Deep Science Publishing, 2025
https://doi.org/10.70593/978-93-7185-537-2_8

Chapter 8: Nano diagnostics for Early Detection of Breast Cancer: Liquid Biopsy, Biosensors and Imaging

Susanta Kumar Sahu[1], Nihar Ranjan Das[2,*], Ganesh Patro[3], Bimalendu Chowdhury[4], Amit Kundu[2], Shujauddin Ahmed[2]

[1]*Department of Pharmacology, Maa Tara Tarini College of Pharmacy, Berhampur, Odisha, India*
[2]*Department of Pharmacology, GITAM Deemed to be University, Visakhapatnam, Andhra Pradesh, India*
[3]*Department of Pharmacology, College of Pharmaceutical Sciences, Berhampur, Odisha, India.*
[4]*Department of Pharmacology, Roland Institute of Pharmaceutical Sciences, Berhampur, Odisha, India.*

Corresponding author
Dr Nihar Ranjan Das: ndas@gitam.edu
ORCID ID: https://orcid.org/0000-0001-6883-6523

Abstract

Breast cancer remains a leading cause of illness and death among women worldwide especially in low and middle-income countries where early detection tools are often limited. Although traditional diagnostic methods like mammography, ultrasound, MRI and biopsies have played an essential role in identifying breast cancer, they come with challenges such as invasiveness, high cost, limited sensitivity and difficulty in monitoring disease progression in real time. Nanotechnology offers a transformative solution through nano diagnostics the use of nanoscale tools for early, accurate cancer detection. Techniques like nano enhanced liquid biopsies, biosensors and imaging agents can identify minute cancer markers in body fluids or tissues, allowing for less invasive and more personalized approaches. Nanomaterials such as gold nanoparticles, quantum dots, magnetic particles and graphene oxide enhance sensitivity and speed in diagnostics. These tools enable detection of DNA mutations, cancer proteins and improved imaging clarity with nano-contrast agents. Despite hurdles like regulatory challenges and production costs, ongoing research is advancing the clinical adoption of nano diagnostics. Future developments may include wearable nano sensors and AI-powered digital platforms for real-time monitoring. In summary, nanotechnology is reshaping breast cancer diagnosis enabling earlier, smarter and more accessible care with the potential to improve outcomes and save lives.

Keywords: *Breast Cancer Diagnosis, Cancer Biomarkers, Liquid Biopsy, Nano diagnostics, Nano-imaging, Nanotechnology in Cancer.*

1. Introduction

Breast cancer continues to be a major global health challenge, affecting significant percentage of cancer-related morbidity and mortality in women (Zhang, Jin, Bao, & Shu, 2024). According to recent reports, its incidence is steadily rising, especially in low and middle-income countries. While advancements in treatment have improved survival rates, the key to saving more lives lies in detecting the disease at an early stage before it has spread (Danciulescu, Jude, & Manoj, 2024). Early diagnosis gives patients a better chance of recovery and allows doctors to use less aggressive treatment strategies(Theivendren *et al*., 2025). However, in reality many cases are detected late, mainly due to the limitations of current diagnostic tools.

According to the International Agency for Research on Cancer (IARC), breast cancer is the most commonly diagnosed cancer in women worldwide(Kim *et al*., 2025). In 2022 around 2.3 million new cases were reported globally(Bray *et al*., 2024). This number is expected to rise to 3.2 million per year by 2050 without effective prevention and early detection(Hasi *et al*., 2025).

Traditional diagnostic methods such as mammography, ultrasound, magnetic resonance imaging (MRI) and histopathological tissue biopsies have played a vital role in breast cancer screening and diagnosis(Cerdas *et al*., 2025). However, these methods face several challenges including limited sensitivity in dense breast tissue, false positives/negatives, high costs, requirement for trained personnel and the inability to detect subclinical or early molecular changes(Rehman, 2024). Additionally, these conventional approaches are often not suitable for frequent monitoring which is crucial for evaluating disease progression or recurrence. Recent advancements in nanotechnology have opened new scopes in the field of medical diagnostics. Nano diagnostics, which involve the application of nanomaterials and nanoscale systems to detect biomarkers of disease with exceptional precision(Ahmad, Imran, & Ahsan, 2023). They have emerged as a transformative approach for the early detection of breast cancer. These tools leverage the unique physical, chemical and biological properties of nanomaterials to identify cancer-related signals at the molecular level even before phenotypic changes become visible(Salaudeen & Akinniranye, 2024). By integrating nanotechnology into diagnostic systems, researchers and clinicians are now able to achieve higher sensitivity, faster turnaround times and less invasive procedures(Malik, Muhammad, & Waheed, 2023).

This chapter provides an in-depth exploration of three major pillars of nanotechnology-based diagnostics such as liquid biopsy, biosensors and imaging modalities and how they are revolutionizing the landscape of breast cancer detection. These technologies promise to bridge the longstanding gap between laboratory research and real-world clinical application. Each of these pillars represents a shift from traditional diagnostic thinking to more precise, efficient and patient-centered approaches. This chapter provides a detailed overview of how nano diagnostics can be applied for early detection and personalized treatment strategies in breast cancer.

2. Clinical Limitations of Current Diagnostic Methods

Despite the availability of several diagnostic techniques, many existing methods still lack universal applicability. They often fall short in offering early detection, especially for fast-growing and aggressive subtypes of breast cancer. Additionally, these tools are limited in providing real-time monitoring of the disease, which is critical for effective management and treatment planning. Mammography is the most commonly used screening tool worldwide(Balali, 2020). However, it is less effective in women with dense breast tissue, where overlapping fibroglandular structures can obscure malignant lesions. Moreover, repeated exposure to even low-dose radiation adds a cumulative risk. The high rate of false positives often leads to unnecessary biopsies and increases psychological stress among patients(Freitas, 2025).

Ultrasound is widely accessible, non-invasive, and cost-effective(Gravante *et al*., 2025). It is often used as an additional tool to mammography. However, its accuracy heavily depends on the operator's skill. Furthermore, it lacks standardization and has limited capability in differentiating benign from malignant lesions without additional testing(Termite *et al*., 2025). MRI is valuable for detecting breast cancer in high-risk individuals due to its high imaging precision(Hirsch *et al*., 2025). Still, it remains expensive and is not widely available in all healthcare settings. Its contraindicated in patients with certain implants or renal dysfunction due to the need for gadolinium-based contrast agents(Takahashi, 2025).

Tissue biopsy is considered the gold standard for confirming cancer through histological and molecular analysis(M. U. Khan *et al*., 2025). However, the procedure is invasive often painful and carries risks like bleeding or infection(Alrumaihi, 2025). Since biopsies are typically not repeated unless clinically required, they fail to offer real-time insights into tumor progression or treatment response. Testing for hormone receptors (ER, PR) and HER2 expression is crucial for deciding targeted therapies(C. Liu *et al*., 2025). However, these tests require physical tissue samples and cannot be repeated non-invasively. As a result, they are not suitable for provide information about tumor progression or treatment response.

The limitations mentioned above highlight the need for diagnostic technologies that are minimally invasive, cost-effective, highly specific and capable of real-time disease monitoring.

Nano diagnostic platforms hold great promise in addressing these gaps. They can detect extremely low levels of circulating tumor markers, support remote monitoring through integration with digital platforms and enable personalized treatment strategies(Tiwari, Mishra, & Kuo, 2025). These innovations represent a major step forward in improving breast cancer diagnosis and management (Figure 8.1; Table 8.1).

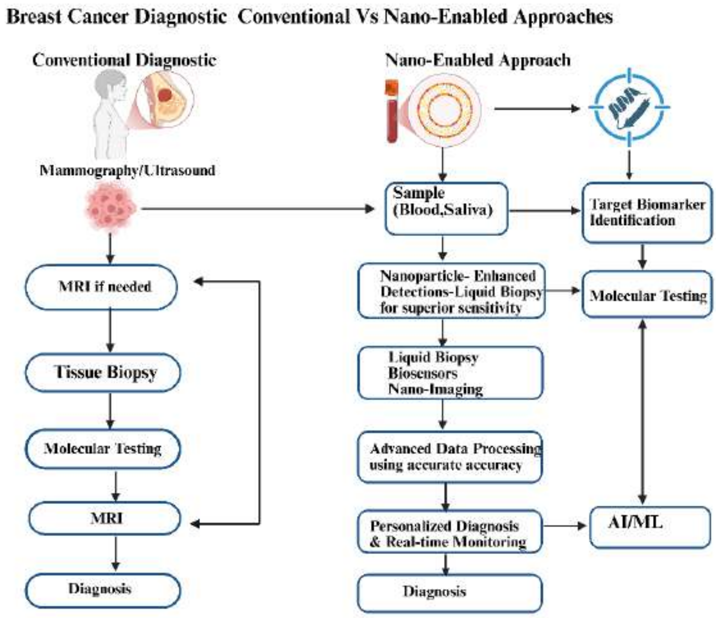

Figure 8.1. Overview of Conventional and Nano-Enabled Diagnostic Techniques for Breast Cancer Detection: This comparative flowchart visually contrasts the traditional breast cancer diagnostic pipeline (involving mammography, biopsy, MRI, molecular testing) with the more advanced nano-enabled approach. It emphasizes how nanotechnology introduces non-invasive, highly sensitive detection methods and integrates AI/ML for personalized and real-time monitoring (Chaudhari, Patel, & Kumar, 2024).

Table 8.1: Comparative Evaluation of Breast Cancer Diagnostic Tools Based on Sensitivity, Invasiveness, Turnaround Time and Limitations

Diagnostic Tool	Sensitivity	Invasiveness	Turnaround Time	Limitation(Zubair, Wang, & Ali, 2021)
Mammography	Moderate	Non-invasive	Moderate	Low sensitivity in dense tissue
Ultrasound	Variable	Non-invasive	Immediate	Operator-dependent

MRI	High	Non-invasive	High	Expensive and contraindicated in some cases
Tissue Biopsy	Very High	Invasive	Days	Risk of complications and sampling errors
Molecular Testing	High	Invasive	Days	Not suitable for dynamic monitoring
Nano diagnostics	Very High	Minimally invasive	Rapid	Still under clinical validation

3. Nanotechnology: Transforming Cancer Diagnostics

Nanotechnology involves the deals with manipulating materials at the nanoscale, typically between 1 to 100 nanometers (W. S. Khan, Asmatulu, & Asmatulu, 2025). At this scale, materials show unique properties such as a high surface-to-volume ratio, enhanced reactivity and quantum effects. These features make nanomaterials especially useful in medical applications, including cancer diagnostics, where they improve sensitivity and accuracy in detecting tumor markers (Figure 8.2).

3.1 Types of Nanomaterials Used in Diagnostics

1. **Gold Nanoparticles (AuNPs):** These are commonly used in colorimetric and optical sensors due to their special optical property called surface plasmon resonance(Farshi, Bayat, Chaghamirzaei, Jawad, & Amani-Ghadim, 2025).

2. **Quantum Dots (QDs):** These semiconductor nanocrystals provide intense fluorescence signals and are useful for high-resolution imaging and multiplexed biomarker detection(Pandey *et al*., 2025).

3. **Magnetic Nanoparticles (MNPs):** Commonly used in magnetic resonance imaging and biomarker isolation due to their ability to be guided by external magnetic fields(Dinari, Ahmad, Oh, Kim, & Yoon, 2025).

4. **Carbon Nanotubes (CNTs) and Graphene Oxide (GO):** Their electrical conductivity and functional surface chemistry make them ideal for electrochemical biosensors(Ozbey, Keles, & Kurbanoglu, 2025).

5. **Lipid-Based and Polymeric Nanoparticles:** These are often used for both diagnostics and drug delivery, enhancing the theranostic potential of nanoplatforms(Puttasiddaiah *et al*., 2025).

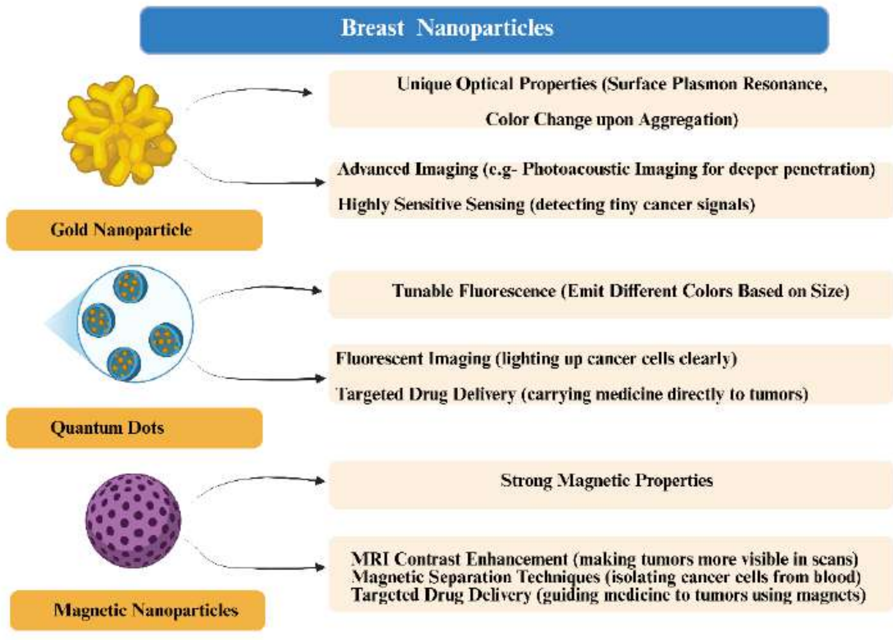

Figure 8.2. Key Nanomaterial Types and Their Role in Breast Cancer Diagnostics: This diagram details specific types of nanoparticles such as Gold Nanoparticles (AuNPs), Quantum Dots (QDs) and Magnetic Nanoparticles, highlighting their unique properties (e.g., optical, fluorescent, magnetic) and illustrating how these properties are precisely utilized for various diagnostic applications in breast cancer (Oehler, Rajapaksha, & Albrecht, 2024).

3.2 Mechanisms of Action in Nano diagnostics

Nanomaterials help in signal amplification, which makes it easier to detect very small amounts of cancer-related markers like microRNAs, exosomes or circulating tumor DNA (ctDNA)(Hussein, Al-Shammari, Alqaisy, & Mohsein, 2025). They can be customized to specifically bind to cancer biomarkers using antibodies, aptamers or other molecules(M. S. Khan, Gupta, Alsayari, Wahab, & Kesharwani, 2025). Additionally, nanomaterials support multi-modal detection, they can be used in various platforms like optical, magnetic or electrochemical systems which is allowing for more comprehensive diagnostic strategies(M. Liu *et al*., 2025).

3.3 Clinical Relevance and Advantages

Nanotechnology offers a significant leap forward in cancer diagnostics by enabling the detection of biomarkers at extremely low concentrations, often before phenotypic manifestation(M. Kumar *et al*., 2025). Many nano-enabled diagnostic systems can operate using non-invasive or minimally invasive methods, such as liquid biopsies that analyze blood, urine or saliva (Bhatti & Kaur, 2025). This adds advantage of reducing patient discomfort and enables repeated testing for ease in monitoring the disease progression. Further by linking these to digital health tools, it becomes easier for remote diagnostics and real-time data sharing with healthcare professionals (Ramachander & Gowri, 2025).

Integration of nanotechnology with digital health platforms makes nano diagnostics easier through transmission of real time data to healthcare providers making decision rapid with improved patient management. Furthermore, false positives or false negatives could be minimized with high specificity of functionalized nanomaterials. By tailoring nanoparticles personalized diagnostic solutions can also be achieved by detecting patient specific biomarkers. This aligns diagnostic methods with the principles of precision medicine.

3.4 Future Outlook

Advancements in material science, bioengineering and computational analysis may change the future of nanotechnology-based cancer diagnostics significantly in the coming years. Emerging trends include the development of multifunctional nanoplatforms capable of performing simultaneous diagnosis and targeted therapy known as theranostics. Such systems could allow clinicians to detect cancer, deliver treatment and monitor therapeutic outcomes in a single, integrated process.

In the near future, the combination of nano enabled diagnostics with artificial intelligence and machine learning will likely enhance pattern recognition, automate image interpretation and improve predictive modelling for patient risk assessment. Additionally, efforts are underway to make nanodiagnostic devices more portable, affordable and user friendly, which could significantly improve access to advanced cancer detection.

The upcoming sections will explore its application in liquid biopsy, biosensors and imaging technologies, highlighting how these innovations are improving the detection and management of breast cancer (Figure 8.3).

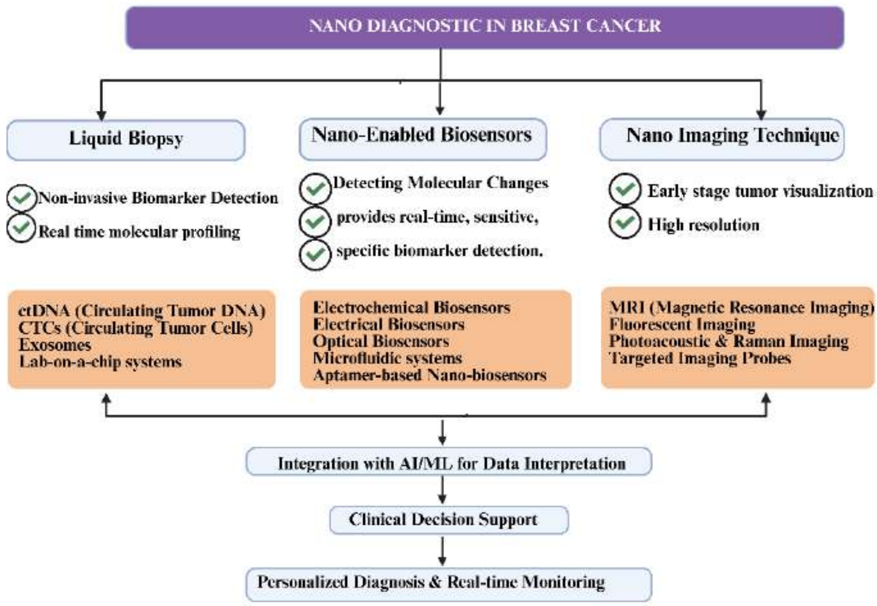

Figure 8.3. Key Pillars of Nano-Diagnostics in Breast Cancer: This diagram outlines the three primary categories of nano diagnostic technologies applied in breast cancer detection: Liquid Biopsy, Nano-Enabled Biosensors and Nano-Imaging Techniques. It highlights key sub-components and benefits of each, emphasizing their collective integration with AI/ML for data interpretation (Rudrangi *et al*., 2025).

4. Liquid Biopsy Powered by Nanotechnology

Liquid biopsy is a revolutionary diagnostic method that analyzes body fluids, mainly blood to detect cancer markers (Coppola *et al*., 2025). Unlike traditional tissue biopsy which is invasive and difficult to repeat, liquid biopsy offers a safe, non-invasive way to monitor cancer in real time(Qureshi *et al*., 2025). It helps detect various tumor-derived elements such as circulating tumor cells (CTCs), cell-free DNA (cfDNA), circulating tumor DNA (ctDNA), exosomes and microRNAs (Netti *et al*., 2025). These components provide valuable information about cancer presence, stage and progression (Figure 8.4; Table 8.2).

Nanotechnology significantly improves the sensitivity and accuracy of liquid biopsy techniques. Since tumor markers in blood are often found in very small quantities, they can be missed by standard tests especially during the early stages of cancer. Nanomaterials like gold nanoparticles, magnetic nanoparticles, graphene oxide and quantum dots are excellent tools for capturing these markers and amplifying their detection signals(Sadr, Hajjafari, *et al*., 2025).

4.1 Key Biomarkers and Nano-Enabled Detection Techniques

1. **Circulating Tumor DNA (ctDNA):**
   - ctDNA contains genetic mutations and epigenetic changes specific to tumors.
   - Gold nanoparticles are used to enhance PCR and electrochemical sensor techniques, making ctDNA detection more sensitive and faster (Kumari, Aiyar, & Dang, 2025).
2. **Circulating Tumor Cells (CTCs):**
   - These are rare cancer cells found in the bloodstream.
   - Magnetic nanoparticles coated with EpCAM antibodies help isolate CTCs effectively by binding specifically to these cells (Ma, Wang, Lin, & Lei, 2025).
3. **Exosomes and Extracellular Vesicles:**
   - Exosomes are small vesicles released by tumor cells that carry proteins, RNA and DNA.
   - Nanostructured surfaces like graphene oxide (GO)-coated chips allow efficient capture and analysis of these vesicles (Saghezi, Mansouri, & Hallaj, 2025).
4. **MicroRNAs (miRNAs):**
   - These are short, non-coding RNAs molecules which can regulate gene expression.
   - Nanotechnology-based tools like fluorescence detection and surface-enhanced Raman spectroscopy (SERS) are found useful for multiplexed microRNA analysis in cancer with high precision (Gupta *et al*., 2025).

4.2 Advantages of Nano-Liquid Biopsy

- Nano-enhanced liquid biopsy is minimally invasive that allows frequent testing in patients with ease.

- Real-time disease monitoring becomes easier by tracking tumor growth, recurrence and its response to the treatment.

- High sensitivity helps in early-stage cancers diagnosis before its symptoms arise.

- Esay identification of tumor heterogeneity is useful in personalized treatment.

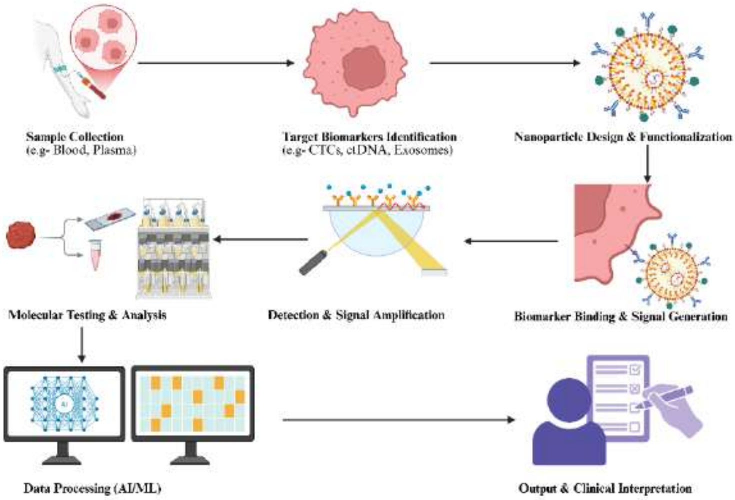

Figure 8.4. The Process of Nano-Enhanced Liquid Biopsy for Breast Cancer Detection: This diagram shows how nanoparticles are used to isolate and enrich circulating tumor DNA (ctDNA), circulating tumor cells (CTCs) and exosomes from a blood sample. Also shown in the figure is amplified signal detection, analysis and clinical interpretation for breast cancer (M. U. Khan *et al*., 2025).

Table 8.2: Nanomaterials in Liquid Biopsy Platforms

Biomarker Type	**Nanomaterial Used**	**Detection Technique**	**Advantages (Sadr, Rahdar, *et al*., 2025)**
ctDNA	Gold nanoparticles	PCR, Electrochemical sensors	High sensitivity, fast detection
CTCs	Magnetic nanoparticles	Immunomagnetic separation	Efficient cell capture
Exosomes	Graphene oxide surfaces	Microfluidic chip integration	Large surface area, label-free detection
miRNA	Quantum dots	Fluorescence-based detection	Multiplexing, stable signals

Several nano-liquid biopsy platforms are showing great promise in clinical trials. For instance, the Exo-Dx Prostate IntelliScore test has been successful in prostate cancer diagnosis & Similar technologies are being explored for breast cancer.

However, challenges remain:

- Standardization across laboratories

- Regulatory approvals from bodies like FDA
- Cost and accessibility in low-resource settings
- Integration into existing clinical workflows

Despite these challenges, the promise of nano-enabled liquid biopsy in revolutionizing breast cancer diagnostics holds enormous potential. Its ability to provide early, accurate and personalized insights hold the potential to transform patient outcomes.

5. Nano-Enabled Biosensors for Breast Cancer Detection

Biosensors are analytical devices that convert a biological response into a quantifiable signal(Goyal, Chauhan, Baliyan, & Singh, 2025). When integrated with nanotechnology, biosensors gain enhanced sensitivity, specificity and real-time detection capabilities(Rathore, Yadav, Suhag, & Thakur, 2025). These are making them valuable tools in breast cancer diagnostics. Nano-enabled biosensors can identify various breast cancer-related biomarkers such as DNA, RNA, proteins and even whole tumor cells from body fluids like blood, saliva or urine making them ideal for non-invasive diagnostics (Grasso *et al*., 2025) (Figure 8.5; Table 8.3).

5.1 Types of Nano-Biosensors

1. **Electrochemical Biosensors**:
   - These sensors detect electrical changes when a biomarker binds to a nanomaterial-coated electrode(Abul Rub *et al*., 2025).
   - Commonly used materials include gold nanoparticles and graphene.
   - They are affordable, portable, and provide high sensitivity, making them suitable for widespread clinical use.
2. **Optical Biosensors:**
   - These include surface plasmon resonance (SPR), fluorescence-based sensors, and surface-enhanced Raman scattering (SERS) techniques(Kamal Eddin *et al*., 2025).
   - Nanoparticles such as quantum dots and silver or gold nanostructures enhance signal strength and are used to detect important markers like HER2 and BRCA1(Sadr, Rahdar, *et al*., 2025).
3. **Piezoelectric Biosensors:**
   - These sensors work by detecting slight mass changes on a surface through the oscillation of crystals.
   - When combined with nanostructured coatings, they provide more surface area, leading to better sensitivity in detecting cancer-specific molecules(Aleixandre & Horrillo, 2025).
4. **Microfluidic and Lab-on-a-Chip Devices:**
   - These advanced platforms integrate biosensors with nanoscale channels to test very small sample volumes quickly and accurately.

➢ They are used in point-of-care (POC) settings and allow rapid screening of breast cancer markers outside traditional lab environments.

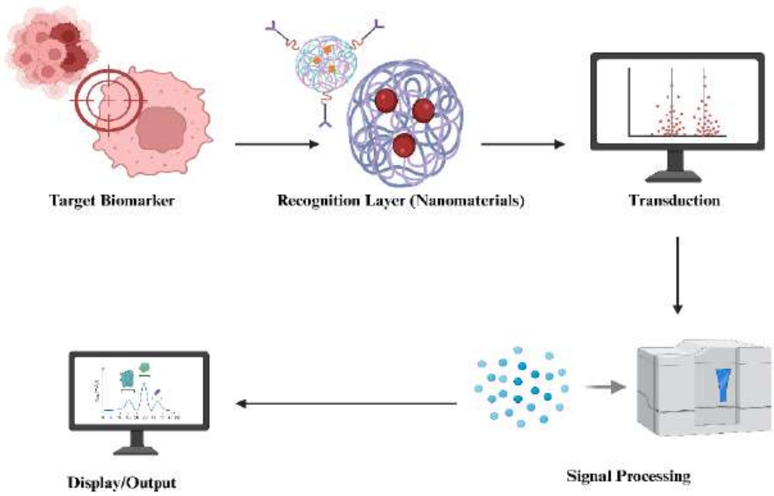

Figure 8.5. Core Components and Mechanism of a Nano-Enabled Biosensor: A target biomarker interacts with a recognition layer (often functionalized with nanomaterials), generating a signal. The signal is then converted by a transducer, processed and displayed as an output indicating the presence of the biomarker (Grasso *et al*., 2025).

5.2 Applications in Breast Cancer Detection

1. Detection of Key Biomarkers:

➢ Nano biosensors can identufy breast cancer biomarkers such as HER2, CA 15-3 and BRCA1/2 mutations (Kudreyeva *et al*., 2025).

2. Real Time Monitoring:

➢ By continuously tracking circulating proteins, tumor derived DNA or exosomes in body fluids, nano-biosensors provide real time insights into tumor activity. This is useful for assessment of disease progression or treatment response without the intervention for invasive procedures.

3. Multiplexed Detection:

➢ Simultaneous detection of multiple biomarkers is one of the unique advantages of nano biosensors. It is a multiplexing capability that could differentiate between cancer subtypes within a single test, useful for personalized treatment strategies.

4. **Minimally Invasive Testing:**

   - Nano biosensors can analyze biomarkers from blood, urine or saliva. This adds to reduction in patient discomfort compared to biopsies and frequent monitoring throughout the treatment cycle.

5. **Early Diagnosis and Prognosis:**

   - Biomarkers detection of at very low concentrations due to high sensitivity of nanomaterials makes it possible to identify cancer at an earlier stage leading to improved prognosis and better clinical outcomes.

Table 8.3: Types of Nano-Enabled Biosensors for Breast Cancer Detection: Target Biomarkers, Sensitivity and Applications

Sensor Type	**Nanomaterial Used**	**Target Biomarker**	**Sensitivity (LOD)**	**Application (Khajuria *et al.*, 2024)**
Electrochemical	Gold nanoparticles	HER2, CA15-3	pg/mL to fg/mL	Serum analysis
Optical (SPR/SERS)	Silver nanoparticles	BRCA1, miRNA-21	Attomolar range	Genetic screening
Microfluidic Chip	Graphene oxide	CTCs, Exosomes	~90% capture rate	Point-of-care testing

5.3 Clinical Relevance and Limitations

High sensitivity and rapid analysis of nano enabled biosensors represent a promising advancement in breast cancer diagnostics. Their ease of use, portability and cost effectiveness make them particularly valuable in low resource settings, where access to advanced diagnostic infrastructure is limited. Irrespective of point of care e.g.big hospital set up to home-based settings, biomarker identification at an early stage is advantageous in taking timely clinical decisions and improve patient outcomes.

However, biomarker identification-based approaches are associated with some challenges like long term sensor stability under varying environmental conditions, achieving reproducible results across different devices or batches and developing scalable manufacturing processes without compromising quality. These challenges must be addressed in whole before its successful integration into healthcare systems. Further, it requires rigorous regulatory approvals, clinical validation and adequate training for end users to ensure accuracy and reliability.

Overall, nano enabled biosensors are poised to play a transformative role in breast cancer screening and monitoring, bridging the gap between cutting edge nanotechnology and practical, accessible healthcare solutions.

6. Nano-Imaging Techniques in Breast Cancer

Imaging remains essential in breast cancer diagnosis, staging and treatment planning. Nanotechnology has significantly enhanced the capabilities of imaging systems by enabling better contrast, targeted delivery and real-time monitoring. Nano-imaging agents can accumulate specifically in tumor tissues which allows for high-resolution visualization and functional imaging (Figure 8.6; Table 8.4).

6.1 Common Nano-Enabled Imaging Modalities

1. **Magnetic Resonance Imaging (MRI):**
    - ➢ Uses superparamagnetic iron oxide nanoparticles (SPIONs) to enhance image contrast and accuracy(Moeini *et al*., 2025).
2. **Positron Emission Tomography (PET):**
    - ➢ Involves radiolabeled nanoparticles to detect specific tumor receptors at the molecular level(Pires, Filho, Nunes, Junior, & Mathis, 2025).
3. **Photoacoustic Imaging:**
    - ➢ Uses gold nanorods that convert light into sound, enabling deep tissue, high-resolution imaging(Barlow & Kim, 2025).
4. **Near-Infrared (NIR) Fluorescence Imaging:**
    - ➢ Uses quantum dots or carbon dots to provide bright and stable signals for early tumor detection(Gao *et al*., 2025).

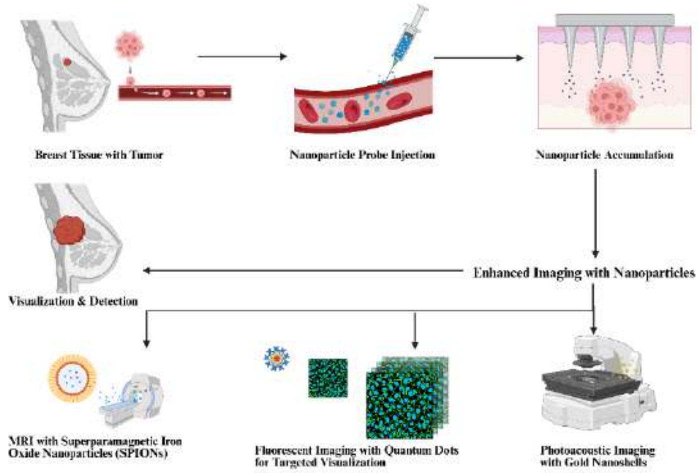

Figure 8.6. Nanoparticle-Enhanced Imaging Workflow for Breast Cancer Detection: This figure illustrates the workflow of using nanoparticles to enhance imaging in breast cancer diagnostics. Starting from the identification of a breast tumor, nanoparticle probes are injected into the bloodstream, where they accumulate in the tumor site. This targeted accumulation allows for enhanced imaging using various nanoparticle-based techniques such as MRI with Superparamagnetic Iron Oxide Nanoparticles (SPIONs), Fluorescent Imaging with Quantum Dots, and Photoacoustic Imaging with Gold Nano shells, ultimately improving tumor visualization and detection (Chow, 2025).

Table 8.4: Nanoparticles Used in Breast Cancer Imaging

Imaging Modality	**Nanoparticle Used**	**Target Application**	**Advantages (Oehler *et al*., 2024)**
MRI	SPIONs	Tumor boundary visualization	High resolution, biocompatible
PET	Radio labelled gold NPs	HER2 receptor mapping	Molecular-level detection
NIR Fluorescence	Quantum dots	Tumor localization	Long-term imaging, multiplexing
Photoacoustic	Gold nanorods	Deep tissue lesion detection	Non-invasive, high contrast

6.2 Clinical Application and Future Prospects

Nano enabled imaging technologies are transforming breast cancer diagnostics by offering high resolution, targeted and real time visualization. When integrated into theranostic platforms, they allow simultaneous tumor detection and targeted therapy, enabling more precise and personalized treatment(Gattu, Somvanshi, & Thorat, 2025).

Functionalized nanoparticles can selectively bind to tumor specific biomarkers, improving early detection, accurate tumor boundary mapping and real time monitoring of treatment response.

In clinical practice, these advances promise earlier diagnosis, better treatment planning and improved patient follow up. The future lies in combining nano imaging agents with artificial intelligence for faster, more accurate interpretation, potentially automating tumor detection and enhancing precision oncology. However, safety, large scale manufacturing and regulatory approval remain challenges that must be addressed. With continued research and validation nano imaging could soon become a standard tool in breast cancer management.

Looking to the future, innovations in nanomaterial design, multimodal imaging probes and AI assisted diagnostics are poised to push nano enabled imaging beyond the research phase into everyday clinical workflows. If these developments align with safety and regulatory standards, they have the potential to transform breast cancer management into a more precise, targeted and patient centered discipline.

7. Translating Nano diagnostics from Lab Innovation to Clinical Application

Nano diagnostic tools have emerged as powerful platforms in early cancer detection and monitoring(Nasir *et al.*, 2021). However, their clinical translation from laboratory innovation to bedside application remains complex due to several interlinked factors:

- **Standardization Gaps**: Currently, there is no universally accepted guideline for the synthesis, surface functionalization or physicochemical characterization of nanoparticles. This variation leads to inconsistent results across laboratories, limiting reproducibility and cross-validation.
- **Regulatory and Safety Hurdles**: Regulatory agencies such as the FDA and EMA demand extensive data on biocompatibility, toxicity, long-term safety and environmental impact(P. Kumar, Singh, & Kush, 2024). Very few nanoparticle-based diagnostics have gained clinical approval due to the high burden of proof and evolving regulatory frameworks for nanomedicine.
- **Scalability and Manufacturing Challenges**: Scaling up nanoparticle production from bench-scale to commercial levels is often hindered by high costs, difficulty in maintaining uniformity.
- **Clinical Trial Limitations**: Most studies on nano diagnostics are limited to small cohorts or animal models. There is an urgent need for multi-centre, double-blind, randomized clinical trials involving diverse patient populations to assess real-world efficacy and safety.
- **Bio-distribution and Clearance**: Understanding how nanoparticles behave in the human body like how they are distributed, metabolized and excreted is crucial(Negi, Yadav, Upadhye, Jain, & Berdimurodov, 2025). Unpredictable

interactions with the immune system or unintended accumulation in non-target tissues can compromise safety.

- **Patient Acceptance and Ethical Considerations**: Public awareness and perception about nanotechnology in healthcare can influence adoption. Transparent communication and addressing ethical concerns are necessary for smooth clinical integration.

Despite these obstacles, continuous advancements in material science, regulatory science and clinical pharmacology coupled with active partnerships between academia, biotech firms and health authorities. The goal is to make nano diagnostics a routine and safe component of personalized cancer management in the near future.

8. Emerging Next-Gen Diagnostics in Breast Cancer Diagnostics

The future of breast cancer diagnostics is shifting beyond the confines of traditional hospital based testing, moving toward a model of continuous, personalized and patient centered care (Sharma, White, Appavoo, & Yong-Hing, 2024). With rapid progress in nanotechnology, artificial intelligence (AI) and remote health monitoring, cancer detection is becoming faster, more accurate and accessible outside conventional clinical environments(Chugh, Basu, Kaushik, Bhansali, & Basu, 2024).

Nano enabled devices can capture disease signals at very early stages, while AI driven tools assist in interpreting complex diagnostic data with greater precision. In parallel, remote monitoring platforms and wearable technologies allow real time tracking of patient health, enabling proactive interventions rather than delayed responses. Together, these innovations are reshaping not only the timing and methods of detection but also the overall delivery of cancer care, making it more preventive, responsive and tailored to individual patient needs (Figure 8.7).

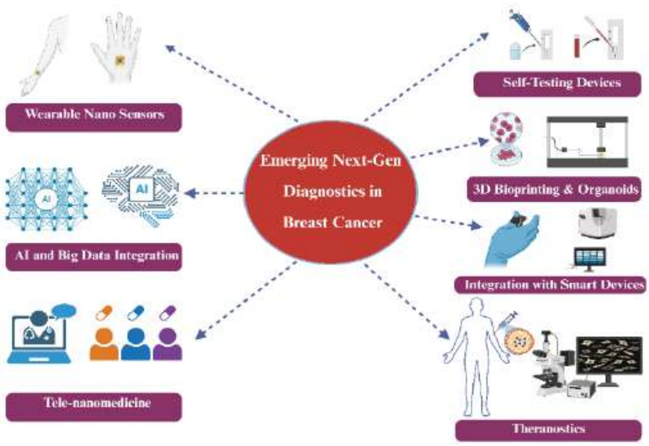

Figure 8.7. Next-Generation Diagnostics for Personalized Breast Cancer Care: This diagram illustrates the exciting future of breast cancer diagnostics, moving towards a

patient-centered and continuous care model. It highlights how cutting-edge innovations including wearable nano sensors, AI-driven data analysis, remote tele-nanomedicine, all-in-one theranostics, self-testing devices, smart device integration and 3D bioprinting for personalized testing are transforming detection and management. By enabling non-invasive, precise and real-time insights, these technologies promise earlier diagnosis and more effective, tailored treatments & shaping the way for truly personalized breast cancer care (Parvin, Joo, Jung, & Mandal, 2025).

8.1 Key Innovations on the Horizon

- **Wearable Nano sensors**
  Small, flexible devices integrated into clothing, watches or skin patches can continuously monitor body fluids like sweat or interstitial fluid to detect cancer-related biomarkers in real-time(Coskun, Savas, Can, & Lippi, 2025). These sensors promise early warnings even before symptoms appear.

- **AI and Big Data Integration**
  Artificial Intelligence (AI) combined with nano diagnostics helps analyze large sets of patient data. AI models can identify patterns, predict cancer risk and suggest personalized diagnostic pathways, reducing time and error in decision-making(Alum, 2025).
- **Tele-nanomedicine**
  With the rise of telemedicine diagnostic data collected from nano sensors can be transmitted instantly to healthcare professionals(Anthony & Monroe, 2025). This makes it easier to monitor patients remotely, especially in rural or underdeveloped areas with limited access to hospitals.
- **Theranostics (Therapy + Diagnostics)**
  In Theranostics, a single nanoparticle acts both as a diagnostic agent and a drug delivery system(Mahammad, Akbar, & Mukhtar, 2025). It can detect cancer cells, deliver drugs specifically to those cells and track treatment effectiveness. These brings all in one system which improves the precision and reducing side effects.
- **Self-Testing-Devices**
  Portable nano diagnostic kits are under development to enable patients to test themselves at home especially for follow-up care and recurrence monitoring.
- **Integration-with-Smart-Devices**
  Future smartphones may have the ability to connect with nano based biosensors to track changes in body chemistry, upload data and even give alerts when abnormal patterns are detected.
- **3D Bioprinting & Organoids for Personalized Testing**
  With patient-derived tumor models, nano-enabled diagnostic tools can be tested on lab-grown tissues or organoids, enabling more precise prediction of treatment responses(Xu *et al.*, 2024).

These advancements aim to empower patients and clinicians with tools for early intervention and precision care.

Conclusion

Nano-diagnostics marks a groundbreaking shift in how breast cancer is detected, monitored, and managed. By harnessing the unique properties of nanomaterials-such as their small size, surface versatility, and ability to interact at the molecular level-these tools offer superior sensitivity and specificity compared to traditional diagnostic methods. Few innovations like liquid biopsies, nano-enabled biosensors, targeted imaging probes, and wearable nanosensors empowering the health professionals to detect cancer at earlier stages before the appearance of symptoms. Today real-time monitoring of treatment response and understanding the disease progression is only possible due to advancement in these techniques paving the way for personalized, non-invasive, and patient-centric care. However, the journey from the laboratory to the clinic is quite challenging. Rigorous standardization, large-scale manufacturing, cost-effectiveness, and regulatory approval are still need to be addressed. Moreover, long-term safety data and clinical validation through multicentric trials are prudent prior to widespread adoption. In future, the integration of artificial intelligence with nano diagnostics can further enhance diagnostic accuracy with automated data interpretation leading to minimal human error. With sustained research funding, interdisciplinary collaboration and supportive regulatory pathways, nano-diagnostics holds the potential to drastically improve patient outcomes, reduce healthcare burdens and transform breast cancer care into a more proactive and preventive model. By merging nanotechnology with modern diagnostic tools, they provide unmatched sensitivity, specificity and versatility. From liquid biopsy and biosensors to imaging and wearable devices, these advances are moving cancer detection toward real-time, personalized and patient-focused care. It is not far from reality that Nano diagnostics could mark a paradigm shift in breast cancer detection and management.

Acknowledgement
The authors would like to express their sincere gratitude to *Deep Science Publisher* and the editorial team of this book for their invaluable support in the final publication process and for providing the opportunity to contribute to this esteemed volume.
Conflicts of Interest
The authors declare that there are no conflicts of interest related to this work.
Funding Source
No funding was received for the preparation of this book chapter.
Author Contribution
All authors have contributed equally to the conception, preparation, and completion of this book chapter.

References

Abul Rub, F., Moursy, N., Alhedeithy, N., Mohamed, J., Ifthikar, Z., Elahi, M. A., . . . Alabudahash, M. (2025). Modern emerging biosensing methodologies for the early diagnosis and screening of ovarian cancer. *Biosensors, 15*(4), 203.

Ahmad, A., Imran, M., & Ahsan, H. (2023). Biomarkers as biomedical bioindicators: approaches and techniques for the detection, analysis, and validation of novel biomarkers of diseases. *Pharmaceutics, 15*(6), 1630.

Aleixandre, M., & Horrillo, M. C. (2025). Recent Advances in SAW Sensors for Detection of Cancer Biomarkers. *Biosensors, 15*(2), 88.

Alrumaihi, F. (2025). Role of Liquid Biopsy for Early Detection, Prognosis, and Therapeutic Monitoring of Hepatocellular Carcinoma. *Diagnostics, 15*(13), 1655.

Alum, E. U. (2025). AI-driven biomarker discovery: enhancing precision in cancer diagnosis and prognosis. *Discover Oncology, 16*(1), 1-12.

Anthony, O., & Monroe, M. (2025). Development of Smart Wearable Devices Utilizing AI, IoT, and Nanotechnology for Continuous Health Monitoring and Early Disease Detection in Patients.

Balali, G. I. (2020). Breast cancer: a review of mammography and clinical breast examination for early detection of cancer. *Open Access Library Journal, 7*(10), 1.

Barlow, B. R., & Kim, J. (2025). Next generation gold nanomaterials for photoacoustic imaging. *Nanomedicine, 20*(12), 1479-1493.

Bhatti, E., & Kaur, P. (2025). Advances in sensor technologies for breast cancer detection: a comprehensive review of imaging and non-imaging approaches. *Discover Artificial Intelligence, 5*(1), 1-16.

Bray, F., Laversanne, M., Sung, H., Ferlay, J., Siegel, R. L., Soerjomataram, I., & Jemal, A. (2024). Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA: a cancer journal for clinicians, 74*(3), 229-263.

Cerdas, M. G., Farhat, J., Elshafie, S. I., Mariyam, F., James, L., Qureshi, A. K., . . . Abraham, G. (2025). Exploring the Evolution of Breast Cancer Imaging: A Review of Conventional and Emerging Modalities. *Cureus, 17*(4).

Chaudhari, R., Patel, V., & Kumar, A. (2024). Cutting-edge approaches for targeted drug delivery in breast cancer: beyond conventional therapies. *Nanoscale Advances, 6*(9), 2270-2286.

Chow, J. C. (2025). Nanomaterial-based molecular imaging in cancer: advances in simulation and AI integration. *Biomolecules, 15*(3), 444.

Chugh, V., Basu, A., Kaushik, A., Bhansali, S., & Basu, A. K. (2024). Employing nano-enabled artificial intelligence (AI)-based smart technologies for prediction, screening, and detection of cancer. *Nanoscale, 16*(11), 5458-5486.

Coppola, C. A., De Summa, S., Matera, G., Pilato, B., Traversa, D., & Tommasi, S. (2025). Liquid Biopsy: The Challenges of a Revolutionary Approach in Oncology. *International Journal of Molecular Sciences, 26*(11), 5013.

Coskun, A., Savas, I. N., Can, O., & Lippi, G. (2025). From population-based to personalized laboratory medicine: continuous monitoring of individual laboratory data with wearable biosensors. *Critical Reviews in Clinical Laboratory Sciences, 62*(3), 198-227.

Danciulescu, D., Jude, A., & Manoj, M. (2024). Computational techniques for analysis of breast cancer using molecular breast imaging *Computational Intelligence and Modelling Techniques for Disease Detection in Mammogram Images* (pp. 203-234): Elsevier.

Dinari, A., Ahmad, H. A., Oh, S., Kim, Y.-H., & Yoon, J. (2025). Advanced Detection of Pancreatic Cancer Circulating Tumor Cells Using Biomarkers and Magnetic Particle Spectroscopy. *Nanotheranostics, 9*(2), 171.

Farshi, Z. S., Bayat, F., Chaghamirzaei, P., Jawad, M., & Amani-Ghadim, A. R. (2025). Effect of Au nanoparticles' arrangement on melamine detection sensitivity in localized surface plasmon resonance sensors. *Microchemical Journal, 208*, 112532.

Freitas, V. (2025). Optimizing breast MRI diagnosis: the Kaiser Score's impact on reducing unnecessary biopsies. *European Radiology, 35*(3), 1502-1503.

Gao, Y., Zhang, C., Zhu, L., Du, Z., Ma, R., Guo, L., . . . Zhang, X. (2025). Ultrabright quantum dots assisted in vivo NIR-II fluorescence microscopic imaging for brain metastases in triple-negative breast cancer. *Journal of Innovative Optical Health Sciences, 18*(03), 2441001.

Gattu, K. P., Somvanshi, S. B., & Thorat, N. D. (2025). Introduction to nanoplatform-based biomedical imaging *Nanoplatforms for Cancer Imaging* (pp. 1-1-1-27): IOP Publishing Bristol, UK.

Goyal, S., Chauhan, S., Baliyan, D., & Singh, B. (2025). Advances in Breast Cancer Detection: Biomarkers, Mechanisms, and Biosensor Technologies. *Critical Reviews in Analytical Chemistry*, 1-32.

Grasso, A., Altomare, V., Fiorini, G., Zompanti, A., Pennazza, G., & Santonico, M. (2025). Innovative Methodologies for the Early Detection of Breast Cancer: A Review Categorized by Target Biological Samples. *Biosensors, 15*(4), 257.

Gravante, G., De Simone, V., Sorge, R., La Torre, M., D'Andrea, V., Romano, S., & Gallo, G. (2025). Transperineal ultrasound in hemorrhoidal disease: pioneering the unseen. *International Journal of Colorectal Disease, 40*(1), 138.

Gupta, S., Mishra, V., Aljabali, A. A., Albutti, A., Kanday, R., El-Tanani, M., & Mishra, Y. (2025). Breaking barriers in cancer diagnosis: unveiling the 4Ms of biosensors. *RSC advances, 15*(10), 8019-8052.

Hasi, S. N., Tabassum, S., Arny, R. T., Pervin, M. D., Hossain, M. G., Hasan, F., & Kibria, M. K. (2025). Breast Cancer Knowledge and Self-Examination Practices Among University Female Students in Dinajpur, Bangladesh: A Cross-Sectional Study. *Health Science Reports, 8*(7), e71048.

Hirsch, L., Huang, Y., Makse, H. A., Martinez, D. F., Hughes, M., Eskreis-Winkler, S., . . . Sutton, E. J. (2025). Early detection of breast cancer in MRI using AI. *Academic radiology, 32*(3), 1218-1225.

Hussein, A. D., Al-Shammari, M., Alqaisy, M. R. K., & Mohsein, O. A. (2025). Emerging biomarkers in cancer detection and prognosis: A comprehensive review. *International Journal of Immunology, 7*(1), 01-12.

Kamal Eddin, F. B., Fan, H., Liu, Z., Donati, P., Amin, Y., Fen, Y. W., . . . He, S. (2025). Progress in Surface Plasmon and Other Resonance Biosensors for Biomedical Applications. *Advanced Materials Technologies*, 2500536.

Khajuria, A., Alajangi, H., Singh, J., Passi, G., Barnwal, R. P., Singh, G., & Kaur, I. P. (2024). Applications of Nanotechnology in Converging the Biomarker Science for Advancement in

Cancer Detection and Treatment *Handbook of Oncobiology: From Basic to Clinical Sciences* (pp. 1495-1524): Springer.

Khan, M. S., Gupta, G., Alsayari, A., Wahab, S., & Kesharwani, P. (2025). Harnessing MUC1 aptamer-targeted nanoparticles for precision medicine in breast cancer. *International Journal of Pharmaceutics*, 125721.

Khan, M. U., Khawar, A., Ullah, M. I., Shan, M. A., Falzone, L., Libra, M., . . . Calina, D. (2025). Liquid biopsy in breast cancer: clinical implications of ctDNA and CTCs in diagnosis, treatment and monitoring. *Molecular and Cellular Biochemistry*, 1-15.

Khan, W. S., Asmatulu, E., & Asmatulu, R. (2025). Nanotechnology emerging trends, markets and concerns *Nanotechnology safety* (pp. 1-21): Elsevier.

Kim, J., Harper, A., McCormack, V., Sung, H., Houssami, N., Morgan, E., . . . Fidler-Benaoudia, M. M. (2025). Global patterns and trends in breast cancer incidence and mortality across 185 countries. *Nature Medicine*, 1-9.

Kudreyeva, L., Kanysh, F., Sarsenbayeva, A., Abu, M., Kamysbayev, D., & Kedelbayeva, K. (2025). HER-2-Targeted Electrochemical Sensors for Breast Cancer Diagnosis: Basic Principles, Recent Advancements, and Challenges. *Biosensors, 15*(4), 210.

Kumar, M., Sahu, S., Verma, A., Kumar, N., Yadav, G., & Singh, A. P. (2025). Emerging Imaging Modalities for Early Cancer Detection: A Review.

Kumar, P., Singh, R., & Kush, P. (2024). Biocompatibility, toxicity concerns, environmental and safety considerations, and legal aspects of functionalized magnetic nanoparticles. *Functionalized magnetic nanoparticles for theranostic applications*, 533-558.

Kumari, P., Aiyar, A., & Dang, S. (2025). Liquid Biopsy-Based Smart Sensors for Ovarian Cancer Detection. *Critical Reviews in Analytical Chemistry*, 1-16.

Liu, C., Sun, L., Niu, N., Hou, P., Chen, G., Wang, H., . . . Zhao, Y. (2025). Molecular classification of hormone receptor-positive/HER2-positive breast cancer reveals potential neoadjuvant therapeutic strategies. *Signal Transduction and Targeted Therapy, 10*(1), 97.

Liu, M., Wang, Y., Li, Y., Zhang, Y., Zhou, B., Yang, L., . . . Yang, L. (2025). Beyond Conventional Approaches: The Revolutionary Role of Nanoparticles in Breast Cancer. *MedComm–Biomaterials and Applications, 4*(2), e70012.

Ma, S., Wang, X., Lin, P. P., & Lei, L. (2025). Circulating Tumor Cell Detection for Therapeutic and Prognostic Roles in Breast Cancer. *Cancer Medicine, 14*(11), e70902.

Mahammad, A., Akbar, I., & Mukhtar, S. (2025). Theranostic Application of Smart Nanomaterials in Target Drug Delivery *Smart Nanosensors* (pp. 25-54): Springer.

Malik, S., Muhammad, K., & Waheed, Y. (2023). Emerging applications of nanotechnology in healthcare and medicine. *Molecules, 28*(18), 6624.

Moeini, A., Ghiasi, A., Abadi, M. D. M., Khachatourian, A. M., Hosseini, H. R. M., & Malek, M. (2025). Zn-doped superparamagnetic iron oxide nanoparticles–LCysteine functionalized@ N-doped graphene quantum dots as multifunctional contrast agents for dual-model imaging (MRI & FI). *Materials & Design*, 114269.

Nasir, A., Khan, A., Li, J., Naeem, M., Khalil, A. A., Khan, K., & Qasim, M. (2021). Nanotechnology, a tool for diagnostics and treatment of cancer. *Current topics in medicinal chemistry, 21*(15), 1360-1376.

Negi, R., Yadav, R., Upadhye, V. J., Jain, B., & Berdimurodov, E. (2025). Design and Movements of Drug in Human Metabolism by Multifunctional Magnetic Nanoparticles

Multifunctional Magnetic Nanoparticles in Therapy, Biology, and Pharmacy (pp. 92-113): CRC Press.

Netti, G. S., De Luca, F., Camporeale, V., Khalid, J., Leccese, G., Troise, D., . . . Ranieri, E. (2025). Liquid Biopsy as a New Tool for Diagnosis and Monitoring in Renal Cell Carcinoma. *Cancers, 17*(9), 1442.

Oehler, J. B., Rajapaksha, W., & Albrecht, H. (2024). Emerging applications of nanoparticles in the diagnosis and treatment of breast cancer. *Journal of personalized medicine, 14*(7), 723.

Ozbey, S., Keles, G., & Kurbanoglu, S. (2025). Innovations in graphene-based electrochemical biosensors in healthcare applications. *Microchimica Acta, 192*(5), 290.

Pandey, S. N., Afzal, M., Goyal, A., Priya, G. P., Mohanty, B., Goyal, K., . . . Imran, M. (2025). Quantum dot biosensors for Glioblastoma: Merging nanotechnology with precision oncology. *Inorganic Chemistry Communications*, 114671.

Parvin, N., Joo, S. W., Jung, J. H., & Mandal, T. K. (2025). Multimodal AI in Biomedicine: Pioneering the Future of Biomaterials, Diagnostics, and Personalized Healthcare. *Nanomaterials, 15*(12), 895.

Pires, I. C., Filho, I. A., Nunes, C. T., Junior, S. A., & Mathis, J. M. (2025). Mesoporous silica nanoparticles for breast cancer theranostics: advances in imaging and therapy. *Journal of Nanoparticle Research, 27*(7), 181.

Puttasiddaiah, R., Basavegowda, N., Lakshmanagowda, N. K., Raghavendra, V. B., Sagar, N., Sridhar, K., . . . Sharma, M. (2025). Emerging nanoparticle-based diagnostics and therapeutics for cancer: innovations and challenges. *Pharmaceutics, 17*(1), 70.

Qureshi, Z., Altaf, F., Khanzada, M., Safi, A., Asghar, Z., Warraich, D., & Shah, S. (2025). Liquid biopsies for early detection and monitoring of cancer: advances, challenges, and future directions. *Annals of Medicine and Surgery, 87*(6), 3244-3253.

Ramachander, A., & Gowri, D. P. (2025). The future of digital health in transforming healthcare *Digital Technology in Public Health and Rehabilitation Care* (pp. 363-385): Elsevier.

Rathore, R., Yadav, A., Suhag, D., & Thakur, A. (2025). Nanoscale Biosensors for Diagnostics *Advancements in Nanobiology* (pp. 87-104): CRC Press.

Rehman, F. (2024). Early Detection of Breast Cancer: Innovative Screening Methods. *Health and Medical Discoveries, 1*(02), 50-72.

Rudrangi, S. R. S., Basavaraj, H., Pawar, A. K., Rajendran, S. P., Velaga, V. A. R., & Tiwari, G. (2025). An overview of nanotherapeutics and nanodiagnostics. *Applications of Nanotherapeutics and Nanotheranostics in Managing Infectious Diseases*, 19-40.

Sadr, S., Hajjafari, A., Sazmand, A., Santucciu, C., Masala, G., Soroushianfar, M., . . . Guettari, M. (2025). Nanobiosensors for revolutionizing parasitic infections diagnosis: a critical review to improve global health with an update on future challenges prospect. *European Journal of Medical Research, 30*(1), 484.

Sadr, S., Rahdar, A., Pandey, S., Hajjafari, A., Soroushianfar, M., Sepahvand, H., . . . Borji, H. (2025). Revolutionizing cancer detection: harnessing quantum dots and graphene-based nanobiosensors for lung and breast cancer diagnosis. *BioNanoScience, 15*(1), 111.

Saghezi, B. V., Mansouri, K., & Hallaj, R. (2025). Microfluidic systems in cancer diagnosis: advancing exosome and CTC detection from laboratory research to clinical application. *Nano Select*, e202400108.

Salaudeen, H. D., & Akinniranye, R. D. (2024). Precision nanotechnology for early cancer detection and biomarker identification. *International Journal of Research Publication and Reviews, 5*(11), 6313-6327.

Sharma, S., White, C., Appavoo, S., & Yong-Hing, C. J. (2024). Optimizing patient-centered care in breast imaging: strategies for improving patient experience. *Academic radiology, 31*(10), 3889-3897.

Takahashi, S. (2025). Non-contrast MRI and Contrast-Enhanced MRI *MRI and CT for Decision-Making in Obstetrics and Gynecology Practice* (pp. 15-25): Springer.

Termite, F., Galasso, L., Capece, G., Messina, F., Esposto, G., Ainora, M. E., . . . Maccauro, G. (2025). Multiparametric Ultrasound in the Differential Diagnosis of Soft Tissue Tumors: A Comprehensive Review. *Biomedicines, 13*(7), 1786.

Theivendren, P., Narayanasamy, P., Chidamabaram, K., Menon, S., Sahayaraj, J. A. D. A., Kiruthiga, N., & Pandiyan, B. (2025). In-Depth Review of Breast Cancer and Inflammation Pre-and Post-Treatment Strategies with Conventional and Novel Steroid Agents. *Advances in Biological Regulation*, 101102.

Tiwari, A., Mishra, S., & Kuo, T.-R. (2025). Current AI technologies in cancer diagnostics and treatment. *Molecular Cancer, 24*(1), 159.

Xu, B., Liu, L.-H., Lin, H., Zhang, Y., Huang, Y., He, Q., . . . Jiang, A. (2024). A cell-free bacteriophage synthesis system for directed evolution. *Trends in Biotechnology*.

Zhang, S., Jin, Z., Bao, L., & Shu, P. (2024). The global burden of breast cancer in women from 1990 to 2030: assessment and projection based on the global burden of disease study 2019. *Frontiers in oncology, 14*, 1364397.

Zubair, M., Wang, S., & Ali, N. (2021). Advanced approaches to breast cancer classification and diagnosis. *Frontiers in Pharmacology, 11*, 632079.