Analysis of Biosensors and Their Frontier Application in the Medical Field

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Abstract. With the progress of science and technology, the application of biosensors is more and more widespread. At present, traditional medical detection has the disadvantages of long cycles, low accuracy, and a cumbersome process. Because biosensors perfectly meet the requirements of timeliness and accuracy in medical detection, they are increasingly used in the field of cutting-edge medicine, which greatly improves the efficiency of diagnosis and treatment, reduces the probability of misdiagnosis, and reduces the pressure on the medical system. It is crucial for the early detection of the illness, particularly for the early detection of malignancy. Biosensors have bright prospects and high value in the field of modern medicine. In this paper, the composition and operation principle of biosensors is introduced. The frontier applications of biosensors in some medical fields are analyzed, and their advantages and disadvantages are obtained. The future development of biosensors is prospected, aiming to provide a certain direction for its future development.

Keywords: Biosensors, Medical detection, Modern medicine field.

1. Introduction

The concept of biosensors was first proposed in 1962, which is a multidisciplinary advanced technology [1]. It is a chemical sensor based on biological reaction detection. It is based on the specific binding of the bio-sensitive element to the active unit and the related chemical reaction and then analyzes the concentration of the reaction product to achieve the measurement purpose. It has high sensitivity, strong stability, and good timeliness. At present, traditional medical tests are usually laboratory tests. Their detection cycle is long, the operation is cumbersome, and the patient needs to be highly cooperative. Often the test results have lost their timeliness when they come out. Therefore, developing a quick test technique is crucial. The emerging technology of biosensors is well suited to these requirements and has a bright prospect in the medical field.

This paper first introduces the composition and operation principle of the sensor, analyzes the characteristics and advantages of the sensor, and then analyzes several application examples of the sensor in the frontier medical field. Then it analyzes the shortcomings and challenges of the sensor in the medical field, and looks forward to the future, hoping to provide direction for the development of the sensor and its application in medicine.

2. Introduction of composition and principle

2.1. Composition

The biosensor consists of two main parts: a bio-sensitive element, and a physical and chemical transducer [1]. Bio-sensitive elements are generally biological receptors, such as enzymes, proteins, DNA (deoxyribonucleic acid), antibodies, antigens, biofilms, etc., which can effectively identify the molecules of the analyte and bind specifically. The transducer, also known as the signal converter, can convert the signal generated after the recognition of bio-molecules into an equal amount of visual or readable signal, to quantitatively analyze the target. The composition of the biosensor is shown in Figure 1.

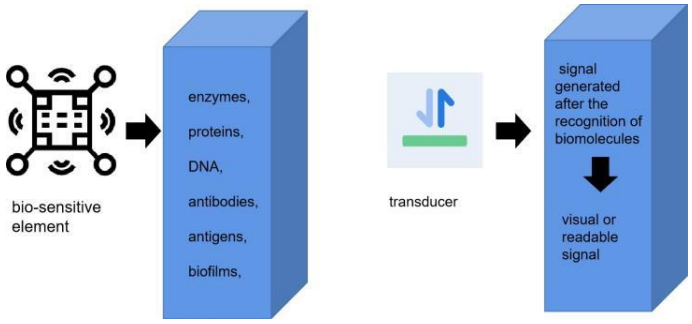


Figure 1. The composition of the biosensor (Photo/Picture credit: Original)

2.2. The working principle of the biosensor

The substance to be tested enters the molecular recognition element, such as enzyme, protein, DNA, antibody, antigen, biofilm, etc., through diffusion, and specifically binds to the biologically sensitive element through molecular recognition to produce physical or chemical reactions; the transducer, also known as signal converter, converts the received physical or chemical reaction signals into measurable electrical, acoustic, optical and other signals, and amplifies, processes and outputs the generated signals. The measured signal can indirectly reflect the concentration of the substance to be measured [2]. Compared with traditional detection methods, biosensors use immobilized bio-active substances as catalysts, which can be reused many times, greatly reducing the preparation cost, simplifying the detection steps, and saving manpower [3]. Furthermore, the riding has specificity, can accurately identify specific substrates, has strong pertinence, reduces errors, and greatly improves the analysis speed. The working principle is shown in Figure 2.

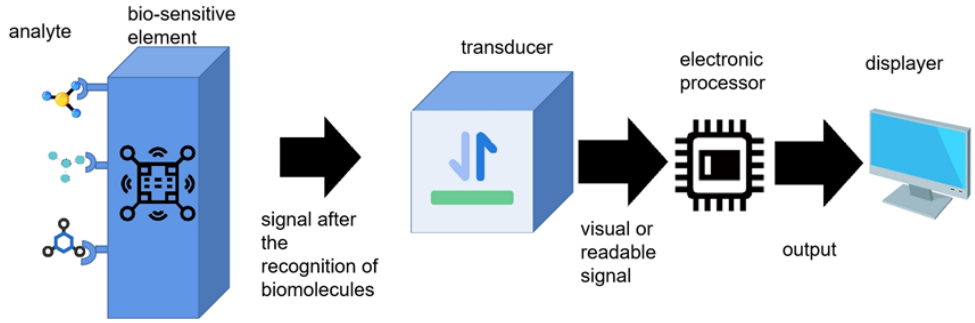


Figure 2. Working principle of the biosensor (Photo/Picture credit: Original)

3. Frontier Application of biosensors in the medical field

3.1. Localized surface plasmon resonance (LSPR)

The interaction between incident light and free electrons on the surface of metal nanoparticles causes the physical optical phenomenon known as LSPR to occur. The size and form of the metal nanoparticles as well as the surrounding dielectric environment have a significant impact on the peak of the LSPR absorption spectrum. By utilizing this property, LSPR biosensors can be made to effectively detect molecules on their surface by converting the slight change in local surface refractive index brought on by biomolecule adsorption into a quantifiable wavelength shift. LSPR biosensor has been proven to be able to successfully detect a variety of important clinical indicators, such as prostate cancer-specific antigen PSA (Prostate Specific Antigen), blood group, AID (acquired immunodeficiency syndrome) virus, gene mutation, etc. It has been proved that the sensor has the advantages of fast, convenient operation, label-free, and high sensitivity, and has great clinical application potential [4].

Duan Ruiqi's team through physical method calculation and design simulation, successfully prepared the biological sensitive layer, effectively improving the sensor performance [4]. By immobilizing the antibody on the metal nano-surface and analyzing the refractive index change of

the local surface of the sensor chip when the monoclonal antibody binds to the target standard or the target marker in the patient's serum, the biological signal is converted into an optical signal. It is found that the method is reliable, effective, simple, and easy to operate. In the study, urine micro-proteinuria in patients with mild preeclampsia in obstetrics and gynecology was successfully detected. Compared with the clinical biochemical test, it has a high coincidence rate, which has important clinical significance and application prospects for the clinical census and management of patients with mild preeclampsia in clinical obstetrics. Squamous cell carcinoma antigen can be found with this technique, allowing for the early detection and diagnosis of cervical cancer patients. Has a bright prospect.

3.2. Silicon nanowires field-effect transistor biosensor (SiNWs-FET)

Based on the field effect transistor, the silicon nanowire field effect transistor biosensor has the following components: a substrate, an insulating oxide layer, a gate, a source, and a drain. Monoclonal antibodies, single-stranded DNA, and other specialized probes that can precisely capture the target molecule in the detection sample are added to the surface of silicon nanowires [5]. When the surface of silicon nanowires is combined with charged molecules, it will cause a change in the number of charges inside the silicon nanowires. The silicon nanowire field effect transistor can respond quickly and in real-time to the change of electrical signal caused by the combination of molecules on the surface of silicon nanowires. At the same time, no additional labeling signal is needed in the detection, to realize label-free detection, which is expected to become an ideal tool for the analysis of biological samples. In illness diagnosis and medical research, highly sensitive quantitative detection of proteins, nucleic acids, viruses, and other substances is crucial. SiNWs-FET biosensor is of great value in label-free, fast real-time response and ultra-sensitive detection of proteins and other molecules.

Kim etc. used SiNWs-FET to detect specific protein content, and their detection limits were much lower than other detection methods at that time [6]. Patolsky etc. studied multi-channel silicon nanowire biosensors [7]. The detection limit is as low as fmol/L, which is several orders of magnitude higher than that of enzyme-linked immunosorbent assay (ELISA). This highlights the benefits of silicon nanowire field effect transistor biosensors for the detection of proteins even more.

Patolsky etc. used silicon nanowire field effect transistor sensors for the detection of influenza A virus [8]. The mechanism is that the combination of the virus and the monoclonal antibody causes a change in the conductivity of the silicon nanowire, and the detection sensitivity reaches the level of a single virus. Moreover, a silicon nanowire sensor modified with antibodies against two similar viruses can simultaneously detect these two viruses. These studies have further confirmed the unique advantages of silicon nanowire field effect transistor sensors for virus infection detection.

3.3. Colorimetric biosensor based on enzymes

Colorimetric sensing technology mainly obtains the concentration of the analyte through visual observation and color comparison and makes qualitative judgments. Colorimetric sensing based on enzymes can catalyze the oxidation reaction of some chromogenic substrates in the presence of hydrogen peroxide (H2O2) so that the chromogenic substrate can be discolored. The recognition element of the colorimetric biosensor is identified and converted into a visual signal, to achieve the purpose of detection [9].

Compared with natural enzymes, enzymes have the advantages of stable properties, easy synthesis, and signal amplification. Therefore, colorimetric biosensors based on enzymes have higher sensitivity and lower cost and have bright application prospects in the detection of related markers in vivo and early screening of cancer.

At present, the detection methods of cancer cells in medicine have certain harm to the body, and the content of H2O2 in cancer cells is significantly higher than that in normal cells. Therefore, the detection of cancer cells by detecting the content of H2O2 has become a feasible scheme for early cancer screening. In 2014, Zhang, etc. successfully performed colorimetric detection of H2O2 in breast cancer cells (MCF-7) [10]. In 2021, Lian, etc. designed NiCo2S4 (PVP) and NiCo2S4 (CTAB) nanomaterials with higher specificity to detect H2O2 produced in human breast cancer (MDA-MB-

231) cells, which undoubtedly provides an effective way for early screening and diagnosis of cancer [11].

4. Conclusion

At present, the application of biosensors in medicine has achieved initial results, but there are still deficiencies and challenges. Firstly, the sensitivity of the sensor needs to be improved, and the detection limit still has room for improvement. Secondly, under the requirements of high integration and portability in the future, the machining accuracy of biosensors is severely challenged. How to improve the machining accuracy and reduce the machining error is an urgent problem to be solved. Furthermore, for some implantable biosensors, the battery life and surface corrosion resistance of the sensor are demanding, and it is a difficult problem to find suitable functional methods and anti-corrosion materials.

With the development of science and technology and the progress of detection methods, to meet the more stringent requirements, the miniaturization and high integration of biosensors have become an inevitable trend. A biosensor may simultaneously detect a variety of substances and integrate multiple functions. Smaller sizes and more powerful functions will provide greater help for the medical industry and play a significant role in the early screening and diagnosis of cancer. At the same time, the development of implantable biosensors is also in full swing and fruitful, which will greatly simplify the detection cycle, simplify the diagnosis and treatment steps, so that the patient's health status can be detected and reported in real-time, reduce the burden of hospital admissions, and improve work efficiency.

References

[1] Luo Juan, Shang Jiajing, Li Dan, etc. Overview of biosensors and their application in animal disease detection. Animal quarantine in China, 2023, 40 (01): 72-79.

[2] Lawrence H, Mark E, James S, et al. Smart Chemical Sensor and Biosensor Networks for Healthcare 4.0. Sensors (Basel, Switzerland), 2023, 23 (12).

[3] Dean G, Serena N, Qian L, et al. A universal stimuli-responsive biosensor for disease biomarkers through their cysteine residues: A proof of concept on carcinoembryonic antigen (CEA) biomarker. Sensors and Actuators: B. Chemical, 2023, 393.

[4] Duan Ruiqi, Yu Xiuzhang, Lan Zhu, et al. Research progress of LSPR biosensor in clinical medical detection applications. Electro-optical engineering. 2017, 44 (02): 152-160+248.

[5] Bao Zengtao, Wang Tong. Medical applications of silicon nanowire field effect transistor biosensors. Journal of Biomedical Engineering, 2017, 34 (05): 807-811.

[6] Kim K, Park C, Kwon D, et al. Silicon nanowire biosensors for detection of cardiac troponinI (cTnI) with high sensitivity. Biosens Bioelectron, 2016, 77: 695-701.

[7] Patolsky F, Zheng Gengfeng, Lieber C M. Nanowire sensors for medicine and the life sciences. Nanomedicine, 2006, 1 (1): 51-65.

[8] Patolsky F, Zheng G, Hayden O, et al. Electrical detection of single viruses. Proc Natl Acad Sci U S A, 2004, 101 (39): 14017-14022.

[9] Yuan Lin, Lu Dongxiao, Li Jinhua. Application of colorimetric biosensors based on enzymes in biomedical detection. Advances in biochemistry and biophysics 2022, 1-17.

[10] Zhang Lin, Deng Hong, Lin Fei, et al. In situ growth of porous platinum nanoparticles on graphene oxide for colorimetric detection of cancer cells. Anal Chem, 2014, 86 (5): 2711-2718.

[11] Lian Meng, Liu Ma, Zhang Xue, et al. Template-regulated bimetallic sulfide enzymes with high specificity and activity for visual colorimetric detection of cellular H2O2. ACS Appl Mater Interfaces, 2021, 13 (45): 53599-53609.