NEW ERA MEDICAL JOURNAL

Narrative Review

Early Diagnosis and Management of Cancer Using Biomarkers and Imaging

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ABSTRACT

Background: Early diagnosis of cancer is essential for improving survival rates and reducing disease-related complications. Conventional diagnostic methods often detect cancer at advanced stages, limiting treatment options. Advances in molecular biomarkers and medical imaging have improved the ability to identify cancer at earlier stages and support personalized management strategies.
Aim: This short communication aims to highlight recent advances in molecular biomarkers, radiomics, and imaging techniques and to evaluate their role in the early diagnosis and management of cancer.
Methods: A narrative review of peer-reviewed literature was conducted using major scientific databases. Studies focusing on cancer biomarkers, advanced imaging modalities, radiomics, and personalized treatment planning were analyzed. Key findings were synthesized to provide an overview of current clinical applications and emerging trends.
Results: Molecular biomarkers, including circulating tumour DNA and tumour-specific genetic markers, demonstrated high sensitivity for early cancer detection, monitoring treatment response, and identifying disease recurrence. Advanced imaging techniques such as PET-CT and multiparametric MRI improved tumour localization, staging accuracy, and assessment of therapeutic response. Radiomics enabled extraction of quantitative imaging features that reflect tumour heterogeneity and biological behaviour. Integration of biomarkers and imaging supported individualized treatment planning and enhanced clinical decision-making.
Conclusion: The combined use of molecular biomarkers and advanced imaging techniques represents a significant advancement in precision oncology. This integrated approach enables earlier diagnosis, supports personalized treatment strategies, and has the potential to improve clinical outcomes. Continued validation and standardization are required for broader clinical implementation.

Keywords: Early cancer diagnosis; Molecular biomarkers; Radiomics; Advanced imaging; Precision oncology; Personalized cancer management

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DOI: 10.62502/nemj/v1i1art3

Received: 20/09/2025
Accepted: 02/12/2025
Published: 20/12/2025

INTRODUCTION

Cancer remains one of the leading causes of morbidity and mortality worldwide, accounting for millions of new cases and deaths each year. Despite advances in treatment, the overall prognosis of many cancers continues to depend heavily on the stage at which the disease is diagnosed. Early-stage cancers are often curable or manageable with less aggressive therapy, whereas advanced-stage disease is frequently associated with poor survival and reduced quality of life. Consequently, early diagnosis and timely management are central goals in modern oncology and public health strategies. [1,2] Traditional approaches to cancer diagnosis have relied on clinical examination, histopathology, and conventional imaging techniques. While these methods remain essential, they often detect disease only after structural or functional changes have occurred. In many cancers, molecular and cellular alterations precede anatomical changes by months or even years. This delay can limit opportunities for early intervention and contribute to disease progression. The growing understanding of cancer biology has therefore driven the search for sensitive biomarkers and advanced imaging methods capable of identifying malignancy at its earliest stages. [3,4] Biomarkers have emerged as powerful tools in cancer detection and management. Cancer biomarkers include genetic mutations, epigenetic changes, proteins, metabolites, and circulating tumour components that reflect the presence or behaviour of a malignancy. Advances in molecular biology and high-throughput technologies have enabled the identification of biomarkers that can be detected in tissue, blood, urine, or other body fluids. Circulating tumor DNA (ctDNA),

circulating tumour cells, and cancer-associated proteins have shown promise in early diagnosis, prognosis, and monitoring of treatment response. [5–7] These biomarkers provide insights into tumour biology and allow for minimally invasive testing, often referred to as "liquid biopsy," which has gained increasing clinical relevance. At the same time, medical imaging has undergone significant technological evolution. Imaging modalities such as computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and hybrid systems like PET-CT and PET-MRI have greatly improved tumour detection, staging, and response assessment. Functional and molecular imaging techniques now enable visualization of tumour metabolism, perfusion, hypoxia, and receptor expression, offering information beyond simple anatomical detail. [8,9] These developments have enhanced diagnostic accuracy and reduced uncertainty in treatment planning.

More recently, the field of radiomics has expanded the role of imaging in oncology. Radiomics involves the extraction of large numbers of quantitative features from medical images, capturing tumour shape, texture, intensity, and spatial relationships that may not be visible to the human eye. These imaging-derived biomarkers can reflect tumour heterogeneity and underlying molecular characteristics. When combined with machine learning and clinical data, radiomics has demonstrated potential in predicting treatment response, disease progression, and patient outcomes across multiple cancer types. [10–12] The integration of molecular biomarkers with advanced imaging has become a cornerstone of personalized cancer care. Rather than relying solely on tumour size or location, clinicians can now incorporate biological and functional information into diagnostic and therapeutic decision-making. For example, biomarker-driven imaging can help select patients for targeted therapies, guide biopsy to the most aggressive tumour regions, and monitor early treatment response. This integrated approach reduces unnecessary interventions and supports more precise, individualized treatment strategies [13,14] Early diagnosis using biomarkers and imaging also plays a crucial role in cancer screening and risk stratification. High-risk populations, such as individuals with genetic predisposition or strong environmental exposures, may benefit from tailored screening protocols that combine molecular testing with sensitive imaging techniques. Such strategies have shown promise in cancers of the breast, lung, prostate, and colon, where early detection significantly improves survival rates. [15–17] Moreover, early identification of treatment resistance or recurrence through biomarker and imaging surveillance allows timely modification of therapy. Despite these advances, challenges remain in the clinical implementation of biomarker- and imaging-based approaches. Issues such as cost, standardization, accessibility, and validation across diverse populations continue to limit widespread adoption. Variability in imaging acquisition, biomarker assays, and data interpretation can affect reproducibility and clinical reliability. Addressing these challenges requires interdisciplinary collaboration among clinicians, radiologists, pathologists, molecular scientists, and data analysts [18–20]

Aim: The aim of this study is to evaluate the role of molecular biomarkers and advanced imaging techniques in the early diagnosis and management of cancer, with emphasis on their contribution to timely detection, radiological characterization, and personalized treatment planning.

MATERIALS AND METHODS

This short communication is based on a narrative and evidence-focused review of published scientific literature examining the role of molecular biomarkers and advanced imaging techniques in the early diagnosis and management of cancer. The methodology was designed to align with the stated aim of evaluating how biomarkers, radiomics, and imaging contribute to early detection and personalized treatment planning.

Literature Search Strategy: A comprehensive literature search was conducted using established electronic databases, including PubMed, Scopus, and Web of Science. Peer-reviewed articles published in English were considered. The search focused on studies related to cancer biomarkers, advanced imaging modalities, radiomics, and personalized oncology. Key search terms included combinations of "cancer biomarkers," "early cancer diagnosis," "molecular imaging," "radiomics," "PET-CT," "MRI," and "personalized cancer management."

Study Selection: Original research articles, systematic reviews, meta-analyses, and key clinical guidelines were included if they addressed the use of molecular biomarkers or imaging techniques for early cancer detection, staging, treatment planning, or monitoring. Studies focusing on solid tumours and haematological malignancies were considered. Articles lacking clear clinical relevance or methodological clarity were excluded.

Data Extraction and Synthesis: Relevant data were extracted manually, focusing on the type of biomarker or imaging technique used, clinical application, diagnostic or prognostic value, and impact on patient management. Particular attention was given to emerging approaches such as liquid biopsy, radiomics, and hybrid imaging systems. The findings were synthesized narratively to highlight current trends, clinical benefits, and practical challenges.

RESULTS AND DISCUSSION

The reviewed evidence demonstrates that the combined use of molecular biomarkers (Table-1) and advanced imaging techniques (Table-2) significantly improves early cancer detection and clinical decision-making. Multiple studies report that molecular biomarkers can identify malignant changes before visible anatomical alterations occur, allowing cancer to be detected at an earlier and potentially more treatable stage. [16–18] Circulating tumour DNA (ctDNA) and tumour-specific genetic mutations were shown to be particularly sensitive in detecting early disease, minimal residual disease, and early recurrence across several solid tumours, including lung, breast, and colorectal cancers. [19–21] These findings support the growing clinical role of liquid biopsy as a minimally invasive diagnostic and monitoring tool.

Table 1. Key Biomarkers Used in Early Cancer Diagnosis

Biomarker Type	Sample Source	Clinical Utility	Evidence
Circulating tumour DNA (ctDNA)	Blood	Early detection, recurrence monitoring	[19–21]
Tumour-associated proteins	Blood/Tissue	Screening, prognosis	[16–18]
Genetic mutations (EGFR, KRAS, BRCA)	Tissue/Blood	Therapy selection	[33–35]
MicroRNAs	Blood	Early diagnosis, prognosis	[17,18]

Advanced imaging modalities such as multiparametric MRI and PET-CT further enhanced diagnostic accuracy by providing functional and metabolic information in addition to structural detail. Evidence indicates that PET-CT improves tumour staging and detection of occult metastases compared to conventional imaging alone, directly influencing treatment planning and prognosis. [22–24] Functional MRI parameters, including diffusion-weighted imaging, were shown to correlate with tumour cellularity and aggressiveness, supporting their use in early diagnosis and response assessment. [25, 26] Radiomics has emerged as an important advancement in imaging-based cancer evaluation. Studies consistently show that quantitative imaging features extracted through radiomics can reflect tumour heterogeneity and biological behaviour more accurately than visual assessment alone. [27–29] When radiomic data were integrated with molecular biomarkers and clinical parameters, predictive models demonstrated improved performance in forecasting treatment response and patient outcomes. [30–32] This evidence highlights the role of radiomics in supporting personalized treatment strategies.

Table 2. Imaging Techniques and Their Clinical Role

Imaging Modality	Key Advantage	Clinical Application	Evidence
PET-CT	Functional and metabolic imaging	Staging, metastasis detection	[22–24]
Multiparametric MRI	Tissue characterization	Early detection, response assessment	[25,26]
Hybrid PET-MRI	Combined anatomical and molecular data	Personalized treatment planning	[23,24]
Radiomics	Quantitative image biomarkers	Prognosis, treatment prediction	[27–32]

Clinically, the integration of biomarkers and imaging reduced diagnostic uncertainty and improved early therapeutic decision-making. In cancers such as lung, prostate, and breast malignancies, combined biomarker–imaging approaches enabled more accurate risk stratification and selection of targeted therapies, resulting in better treatment outcomes. [33–35] Early detection of treatment resistance and disease recurrence through biomarker surveillance and follow-up imaging also allowed timely modification of therapy. However, despite these benefits, challenges remain. Variability in biomarker assays, lack of standardized imaging protocols, and high costs limit widespread clinical implementation. Evidence emphasizes the need for standardized guidelines, multicenter validation studies, and interdisciplinary collaboration to ensure reproducibility and accessibility.

CONCLUSION

Early diagnosis and effective management of cancer are critical determinants of patient survival and quality of life. The evidence reviewed in this study clearly demonstrates that molecular biomarkers and advanced imaging techniques play a complementary and increasingly important role in achieving these goals. Molecular biomarkers, particularly circulating tumour

DNA and tumour-specific genetic alterations, enable early detection of malignancy, monitoring of treatment response, and identification of disease recurrence in a minimally invasive manner. Advanced imaging modalities such as PET-CT, multiparametric MRI, and hybrid imaging systems provide valuable functional and metabolic information that improves tumour detection, accurate staging, and assessment of treatment response. The emergence of radiomics further strengthens the diagnostic and prognostic value of imaging by converting visual data into quantitative biomarkers that reflect tumour heterogeneity and biological behaviour. The integration of biomarkers with advanced imaging supports personalized treatment planning by guiding targeted therapies, optimizing therapeutic decisions, and reducing unnecessary interventions. This combined approach enhances clinical confidence and contributes to more precise and timely cancer care. However, challenges related to standardization, cost, and accessibility remain and must be addressed through validated protocols, interdisciplinary collaboration, and continued research.

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How to cite this article: Ali N, Khatun S, Khan A. Early Diagnosis and Management of Cancer Using Biomarkers and Imaging. New Era Med. J. 2025;1(3): 14-18. doi: 10.62502/nemj/v1i3art3