific detection methods. Among the various types of biosensors, aptamer-based biosensors have emerged as promising tools due to their unique properties and versatile applications. This article explores the latest developments in aptamer-based biosensors for the identification of bacteria, focusing on their design principles, detection mechanisms, recent advancements, and potential future directions. Aptamers are single-stranded DNA or RNA molecules that can bind to target molecules with high affinity and specificity. They are selected through a process called Systematic Evolution of Ligands by EXponential enrichment (SELEX), where a pool of random oligonucleotides is iteratively enriched for sequences that bind to the target bacterium or its specific biomolecules [1-3].

Aptamers offer several advantages over traditional antibodies in biosensor applications. They are chemically synthesized, making them more cost-effective and reproducible than antibodies. Moreover, aptamers are stable under a wide range of conditions, including temperature and pH variations, which enhances the robustness of biosensor platforms. the aptamer, a transducer, and a signal processor. The aptamer specifically binds to the target bacterium or its biomolecules, acting as a recognition element. The transducer converts the binding event into a measurable signal, such as electrochemical, optical, or mass-based signals. The signal processor analyzes the signal and provides qualitative or quantitative information about the presence of the target bacterium. Recent advancements in biosensor design have focused on improving the sensitivity, selectivity, and response time of aptamer-based systems. For instance, researchers have developed novel materials for transducers (e.g., graphene, carbon nanotubes) to enhance signal amplification and reduce background noise. Integration of microfluidics has also enabled miniaturization and automation of biosensor platforms, facilitating point-of-care applications.

Description

Biosensors detect changes in electrical properties (e.g., current, impedance) upon aptamer-target binding. Recent advances include the use of nanostructured electrodes and redox-active labels to improve sensitivity and detection limits. Optical biosensors measure changes in light absorbance, fluorescence, or Surface Plasmon Resonance (SPR) upon aptamer-target interaction. Advances in this area include the development of plasmonic nanoparticles and quantum dots for signal enhancement. These biosensors detect changes in mass upon aptamer-target binding using Quartz Crystal Microbalances (QCM) or Surface Acoustic Wave (SAW) devices. Recent developments include the use of micro- and nano-scale resonators for enhanced sensitivity. These biosensors use aptamer-functionalized nanoparticles that migrate across a strip coated with capture molecules, generating a visible signal in the presence of the target bacterium. They are particularly useful for rapid, on-site detection. Researchers have developed multiplex biosensors capable of detecting multiple bacterial strains or biomarkers simultaneously. This advancement is crucial for rapid screening in clinical diagnostics and environmental monitoring [4].

Integration of biosensors with smartphone platforms has enabled real-time data acquisition and remote monitoring of bacterial contamination. This technology holds promise for field applications and resource-limited settings. AI algorithms have been employed to analyse biosensor data patterns, improving the accuracy and reliability of bacterial identification. Machine learning models can distinguish between different bacterial species based on complex biosensor outputs. Advances in SELEX technology have led to the discovery of aptamers with higher binding affinity and specificity toward bacterial targets. Rational design approaches and computational modelling have accelerated the development of aptamers tailored for biosensor applications. Improving the detection limits of biosensors to detect low concentrations of bacteria remains a priority. Innovations in nanomaterials and signal amplification strategies are expected to address this challenge. Developing portable, user-friendly biosensor platforms for on-site testing in diverse environments (e.g., hospitals, food processing facilities) requires overcoming technical and regulatory hurdles. Ensuring the affordability and scalability of aptamer-based biosensors is crucial for their integration into routine diagnostic practices and large-scale surveillance programs. Robust validation protocols and standardized procedures are essential to ensure the reliability and reproducibility of biosensor results across different settings and user groups [5].

Conclusion

Looking forward, interdisciplinary collaborations between biochemists, material scientists, engineers, and clinicians will play a pivotal role in overcoming these challenges and realizing the full potential of aptamer-based biosensors for bacterial identification. In conclusion, aptamer-based biosensors represent a promising technological advancement for the rapid and accurate identification of bacteria. Recent developments in biosensor design, detection mechanisms, and integration with advanced technologies have significantly enhanced their performance and applicability. With ongoing research efforts and innovations, aptamer-based biosensors are poised to transform bacterial detection across various fields, from clinical diagnostics to food safety and environmental monitoring. As these technologies continue to evolve, their impact on public health, biodefense, and industrial processes is expected to grow, paving the way for a future where timely and precise bacterial identification becomes more accessible and reliable than ever before.

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Conflict of Interest

None.

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