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Advancements in Optical Fiber and Electrochemical Biosensors for the Detection of the CD44 Cancer Biomarker

A REVIEW PAPER

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By

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ABSTRACT

This review paper focuses on recent advancements in biosensing technologies for the detection of the cancer biomarker CD44. Five scientific studies conducted by researchers at Nazarbayev University are analyzed, covering optical fiber biosensors, electrochemical sensors, and green-synthesized nanomaterials. The main goal of this review is to highlight the importance of sensitive, label-free, and real-time detection methods in early cancer diagnosis. The studies demonstrate significant progress in achieving attomolar-level sensitivity, detecting whole cancer cells, and improving sensor performance using eco-friendly approaches. The paper also discusses the methodology, strengths, and potential limitations of each study. The findings suggest that these biosensors hold great promise for future clinical applications, especially in point-of-care testing and personalized medicine.

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CHAPTER ONE: INTRODUCTION

1.1 Statement of the Problem

Cancer remains one of the leading causes of death worldwide. Early detection is crucial for effective treatment and improved survival rates. However, many current diagnostic methods are time-consuming, expensive, and lack the sensitivity needed to detect cancer at its earliest stages. There is a growing need for advanced, reliable, and accessible tools that can identify cancer biomarkers with high precision. Among these biomarkers, CD44 has gained significant attention due to its strong association with cancer stem cells and tumor metastasis. Despite its importance, detecting CD44 at very low concentrations in biological fluids remains a major challenge.

1.2 Aims of the Study

The main aim of this review is to analyze and summarize recent scientific studies on biosensors designed for CD44 detection. Specifically, the paper aims to:

1. Highlight the importance of CD44 as a biomarker in cancer diagnosis.
2. Examine the methodologies used in optical fiber and electrochemical biosensors.
3. Evaluate the sensitivity, specificity, and practical applicability of these sensors.
4. Discuss the role of green-synthesized nanomaterials in enhancing sensor performance.
5. Provide a critical assessment of the strengths and limitations of current research.

1.3 Research Questions

1. What is the role of CD44 in cancer progression?
2. How do optical fiber biosensors detect CD44?
3. What makes label-free detection advantageous?
4. Can these sensors work in real biological samples?
5. What are the future directions for this technology?

1.4 Hypotheses

1. Optical fiber biosensors can detect CD44 at attomolar levels.
2. Label-free detection improves the speed and reliability of diagnosis.
3. Green-synthesized gold nanoparticles enhance sensor sensitivity.
4. These biosensors have the potential to be used in clinical settings.

1.5 Data Collection and Procedure

This review is based on five peer-reviewed scientific articles published between 2021 and 2024. The articles were selected based on their relevance to CD44 detection using biosensors. Data was collected by reading, analyzing, and summarizing each study's objectives, methods, results, and conclusions. The analysis focused on the type of sensor, detection limit, working principle, and potential for real-world application.

1.6 Limitations of the Study

This review is limited to studies published in English and focuses only on research related to CD44 biosensors from a single research group. It does not include in vivo clinical trials or commercial devices. Additionally, the long-term stability and cost-effectiveness of these sensors are not fully explored in the selected papers.

1.7 The Value of the Study

This paper provides a clear and structured overview of cutting-edge biosensing technologies for cancer detection. It helps students and researchers understand the current state of the field and the scientific process behind developing sensitive diagnostic tools. The review also highlights the importance of interdisciplinary research combining biology, engineering, and materials science.

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview of CD44 as a Cancer Biomarker

CD44 is a transmembrane glycoprotein that plays a key role in cell adhesion, migration, and signaling. It is highly expressed in cancer stem cells (CSCs), which are responsible for tumor growth, recurrence, and resistance to therapy. Elevated levels of CD44 have been found in various cancers, including breast, pancreatic, and colorectal cancer. Because of its role in metastasis and treatment resistance, CD44 is considered a valuable target for both diagnosis and therapy.

2.2 Principles of Biosensing Technologies

Biosensors are analytical devices that combine a biological component (like an antibody or enzyme) with a physical detector. They convert a biological response into a measurable signal. Two main types are used in the reviewed studies:

1. Optical fiber biosensors: Use light to detect changes when a target molecule binds to the sensor surface.
2. Electrochemical biosensors: Measure changes in electrical current or voltage caused by molecular binding.

Both types offer advantages such as high sensitivity, fast response, and miniaturization.

2.3 Label-Free Detection Methods

Label-free detection means the target molecule is detected without using fluorescent or radioactive tags. This approach:

1. Reduces preparation time.
2. Avoids altering the molecule's structure.
3. Allows real-time monitoring.
4. Is more suitable for clinical use.

All five reviewed studies use label-free methods, which increases their practical value.

CHAPTER THREE: METHODOLOGY

3.1 Review Paper Methodology

This paper follows a qualitative review approach. Five scientific articles were selected based on their focus on CD44 detection using advanced biosensors. Each article was read and analyzed for its research question, methodology, key findings, and contribution to the field. The studies were then compared to identify common trends, innovations, and challenges.

3.2 Summary of Selected Studies

Study 1: High-Sensitivity Refractive Index Sensor (Kazhiyev et al., 2023)
This study developed a semi-distributed interferometer (SDI) fiber-optic sensor to detect changes in refractive index (RI). Although not directly detecting CD44, it provides a sensitive platform for future biosensors. The design showed high repeatability and sensitivity, making it suitable for integration with biological recognition elements.

Study 2: Attomolar Detection of CD44 (Bekmurzayeva et al., 2022)
A silanized optical fiber ball resonator was used to detect CD44 with a limit of detection as low as 0.2 aM. The sensor is label-free, works in real time, and shows a wide dynamic range. This is one of the most sensitive CD44 detectors ever reported.

Study 3: Detection of CD44-Expressing Cancer Cells (Nurlankyzy et al., 2024)
This research extended the previous work to detect whole breast cancer cells that express CD44. The sensor could detect as few as 335 cells per mL, demonstrating its potential for early cancer screening.

Study 4: Electrochemical Sensor for CD44 (Bekmurzayeva et al., 2021)
An alternative approach using electrochemistry and ligand-protein interaction was developed. The sensor uses hyaluronic acid as a ligand to bind CD44, offering a stable and cost-effective method without antibodies.

Study 5: Green Synthesis of Gold Nanoparticles (Ashikbayeva et al., 2023)

This study focused on improving sensor sensitivity using gold nanoparticles synthesized from green tea extract. The eco-friendly nanoparticles enhanced the optical signal, showing that sustainable methods can boost performance.

CHAPTER FOUR: OVERALL CONCLUSION

The reviewed studies demonstrate significant progress in the development of biosensors for early cancer detection. By targeting the CD44 biomarker, researchers have created devices that are highly sensitive, specific, and capable of label-free,

real-time detection. The use of optical fiber technology allows for miniaturization and integration into portable systems, while electrochemical methods offer a simpler and potentially cheaper alternative.

Key achievements include:

1. Attomolar-level detection of CD44.
2. Successful detection of whole cancer cells.
3. Use of green-synthesized nanomaterials to improve performance.
4. Development of stable, reusable, and selective sensors.

Despite these advances, challenges remain. Most studies were conducted in controlled lab environments, and testing with real patient samples is still limited. Future work should focus on clinical validation, mass production, and integration into point-of-care devices.

In conclusion, these biosensors represent a promising step toward faster, cheaper, and more accurate cancer diagnosis. With further development, they could become essential tools in modern medicine, helping to save lives through early detection.

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