https://rijournals.com/biological-and-applied-science/

RESEARCH INVENTION JOURNAL OF BIOLOGICAL AND APPLIED SCIENCES 3(3):17-20, 2024

©RIJBAS Publications Online ISSN: 1115-6171

Print ISSN: 1597-2879

Development of Bio-Sensors for Early Disease Detection

Nyambura Achieng M.

School of Natural and Applied Sciences Kampala International University Uganda

ABSTRACT

The rapid evolution of biosensor technology has revolutionized early disease detection, offering significant advancements in healthcare monitoring and diagnostic practices. Biosensors, which utilize biological recognition elements coupled with physicochemical transducers, provide a swift and precise detection method for various biomarkers associated with diseases. This paper discusses the types of biosensors, including optical, electrochemical, non-invasive, and miniaturized variants, emphasizing their role in detecting analytes at molecular levels. The paper also highlights the importance of early disease detection, current challenges in the field, and the integration of nanotechnology in biosensor development. Case studies and applications in medical diagnostics are reviewed to illustrate the practical implications of biosensors in improving patient outcomes. Despite the potential, several challenges remain, particularly in the sensitivity and specificity of biosensors for complex disease markers. Continued research and innovation are essential to overcoming these challenges and realizing the full potential of biosensors in early disease detection.

Keywords: Biosensors, Early Disease Detection, Nanotechnology, Biomarkers, Optical Biosensor.

INTRODUCTION

A biosensor detects chemicals or biological material. Nanostructured materials are needed for surface operation. Biosensors combine detection of analytes with a transducer. They play a role in health monitoring and environmental security. There are challenges in cancer detection. Fuel cell developments have influenced portable device development. Molecular level detection refinement is still needed [1]. Biosensors have a biologically derived sensitive biological component or biosensing element such as antibodies or enzymes that is interconnected or attached to signal transducers (optical, electrochemical, and others) converting the detection event into a quantifiable signal. It relies on physiological and biochemical recognition that generates a signal proportional to the concentration of an analyte (blood glucose level in the case of diabetes) which can be used for early screening of diseases. They are either Ex-Situ (requires manual intervention to supply the analyte to the detection part) or In-Situ (monitoring real-time changes in the specimen). Following are a few categorizations of biosensors:

1. Optical Biosensors:
    a. Fiber Optic Biosensors.
    b. Reflective Optical Biosensors.
    c. Sensors based on Fluorescence Excitation.
    d. Sensors based on Evanescent Light Wave.
    e. Sensors Based on Surface Plasmon Resonance.
    f. Sensors Based on Surface Enhanced Raman.
    g. Acoustic Wave Sensors.
    h. Infrared Sensors.
2. Electrochemical Biosensors:
    a. Amperometric Biosensors (current measuring).
    b. Potentiometric.
    c. Conductometric (resistance measuring).
3. Non-Invasive Biosensors:

a. Optical reflectometry / photoplethysmography (monitoring heart rate, blood level, etc).
b. Thermal parameters.
c. Microwaves.
d. Electric field (detecting skin temperature, acidity, etc).

4. Miniaturized Biosensors:
   a. Stand Alone (fully portable).
   b. Integrated (lab-on-chip).

Disentangling the complicated specimen, ensuring a clean reading without contaminant interference, and linking the signal to the device for examination [2].

DEFINITION AND TYPES OF BIO-SENSORS

When human diseases are detected, it becomes complicated for patients. If diseases are detected in early stages, it becomes easy for the patients to continue and find the suitable remedy. There are several techniques through which diseases are detected. These techniques normally consume more time like 15 days to get the results placed in the laboratory. Nowadays technology is flourishing at a rapid pace. Prior to laboratory tests, modern technology can give some hints regarding the health status of the human. In this regard, biosensors are coming into the trend. Biosensors are instruments which identify the analyte present in the sample. By placing the sample into the biosensors, there is no need of waiting for a long time. The biosensors will give the results in fraction of seconds [3].

Biosensors: Biosensors are mechanical devices which exploit biological materials to monitor bodily fluid or food toxicity. Biosensors very selectively and sensitively detect dangerous elements with the help of affinitive biological elements i.e. antigens/antibodies, chemicals, peptoids or cells. The sensitive detection is done with diffusive or abrasive materials i.e. nanomaterials, plasmonic or optical materials placed on the electrodes. These biosensors will be installed connection with smart devices which will help in sending the results to other places via internet. Generally, biosensors will not identify the diseases exactly. The biosensors will only detect the presence of proteins, hormones, bacteria or any toxins or compounds etc and they signal early diagnosis [4]. There are four major types of biosensors: piezoelectric biosensor, electrochemical biosensor, thermal biosensor and optical biosensor. The piezoelectric biosensor generates electrical signals when the analyte is placed on the sensor. These piezoelectric biosensors are highly sensitive but costs more in the preparation of the sensor. The electrochemical biosensor is the cheapest among all biosensors and most ubiquitous. The electrochemical biosensors will sense the current or voltage changes and hence the results are known. The thermal biosensors measure the temperature change on the analyte. Then with the help of numerical methods, the detection of analyte concentration is predicted. Finally, the optical biosensors will detect the change of the conduction index or fluorescent change in the biosensors. The presence of analyte causes these changes in the biosensor [5].

IMPORTANCE OF EARLY DISEASE DETECTION

Disease detection continues to be a crucial issue faced by the population for a long period of time. Early detection of diseases can promote quality treatment and better recovery rates. Biosensors have emerged as a powerful tool for the detection of various diseases owing to their unique properties. Therefore, the development of biosensors for early disease detection holds a promise to tackle all these issues [6]. The importance of early disease detection is focused. Scientists have studied biomarkers for understanding diseases. Experimental techniques use patient sample fluids for detection. Invasive biosensors use blood for various applications. Non-invasive biosensors with sweat or urine samples are researched for patient compliance. These techniques have limitations [7]. Biosensors refer to devices used for the detection of bio-contaminants at lower concentrations using biological receptors (biomolecules) as recognition elements. Biosensors have the potential to be used as an effective detection method for early disease detection based on the study and understanding of biomarkers. Biosensors are being widely classified as electrochemical, piezoelectric, and photonic devices. They are gradually emerging as a powerful tool for the detection of bio-contaminants with properties such as: [8].

1) Biosensors are capable of the quantification of even a single molecule of a biomolecule.
2) Biosensors are highly sensitive, specific, and selective towards the detection of biomolecules.
3) Biosensors can be used for downstream biological studies.
4) Integration of micro/nano technology with biosensors results in smaller size, low cost, and user-friendly devices.
5) Biosensors can be incorporated with portable screens to monitor health on a daily basis.

With so many promising properties, biosensors have been a popular choice for the detection of biomarkers pertaining to diseases.

CURRENT CHALLENGES IN DISEASE DETECTION

The increasing prevalence of diseases, trajectory of the acute stage of a disease, and catastrophic health burden are high on the agenda of health and economic problems worldwide. Early detection is the most effective and efficient way to maintain a disease-free state before developing its full-blown state and associated health burden. Detection usually involves identification of early signal changes in the disease's biological, chemical or biophysical environment. The early disease signals need to be detectable by a bio-sensor using bio-sensing techniques. The transduction principle of a bio-sensing technique relies on i) readout of the signal change in the transducible environment using a physicochemical probe or receptor and ii) detection of the analyte by the probe or receptor [9].

Detection of early disease signals from the transducible disease environment is challenging for multiple reasons. Most diseases cannot be detected early using current bio-sensors. The transducible signals of diseases like solid tumors, neurodegeneration, sepsis, congestive heart failure, etc. cannot be detected by existing bio-sensors. This is the primary challenge in early disease detection. Even if these signals or biomarkers are transducible in a platformable environment, their concentrations are often low and complex due to physiological conditions or large sample volume. This limit makes detection difficult due to poor signal to noise ratio. Enrichment or concentration is needed to detect disease biomarkers, but it has low recovery and can result in signal loss. This is the second challenge in early disease detection for diseases like solid tumors, cardiac damage, Alzheimer's disease, septicemia, etc [10].

KEY COMPONENTS OF BIO-SENSORS

Bio-sensors encompass a range of components characterized by their nominal structure, which contains three key elements: a recognition element, a physicochemical transduction component, and a signal processing unit. These components are assembled on a transducer's surface or at the biocompatible interface of a biocompatible scaffold, allowing bio-sensors to be designed as portable, micro-scale, or miniaturized devices [11]. Biocompatible scaffolds are generally used to host recognition elements in bio-sensors for in vitro analysis of bio-active elements to be analyzed. Many bio-active nanoparticle probes can show high-affinity and selectivity towards a bio-active element of interest with excellent XPS and FT-IR spectra identity. These recognition elements can be designed to selectively accommodate an active insertion of a biomolecule. The integration of a recognition probe onto a bio-sensor is an important step in the preparation of this type of multi-scale device. By the transduction limit reached by bio-sensors, important insights on the diseased microbiome or on the diseased organisms translated from the bio-sensor's inner recognition probe [12]. The physicochemical signal response is then used to evaluate the occurrence of an event of interest, such as the attended capture of a target nucleic acid sequence of interest. Currently, one of the ultimate goals of researchers dealing with new bio-sensors is to increase their output effectiveness and applicability, particularly in underdeveloped countries or in at-risk environments. This trend is observed in the design of micro or miniaturized bio-sensors portable in point-of-care application settings [13].

CASE STUDIES AND APPLICATIONS

The rapid development of biosensors for monitoring vital parameters in patients' health has increased the interest of many research laboratories in the academic and industrial domains. This sensor technology is directly involved in critical discussions relating to everyday life, escaped from laboratory settings, and was integrated into portable devices by large companies such as Medtronic or Alivecor, among others. These sensors attempt to monitor glucose, lactic acid, cholesterol, and blood pressure, while keeping in mind preferences by patients and physicians. They must be simple and cheap, disposable and reliable, and acceptable by patients and medical staff handling them. Strong evaluation methods would also need to be included in the testing strategy. The first three have already been tested, and great effort is devoted to the last one [14]. Surface plasmon resonance biosensors are versatile platforms for bioanalytical applications. They enable high-throughput bioassays and label-free detection of binding events. However, reproducibility issues with sensing surfaces can limit their abilities in controlled environments and precise measurements. Commercial SPR biosensors are widely used, but there is potential for further improvement in data processing systems [15]. Nanomaterials-based electrochemical biosensors have gained attention in the last decade. Advances in nanotechnology and nanomaterials enable the development of effective devices with superior analytical characteristics. Nanobiosensors require collaboration among various disciplines and rely on physical and/or chemical interactions to induce a transducer signal change. Improvements in the field come from advancements in nanomaterial design, bioconjugation, immobilization techniques, and novel methodologies. These biosensors find practical applications in medical diagnostics, environmental monitoring, food safety control, and biowarfare protection [16].

CONCLUSION

Biosensors represent a transformative advancement in early disease detection, offering the potential to significantly enhance healthcare outcomes by enabling rapid, accurate, and minimally invasive diagnostics. The integration of nanotechnology and the development of highly sensitive and specific biosensors can address the current challenges associated with detecting complex disease markers. While there is substantial progress in the design and application of biosensors, ongoing research is crucial to overcoming limitations related to signal detection, noise interference, and device miniaturization. The future of biosensors lies in their ability to provide reliable and accessible diagnostic solutions, particularly in point-of-care settings, thereby contributing to better disease management and improved public health.

REFERENCES

1. Abdel-Karim R, Reda Y, Abdel-Fattah A. Nanostructured materials-based nanosensors. Journal of The Electrochemical Society. 2020 Jan 29;167(3):037554. iop.org
2. Qazi S, Raza K. Smart biosensors for an efficient point of care (PoC) health management. Smart biosensors in medical care. 2020. [HTML]
3. Cui F, Zhou HS. Diagnostic methods and potential portable biosensors for coronavirus disease 2019. Biosensors and bioelectronics. 2020. sciencedirect.com
4. Pourmadadi M, Yazdian F, Hojjati S, Khosravi-Darani K. Detection of microorganisms using graphene-based nanobiosensors. Food Technology and Biotechnology. 2021 Dec 22;59(4):496-506. srce.hr
5. Singh A, Sharma A, Ahmed A, Sundramoorthy AK, Furukawa H, Arya S, Khosla A. Recent advances in electrochemical biosensors: Applications, challenges, and future scope. Biosensors. 2021 Sep 14;11(9):336. mdpi.com
6. Mao K, Zhang H, Pan Y, Yang Z. Biosensors for wastewater-based epidemiology for monitoring public health. Water research. 2021. sciencedirect.com
7. Condrat CE, Thompson DC, Barbu MG, Bugnar OL, Boboc A, Cretoiu D, Suciu N, Cretoiu SM, Voinea SC. miRNAs as biomarkers in disease: latest findings regarding their role in diagnosis and prognosis. Cells. 2020 Jan 23;9(2):276. mdpi.com
8. Han Q, Pang J, Li Y, Sun B, Ibarlucea B, Liu X, Gemming T, Cheng Q, Zhang S, Liu H, Wang J. Graphene biodevices for early disease diagnosis based on biomarker detection. ACS sensors. 2021 Oct 26;6(11):3841-81. [HTML]
9. Brett TS, Rohani P. Dynamical footprints enable detection of disease emergence. PLoS biology. 2020. plos.org
10. Thakur A, Kumar A. Recent advances on rapid detection and remediation of environmental pollutants utilizing nanomaterials-based (bio) sensors. Science of The Total Environment. 2022. [HTML]
11. Polshettiwar SA, Deshmukh CD, Baheti AM, Wani MS, Bompilwar E, Jambhekar D, Choudhari S, Tagalpallewar A. Recent Trends on Biosensors in Healthcare and Pharmaceuticals: An Overview. International Journal of Pharmaceutical Investigation. 2021 Apr 1;11(2). academia.edu
12. Singhal J, Verma S, Kumar S, Mehrotra D. Recent advances in nano-bio-sensing fabrication technology for the detection of oral cancer. Molecular Biotechnology. 2021. [HTML]
13. Wang R, Jia J. Design of intelligent martial arts sports system based on biosensor network technology. Measurement. 2020. [HTML]
14. Chadha U, Bhardwaj P, Agarwal R, Rawat P, Agarwal R, Gupta I, Panjwani M, Singh S, Ahuja C, Selvaraj SK, Banavoth M. Recent progress and growth in biosensors technology: A critical review. Journal of Industrial and Engineering Chemistry. 2022 May 25;109:21-51. [HTML]
15. Matharu Z, Bee C, Schwarz F, Chen H, Tomlinson M, Wu G, Rakestraw G, Hornsby M, Drake A, Strop P, Rajpal A. High-throughput surface plasmon resonance biosensors for identifying diverse therapeutic monoclonal antibodies. Analytical Chemistry. 2021 Dec 2;93(49):16474-80. [HTML]
16. Malik S, Singh J, Goyat R, Saharan Y, Chaudhry V, Umar A, Ibrahim AA, Akbar S, Ameen S, Baskoutas S. Nanomaterials-based biosensor and their applications: A review. Heliyon. 2023 Sep 7. cell.com

CITE AS: Nyambura Achieng M. (2024). Development of Bio-Sensors for Early Disease Detection. RESEARCH INVENTION JOURNAL OF BIOLOGICAL AND APPLIED SCIENCES 3(3):17-20.