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Review

Emerging frontiers: Harnessing the power of CNT/GO-based biosensors for early disease biomarker detection

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Abstract: This review discusses the significant progress made in the development of CNT/GO-based biosensors for disease biomarker detection. It highlights the specific applications of CNT/GO-based biosensors in the detection of various disease biomarkers, including cancer, cardiovascular diseases, infectious diseases, and neurodegenerative disorders. The superior performance of these biosensors, such as their high sensitivity, low detection limits, and real-time monitoring capabilities, makes them highly promising for early disease diagnosis. Moreover, the challenges and future directions in the field of CNT/GO-based biosensors are discussed, focusing on the need for standardization, scalability, and commercialization of these biosensing platforms. In conclusion, CNT/GO-based biosensors have demonstrated immense potential in the field of disease biomarker detection, offering a promising approach towards early diagnosis. Continued research and development in this area hold great promise for advancing personalized medicine and improving patient outcomes.

Keywords: CNT/GO-based biosensors; disease biomarker detection; early diagnosis; biosensing; cancer; cardiovascular diseases; infectious diseases; neurodegenerative disorders

1. Introduction

Emerging as quite promising systems for identifying disease biomarkers are CNT/GO-based biosensors. Carbon nanotubes (CNTs) and graphene oxide (GO) are attractive for this use. Firstly, CNTs and GO have outstanding electrical conductivity, which helps detect biomolecules sensitively. Between biomarkers and recognition elements, their electrical characteristics can transduce particular binding events into detectable electrical signals [1,2]. Secondly, CNTs and GO have a high surface area-to-volume ratio, offering a lot of binding surfaces for biomarker capture. This improves the biosensor's sensitivity. Selective detection of target biomarkers becomes feasible by functionalizing CNTs and GO with particular recognition elements like antibodies or aptamers [3–5].

The label-free detection capability of CNT/GO-based biosensors adds still another benefit. This simplifies the assay process and removes the necessity of extra labeling steps. Moreover, CNTs and GO fit microfabrication methods, which enables integration with miniature devices [6,7]. This makes point-of-care diagnostics portable, and successful detection of several disease biomarkers has been shown by CNT/GO-based biosensors [8–10]. They have shown great sensitivity and specificity for identifying particular tumor markers in cancer diagnosis, thus facilitating early cancer detection and treatment monitoring [11,12]. By identifying cardiac biomarkers linked with heart failure and myocardial infarction, they have also shown promise in diagnosing cardiovascular disease [13–15]. CNT/GO-based biosensors have been applied for fast and sensitive identification of pathogen-associated biomarkers in infectious disease diagnostics, enabling early identification of infectious agents [16]. Furthermore, these biosensors could identify disease-specific biomarkers in neurodegenerative diseases, supporting early diagnosis and disease progression monitoring [17,18].

This review intends to analyze the progress in CNT/GO-based biosensors, emphasizing their fabrication techniques, functionalization approaches, and integration with transducing components to improve sensitivity and selectivity. It examines the particular applications of these biosensors in identifying various disease biomarkers, including those linked to cancer, cardiovascular diseases, infectious diseases, and neurodegenerative disorders. Additionally, the review highlights the superior performance of CNT/GO-based biosensors, such as their high sensitivity, low detection limits, and real-time monitoring capabilities, which contribute to their potential in facilitating early disease diagnosis. Finally, it discusses the challenges and future trajectories in the domain, highlighting the necessity for standardization, scalability, and commercialization to enhance personalized medicine and optimize patient outcomes.

2. Cancer diagnosis

Biosensors using graphene oxide (GO) and carbon nanotubes (CNT) have shown significant potential for cancer detection [19,20]. These biosensors possess exceptional qualities such as high sensitivity, selectivity, and compatibility with biological systems. [21,22]. They can identify specific cancer biomarkers, such as proteins and nucleic acids, in diverse biological specimens, including blood, urine, and saliva [23]. The elevated surface area and superior electrical conductivity of CNTs and GO enhance the immobilization of capture probes that specifically attach to target biomarkers [24,25]. The detection of cancer utilizing a biosensor is depicted in **Figure 1**. Binding events induce alterations in electrical, optical, or electrochemical signals, facilitating the sensitive detection of cancer biomarkers [26,27]. Liquid biopsy is a non-invasive method utilized for cancer diagnosis and monitoring [28–30]. CNT/GO-based biosensors have been investigated to detect circulating tumor cells (CTCs) and circulating tumor DNA (ctDNA) in blood specimens. These biosensors can detect circulating tumor cells (CTCs) or assess genetic modifications in circulating tumor DNA (ctDNA), yielding critical insights regarding tumor existence, advancement, and therapeutic response [31].

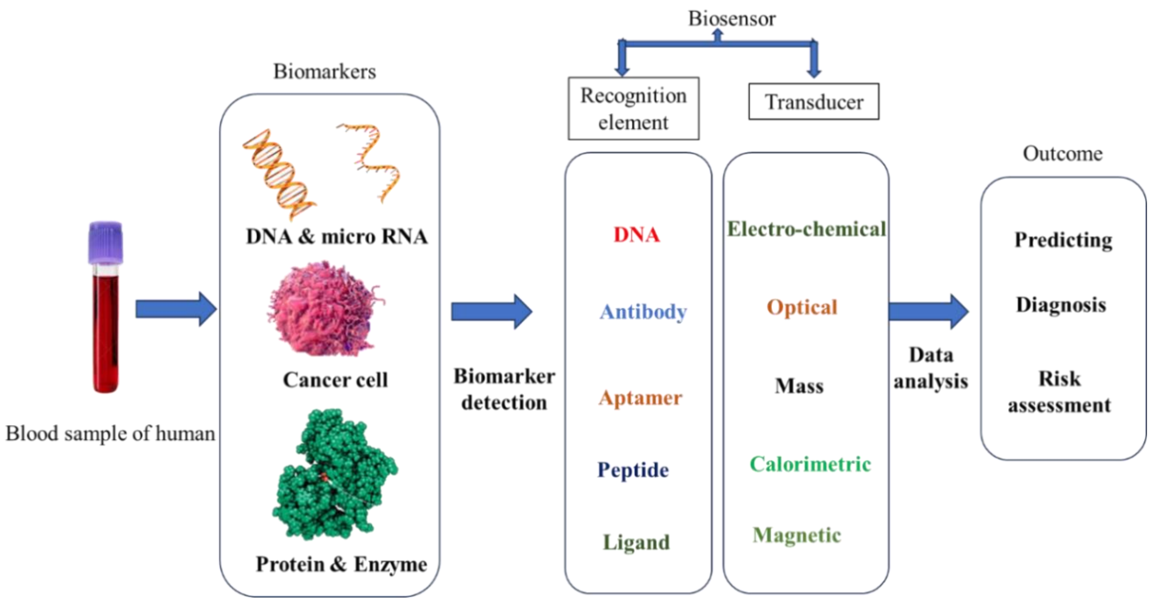

Figure 1. Detection of cancer using biosensor.

Another advantage is the potential for multiplexed detection, allowing simultaneous analysis of multiple cancer biomarkers [32–34]. By integrating different capture probes specific to distinct biomarkers, CNT/GO-based biosensors can detect and quantify multiple analytes in a single assay. Multiplex biomarker detection employs modern techniques such as microarrays, multiplexed enzyme-linked immunosorbent assay, mass spectrometry, and biosensors to recognize many targets at once [35]. Techniques use unique probes, spectral signatures, or chemical interactions to provide high-throughput and specific detection [36]. This multiplexed approach improves diagnostic accuracy and efficiency by providing a comprehensive profile of the disease [37]. CNT/GO-based biosensors are also well-suited for point-of-care cancer testing due to their portability, rapid response, and ability to detect low analyte concentrations [38]. They can be integrated into portable devices or wearable sensors, enabling real-time and on-site cancer diagnosis. By continually monitoring physiological or chemical signals from the body, wearable sensors can identify cancer biomarkers. These devices detect cancer-related markers in physiological fluids such blood, saliva, perspiration, or interstitial fluid by using cutting-edge materials and technology [39]. Point-of-care testing facilitates early detection, personalized treatment, and improved patient outcomes, particularly in resource-limited settings [40–42]. Furthermore, CNT/GO-based biosensors have been investigated for cancer imaging and visualization. Functionalized CNTs or GO can act as contrast agents in various imaging techniques such as photoacoustic imaging, fluorescence imaging, and magnetic resonance imaging (MRI) [43–46]. These biosensors enhance sensitivity and specificity in cancer imaging, aiding in tumor localization, staging, and monitoring [47,48]. It's important to note that while CNT/GO-based biosensors hold promise for cancer diagnosis, further research and development are necessary to optimize their performance, validate their clinical utility, and ensure integration into routine clinical practice [49,50]. The field of biosensors is rapidly evolving, and recent advancements may have occurred since my knowledge cutoff. Therefore, referring to the latest scientific literature and research updates is recommended for the most recent progress in CNT/GO-based biosensors for cancer diagnosis.

3. Infectious disease diagnosis

Biosensors based on CNT/GO have shown great promise as tools for diagnosing infectious diseases. These biosensors allow for the quick and accurate identification of particular biomarkers linked to contagious agents using the unique qualities of graphene oxide (GO) and carbon nanotubes (CNTs). They can identify various biomarkers that indicate the presence of pathogens or host immune responses, such as proteins, nucleic acids, and other molecular targets [51,52]. **Figure 2** shows how infectious diseases are detected. The high sensitivity and selectivity of CNT/GO-based biosensors is one of their main benefits. They improved sensitivity results from the effective capture of biomarkers made possible by the high surface area-to-volume ratio of GO and CNTs [53–55]. Accurate diagnosis is also ensured by functionalizing CNTs and GO with particular recognition elements, like aptamers or antibodies, which allow for the selective detection of target biomarkers. Multiplexed detection is another significant characteristic of CNT/GO-based biosensors [56–58]. These systems enable the simultaneous detection of multiple infectious disease biomarkers by attaching multiple capture probes to the biosensor. This feature allows for thorough disease profiling and improves diagnostic efficiency and accuracy [59,60].

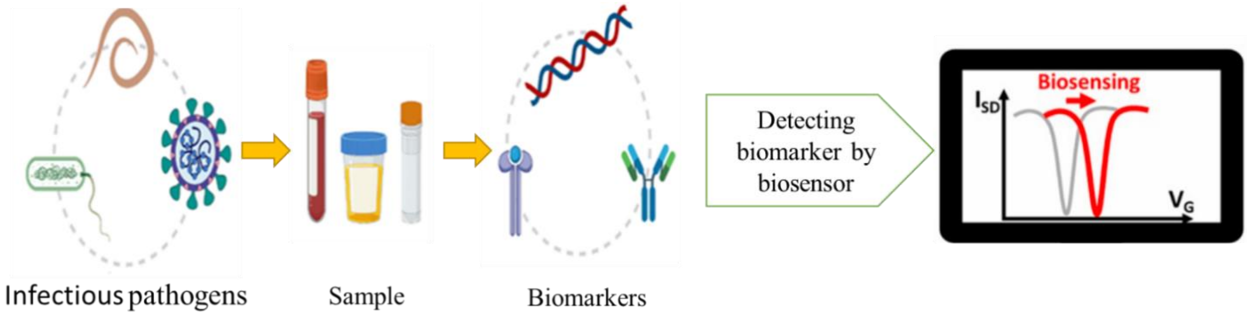

Figure 2. Infectious disease detection.

Ongoing research efforts in this field focus on enhancing the sensitivity, stability, and scalability of CNT/GO-based biosensors for infectious disease diagnosis. Additionally, there is a concerted effort to address challenges related to standardization, validation, and the integration of these biosensors into routine clinical practice.

4. Neurological disorder diagnosis

The use of CNT/GO-based biosensors in diagnosing neurological conditions, such as Parkinson's and Alzheimer's diseases, has shown encouraging results [61,62]. These biosensors can detect Specific biomarkers closely linked to the pathophysiology of these disorders, such as alpha-synuclein and amyloid-beta proteins. Amyloid-beta plaques and tau protein tangles are two characteristics of Alzheimer's disease found in the brain [63,64]. Amyloid-beta peptides or tau proteins in blood or cerebrospinal fluid can be detected by CNT/GO-based biosensors, allowing for the early diagnosis and tracking of Alzheimer's disease progression. Similarly, Lewy bodies, which are aggregates of alpha-synuclein proteins, are a hallmark of Parkinson's disease [65,66]. **Figure 3** shows a schematic diagram for detecting neurological diseases using a biosensor based on CNT/GO. One possible diagnostic tool for Parkinson's disease is biosensors based on carbon nanotubes and graphene oxide that detect alpha-synuclein in blood and cerebrospinal fluid. Initiating effective treatments, tracking disease progression, and enhancing patient outcomes depend on early and accurate diagnosis of neurological disorders [67–69]. The creation of biosensors based on carbon nanotubes and graphene oxide shows potential for the sensitive and selective detection of biomarkers linked to these diseases, which could lead to earlier diagnoses and more tailored treatments. Clinical translation of these biosensors for neurological disorder diagnosis will be advanced by ongoing research and validation studies [70–73].

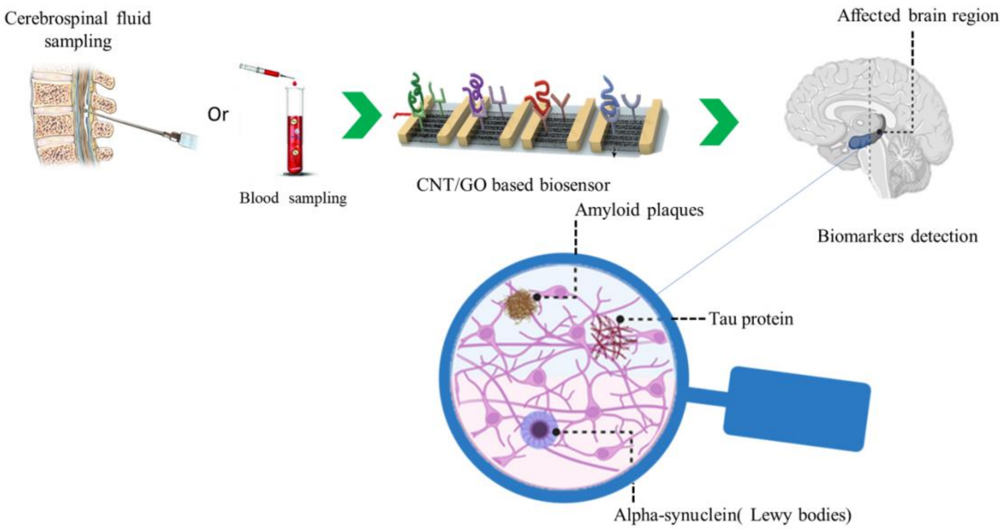

Figure 3. Schematic diagram of neurological disease detection using CNT/GO based biosensor.

5. Glucose monitoring in diabetes management

One exciting development in diabetes management is using biosensors based on carbon nanotubes and gonads (CNTs/GO). These biosensors provide an alternative to the invasive and time-consuming finger-prick test for monitoring glucose levels. They reduce patient pain and infection risk by detecting glucose in non-invasive bodily fluids such as saliva, sweat, or tears rather than blood [74–76]. Thanks to their distinct electrical characteristics, CNTs and GO make it possible to track glucose levels in real-time. Changes in electrical conductivity or other sensing mechanisms provide quick feedback on glucose fluctuations, enabling patients to make timely adjustments to their diabetes management. Wearable devices like smartwatches, patches, or contact lenses can incorporate these biosensors, allowing for more accessible and convenient continuous glucose monitoring [77,78]. Patients can benefit greatly by having their glucose profiles monitored continuously throughout the day. Glucose detection using CNT/GO-based biosensors is exact and sensitive—**Figure 4** displays glucose monitoring for diabetes management. Accurate readings are guaranteed by functionalizing the biosensor surface with molecules or enzymes specific to glucose, increasing sensitivity and selectivity [79,80]. Patients can then better manage their diabetes as a whole because they can control their blood glucose levels through dietary, exercise, and medication choices [81]. However, there are still challenges to address in the field. Researchers are actively working on improving sensor stability, calibration, and long-term performance to enhance the reliability, accuracy, and durability of CNT/GO-based biosensors [82,83].

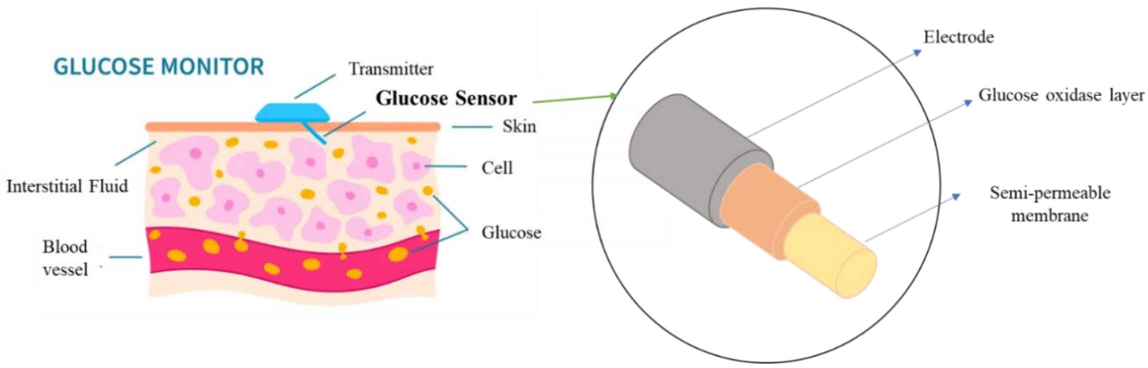

Figure 4. Glucose monitoring in diabetes management.

Standardization and regulatory approval are also vital for the widespread adoption of these biosensors in clinical practice. Despite these challenges, CNT/GO-based biosensors hold significant potential to transform diabetes management by providing non-invasive, real-time glucose monitoring [84,85]. Continued research and development efforts aim to overcome the current limitations and pave the way for their integration into routine clinical care.

6. Cardiovascular diseases detection

The promising diagnosis of cardiovascular disease is CNT/GO-based biosensors. In this discipline, biosensors have many advantages. Accurately identifying cardiovascular disease biomarkers, including cardiac troponins, CRP, and BNP, which expose heart muscle damage, inflammation, and heart failure [86–88], they expose to diagnosis and track cardiovascular disease, CNT/GO-based biosensors measure biomarkers in blood or other non-invasive samples. **Figure 5** shows cardiovascular disease detection methods. High sensitivity and selectivity are CNT/GO biosensor strengths [89,90]. They can detect low cardiovascular biomarker concentrations in complex biological matrices, enabling early cardiac event detection and precise disease progression monitoring. Early intervention and treatment may improve patient outcomes. The detection and monitoring of cardiovascular disease using CNT/GO-based biosensors from blood or saliva samples is easy and patient-friendly. Eliminating invasive treatments helps biosensors lower patient discomfort and improve monitoring [91–94]. Real-time tracking of CNT/GO-based biosensors would help management of cardiovascular diseases. Their dynamic character and rapid biomarker feedback help to enable quick medical interventions and treatment plan modifications related to cardiovascular diseases.

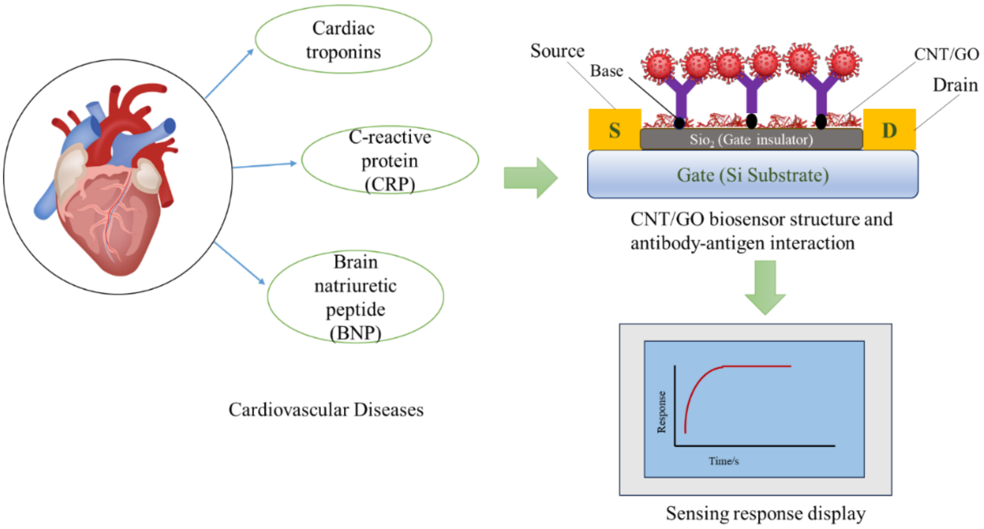

Figure 5. Detection technique of various cardiovascular disease.

Moreover, the use of CNT/GO-based biosensors aligns with the principles of personalized medicine. By providing real-time monitoring and precise quantification of cardiovascular biomarkers, these biosensors facilitate tailored treatment plans and patient-specific interventions, optimizing patient outcomes. While ongoing research and development are still needed, CNT/GO-based biosensors hold great promise for the detection and monitoring of cardiovascular diseases. Continued collaboration among researchers, clinicians, and industry partners is essential to further refine the technology, establish robust validation protocols, and ensure the successful integration of these biosensors into routine clinical practice [95].

7. Challenges and future directions

In the field of CNT/GO-based biosensors, there are several challenges that need to be addressed for their widespread adoption, standardization, scalability, and commercialization. These challenges include:

7.1. Standardization of fabrication processes

One of the key challenges is the standardization of fabrication processes for CNT/GO-based biosensors. Variations in synthesis methods, functionalization techniques, and sensor assembly can lead to inconsistent performance and hinder reproducibility. Establishing standardized protocols and quality control measures is crucial to ensure consistent and reliable biosensor performance across different laboratories and manufacturing facilities.

7.2. Sensor stability and longevity

The stability and longevity of CNT/GO-based biosensors are important factors for their practical implementation. The performance of these biosensors should be maintained over extended periods, ensuring reliable and accurate detection of cardiovascular biomarkers. Addressing issues related to sensor degradation, biofouling, and long-term stability will be crucial for their successful commercialization.

7.3. Scalability and manufacturing processes

For wide-scale adoption, CNT/GO-based biosensors need to be manufactured in large quantities using scalable and cost-effective processes. It is important to develop manufacturing techniques that can produce biosensors with consistent quality, while also ensuring affordability and accessibility for healthcare settings.

7.4. Integration with point-of-care devices

The integration of CNT/GO-based biosensors with portable and user-friendly point-of-care devices is a significant challenge. These biosensors need to be compatible with miniaturized and low-power electronics, enabling their integration into handheld or wearable devices. This integration would facilitate on-site testing, remote monitoring, and real-time data analysis, thereby enhancing their clinical utility. Point-of-care (POC) cancer detection technologies include i-STAT for Prostate-specific antigen assessment, Lateral Flow Assays for visual biomarker detection, and wearable microneedle biosensors for noninvasive monitoring.

7.5. Regulatory and commercialization aspects

The regulatory landscape and commercialization pathways for CNT/GO-based biosensors need to be addressed. Meeting regulatory requirements, obtaining necessary certifications, and navigating the complex commercialization process are critical steps for bringing these biosensors to the market and making them available for widespread clinical use.

7.6. Additional challenges

Robust clinical validation studies are essential to demonstrate the efficacy, accuracy, and clinical relevance of CNT/GO-based biosensors for cardiovascular disease detection and monitoring. Collaboration between researchers, clinicians, and industry partners is crucial for conducting large-scale clinical trials, validating the biosensor performance, and refining the technology based on feedback from end-users.

Future directions in the field of CNT/GO-based biosensors should focus on addressing these challenges. Collaborative efforts among researchers, regulatory agencies, and industry partners are necessary to establish standardized protocols, optimize manufacturing processes, ensure sensor stability, and navigate the regulatory and commercialization landscape. By overcoming these challenges, CNT/GO-based biosensors can become valuable tools for cardiovascular disease diagnosis and management in clinical settings.

8. Conclusion

In conclusion, CNT/GO-based biosensors have shown significant potential in various areas of medical diagnosis, including cancer, infectious diseases, neurological disorders, diabetes management, and cardiovascular diseases. These biosensors offer advantages such as high sensitivity, selectivity, multiplexed detection, and real-time monitoring. They can detect specific biomarkers associated with different diseases, enabling early diagnosis, treatment monitoring, and personalized medicine approaches. The non-invasive sampling methods and compatibility with portable devices make them suitable for point-of-care testing and resource-limited settings. However, further research and development are necessary to optimize their performance, validate their clinical utility, and integrate them into routine clinical practice. The field of biosensors is rapidly evolving, and staying updated with the latest scientific literature and research advancements is crucial for the most recent progress in CNT/GO-based biosensors for medical diagnosis.

Conflict of interest: The authors declare no conflict of interest.

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