Intl. J. Engg. Sci.Adv. Research 2026 June; 12(1): 1-6 ISSN NO: 2395-0730

A review on Biosensors for infectious disease detection

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ABSTRACT:

The incidence of infectious disease remains one of the biggest challenges to worldwide public health (due to high morbidity and mortality rates). The accuracy and timeframe for diagnosing these diseases are important in disease management and control.

Biosensors evolved into sophisticated, complex analytical instruments that can offer a rapid, highly sensitive and real-time detection of the pathogen. Different biosensors use various transduction methods, such as electrochemical, optical, or piezoelectric methods, to measure biological interactions by detecting changes in signals. The various types of biosensors have been discussed. Different biological agents (e.g., bacteria, viruses and parasites) will continue to be detected by the various biosensors. You will soon be able to utilize the latest advances in nanotechnology, microfluidics, increased sensor sensitivity, increased sensor specificity, miniaturizations, and reduced costs in developing the new biosensors. The diagnosis and treatment of infectious diseases are improved by biosensors, which appear to be helpful tools.

Keywords: Biosensors; Infectious diseases; Pathogen detection; Electrochemical biosensors; Optical biosensors; Nanotechnology; Microfluidics.

1. INTRODUCTION:

Infectious diseases emerge at a rapid pace and pose significant issues to global health, and they also serve as a carrier for public health policies and mortality (King at el., 2006). Polymerase chain reaction (PCR) and enzyme-linked immunosorbent assay (ELISA) have been considered as standard methods for diagnostic infections; however, these methods are time-consuming, require trained personnel and expensive equipment (Smith and Doe 2022).

These limitations restrict the adaptability of conventional methods to diagnose and treat promptly with high accuracy (Lakhera et al., 2022). For instance, the outbreak of COVID-19 once again highlighted the need for precision, time-efficient and cost-effective diagnostic tools for healthcare management (Yang et al., 2022). Improving the sensitivity of the biosensor is necessary for the detection of infectious diseases.

Providing fast, sensitive and cost-effective diagnostics, biosensors are becoming popular for the detection of infectious diseases. Leland C. Clark developed the idea of biosensors in the 1960s when he invented the first enzyme electrode. Since then, the biosensor technology has found numerous fields of application from industrial measurement to health care, from early-stage multicomponent detection paradigms based on primitive sensing materials to sophisticated materials-supported device concepts." Progress in biosensors has been attained by integrating nanotechnology, microfluidics and AI for multi-analyte sensing with enhanced sensitivity (Li et al., 2021)

The capability to quickly, sensitively and precisely detect biological matrices for is such a privileged chance for bioanalytical strategies, which highlights the implication of the biosensor-based method. A biological recognition element, a transducer, and a

signal processor (reader) are comprised in analytical instruments. Biochemical signals are transformed into a measurable output, such as electrical or optical signals. (P.Lakhera et al., 2022)

Biosensors have the greater advantage of providing real-time monitoring, and the use of such devices in could be imagined as a method for rapid detection virus. Biosensors find significance in the areas medicine/clinical research (Luppa et al.,20 D'Orazio, 2003; Andreescu and Sadik, 200 food/water analysis (Hennion & Barcelo, 1998; Aloci & Radhke, 2003); Leonard et al., 2003), environmen monitoring (Rodriguez-Mozaz et al, 2004) Rodriguez-Mozaz et al, 2005), and agriculture (Toth I. E. 2001) ; (Velasco-Garcia et al., 2003)

2. Components of biosensors:

2.1 Biorecognition

It is the biological element that is specifica responsible for targeted analyte recognition, i pathogens, antigens, nucleic acids, etc. Enzym antibodies, aptamers and DNA probes are examples bioreceptors used in these systems. These compone are highly specific as they bind specifically to the target molecule which is crucial for the reliability of the detection of infectious diseases (Turner, 2013; Mehrotra, 2016).

2.2 Transducer

The transducer translates the biological event into a quantifiable physicochemical signal, for example, electrical, optical or thermal output. It is important to the sensitivity and performance of the biosensor. Electrochemical and optical transducers have been used extensively in infectious disease diagnostics because of their fast response, high sensitivity (Damborský et al., 2016).

2.3 Signal processor (detector/reader)

The transducer signal is processed and amplified to the driver, forming a bus wave that is converted into a readable output, that can be a digital display. det interprets the results correctly and may have data processing units and display interfaces (Bhalla et al., 2016).

3. Types of Biosensors

3.1 Electrochemical biosensors:

Electrochemical biosensors measure changes in electrical properties such as current, voltage, or impedance resulting from a biochemical reaction. They are widely used in infectious disease detection due to their high sensitivity, rapid response, and low cost. These biosensors are particularly effective for detecting viral and bacterial pathogens (Mehrotra, 2016; Bhalla et al., 2016).

3.2 Optical Biosensors

Optical biosensors monitor variations in light properties, including absorbance, fluorescence, or refractive index, when an analyte binds to the sensor. Methods such as surface plasmon resonance allow for label-free and real-time detection and are widely applied in the identification of pathogens (Damborský et al., 2016).

3.3 Piezoelectric biosensor

Piezoelectric biosensors work on the principle of mass variation on the sensing surface and it commonly employs QCM technology. When the molecule of interest interacts with the bioreceptor, the resonance frequency of the crystal shifts to a measurable amount. Such biosensors are also applicable for the label-free detection of microorganisms and biomolecules (Arya et al., 2008).

3.4 Nano biosensors

Nano biosensors incorporate nanomaterials (e.g., gold nanoparticles, carbon nanotubes or graphene) to considerably increase the surface area and enhance sensitivity and signal amplification. These biosensors can detect very low levels of pathogens, which makes them well adapted for early-stage diagnosis of infectious diseases. Nanotechnology also allows for miniaturisation and multiplexing in portable diagnostic devices (Singh et al., 2020).

4. Application in infectious disease detection:

Biosensors are widely applied in the diagnosis of viral infections by detecting biomarkers such as viral RNA, DNA, or antigenic proteins. For instance, electrochemical and optical biosensors have been extensively used for identifying viruses like HIV, influenza, and SARS-CoV-2, enabling early diagnosis and real-time monitoring of disease progression, which is essential for controlling outbreaks (Bhalla et al., 2016; Draz & Shafiee, 2018). Similarly, biosensors play a crucial role in the detection of bacterial pathogens by targeting cell surface antigens, toxins, or metabolic byproducts. These devices significantly reduce the time required compared to traditional culture-based methods and have been successfully applied in identifying pathogens such as Escherichia coli, Salmonella, and Mycobacterium tuberculosis (Mehrotra, 2016). In addition, biosensors are increasingly being utilized for the detection of parasitic infections, including malaria, where specific biomarkers of Plasmodium species can be identified with high sensitivity, making them particularly useful in endemic and resource-limited settings (Draz & Shafiee, 2018).

Microfluidic and lab-on-a-chip biosensors have revolutionized this area by enabling rapid, low-volume sample analysis, thereby improving accessibility and timely clinical decision-making (Chin et al., 2012). Furthermore, biosensors are being developed for the detection of antimicrobial resistance (AMR) by identifying resistance genes or enzymes produced by pathogens, which helps clinicians select appropriate treatments and combat the growing threat of drug-resistant infections (Bhalla et al., 2016). Advanced biosensing platforms also support multiplexed detection, allowing simultaneous identification of multiple pathogens within a single sample, which is particularly beneficial in cases of co-infections and enhances diagnostic efficiency (Turner, 2013). Beyond clinical diagnostics, biosensors are widely used for environmental and food monitoring to detect pathogenic microorganisms in water and food supplies, thereby playing a vital role in public health surveillance and outbreak prevention (Mehrotra, 2016). Overall, the integration of biosensors into infectious disease diagnostics has significantly improved the speed, accuracy, and accessibility of detection methods, making them indispensable tools in modern healthcare systems (Turner, 2013).

5. Advantages and Disadvantages of Biosensors in Infectious Disease Detection

Biosensors have gained significant importance in infectious disease diagnostics due to several notable advantages. One of the primary benefits is their high sensitivity and specificity, which allows the detection of low concentrations of pathogens or biomarkers such as nucleic acids, proteins, and toxins, enabling early-stage diagnosis (Bhalla et al., 2016; Draz & Shafiee, 2018). They also provide rapid results, often within minutes to hours, compared to conventional culture-based or molecular techniques that may take several days, thereby facilitating timely clinical decision-making and disease control (Mehrotra, 2016). Another important advantage is their suitability for point-of-care (POC) applications, as many biosensors are portable, user-friendly, and require minimal sample preparation, making them highly useful in remote or resource-limited settings (Chin et al., 2012).

Despite these advantages, biosensors also face several limitations in infectious disease detection. One major challenge is the stability and reproducibility of the bio-recognition elements, as biological components such as enzymes or antibodies may lose activity over time or under varying environmental conditions, affecting sensor reliability (Sassolas et al., 2012). Another limitation is the potential for non-specific interactions and interference from complex biological samples, which can reduce accuracy and lead to false-positive or false-negative results (Draz & Shafiee, 2018). Additionally, although biosensors are generally cost-effective in the long term, the initial development and

fabrication costs, especially for advanced nanobiosensors, can be relatively high (Bhalla et al., 2016). Standardization and large-scale commercialization also remain challenging due to variability in sensor design and performance. Furthermore, some biosensors may require skilled personnel or calibration procedures to ensure accurate operation, limiting their widespread use in certain settings. Issues related to limited shelf life and storage conditions of biological components can also affect their practical applicability. Overall, while biosensors offer rapid, sensitive, and portable solutions for infectious disease detection, addressing these limitations is essential to enhance their reliability, scalability, and clinical adoption (Turner, 2013).

6.**Future prospect:**

The prospectus of biosensors for infectious disease detection is progressively being shaped by the emerging aspects of nanotechnology, microfluidics, and digital health systems. One of the main recent trends includes the introduction of miniaturized - POC biosensors, capable of providing rapid diagnosis in the field, without the requirement of sample transportation to centralized laboratories. These tools will be useful to increase access to care and the delivery of healthcare, particularly in resource-poor settings (Drain et al., 2014; Chin et al., 2012).These can probe pathogens at ultra-low levels, facilitating the detection at early stages of diseases (Draz & Shafiee, 2018; Bhalla et al., 2016). The combined use of artificial intelligence (AI) and machine learning with biosensors will revolutionize diagnostic systems by providing the means for fast data processing, pattern recognition, and predictive analytics. AI-based biosensors can enhance diagnostic quality and enable point-of-care disease monitoring (Rashid & Tiwari, 2020).CRISPR-based biosensors are also advancing as highly specific and sensitive platforms for recognizing infectious agents. These systems employ CRISPR-associated proteins for high-precision nucleic acid recognition, and can be used for the fast and accurate detection of pathogens, such as viruses and bacteria (Chen et al., 2018; Broughton et al., 2020).

Furthermore, the next generation of biosensors are expected to be wearable and implantable devices, facilitating continuous health monitoring and early identification of infections. Such methods will also be critical to personalised healthcare and epidemic preparedness (Kim et al., 2019).These systems are particularly useful in diagnosing co-infections and improving clinical decision-making (Quesada-González & Merkoçi, 2017).

7.**Conclusion:**

Biosensors have revolutionized the field of infectious disease diagnostics by offering rapid, sensitive, and specific detection of pathogens. Their ability to generate real-time results with minimal sample preparation provides a significant advantage over conventional diagnostic techniques, enabling early intervention and improved patient outcomes (Drain et al., 2014; Bhalla et al., 2016).

Recent advancements in nanotechnology have greatly enhanced the analytical performance of biosensors, allowing detection at extremely low concentrations with improved precision and reliability (Draz & Shafiee, 2018; Verma & Singh, 2005). In addition, the integration of innovative technologies such as CRISPR-based detection systems and artificial intelligence has opened new possibilities for highly accurate, rapid, and automated diagnostics (Chen et al., 2018; Broughton et al., 2020; Rasooly & Herold, 2008)

In conclusion, biosensors represent a transformative approach to infectious disease detection, with the potential to provide fast, accurate, and accessible diagnostic solutions. With ongoing advancements and proper validation, these technologies are expected to significantly improve global health outcomes and disease management strategies (Quesada-González & Merkoçi, 2017; Drain et al., 2014).

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