OPEN ACCESS
©NIJRMS ONLINE ISSN: 2992-5460
Publications 2025 PRINT ISSN: 2992-6041

NEWPORT INTERNATIONAL JOURNAL OF RESEARCH IN MEDICAL SCIENCES (NIJRMS)

Volume 7 Issue 1 Page 48-52, 2026

https://doi.org/10.59298/NIJRMS/2026/7.1.4852

Nanosensors for Early Detection of Obesity-Related Metabolic Disorders

Nyiramana Mukamurera P.

Faculty of Medicine Kampala International University Uganda

ABSTRACT

Obesity is strongly linked to metabolic disorders such as type 2 diabetes, dyslipidemia, cardiovascular disease, and non-alcoholic fatty liver disease. Early detection of these complications is crucial for timely intervention, yet current diagnostic methods often lack sensitivity, specificity, or the ability to provide real-time monitoring. Nanosensors, designed at the nanometer scale with unique optical, electrochemical, and mechanical properties, offer unprecedented opportunities for detecting biomarkers of metabolic dysfunction with high precision. These devices can identify glucose, lipids, inflammatory cytokines, and oxidative stress markers at very low concentrations, enabling early diagnosis before clinical symptoms appear. This review highlights the principles of nanosensor technology, recent advances in obesity-related biomarker detection, translational challenges, clinical applications, and future directions. The integration of nanosensors with wearable devices and digital health platforms promises a transformative shift toward personalized and preventive obesity care.

Keywords: Nanosensors, Obesity, Metabolic disorders, Early detection, Biomarkers

INTRODUCTION

Obesity has emerged as one of the greatest public health threats of the 21st century, with prevalence continuing to rise in both developed and developing nations[1–3]. It is not only a condition of excessive fat accumulation but also a major driver of metabolic dysfunction. The close association between obesity and metabolic disorders such as type 2 diabetes mellitus, dyslipidemia, cardiovascular disease, and non-alcoholic fatty liver disease underscores the need for early diagnostic and monitoring tools[4–6]. Detecting metabolic changes in their initial stages is critical because interventions at this point are more likely to be successful in preventing disease progression.

Current diagnostic approaches, including blood glucose testing, lipid profiling, and imaging techniques, are valuable but come with limitations. They often require invasive procedures, specialized laboratory equipment, and trained personnel. More importantly, they may not detect subtle molecular changes that precede overt disease manifestations[7]. For example, by the time fasting blood glucose or HbA1c levels indicate diabetes, pancreatic β-cell function has already been significantly compromised. Similarly, conventional lipid testing may not fully capture early atherogenic changes. These limitations have driven the search for more sensitive and accessible tools that can provide earlier and more precise detection of obesity-related metabolic disorders[8].

Nanosensors, which are devices capable of detecting specific molecules or physical changes at the nanometer scale, are rapidly emerging as powerful diagnostic platforms[9–11]. Their unique advantage lies in their high surface-to-volume ratio, tunable chemical properties, and capacity for functionalization with biomolecules such as antibodies, aptamers, or enzymes. This enables them to detect biomarkers at extremely low concentrations, often down to the femtomolar range, which is far below the detection limit of many conventional methods.

The principles of nanosensors encompass various mechanisms, including optical, electrochemical, piezoelectric, and magnetic detection. For instance, plasmonic nanosensors exploit localized surface plasmon resonance to detect changes in refractive index upon biomarker binding. Electrochemical nanosensors measure variations in electrical current or potential resulting from biochemical interactions on the sensor surface. These technologies allow for real-time and label-free detection, which is highly advantageous in clinical settings[12, 13].

In the context of obesity-related metabolic disorders, nanosensors have been designed to detect glucose, insulin, free fatty acids, triglycerides, inflammatory cytokines such as TNF-α and IL-6, and oxidative stress markers. The ability to monitor these biomarkers continuously or at point-of-care can revolutionize patient management by enabling earlier diagnosis, personalized treatment, and timely lifestyle adjustments[14–16]. For example, wearable nanosensors integrated into patches or contact lenses can monitor glucose levels non-invasively, reducing the need for finger-prick blood tests. Similar technologies are being developed for lipid monitoring and detection of inflammatory states associated with obesity.

The integration of nanosensors with digital health platforms further enhances their potential. By coupling nanosensor data with smartphones or cloud-based systems, continuous monitoring becomes possible, allowing patients and clinicians to track metabolic health in real-time. This approach aligns with the growing emphasis on preventive medicine and personalized healthcare[17].

However, despite remarkable progress, several challenges remain. The biocompatibility and stability of nanosensors, potential interference from complex biological fluids, reproducibility of results, and high manufacturing costs limit their widespread adoption. Moreover, regulatory frameworks for nanosensor-based diagnostics are still evolving, requiring robust validation and standardization before clinical translation[18].

This review aims to explore nanosensors as tools for early detection of obesity-related metabolic disorders. Section 2 provides an overview of nanosensor principles and mechanisms. Section 3 highlights advances in detecting obesity-related biomarkers. Section 4 discusses translational challenges. Section 5 examines clinical perspectives and real-world applications. Section 6 outlines future directions, including wearable technologies and integration with personalized medicine.

2. Principles of Nanosensors

Nanosensors operate by transducing a biochemical or physical event into a measurable signal. Their high sensitivity arises from the nanoscale dimensions of the sensing element, which provide a large surface area for biomolecule interaction. Several types of nanosensors are particularly relevant for detecting obesity-related biomarkers[19].

Optical nanosensors rely on changes in light properties when analytes interact with nanostructures. Plasmonic nanosensors, using gold or silver nanoparticles, exploit surface plasmon resonance to detect biomolecules such as glucose or insulin. Fluorescent nanosensors use quantum dots or carbon nanodots that emit light upon binding with specific molecules, enabling sensitive detection even at very low concentrations[20].

Electrochemical nanosensors are widely studied for metabolic applications. They use electrodes modified with nanomaterials such as graphene, carbon nanotubes, or metal oxides to measure changes in current, potential, or impedance resulting from biochemical interactions. These nanosensors have been used extensively for glucose detection and are increasingly applied to lipid and cytokine monitoring[20].

Piezoelectric nanosensors detect changes in mass or mechanical properties when analytes bind to a sensor surface. This principle allows label-free detection of macromolecules such as lipoproteins or inflammatory proteins. Magnetic nanosensors, using magnetic nanoparticles, measure changes in magnetic properties upon analyte binding and are useful for multiplexed detection[21].

The ability to functionalize nanosensors with biomolecules enhances specificity. Antibodies, aptamers, or enzymes can be attached to the sensor surface to ensure selective binding to target biomarkers. Stimuli-responsive nanosensors can even adapt to environmental conditions such as pH or temperature, improving their reliability in complex biological fluids[21].

These principles collectively form the foundation for nanosensor applications in detecting obesity-related metabolic disorders.

3. Advances in Detecting Obesity-Related Biomarkers

Significant progress has been made in developing nanosensors for biomarkers linked to obesity. Glucose nanosensors remain the most advanced, with electrochemical and optical platforms capable of continuous monitoring. Wearable devices such as patches and smart contact lenses demonstrate how nanosensors can replace invasive glucose testing, offering real-time and non-invasive measurements[22].

For lipid monitoring, nanosensors capable of detecting triglycerides, free fatty acids, and cholesterol at low concentrations are under development. Graphene-based nanosensors, for instance, provide rapid and highly sensitive detection of lipoproteins, which are crucial indicators of cardiovascular risk in obese individuals[23].

Inflammation is another hallmark of obesity-related metabolic disorders. Nanosensors functionalized with antibodies or aptamers have been used to detect pro-inflammatory cytokines like TNF-α and IL-6. These sensors can identify inflammation long before it manifests clinically, offering opportunities for early intervention. Similarly, nanosensors targeting oxidative stress markers such as reactive oxygen species (ROS) provide insights into cellular dysfunction associated with obesity[24].

Nucleic acid-based nanosensors are emerging for detecting obesity-related genetic markers, including circulating miRNAs that regulate lipid metabolism. These platforms could serve as early predictors of metabolic complications, enabling preventive strategies.

Collectively, these advances demonstrate the potential of nanosensors to provide comprehensive metabolic profiling in obese individuals, moving beyond single biomarker detection toward multiplexed, real-time monitoring[25, 26].

4. Translational Challenges

Despite advances, translating nanosensor technology into clinical practice faces significant challenges. One major issue is biocompatibility. Sensors must function reliably in complex biological fluids such as blood, saliva, or interstitial fluid without being degraded or producing false signals due to nonspecific interactions. Long-term stability and durability are also concerns, particularly for wearable or implantable devices[27].

Manufacturing poses another challenge. Producing nanosensors with consistent quality, sensitivity, and reproducibility at scale is technically demanding. Variations in nanomaterial synthesis or functionalization can significantly impact performance. Additionally, the cost of large-scale production may limit accessibility, especially in resource-limited settings where obesity prevalence is high[28].

Regulatory hurdles are substantial. Nanosensors must undergo rigorous validation to demonstrate accuracy, reliability, and safety before approval for clinical use. The lack of standardized protocols for evaluating nanodiagnostics further complicates the regulatory landscape. Ethical concerns regarding data privacy also arise, particularly when nanosensors are integrated with digital health platforms[29].

Addressing these translational challenges requires advances in nanomaterial engineering, development of standardized testing protocols, cost reduction strategies, and robust regulatory frameworks.

5. Clinical Perspectives

In clinical practice, nanosensors have the potential to revolutionize the early detection and monitoring of obesity-related metabolic disorders. Continuous glucose monitoring (CGM) devices already represent the first wave of nanosensor integration into healthcare. These technologies have improved glycemic control in diabetic patients and demonstrate how nanosensors can provide real-time metabolic information[30].

Emerging nanosensors for lipid and cytokine detection are poised to complement glucose monitoring by providing broader metabolic profiling. This holistic approach could allow clinicians to detect the earliest signs of metabolic syndrome in obese individuals, guiding preventive interventions. [31] For example, a nanosensor patch capable of simultaneously monitoring glucose, triglycerides, and inflammatory cytokines could provide unparalleled insight into metabolic health.

Integration with wearable devices and smartphones makes nanosensors practical for routine use. Patients can receive continuous feedback on their metabolic status, while clinicians can access longitudinal data for personalized treatment planning. This aligns with precision medicine initiatives that aim to tailor therapy based on individual metabolic profiles.

Nonetheless, clinical translation must address concerns regarding patient acceptance, device accuracy, and cost-effectiveness. Ensuring that nanosensors provide reliable data over extended periods is essential for their adoption in healthcare systems.

6. Future Directions

The future of nanosensors in obesity management lies in their integration with digital health, artificial intelligence, and personalized medicine. AI-driven analysis of nanosensor data can identify subtle trends and predict disease onset before symptoms occur. This predictive capability could transform obesity care from reactive treatment to proactive prevention.

Wearable and implantable nanosensors will become increasingly important. Advances in flexible electronics and biocompatible nanomaterials will allow seamless integration into patches, textiles, or even ingestible devices. Multiplexed nanosensors capable of monitoring multiple biomarkers simultaneously will provide comprehensive insights into metabolic health.

Another promising direction is the development of minimally invasive or non-invasive nanosensors, such as those that analyze sweat, saliva, or breath. These devices could replace invasive blood sampling, improving patient comfort and compliance. Nanosensors for gut microbiome metabolites are also being explored, recognizing the role of microbiota in obesity.

Collaboration across nanotechnology, medicine, data science, and regulatory policy will be essential to realize these advances. If successfully implemented, nanosensors could become central to obesity management, enabling early detection, personalized intervention, and reduced healthcare burden.

CONCLUSION

Nanosensors represent a transformative approach for the early detection of obesity-related metabolic disorders. By providing highly sensitive, real-time, and potentially non-invasive detection of glucose, lipids, cytokines, oxidative stress markers, and nucleic acids, nanosensors can identify metabolic dysfunction before clinical symptoms emerge. While challenges in biocompatibility, manufacturing, and regulation remain, advances in wearable technologies and digital health integration suggest a future where nanosensors play a central role in preventive and personalized obesity care.

ONLINE ISSN: 2992-5460
PRINT ISSN: 2992-6041

REFERENCES

1. Ahmed, S.K., Mohammed, R.A.: Obesity: Prevalence, causes, consequences, management, preventive strategies and future research directions. Metab. Open. 27, 100375 (2025). https://doi.org/10.1016/j.metop.2025.100375
2. Alanazi, A., Craven, A., Spirou, S.V., Santos-Martinez, M.J., Medina, C., Gobbo, O.L.: Nanomedicine as a Promising Treatment Approach for Obesity. J. Nanotheranostics. 6, 21 (2025). https://doi.org/10.3390/jnt6030021
3. Ejemot-Nwadiaro, R.I., Betiang, P.A., Basajja, M., Uti, D.E.: Obesity and Climate Change: A Two-way Street with Global Health Implications. Obes. Med. 56, 100623 (2025). https://doi.org/10.1016/j.obmed.2025.100623
4. Ahmed, B., Konje, J.C.: The epidemiology of obesity in reproduction. Best Pract. Res. Clin. Obstet. Gynaecol. 89, 102342 (2023). https://doi.org/10.1016/j.bpobgyn.2023.102342
5. Izah, S.C., Betiang, P.A., Paul-Chima Ugwu, O., Ainebyoona, C., Uti, D.E., Echegu, D.A., Alum, B.N.: The Ketogenic Diet in Obesity Management: Friend or Foe? Cell Biochem. Biophys. (2025). https://doi.org/10.1007/s12013-025-01878-0
6. Méndez-Sánchez, N., Brouwer, W.P., Lammert, F., Yilmaz, Y.: Metabolic dysfunction associated fatty liver disease in healthy weight individuals. Hepatol. Int. 18, 884–896 (2024). https://doi.org/10.1007/s12072-024-10662-w
7. Villena Gonzales, W., Mobashsher, A.T., Abbosh, A.: The Progress of Glucose Monitoring—A Review of Invasive to Minimally and Non-Invasive Techniques, Devices and Sensors. Sensors. 19, 800 (2019). https://doi.org/10.3390/s19040800
8. Duan, Y., Liu, J., Xu, Y., Yang, N., Yang, W., Wang, G.: Factors That Influence Pancreatic Beta Cell Function and Insulin Resistance in Newly Diagnosed Type 2 Diabetes Patients: A Sub-Analysis of the MARCH Trial. Diabetes Ther. 9, 743–752 (2018). https://doi.org/10.1007/s13300-018-0393-5
9. Ghorbian, M., Ghobaei-Arani, M., Babaei, M.R., Ghorbian, S.: Nanotechnology and nanosensors in personalized healthcare: A comprehensive review. Sens. Bio-Sens. Res. 47, 100740 (2025). https://doi.org/10.1016/j.sbsr.2025.100740
10. Jin, C., Wu, Z., Molinski, J.H., Zhou, J., Ren, Y., Zhang, J.X.J.: Plasmonic nanosensors for point-of-care biomarker detection. Mater. Today Bio. 14, 100263 (2022). https://doi.org/10.1016/j.mtbio.2022.100263
11. Khazaei, M., Hosseini, M.S., Haghighi, A.M., Misaghi, M.: Nanosensors and their applications in early diagnosis of cancer. Sens. Bio-Sens. Res. 41, 100569 (2023). https://doi.org/10.1016/j.sbsr.2023.100569
12. Nocerino, V., Miranda, B., Tramontano, C., Chianese, G., Dardano, P., Rea, I., De Stefano, L.: Plasmonic Nanosensors: Design, Fabrication, and Applications in Biomedicine. Chemosensors. 10, 150 (2022). https://doi.org/10.3390/chemosensors10050150
13. Rheima, A.M., Al-Sharify, Z.T., Mohaimeed, A.A., Kazem, M.A.A.-H., Dhabab, J.M., Athair, D.M., Joseph, T.M., Mahapatra, D.K., Thomas, S., Kianfar, E.: RETRACTED: Nano biosensors: Classification, electrochemistry, nanostructures, and optical properties. Results Eng. 24, 103428 (2024). https://doi.org/10.1016/j.rineng.2024.103428
14. Mukherjee, S., Im, S.-S.: Decoding Health: Exploring Essential Biomarkers Linked to Metabolic Dysfunction-Associated Steatohepatitis and Type 2 Diabetes Mellitus. Biomedicines. 13, 359 (2025). https://doi.org/10.3390/biomedicines13020359
15. Patil, B.S., Patil, J.K., Chaudhari, H.S., Patil, B.S.: Oxidative Stress, Inflammation, and Obesity: Insights into Mechanism and Therapeutic Targets. Proceedings. 119, 6 (2025). https://doi.org/10.3390/proceedings2025119006
16. Obasi, D.C., Abba, J.N., Aniokete, U.C., Okoroh, P.N., Akwari, A.Ak.: Evolving Paradigms in Nutrition Therapy for Diabetes: From Carbohydrate Counting to Precision Diets. Obes. Med. 100622 (2025). https://doi.org/10.1016/j.obmed.2025.100622
17. Sedighi, A., Kou, T., Huang, H., Li, Y.: Noninvasive On-Skin Biosensors for Monitoring Diabetes Mellitus. Nano-Micro Lett. 18, 16 (2025). https://doi.org/10.1007/s40820-025-01843-9
18. Awlqadr, F.H., Altemimi, A.B., Qadir, S.A., Hama Salih, T.A., Alkanan, Z.T., AlKaisy, Q.H., Mohammed, O.A., Hesarinejad, M.A.: Emerging trends in nano-sensors: A new frontier in food safety and quality assurance. Heliyon. 11, e41181 (2025). https://doi.org/10.1016/j.heliyon.2024.e41181
19. Darwish, M.A., Abd-Elaziem, W., Elsheikh, A., Zayed, A.A.: Advancements in nanomaterials for nanosensors: a comprehensive review. Nanoscale Adv. 6, 4015–4046. https://doi.org/10.1039/d4na00214h
20. Gulati, S., Yadav, R., Kumari, V., Nair, S., Gupta, C., Aishwari, M.: Nanosensors in healthcare: transforming real-time monitoring and disease management with cutting-edge nanotechnology. RSC Pharm. 2, 1003–1018 (2025). https://doi.org/10.1039/D5PM00125K
21. Martinez-Banderas, A.I., Malki, A., Froehlich, T., Petrich, W.: High-performance nanobiosensing technologies for future diagnostic needs. Trends Biotechnol. (2025). https://doi.org/10.1016/j.tibtech.2025.05.014

22. Wang, M., Zheng, J., Zhang, G., Lu, S., Zhou, J.: Wearable Electrochemical Glucose Sensors for Fluid Monitoring: Advances and Challenges in Non-Invasive and Minimally Invasive Technologies. Biosensors. 15, 309 (2025). https://doi.org/10.3390/bios15050309
23. Młynarska, E., Bojdo, K., Frankenstein, H., Kustosik, N., Mstowska, W., Przybylak, A., Rysz, J., Franczyk, B.: Nanotechnology and Artificial Intelligence in Dyslipidemia Management—Cardiovascular Disease: Advances, Challenges, and Future Perspectives. J. Clin. Med. 14, 887 (2025). https://doi.org/10.3390/jcm14030887
24. Ryan, A.K., Rahman, S., Williams, R.M.: An optical aptamer-based cytokine nanosensor detects macrophage activation by bacterial toxins. bioRxiv. 2024.04.05.588290 (2024). https://doi.org/10.1101/2024.04.05.588290
25. Kargün, K., Aygen, E., Ebiloğlu, M.F., Alayunt, N.Ö., Dalkılıç, L.K.: Evaluation of miRNA Profile and Its Relationship with Metabolic Disorders in Obese and Pre-Obese Patients. Curr. Issues Mol. Biol. 47, 280 (2025). https://doi.org/10.3390/cimb47040280
26. Assmann, T.S., Riezu-Boj, J.I., Milagro, F.I., Martínez, J.A.: Circulating adiposity-related microRNAs as predictors of the response to a low-fat diet in subjects with obesity. J. Cell. Mol. Med. 24, 2956–2967 (2020). https://doi.org/10.1111/jcmm.14920
27. Kudłacik-Kramarczyk, S., Kieres, W., Przybyłowicz, A., Ziejewska, C., Marczyk, J., Krzan, M.: Recent Advances in Micro- and Nano-Enhanced Intravascular Biosensors for Real-Time Monitoring, Early Disease Diagnosis, and Drug Therapy Monitoring. Sensors. 25, 4855 (2025). https://doi.org/10.3390/s25154855
28. Lenar, N., Paczosa-Bator, B.: Nanosensors and Microsensors for Body Fluid Monitoring: Various Analyte Detection and Construction Solutions. Int. J. Mol. Sci. 26, 5001 (2025). https://doi.org/10.3390/ijms26115001
29. 4dm1n_diversatechnologies: Overcoming regulatory hurdles in clinical translation of nanomedicine, https://www.diversatechnologies.com/overcoming-regulatory-hurdles-in-clinical-translation-of-nanomedicine/, (2025)
30. Kaushal, A., Musafir, A., Sharma, G., Rani, S., Singh, R.K., Kumar, A., Bhadada, S.K., Barnwal, R.P., Singh, G.: Revolutionizing Diabetes Management Through Nanotechnology-Driven Smart Systems. Pharmaceutics. 17, 777 (2025). https://doi.org/10.3390/pharmaceutics17060777
31. Lenar, N., Paczosa-Bator, B.: Nanosensors and Microsensors for Body Fluid Monitoring: Various Analyte Detection and Construction Solutions. Int. J. Mol. Sci. 26, 5001 (2025). https://doi.org/10.3390/ijms26115001

CITE AS: Nyiramana Mukamurera P. (2026). Nanosensors for Early Detection of Obesity-Related Metabolic Disorders. NEWPORT INTERNATIONAL JOURNAL OF RESEARCH IN MEDICAL SCIENCES. https://doi.org/10.59298/NIJRMS/2026/7.1.4852