Proceedings of the 3rd International Conference on Biological Engineering and Medical Science
DOI: 10.54254/2753-8818/22/20230940

Advances and application of common biosensors

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Abstract. Biosensors are devices that can detect and measure chemical components in organisms through specialized biological properties or reactions. This paper provides an overview of the three main types of biosensors: enzymatic, immunosensors, and microbial sensors. Enzymatic biosensors utilize enzymes to catalyze specific reactions between target molecules and other components of the biosensor, creating measurable signals. Immunosensors rely on immunological reactions between antigens and antibodies to detect and quantify substances in a solution. Microbial sensors use microbial cells to produce signal outputs being tested. Each type of biosensor has unique applications and mechanisms that make them useful in various scientific studies, including clinical medicine, laboratory research, environmental monitoring, and food engineering. Ongoing advancements in technology will undoubtedly continue to expand the scope of biosensors' uses, making them increasingly important in many fields. This paper aims to provide researchers with an understanding of the mechanisms behind biosensors and strategies to improve their performance for better measurement, detection, and monitoring capabilities.

Keywords: biosensor, enzymatic biosensor, immunosensor, cell biosensor.

1. Introduction

Use of biosensors has been discussed in scientific research, particularly in the fields of chemistry and biology. Biosensors are devices that can detect and measure chemical components in organisms through specialized biological properties or reactions. There are several types of biosensors available today, each with different operating mechanisms suited for various applications.

There are various types of biosensors based on different classification principles. In terms of recognition elements, there are enzymatic biosensors, immunosensors, and cell sensors. Enzymatic biosensors, first introduced by Leland Charles Clark Jr. in 1962, utilize enzymes to catalyze specific reactions between target molecules and other components of the biosensor, creating measurable signals. Due to their high sensitivity and specificity, enzymatic biosensors are widely used in clinical medicine and laboratory research. Immunosensors, on the other hand, rely on immunological reactions between antigens and antibodies to detect and quantify substances in a solution. With their high selectivity, sensitivity, and specificity, they are commonly used in detecting hormones, pathogens, and other microorganisms. Cell sensors are versatile and useful, especially in monitoring environmental pollutants, contaminants, and in the food industry. With over six decades of development, biosensors offer immense potential in various fields of application, including fermentation technology, environmental monitoring, and food engineering. Ongoing advancements in technology will undoubtedly continue to expand the

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scope of biosensors' uses, making them increasingly important in many scientific studies. This paper aims to provide an overview of the three types of biosensors including their mechanisms, applications and strategies to improve their performances.

2. Enzymatic biosensor

2.1. Definition

Enzymatic sensors are a type of biosensor that rely on enzymes as the sensitive primitive of the organism. They work as bioreceptors to react with targets captured by physical and chemical signal transducers, producing a measurable signal proportional to the target sample. This signal is then processed by a microprocessor, which converts it into an electronic form, allowing for easy analysis. The resulting signal provides quantitative information about the target sample's concentration or activity, depending on the application. Enzymatic sensors have significant potential in medical applies, environmental issues, and food safety problems, as they combine high specificity with fast response times and low detection limits. Overall, enzymatic sensors represent an important tool for rapid, accurate, and reliable quantification of a wide range of analytes.

Enzymatic sensors necessitate a lengthy development history. When Guilbault and Montalvo reported a urea sensor based on urease immobilized at an ammonium-selective liquid membrane electrode, they offered the first detailed description of the potentiometric enzyme electrode [1]. Later, the "thermal enzyme probe"—a thermal sensor for biosensor applications—was introduced [2]. By 1976, La Roche had invented the LA 640 lactate analyzer, which used ferricyanate, a soluble medium, to transmit electrons from the lactate dehydrogenase to the electrode. Despite its commercial failure, it paved the way for a new generation of mediated biosensors and lactate analyzers for clinical and sporting purposes.

2.2. Improvements in selectivity and specificity

Enzymatic sensors as an important part of all-area analytical devices, are eager to have higher selectivity and specificity to support the demand of real-life use. Some great advances have been made with conventional sensors on enzyme electrodes, which are made on analytes of interest.

There are primarily two methods for enhancing the selectivity of biosensors. To start, people can reduce interference by improving the specificity of the interaction between the transducer and the biological receptor. Additionally, receptors can be made to have higher affinities or to be more sophisticated. This tactic has already demonstrated its popularity and potential. In conjunction with glucose oxidase in enzyme electrodes, Pyrroloquinoline Quinone can be used as a "natural" medium, as demonstrated by Loughran's study, to measure the amount of sugar in beverages [3]. The latter method involves chemically altering the electrode through Prussian Blue coating in order to boost selectivity. At the oxidation and reduction potentials of lactate and glucose electrodes, respectively, hydrogen peroxide is then employed to detect it at amperage.

2.3. Extensive application

It is well known that enzymatic sensors can be applied in the area of food and agriculture. The food industry can be a field with the usage of biosensor-based analysis. There is a surface plasmon resonance (SPR) biosensor monitor that can bind with the vitamin. The samples contained with vitamin binding protein are injected into the chip surface. As a higher concentration of vitamins is present, the inhibition rate is higher, making a lower response in biosensors. In terms of agriculture, enzymatic sensors can detect the number of pesticides in the soil. They can also be used to diagnosesoil diseases, which gives a way to prevent soil disease in advance.

For medical applications, enzymatic biosensors are able to detect and identify the specific virus in the sample as a diagnostic tool. It can be quite helpful if the virus can be identified in the important phase of infections because it allows people to work out the optimal treatment. SPR biosensors mentioned above

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have also been put into work with HIV studies. It can provide a way for people to observe interactions between macromolecules in real time. It can also give information on the kinetics of the interactions.

Computational studies have previously been conducted on the quantification of the 3D structure of sucralose (SUC) using methods such as high-performance liquid chromatography (HPLC)-UV, high-performance thin layer chromatography (HPTLC), high-performance anion exchange chromatography-pulsed amperometric detecter (HPAEC-PAD), HPLC-ELSD, and liquid chromatography-mass spectrometry [4-10]. Later, at the B3LYP level of theory, density functional theory (DFT) computations were utilized to geometry-optimize the SUC model utilizing the 6-311 + G basis sets as implemented in the Gaussian 09 software package [11, 12]. A frequency calculation provided additional evidence of the global minimum for the modified shape [13]. To address biological diagnosis issues, surface-enhanced Raman scattering (SERS) biosensors have been developed. Sudalaimani et al. developed a modern colorimetric approach for quantifying Cad and Put using ninhydrin [14]. The approach is based on the production of a complex similar to Ruhemann's purple with putrescine and ninhydrin having a molar ratio of 1:2.5 and an absorption peak at 564 nm. With the use of density functional theory (DFT), the observation was theoretically confirmed. At 80 ℃ it was found that the colorimetric detection technique moved quickly. Given that the structures of both biogenic amines are relatively identical aside from the inclusion of a methylene group, a detectable color change was not seen when putrescine and cadaverine reacted with ninhydrin at pH 8.0 [14].

3. Immunosensor

3.1. Definition

Immunosensors are deductive tools that detect the interaction of antigens and antibodies by connecting the immunochemical reaction through transducer's surface. In terms of the antigen-antibody combination theory, people can examine a specific antibody. Based on the technology utilized, immunosensors can be classified into three categories: optical, piezoelectric, and electrochemical immunosensors.

3.2. Classification

3.2.1. Optical immunosensor. Optical immunosensors, which have been created utilizing a variety of optical techniques, make up the first class of immunosensors. The simplest method uses the detection of immunochemical complexes on the device surface without any labels, whereas more advanced procedures rely on the identification of molecules that have been marked. Chemicals coupled to the appropriate antibody or antigen are used in many indirect approaches for making optical immunosensors.

In terms of the application of an optical immunosensor, a compact optical sensing device has been created that can detect creatinine with high accuracy and sensitivity at the point of care. The sensor measures color changes brought on by a sensing probe with antibody functionality that reacts with picric acid and creatinine to provide a measurable optical signal. A palm-sized gadget with the biosensor built in uses a smartphone for quick and customized examination. Simple chemical adjustments were made to the antibody which is able to select ceratinine to make the sensing probe. Extensive testing revealed that the sensor exhibited no cross-reactivity with interference compounds and excellent dose-dependent correlation over two dynamic ranges with a detection limit of 15.37 nM [15].

Molecularly imprinted polymers (MIPs), for instance, are synthetic antibodies used in other domains to target particular molecules. Kshitij used the Jablonski diagram to show how electrons move between energy levels. The use of various receptor and target molecules to anchor synthetic MIPs was also discussed, with an emphasis on the positive synergistic effects achieved [16].

3.2.2. Iezoelectric immunosensor. The piezoelectric immunosensors make up the second class of immunosensors. Due to advancements in transducer technology, piezoelectric devices have gained a lot

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of attention, and current acoustic wave systems enable perform immunosensing. An antibody or antigen adhering to the surface of a modified piezoelectric crystal allows immunosensors to be viable by detecting various responses. Piezoelectric devices can be divided surface acoustic wave devices and quartz crystal microbalances (QCM).

To detect ribavirin, Liu et al. devised a suppressive piezoelectric immunosensor that makes use of an incredibly sensitive quartz crystal microbalance and a highly focused immunosorbent assay. The sensor was created by electropolymerizing carboxyl groups onto the gold electrode surface. To detect ribavirin, Liu et al. devised a suppressive piezoelectric immunosensor that makes use of an incredibly sensitive quartz crystal microbalance and a highly focused immunosorbent assay. The sensor was created by electropolymerizing carboxyl groups onto the gold electrode surface. The piezoelectric sensor's frequency changed as a result of this binding. The sensor's performance was assessed once the concentration of the antibody was tuned. The sensor demonstrated a broad linear range of 1-750 g L^{-1}, a small detection limit (IC15) of 2.64 g L^{-1}, and a good sensitivity (IC50) of 31.49 g L^{-1} under ideal circumstances. With recovery rates ranging from 88.01% to 94.42%, the sensor was effectively employed to detect ribavirin in chicken and milk samples [17]. The piezoelectric sensor's frequency changed as a result of this binding. The sensor's performance was assessed once the concentration of the antibody was tuned. The sensor demonstrated a broad linear range of 1-750 g L^{-1}, a small detection limit (IC15) of 2.64 g L^{-1}, and a good sensitivity (IC50) of 31.49 g L^{-1} under ideal circumstances. With recovery rates ranging from 88.01% to 94.42%, the sensor was effectively employed to detect ribavirin in chicken and milk samples [17].

3.2.3. Electrochemical immunosensor. Electrochemical immunosensors make up the third class of immunosensors. Electrochemical immunosensors are used to test the virus in light of the current COVID-19 outbreak. A type of electrochemical immunosensor applied the quick identification of the virus, the cause of the COVID-19 pandemic, was presented by Mojsoska, B. et al. The experiment made use of a graphene working electrode that was anti-spike antibody functionalized. The immunoassay measured ferri/ferrocyanide after 45 minutes of incubation with a sample containing the spike surface protein antigen in order to identify signal disturbances. At $5.5*10^5$ PFU/mL, which was within the physiologically plausible range, it successfully recognized SARS-CoV-2. Notably, this innovative immunosensor could be operated with a portable device and provided a substantially faster analysis time than traditional qPCR, allowing for on-site infection diagnosis [18].

There are further uses to combat illness. Procalcitonin (PCT) as a disease marker can be identified in the early stages of disease of septicemia and pyemia using a sophisticated ratiometric electrochemical immunosensor based on the ratios of chemical complexes [19].

4. Cell biosensor

4.1. Definition

Cell sensor refers to the study of cell-based stimuli response. There are several applications for cell sensors. The first and most significant one is that functional information can only be obtained using a live component. This may be compared with analytical information, which provides a response to the question of how much of a certain substance is there. Analytical tests are only performed to assess the functional effects of the substances under investigation in many situations when the sort of information needed is really functional. In certain circumstances, a measuring technique utilizing a live system is appealing since it may immediately produce that functional information.

4.2. Application

Cell biosensors are used in the detection of viruses during pandemics, just like immunosensors. To solve this problem, Mavrikou et al. created a proof-of-concept biosensor. The spike protein that is present on the virus surface is detectable by the cell biosensor. It made use of mammalian cells that had been genetically altered and had human chimeric spike S1 antibodies added to their membranes. We

DOI: 10.54254/2753-8818/22/20230940

employed a Bioelectric Recognition Assay to measure the considerable and selective changes in the cellular bioelectric characteristics that the spike protein induced when it connected to these antibodies. Limiting to femtogram per milliliter (fg/mL) and a response range of 10 fg to 1 microgram per milliliter (g/mL), this novel biosensor offered extremely quick findings (within 3 minutes).

5. Conclusion

In conclusion, biosensors have become an essential tool in scientific research, with enzymatic biosensors, immunosensors, and microbial sensors being the most commonly used types. These sensors provide high sensitivity, specificity, and selectivity, making them very useful in clinical medicine, environmental monitoring, and food engineering. Continued advancements in technology will likely allow for further development in terms of accuracy, reliability, and ease of use, particularly with the integration of nanotechnology and artificial intelligence. This advancement can potentially lead to more efficient and cost-effective biosensors suitable for broader use in research and industry.

Prospects for future research include improving biosensor performance by optimizing their sensitivity, selectivity, stability, and reproducibility. There is also a need to develop new sensing mechanisms that can detect targets-beyond substrates, including disease biomarkers and contaminants. Additionally, breakthroughs in biotechnology and synthetic biology may result in robust and versatile biosensors capable of detecting multiple analytes across different mediums simultaneously.

Overall, biosensors' potential importance lies not only in research applications but also in commercial and industrial contexts, highlighting the need for continued investment and research development in this field. With ongoing technological advances in biosensor technology, the vision for a safer, healthier, and more sustainable future looks promising.

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