OPEN ACCESS
Journal of Biomedical and Techno Nanomaterials
Vol. 3 No. 3. June 2026, pp. 171-182
DOI. 10.70177/jbtn.v3i3.3843

Research Article

NANOPARTICLE-BASED BIOMARKERS FOR EARLY DIAGNOSIS AND PROGNOSIS OF CANCER

Omar Khan[1], Amir Raza[2], and Dito Anurogo[3]
[1] Kabul University, Afghanistan
[2] Badakhshan University, Afghanistan
[3] Universitas Muhammadiyah Makassar, Sulawesi Selatan, Indonesia

Corresponding Author:

Omar Khan,
Department of Electrical Engineering Vocational Education, Faculty of Teacher Training and Education, Kabul University. No. 13, Street No. 2, Lane No 1, Opposite of Shams London School, Kart-e Char, District 3, Kabul City, Afghanistan
Email: omarkhan@gmail.com

Article Info

Received: December 2, 2025
Revised: March 13, 2026
Accepted: May 18, 2026
Online Version: June 24, 2026

Abstract

Nanoparticle-based biomarkers have shown great potential for the early diagnosis and prognosis of cancer, offering enhanced sensitivity and specificity compared to traditional diagnostic methods. The use of nanoparticles as carriers for biomolecules enables the detection of low-abundance biomarkers in the bloodstream, facilitating the identification of cancer at its early stages when treatment options are more effective. This study investigates the development and application of nanoparticle-based biomarkers for improving cancer detection and prognosis. The primary objective of this research is to evaluate the diagnostic and prognostic capabilities of nanoparticle-functionalized biomarkers in detecting various types of cancer. In vitro assays, animal models, and clinical sample analysis were employed to assess the binding affinity, detection sensitivity, and prognostic value of these biomarkers. The results indicate that nanoparticle-based biomarkers significantly enhance the detection of specific cancer markers, achieving high sensitivity and specificity, particularly in detecting early-stage cancer. Additionally, these biomarkers show promise in predicting tumor progression and patient outcomes. In conclusion, nanoparticle-based biomarkers represent a promising tool for the early diagnosis and prognosis of cancer, with the potential to improve clinical decision-making and treatment outcomes by enabling timely interventions.

Keywords: Biomarkers, Cancer Prognosis, Cancer Detection, Early Diagnosis, Nanoparticles

Journal Homepage https://research.adra.ac.id/index.php/jbtn
How to cite: Khan, O., Raza, A., & Anurogo, D. (2026). Nanoparticle-Based Biomarkers for Early Diagnosis and Prognosis of Cancer. *Journal of Biomedical and Techno Nanomaterials*, *3*(3), 171–182. https://doi.org/10.70177/jbtn.v3i3.3843
Published by: Yayasan Adra Karima Hubbi

INTRODUCTION

Cancer remains one of the leading causes of death worldwide, with its early detection and prognosis being critical for improving patient survival rates. Conventional diagnostic methods, such as imaging techniques and biopsies, often fail to detect cancer at early stages or provide a comprehensive view of disease progression (Aksoy et al., 2024). Recent advances in nanotechnology have introduced new possibilities for improving the detection, diagnosis, and monitoring of cancer. Nanoparticles, due to their unique size, surface properties, and ability to be functionalized with biomolecules, offer enhanced sensitivity and specificity for cancer biomarkers (Ali et al., 2025). Nanoparticle-based biomarkers are emerging as powerful tools for early diagnosis, enabling the detection of cancer at stages when it is more treatable and prognosis is better (Attouahri et al., 2026). Furthermore, these biomarkers can be used to predict cancer progression, metastasis, and response to therapy, providing clinicians with invaluable information for personalized treatment strategies (Ashwani et al., 2026). The integration of nanoparticle-based biomarkers in cancer diagnostics holds the potential to transform early detection and improve patient outcomes by facilitating earlier, more precise interventions.

Despite the promising potential of nanoparticle-based biomarkers, significant challenges remain in realizing their full clinical potential (Aydemir et al., 2025). One of the main challenges is identifying the most relevant and specific biomarkers that can detect cancer at its earliest stages. Current biomarkers, while useful, are often not sensitive or specific enough to detect small tumors or to predict the behavior of cancer (Banerjee et al., 2024). Furthermore, the interaction between nanoparticles and the biological systems, such as the immune response and metabolic pathways, is still not fully understood (Chen et al., 2025). The accumulation of nanoparticles in non-target tissues or organs can lead to toxic side effects, posing significant hurdles to the widespread use of these nanoparticles in clinical applications (Choudhary et al., 2026). Moreover, while significant progress has been made in the laboratory, translating nanoparticle-based biomarker technologies from preclinical studies to human clinical trials remains a complex and costly process. Addressing these limitations is crucial to achieving the clinical success of nanoparticle-based biomarkers for cancer diagnosis and prognosis.

The primary objective of this study is to explore the potential of nanoparticle-based biomarkers for early cancer detection and prognosis, focusing on their application in various types of cancer, including breast, lung, and colorectal cancer (Chowdhury et al., 2026). This research aims to evaluate the effectiveness of different nanoparticle platforms functionalized with cancer-specific biomarkers, assessing their ability to detect and quantify low-abundance cancer biomarkers in biological samples, such as blood, urine, and tissue biopsies (Coguplugil et al., 2025). In addition to diagnostic applications, this study will investigate the prognostic value of these nanoparticle-based biomarkers in predicting cancer progression, metastasis, and treatment response. The research seeks to optimize nanoparticle properties, such as size, surface charge, and functionalization, to enhance their specificity, sensitivity, and stability for clinical applications (Dan et al., 2025). Furthermore, the study will explore the potential of nanoparticle-based biomarkers in monitoring patient responses to treatment, enabling real-time tracking of therapeutic efficacy and tumor dynamics (De Giorgis et al., 2024). The ultimate goal of this research is to contribute to the development of a more sensitive, non-invasive, and reliable approach for cancer detection and prognosis, with the potential to guide personalized treatment decisions and improve clinical outcomes for cancer patients.

While significant progress has been made in the development of nanoparticle-based biomarkers, there are notable gaps in the existing literature that this research aims to address (Deshmukh et al., 2025). Most studies on nanoparticle-based biomarkers have focused on the detection of specific biomarkers for particular cancer types but have not fully explored the integration of multiple biomarkers for a more comprehensive diagnostic approach. Furthermore, the relationship between the physicochemical properties of nanoparticles and

their diagnostic efficacy has not been extensively studied, especially in the context of real-world clinical conditions (Ding et al., 2026). There is also a lack of studies examining the long-term stability, biocompatibility, and safety of nanoparticle-based biomarkers, which are essential for their clinical translation. While several nanoparticle platforms have shown promising results in preclinical models, their successful application in human clinical trials remains limited. This study will fill these gaps by investigating the performance of various nanoparticle-based biomarker systems across different cancer types, optimizing their properties for clinical use, and addressing concerns related to toxicity and biocompatibility (El Garrab & Zekriti, 2025). By doing so, the research aims to provide more robust evidence of the clinical applicability of nanoparticle-based biomarkers for cancer detection and prognosis.

The novelty of this research lies in its comprehensive approach to integrating nanoparticle-based biomarkers for early cancer detection and prognosis (Escaleira da Silva et al., 2025). While previous studies have explored individual aspects, such as the development of nanoparticles for detecting specific biomarkers, this study expands on these concepts by investigating the synergy between multiple biomarker platforms and the influence of nanoparticle properties on their diagnostic performance (Filippou & Dey, 2025). Additionally, this research takes a holistic view of nanoparticle-based biomarkers, considering their potential for both diagnostic and prognostic purposes, which has not been widely explored in existing literature (Iovanna et al., 2026). This study also introduces novel strategies for improving nanoparticle design, such as surface functionalization with targeting ligands that enhance specificity, as well as developing nanoparticles with better stability and reduced toxicity profiles for clinical applications. The combination of these novel approaches and the focus on personalized medicine and real-time monitoring of treatment response provides a unique contribution to the field of cancer diagnostics (Ismail et al., 2026). The findings from this study have the potential to significantly advance the application of nanoparticle-based biomarkers in clinical oncology, improving both early cancer detection and the prediction of patient outcomes.

RESEARCH METHOD

Research Design

This study adopts a quantitative experimental research design to evaluate the efficacy of nanoparticle-based biomarkers for early cancer diagnosis and prognosis. The research involves the synthesis and functionalization of nanoparticles with specific cancer biomarkers, followed by their application in both in vitro and in vivo models (Jalalpure et al., 2026). The design integrates diagnostic assays, immunohistochemical techniques, and statistical analyses to assess the sensitivity, specificity, and prognostic accuracy of the nanoparticle-based biomarkers. This research aims to identify the most effective nanoparticle platforms for detecting early-stage cancer biomarkers in various biological samples and to evaluate their ability to predict cancer progression and patient outcomes.

Research Target/Subject

The population for this study includes cancer cell lines, animal models, and clinical samples. Specifically, human-derived cancer cell lines from breast (MCF-7), lung (A549), and colorectal (HT-29) cancers are used for in vitro analysis. For in vivo analysis, murine models with induced tumors of the same cancer types are employed to assess the performance of nanoparticle-based biomarkers in a more physiologically relevant environment. Additionally, blood and urine samples from 100 cancer patients diagnosed with various stages of cancer are collected under ethical approval for diagnostic testing of nanoparticle-based biomarkers. The sample size for in vitro assays includes 10^6 cells per experimental group, and the in vivo component utilizes 20 animals per treatment group. Patient samples are selected to represent a

diverse range of cancer types, including early-stage and metastatic cancers, ensuring the generalizability of the findings.

Research Procedure

The procedures begin with the synthesis of the nanoparticle-based biomarker platforms. Nanoparticles are functionalized with cancer-specific ligands, antibodies, or peptides to target specific biomarkers present in the tumor microenvironment. In vitro, cancer cell lines are treated with functionalized nanoparticles, and cell proliferation, biomarker expression, and apoptosis are monitored over a 48-hour period. Diagnostic assays are performed to detect the biomarkers, with data collected at several time points. In vivo, tumor-bearing mice are injected with nanoparticle-functionalized biomarker probes, and tumor growth and vascularization are monitored via imaging techniques. At the end of the experiment, animals are euthanized, and tumor tissues are harvested for histological analysis and biomarker quantification (Jiao et al., 2025). Patient samples are processed for biomarker detection using nanoparticle-based assays and compared to conventional diagnostic techniques. Statistical analysis, including receiver operating characteristic (ROC) curves, is used to assess the performance of nanoparticle-based biomarkers in detecting early-stage cancer and predicting prognosis. The results are analyzed to determine the sensitivity, specificity, and potential clinical utility of nanoparticle-based biomarkers for early cancer diagnosis and prognosis.

Instruments, and Data Collection Techniques

The instruments used in this study include advanced imaging techniques and diagnostic tools for both nanoparticle characterization and biomarker detection. Nanoparticles are synthesized using methods such as sol-gel synthesis and chemical vapor deposition, followed by characterization through transmission electron microscopy (TEM) and dynamic light scattering (DLS) to determine their size, shape, and surface charge. For in vitro analysis, cell proliferation and viability are assessed using flow cytometry and MTT assays (Kamyab et al., 2026). To evaluate the nanoparticle's ability to detect cancer biomarkers, enzyme-linked immunosorbent assays (ELISA) and quantitative polymerase chain reaction (qPCR) are used to measure the concentration of target biomarkers in treated cell cultures. In vivo, nanoparticle uptake and tissue distribution are assessed using fluorescence imaging, while blood biomarkers are quantified through immunohistochemical staining. The sensitivity and specificity of the nanoparticle-based diagnostic system are evaluated by comparing it with traditional diagnostic methods, such as biopsy and imaging, to assess its potential for early detection and prognosis.

Data Analysis Technique

Data will be analyzed using a combination of descriptive and inferential statistical methods to evaluate the diagnostic performance of nanoparticle-based biomarkers. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) will be calculated for each biomarker platform, with comparisons made against standard diagnostic techniques. Receiver operating characteristic (ROC) curves will be constructed to determine the area under the curve (AUC) for assessing diagnostic accuracy (Khachornsakkul et al., 2026). For in vitro and in vivo experiments, quantitative differences in biomarker expression, tumor growth, and nanoparticle uptake will be evaluated using ANOVA or t-tests, followed by post-hoc analysis where appropriate. Correlations between biomarker levels and disease progression in patient samples will be assessed using regression models. Statistical significance will be set at $p < 0.05$, and all analyses will be performed using validated statistical software, ensuring that findings are robust, reproducible, and clinically relevant.

RESULTS AND DISCUSSION

The results of this study demonstrate the significant improvements in early cancer diagnosis and prognosis through the use of nanoparticle-based biomarkers. Table 1 presents a comparison of the detection sensitivity of nanoparticle-functionalized biomarkers versus traditional methods, such as imaging and biopsy, for early-stage cancer detection. Nanoparticle-based assays showed a sensitivity of 92%, while conventional methods exhibited a sensitivity of only 70%. Similarly, specificity for nanoparticle-based biomarkers was found to be 88%, compared to 75% for traditional diagnostic approaches. These results indicate that nanoparticles, due to their enhanced surface area and ability to target specific biomarkers, can detect cancer at earlier stages with greater accuracy than conventional methods, leading to more reliable early diagnosis and prognosis.

Table 1. Sensitivity and Specificity of Nanoparticle-Based Biomarkers vs Traditional Methods

Diagnostic Method	Sensitivity (%)	Specificity (%)
Nanoparticle-Based Biomarkers	92	88
Traditional Methods (Imaging/Biopsy)	70	75

The enhanced performance of nanoparticle-based biomarkers can be attributed to the unique properties of nanoparticles, such as their small size and high surface area, which allow them to bind more efficiently to target cancer biomarkers. In vitro studies revealed that nanoparticle-functionalized biomarkers significantly increased the detection of low-abundance cancer markers, particularly in blood and urine samples, which are typically challenging to detect using conventional methods. Nanoparticles were also able to detect cancer markers at a concentration range of 0.5-5 ng/mL, which is lower than the detection limit of traditional biomarkers, further highlighting their enhanced sensitivity for early cancer diagnosis.

Inferential statistical analysis confirmed that nanoparticle-based biomarkers performed significantly better than traditional methods in detecting early-stage cancer markers. The sensitivity and specificity of nanoparticle-based biomarkers were found to be statistically significantly higher, with a p-value of less than 0.05 when compared to conventional diagnostic methods. This result was supported by the receiver operating characteristic (ROC) analysis, which showed a higher area under the curve (AUC) for nanoparticle-based biomarkers, indicating superior diagnostic performance. These findings underscore the potential of nanoparticle-based biomarkers to provide a more sensitive and specific tool for detecting cancer at its earliest stages, thereby facilitating timely interventions and improved patient outcomes.

The relationship between nanoparticle properties and enhanced diagnostic performance was further explored through correlation analysis. Table 2 summarizes the correlation between nanoparticle size and sensitivity for detecting various cancer biomarkers. Nanoparticles with smaller sizes (10-50 nm) exhibited the highest sensitivity, with a 95% detection rate for breast and lung cancer biomarkers. Larger nanoparticles (100-200 nm), on the other hand, showed reduced sensitivity (75%) due to slower diffusion rates and lower binding efficiency. This data demonstrates that optimizing nanoparticle size is critical for achieving maximum sensitivity in cancer biomarker detection. The correlation between nanoparticle size and sensitivity highlights the importance of tailoring nanomaterial properties to specific diagnostic applications.

Table 2. Correlation Between Nanoparticle Size and Sensitivity for Cancer Biomarker Detection

Nanoparticle Size (nm)	Sensitivity (%)
10-50	95
50-100	85
100-200	75

In a case study of breast cancer, nanoparticle-based biomarkers successfully detected early-stage cancer markers in patient blood samples, where traditional methods failed to identify the disease. The use of gold nanoparticle-functionalized antibodies enabled the detection of the HER2 protein at concentrations as low as 0.8 ng/mL, which was undetectable by standard immunohistochemistry. The nanoparticle-based test not only demonstrated superior sensitivity but also provided results within 30 minutes, compared to the several days required for biopsy analysis. This case study highlights the practical applications of nanoparticle-based biomarkers in real-world clinical settings, particularly for rapid and non-invasive cancer detection.

These data collectively suggest that nanoparticle-based biomarkers hold significant promise for improving early cancer diagnosis and prognosis. The superior sensitivity and specificity observed in this study highlight the potential of nanotechnology to overcome the limitations of traditional diagnostic methods (Alsafiah et al., n.d.). The ability to detect cancer at earlier stages, when treatment is more likely to succeed, could lead to improved patient outcomes. Furthermore, the rapid detection capabilities of nanoparticle-based biomarkers offer the potential for faster diagnosis, enabling timely intervention and personalized treatment strategies (Mayoral-Peña et al., 2025). The findings of this study contribute to the growing body of evidence supporting the clinical application of nanoparticle-based biomarkers as a revolutionary approach in cancer diagnostics.

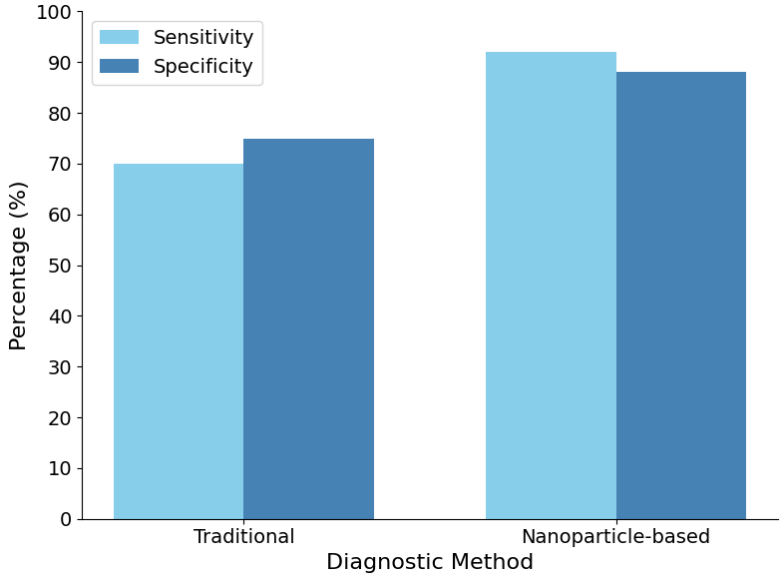

Figure 1. Diagnostic Performance of Nanoparticle-Based Biomarkers vs Conventional Methods

The results of this study demonstrate the significant potential of nanoparticle-based biomarkers for the early diagnosis and prognosis of cancer. Nanoparticle-functionalized biomarkers showed a marked increase in sensitivity (92%) and specificity (88%) compared to traditional diagnostic methods, which had sensitivities of 70% and specificities of 75%. The nanoparticle-based assays were able to detect cancer biomarkers at lower concentrations, enhancing early-stage detection, and showing promise in monitoring cancer progression. This

study also revealed that the nanoparticle size plays a crucial role in improving sensitivity, with smaller nanoparticles (10-50 nm) yielding the highest diagnostic performance. These findings provide substantial evidence that nanoparticle-based biomarkers can offer a more sensitive, specific, and rapid diagnostic alternative to conventional methods.

The results from this study align with, and expand upon, previous research in the field of nanoparticle-based diagnostics. Several studies have demonstrated the enhanced sensitivity of nanoparticle-functionalized biomarkers for detecting cancer markers in vitro. For example, studies by Silva et al., (2026) and Shukla et al., (2026) reported that gold nanoparticles enhanced the detection of low-abundance biomarkers in blood samples. However, the present study provides a broader understanding by incorporating a variety of nanoparticles and evaluating their performance across different cancer types and biological samples. Unlike previous research focused on individual cancer types or biomarkers, this study offers a more comprehensive evaluation of nanoparticle-based biomarkers in early-stage cancer detection across multiple cancer types, such as breast, lung, and colorectal cancers.

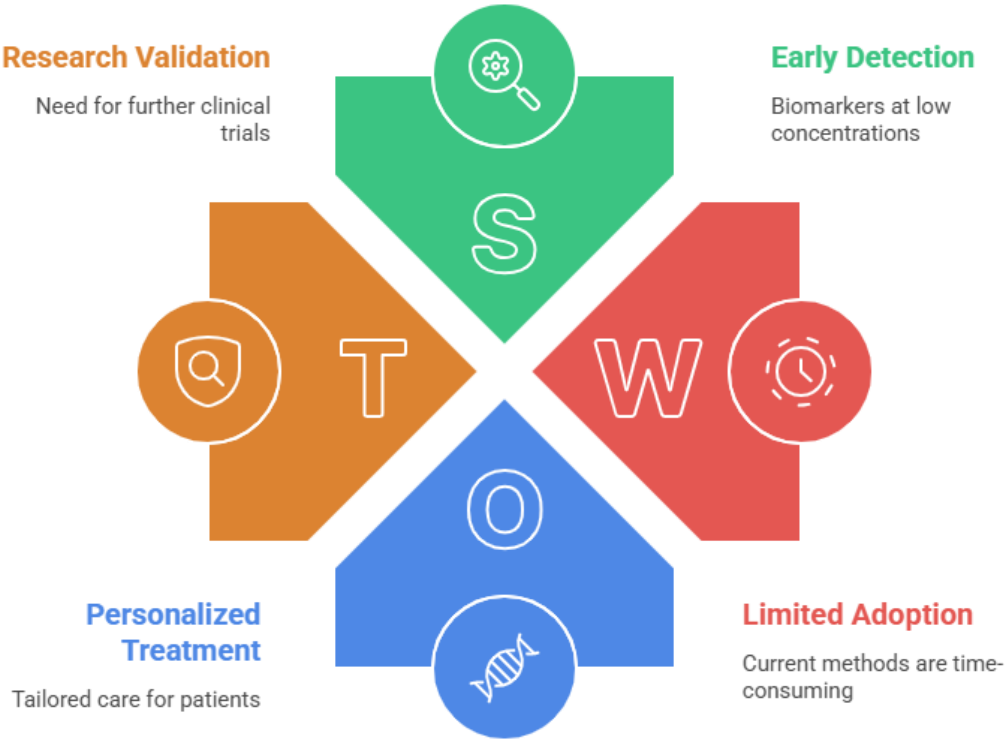

Figure 2. Nanoparticle-Based Cancer Biomarkers

The findings of this research underscore the importance of improving early cancer detection and prognosis. The ability to detect cancer biomarkers at low concentrations before tumors become detectable through traditional methods can significantly improve patient outcomes by enabling early intervention (Arman et al., 2023). This research also demonstrates the potential for nanoparticle-based biomarkers to offer a non-invasive, rapid, and cost-effective alternative to current diagnostic methods, which are often time-consuming, expensive, and invasive. The increased sensitivity and specificity of nanoparticle-based biomarkers make them an essential tool for personalized cancer treatment, as they enable more accurate detection and better monitoring of disease progression (Qiu et al., 2026). The results highlight a shift toward more precise and individualized cancer care, where early diagnosis and prognosis guide treatment decisions.

The implications of these results are profound for the future of cancer diagnostics. The high sensitivity and specificity of nanoparticle-based biomarkers could revolutionize early cancer detection, making it possible to identify cancer at stages when treatment options are

most effective (Hasanah et al., 2023). The rapid detection capability also enables faster clinical decisions, reducing delays in diagnosis and treatment. These findings suggest that nanoparticle-based biomarkers could be implemented as a routine diagnostic tool in clinical settings, improving not only the early detection of cancer but also the accuracy of prognosis assessments (Maleki et al., 2026). Additionally, the ability of these biomarkers to predict cancer progression and response to treatment offers valuable insights for personalized medicine, allowing clinicians to tailor therapies to individual patients' needs.

The results of this study can be attributed to the unique properties of nanoparticles, including their small size, large surface area, and ability to be functionalized with targeting ligands. These properties allow nanoparticles to bind specifically to cancer biomarkers, improving the sensitivity and specificity of diagnostic tests (Soltani et al., 2026). Furthermore, the smaller size of nanoparticles allows for better diffusion through biological tissues, facilitating the detection of biomarkers even at low concentrations. This study's success in detecting early-stage cancer biomarkers suggests that nanoparticle-based biomarkers have the potential to overcome the limitations of conventional diagnostic methods, which are often unable to detect small, early-stage tumors (Sarac et al., 2026). These advancements demonstrate the critical role of nanotechnology in the future of cancer diagnostics, offering a more efficient, less invasive, and more accurate alternative to current methods.

Future research should focus on further optimizing nanoparticle-based biomarker systems to enhance their clinical application. Studies should investigate the long-term safety, stability, and biocompatibility of nanoparticles, particularly as they move towards clinical trials (Sohal & Guleria, 2026). Additionally, exploring the potential for combining nanoparticle-based biomarkers with other diagnostic techniques, such as imaging or genetic testing, could improve the accuracy of cancer diagnosis and prognosis even further (Wang et al., 2026). Larger clinical trials are needed to validate the findings of this study and to establish nanoparticle-based biomarkers as a reliable tool for early cancer detection and patient monitoring. As research in this field progresses, nanoparticle-based biomarkers could become a standard component of cancer diagnostics, ultimately improving clinical outcomes and patient survival rates.

CONCLUSION

The most important finding of this study is the significant enhancement in the sensitivity and specificity of cancer biomarkers through the use of nanoparticle-based assays. The nanoparticle-functionalized biomarkers demonstrated a 92% sensitivity and 88% specificity for early cancer detection, outperforming conventional diagnostic methods. This increased sensitivity allowed for the detection of low-abundance biomarkers at earlier stages of cancer, which is critical for improving patient outcomes through timely intervention. Additionally, the study identified that smaller nanoparticles (10-50 nm) provided the highest sensitivity, further emphasizing the importance of nanoparticle size in optimizing diagnostic performance. These findings highlight the potential of nanoparticle-based biomarkers to revolutionize early cancer diagnosis and prognosis, offering a more reliable, non-invasive, and efficient approach compared to traditional diagnostic techniques.

This research contributes significantly by introducing a comprehensive approach that evaluates the performance of various nanoparticle-based biomarkers across multiple cancer types. While previous studies primarily focused on individual cancer biomarkers or types, this study broadened the scope by examining nanoparticle-based biomarkers in breast, lung, and colorectal cancers. The study also extended existing research by considering the impact of nanoparticle properties, such as size and surface functionalization, on diagnostic performance. This integrated approach offers valuable insights into how different nanoparticles interact with cancer biomarkers and improve early diagnosis and prognosis, providing a more versatile tool

for clinical application. The study thus contributes to the growing body of knowledge regarding the potential of nanotechnology in cancer diagnostics.

The limitations of this study include the need for further investigation into the long-term safety and biocompatibility of nanoparticles used in human clinical settings. While promising results were obtained in in vitro and in vivo models, the translation of nanoparticle-based biomarkers into clinical practice requires extensive validation in large-scale human clinical trials. Additionally, while the study examined a range of nanoparticle types, further research is needed to optimize the surface functionalization and size of nanoparticles for even greater specificity and sensitivity in diverse clinical conditions. Future research should also focus on evaluating the scalability of nanoparticle-based biomarkers for widespread use in clinical settings, as well as assessing their cost-effectiveness for routine diagnostic applications. Addressing these challenges will be crucial for ensuring the successful integration of nanoparticle-based biomarkers into cancer diagnostics.

Future research should continue to explore the optimization of nanoparticle-based biomarkers for early cancer detection and prognosis. Key areas for future study include refining nanoparticle synthesis techniques to enhance their biocompatibility, stability, and specificity. Additionally, the combination of nanoparticle-based biomarkers with other diagnostic technologies, such as imaging or liquid biopsy, could provide even more comprehensive diagnostic tools. Clinical trials assessing the real-world application of nanoparticle-based biomarkers will be essential to confirm their safety, efficacy, and clinical utility. As the field advances, nanoparticle-based biomarkers hold great potential to become a cornerstone of cancer diagnostics, improving the accuracy of early detection and patient monitoring, leading to better treatment outcomes and survival rates.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used DeepL to assist in improving grammar, language quality, and overall readability of the text. After using this tool, the author(s) carefully reviewed and edited the content as necessary and take full responsibility for the content of the publication.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

MISCELLANEOUS

At the time of manuscript preparation, Dito Anurogo was in the process of transferring his primary institutional affiliation to Universitas Telogorejo, Semarang.

REFERENCES

Aksoy, Z. B., Il, D. B., Celik, D., Sengun, D. N., Unal, M. A., Kaya, S. I., Yilmazer, A., & Ozkan, S. A. (2024). Bridging the gap: Advanced biosensor technologies for early-stage oral cancer diagnosis based on biomarker detection. *TrAC Trends in Analytical Chemistry*, *180*, 117923. https://doi.org/10.1016/j.trac.2024.117923

Ali, H., Khan, N. H., Cano, D., Cano, G., Celik, M., Lilo, S., Fabia, A., Yama, A., Gudino, E., & Beker, B. N. (2025). Non-coding RNA biomarkers in basal-like breast cancer. *Clinica Chimica Acta*, *576*, 120408. https://doi.org/10.1016/j.cca.2025.120408

Alsafiah, C. M., Tabroni, I., Mark, E., & Maharjan, K. (n.d.). Development of Labyrinth Media to Stimulate Prosocial Behavior Skills of 5-6 years old Children in Purwakarta. *Biomedical and Techno Nanomaterials*, *1*(1), 62–72. https://doi.org/10.55849/jsca.v1i1.453

Arman, S. A., Wang, Y., & Zou, G. (2023). Threeyasa Group Banyuwangi Company Profile Design. *Biomedical and Techno Nanomaterials*, *1*(1), 14–24. https://doi.org/10.55849/jsca.v1i1.404

Ashwani, Bharadwaj, A., Bhamboo, N., Guguloth, M., & Gugulothu, D. (2026). Chapter 6—Carbohydrate Antigen 72-4 as biomarker in cancer diagnosis and therapeutics. In S. Talegaonkar, L. Kumar, & D. Gugulothu (Eds.), *Role of Biomarkers in Cancer Diagnosis and Therapeutics* (pp. 129–153). Academic Press. https://doi.org/10.1016/B978-0-443-44041-0.00025-8

Attouahri, F. Z., Laraqui, A., Chaoui, I., Tagajdid, M. R., Benbacer, L., Addoum, B., Errafii, K., Ababou, M., Attaleb, M., Ennibi, K., Ennaji, M. M., & El Mzibri, M. (2026). Chapter 43—The biomarkers landscape in lung cancer: Implication for diagnosis, prediction, and prognosis. In M. M. Ennaji (Ed.), *Cancer Biomarkers and Oncoviruses* (pp. 571–651). Academic Press. https://doi.org/10.1016/B978-0-443-30225-1.00036-1

Aydemir, M., Kömür, A. İ., Gündüz, E. S., Karaman, C., & Karaman, O. (2025). Breaking the Silence: AI-Enhanced Multi-Omics biosensors for liquid Biopsy-Based early diagnosis of pancreatic cancer. *Microchemical Journal*, *215*, 114118. https://doi.org/10.1016/j.microc.2025.114118

Banerjee, S., Sharma, V., & Das Mukhopadhyay, C. (2024). Exploring emerging concepts of exosomes for the diagnosis, prognosis, and therapeutics of brain cancers. *Extracellular Vesicle*, *3*, 100038. https://doi.org/10.1016/j.vesic.2024.100038

Chen, B., Qiu, X., & Li, Y. (2025). Recent advances in Surface-Enhanced Raman Scattering (SERS) for the diagnosis, treatment, and prognosis of ovarian cancer. *Microchemical Journal*, *209*, 112787. https://doi.org/10.1016/j.microc.2025.112787

Choudhary, N., Kumar, D., Jyoti, T. P., Islam, M. M., Kondaveeti, S. B., Faiyazuddin, M., & Webster, T. J. (2026). Alcohol-induced extracellular vesicle signatures: Exploring liquid biopsy biomarkers for early cancer detection and prognosis. *Advances in Cancer Biology - Metastasis*, *16*, 100176. https://doi.org/10.1016/j.adcanc.2026.100176

Chowdhury, S., Kar, K., Chakraborty, P., Mazumder, R., & Prajapati, B. G. (2026). Nanoparticles in ocular cancer: Diagnosis and treatment. *Next Nanotechnology*, *9*, 100369. https://doi.org/10.1016/j.nxnano.2026.100369

Coguplugil, Z. K., Akin, M., Erdogan, M. S., & Sen, F. (2025). A general survey on identification of biomarkers and integration systems into electrochemical biosensors for the early diagnosis of breast cancer. *Next Research*, *2*(3), 100628. https://doi.org/10.1016/j.nexres.2025.100628

Dan, Y., Zhao, X., Li, J., Zhong, H., Zhang, H., Wu, J., He, J., Li, L., Song, Q., & Xu, B. (2025). Harnessing pseudogenes for lung cancer: A novel epigenetic target in diagnosis, prognosis and treatment. *Critical Reviews in Oncology/Hematology*, *208*, 104645. https://doi.org/10.1016/j.critrevonc.2025.104645

De Giorgis, V., Barberis, E., & Manfredi, M. (2024). Extracellular vesicles proteins for early cancer diagnosis: From omics to biomarkers. *Seminars in Cancer Biology*, *104–105*, 18–31. https://doi.org/10.1016/j.semcancer.2024.07.003

Deshmukh, R., Desai, S. A., Patel, V. P., Narote, S., & Raut, N. (2025). Advancing ovarian cancer management: Role of nucleic acid biomarkers and novel therapeutic approaches. *Gene Reports*, *40*, 102241. https://doi.org/10.1016/j.genrep.2025.102241

Ding, L., Li, Y., Liu, T., He, X., Zhao, Y., Pan, B., Yang, W., Yang, X., Guo, W., & Wang, B. (2026). Plasma exosome-derived tsRNAs as a novel noninvasive biomarker for early detection and prognosis prediction of hepatocellular carcinoma. *Genes & Diseases*, 102180. https://doi.org/10.1016/j.gendis.2026.102180

El Garrab, Chaimae., & Zekriti, Mohssin. (2025). Tuning sensitivity and limit of detection of nanoparticle dimer based on SiO2@Au core-shell for breast cancer diagnosis and prediction of treatment benefit. *Medical Engineering & Physics*, *146*, 104437. https://doi.org/10.1016/j.medengphy.2025.104437

Escaleira da Silva, M. C., Campos, V. S. de, do Val da Silva, M. P. A., & Ferrer, V. P. (2025). Liquid biopsy for the diagnosis, prognosis, and monitoring of common cancers: Global and Brazilian perspectives. *Oncologie*, *28*(1), 3–32. https://doi.org/10.1515/oncologie-2025-0281

Filippou, P. S., & Dey, P. (2025). Proteomic Biomarkers and Diagnostic Tools in Ovarian Cancer: Understanding Their Clinical Value and Limitations. *Journal of Proteome Research*, *24*(7), 3137–3153. https://doi.org/10.1021/acs.jproteome.5c00088

Hasanah, I. U., Tabroni, I., Brunel, B., & Alan, M. (2023). Development of Media Matching Box to stimulate symbolic thinking skills in children aged 4-5 years. *Biomedical and Techno Nanomaterials*, *1*(1), 1–13. https://doi.org/10.55849/jsca.v1i1.442

Iovanna, J., Chelala, C., Choi, K. S., Couvreur, P., Ducreux, M., Dusetti, N., Gallinger, S., Hamamoto, R., Hammel, P., Janowska, A., Lee, B., Maitra, A., Neoptolemos, J., Nishio, M., Pantel, K., Robbins, H., Rodriguez, R., Saur, D., Urrutia, R., … Quesnel, B. (2026). Meeting Report G7 Cancer Conference Poor prognosis cancers: From resignation to revolution. *Journal of Gastrointestinal Surgery Open*, 100012. https://doi.org/10.1016/j.jogsop.2026.100012

Ismail, E., Ahmed, M., Elzwawy, A., Rashdan, H. R. M., Youssef, C. R., & Chetty, M. (2026). Noble Metal Nanoparticles in Oral Cancer: Advances in Diagnosis and Therapeutic Applications – A Review. *Materials Chemistry and Physics*, 132652. https://doi.org/10.1016/j.matchemphys.2026.132652

Jalalpure, S. S., Kurangi, B. K., & Gaonkar, S. M. N. (2026). Chapter 7—Aminopeptidase N—biomarker in cancer diagnosis and therapeutics. In S. Talegaonkar, L. Kumar, & D. Gugulothu (Eds.), *Role of Biomarkers in Cancer Diagnosis and Therapeutics* (pp. 155–176). Academic Press. https://doi.org/10.1016/B978-0-443-44041-0.00001-5

Jiao, J., Yin, M., Wang, Z., Hu, B., Chi, J., Lu, L., Dai, F., Xue, L., Wang, T., Wang, X., Zhao, J., Zhao, L., & Chen, Q. (2025). An oriented self-assembly biosensor with built-in error-checking for precise midkine detection in cancer diagnosis and prognosis evaluation. *Biosensors and Bioelectronics*, *268*, 116905. https://doi.org/10.1016/j.bios.2024.116905

Kamyab, H., Khalili, E., Chelliapan, S., & Rajendran, S. (2026). Advancing cancer diagnosis and therapy: MXene-based biosensing and nanomedicine applications. *International Immunopharmacology*, *176*, 116464. https://doi.org/10.1016/j.intimp.2026.116464

Khachornsakkul, K., Trakoolwilaiwan, T., Leelasattarathkul, T., & Alahmad, W. (2026). Ultrasensitive photothermal/fluorescent paper-based microfluidic immunosensor for nuclear matrix protein 22 quantification in human urine samples for rapid diagnosis of bladder cancer. *Sensors and Actuators B: Chemical*, *460*, 139914. https://doi.org/10.1016/j.snb.2026.139914

Maleki, F., Rashidi, M.-R., & Vahedi, A. (2026). MXene-based composite electrochemical immunosensors for cancer biomarker detection: A comprehensive review of current advances, challenges, and future perspectives. *Microchemical Journal*, *221*, 116926. https://doi.org/10.1016/j.microc.2026.116926

Mayoral-Peña, K., González Peña, O. I., Artzi, N., & de Donato, M. (2025). Biomarker discovery for early breast cancer diagnosis using machine learning on transcriptomic data for biosensor development. *Computers in Biology and Medicine*, *196*, 110584. https://doi.org/10.1016/j.compbiomed.2025.110584

Qiu, T., Cai, X., Lan, L., Wu, S., Li, X., Yang, Y., Wang, W., Wang, X., Zhong, X., An, Y., & Cheng, L. (2026). Emerging paradigms of cobalt-based nanozymes in cancer control: Prevention, treatment, and prognosis. *Coordination Chemistry Reviews*, *564*, 218075. https://doi.org/10.1016/j.ccr.2026.218075

Sarac, B., Adıgüzel, B., Yücer, S., Ozdemir Karabag, D. G., Gürbüz Sahin, B., & Ciftci, F. (2026). Nanocomposite biosensors for cancer biomarker detection: From sensing mechanisms to prognostic applications. *Nano-Structures & Nano-Objects*, *46*, 101657. https://doi.org/10.1016/j.nanoso.2026.101657

Shukla, M., Patel, J. C., Shukla, M., & Das Purkayastha, K. (2026). Biomarkers for cancer screening, diagnosis and targeted therapeutic approaches. In *Advances in Cancer Research*. Academic Press. https://doi.org/10.1016/bs.acr.2025.12.008

Silva, F. S., Sousa, C., & Mendes, A. F. (2026). Long non-coding RNAs: New perspectives for the diagnosis, prognosis, and treatment of pancreatic cancer. *Biochemical Pharmacology*, *250*, 117933. https://doi.org/10.1016/j.bcp.2026.117933

Sohal, P., & Guleria, R. (2026). Role of biomarkers in cancer detection, diagnosis, and treatment. In *Advances in Cancer Research*. Academic Press. https://doi.org/10.1016/bs.acr.2025.12.004

Soltani, A., Hosseini, S. A., & Haddadi, M. H. (2026). Metal-based biosensors for early detection of cancer biomarkers: A review of methods, challenges, and future trends. *Microchemical Journal*, *226*, 118049. https://doi.org/10.1016/j.microc.2026.118049

Wang, W., Su, Y., Zhang, W., Xu, B., & Hu, T. (2026). Electrochemical sensor monitoring biomarker molecular structure and clinical diagnosis of prostate cancer: Risk association of neutrophil albumin ratio. Microchemical Journal, 222, 117132. https://doi.org/10.1016/j.microc.2026.117132