Chapter 51

Innovative Nanomaterials: Applications and Challenges in Molecular Diagnostics

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ABSTRACT

The field of molecular diagnostics has been revolutionized by nanotechnology as it has provided an opportunity to get precise detection and monitoring of diseases at the molecular level. This book chapter aims to highlight the applications of innovative nanomaterials, while also addressing the limitations and challenges encountered in their implications. Fundamental principles of nanomaterials along with their unique properties are discussed. Various nanomaterials such as quantum dots, gold nanoparticles, and carbon nanotubes are explored with an elucidation of their specific role and functions in diagnostic assays. They have a vast range of applications in nucleic acid detection, protein biomarker analysis, and imaging techniques. Nanomaterials enhance sensitivity, specificity, and multiplexing capabilities. Thus, they have revolutionized disease detection and monitoring. Alongside the advancements in molecular diagnostics due to nanotechnology, issues such as biocompatibility, toxicity, scalability, and reproducibility are thoroughly examined, providing an insight into the current hurdles hindering widespread adoption. Thus, a comprehensive overview of innovative nanomaterials will be provided driving advancements in molecular diagnostics. It will provide a better understanding to researchers and practitioners about the challenges and inherent potential of using nanotechnology for molecular diagnosis.

KEYWORDS		
Molecular diagnostics, Nanotechnology, Nanoparticles, Diagnostic assays, Biomarkers	Received: 21-Jun-2024 Revised: 28-Jul-2024 Accepted: 19-Aug-2024	A Publication of Unique Scientific Publishers

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INTRODUCTION

Molecular diagnostics is a part of a clinical laboratory that includes tests and methods involved in the identification of disease. Advancements in molecular diagnostics have enabled basic research and better results in diagnostics. Still, the use of molecular diagnostics can be improved beyond current nucleic acid testing. Overall, molecular diagnostics has a role in public health, medicine, the pharmaceutical industry, forensics, drug discovery, and biological warfare (Nishonov and Nuriddinova, 2022).

Due to nanotechnology, the limits of molecular diagnostics have been extended to the nanoscale. This increase in precision has improved the flexibility and sensitivity of tests. Each type of nanomaterial has its functions in diagnostics. Magnetic nanomaterials are bound to suitable antibodies and then can be used in labeling specific molecules, microorganisms, or structures. Gold nanomaterials are used for the detection of genetic sequences in a sample by tagging them with short sequences of DNA. Similarly, quantum dots are involved in multicolor optical coding for biological assays. Developments in nanoengineering have increased the use of nanostructures in biosensors. Different types of nanostructures including 0D, 1D, and 2D are being used to enhance sensitivity, selectivity, time, and limit of detection in biosensors (Welch et al., 2021).

Fundamentals of Nanomaterials in Molecular Diagnostics

Nanomaterials are a group of small-scale substances having structural components less than 1 μm in at least one dimension. They can be categorized into three types based on their source which include: natural, incidental, or engineered. They can be single, fused, aggregated, or agglomerated having tubular, spherical, or irregular shapes.

Nanomaterials can have a natural origin, but engineered nanomaterials are of more interest as they are used in many processes and commercial goods. They are present in cosmetics, sunscreens, electronics, stain-resistant clothing, and medicines etc. (Mohd-Setapar et al., 2022).

Types of Nanomaterials

Nanomaterials can be divided into various types. Based on their applications in molecular diagnostics, they have the following types.

Quantum Dots

These are semiconductor crystals and were first discovered by a Russian physicist. Quantum dots are composed of groups II-VI or III-V elements of the periodic table. They have physical dimensions smaller than the Bohr radius of exciton (Kargozar et al., 2020). They have unique characteristics of sensitivity and selectivity when used in nano-sized particles. They also possess unique optical properties which enhance their widespread use in biomedical applications. For example, an exhibition of strong and long-lived photoluminescence emission makes it suitable as a luminescent dye having biomedical applications such as biomarker quantification, molecular imaging, and biomolecule targeting (Soldado et al., 2022).

Metallic Nanoparticles

Metallic nanoparticle is a new terminology that originated in recent years. Noble metals such as gold, silver, and platinum have beneficial effects on health and are being utilized for the synthesis of nanomaterials thus designated as “metallic nanoparticles”. Due to their useful properties, they are used for catalysis, composite-like polymer preparations, disease diagnosis as well as treatment, and labeling of optoelectronic recorded media, etc. (Jamkhande et al., 2019). They can be fabricated, modified in their shape and size, and can be linked to various types of chemical functional groups. Such abilities allow them to bind and attach to ligands which include antibodies, drugs, polymers, and peptides (Mughal, 2022).

Dendrimers

A dendrimer is a nanotechnology-based three-dimensional nano-engineered polymeric structure that provides uniform size for surface functionalization thus developing an attractive tool for biomedical applications (Choudhury et al., 2021). A combined advantage of the particle-defined structure and the functionalized surface is provided by optical dendrimers. They improve bloodstream visualization and are used in MRIs. They resemble biomolecules and can be used as antiviral, antibacterial, and anticancer agents.

Carbon Nanotubes

They have useful electronic, intrinsic mechanical, and physio-chemical properties. Carbon nanotubes can diagnose and treat neurological pathologies which include Parkinson’s and Alzheimer’s disease (Waris et al., 2022).

Polymeric Nanoparticles

Polymer materials are stable and are safe to use in humans. They improve diagnosis when incorporated with different contrast agents. Polymeric nanoparticles possess the ability to encapsulate different contrast agents within a single matrix which enables multimodal imaging (Srikar et al., 2014). They have a vast range of applications, such as for ocular drug delivery, oncologic treatment, cancer diagnosis and imaging, etc. (Begines et al., 2020).

Liposomes

They consist of lipid bilayers and are spherical vesicles. They are highly compatible due to very low toxicity and least side effects in the drug delivery system. They have useful properties of biodegradability, and biocompatibility too. They can be specifically targeted to desired tissues when combined with specific targeting ligands and probes. They can be modified with PEG (polyethylene glycol) chains to prolong blood circulation thus they can enable passive targeting. Active targeting of anticancer drugs to tumor sites can also be done by grafting targeting ligands on liposomes (Allahou et al., 2021).

Applications of Nanomaterials in Disease Detection

Nanomaterials possess unique properties such as high surface-to-volume ratio and customizable size and shape, which makes them ideal for biosensing techniques. Their enhanced adsorption and reactivity compared to bulk materials enable surface modification with biological species via bonding, enhancing biosensing characteristics. This customization significantly improves sensitivity, and selectivity, and enables rapid responses to sample analytes, with detection limits reduced by several orders of magnitude (Srivastava et al., 2021).

Fluorescent Nanomaterials for Imaging

There has been a growing interest in the utilization of self-assembled fluorescent nanomaterials derived from small-molecule organic dyes for imaging and sensing applications. The increasing appeal of self-assembled fluorescent nanomaterials from organic dyes lies in their ability to blend the spectral tunability and biocompatibility of small organic fluorophores with the brightness and stability of inorganic materials, yielding versatile nanostructures, including core-shell architectures with hyperbranched polymers (Svechkarev and Mohs, 2019).

Magnetic nanomaterials for separation and detection

Magnetic nanomaterials' large surface area and strong magnetic response enable easy isolation with external magnets. Their functionalization offers rapid enantioselective separation, surpassing traditional methods (Deng et al., 2020). Magnetic nanomaterials simplify sample preparation in solid-phase extraction, enhancing selectivity and sensitivity in new analytical methods (Rios and Zougagh, 2016). Surface-modified with antibodies, oligonucleotides, or aptamers, magnetic nanomaterials selectively bind target viruses or biomarkers in biological samples, aiding isolation and detection processes (Rezvani Jalal et al., 2021).

Quantum Dots and their Applications

Semiconductor nanocrystals, with nanometer-scale diameters, display quantum size effects, leading to tunable and efficient photoluminescence. Core-shell structures are common, enabling various device applications, including commercially available quantum dots-based displays in everyday life (Cotta, 2020). Quantum dots find diverse applications in biotechnology and biomedicine, including cell sensing, bioimaging, gene therapy, and drug delivery, addressing challenges like off-target effects in cancer treatment (Armăşelu and Jhalora, 2023).

Successful Nanomaterials-based Diagnostic Techniques

Nanomaterials have changed demonstrative procedures through convincing contextual analyses in different ways**:**

Nanoparticle-based Polymerase Chain Reaction (PCR) Assay

Gold nanoparticles (AuNPs) are key in virus detection, notably enhancing PCR. Recent studies highlight their antiviral activities and applications in diverse analysis techniques and potential therapies, alongside toxicity assessments for respiratory viruses. Magnetic nanoparticles are also being used in PCR assays (Rasmi et al., 2023).

Nanosensors for Rapid Detection of Biomarkers

Biosensors with micro- and nanostructured elements are used for frequent and rapid detection of various sepsis biomarkers (Alba-Patiño et al., 2022). Nanosensors are used to detect cardiovascular disease (Tang et al., 2022). Methyl probe, an ultra-sensitive nano-sensor synthesized via ultrashort pulsed ionization, enables direct detection of methylated DNA in plasma for metastasis detection. Integrated with biomarkers and machine learning, it offers scalable clinical adaptability (Ganesh et al., 2024).

Nanomaterial-enhanced Imaging in Molecular Diagnosis

Metal-enhanced fluorescence (MEF) boosts fluorescence signal by positioning metal close to a fluorophore, popular for sensitive molecule detection in biosensors. Metal size and structure impact optical properties, enhancing photostability and light characteristics (Goodrum and Li, 2024). These nanoparticles can accommodate imaging agents, enabling real-time treatment monitoring by physicians, and enhancing cancer care effectiveness and personalization through therapy adjustments (Zhang et al., 2018). Biomedical scientists appreciate nanomaterials' extensive surface area, aiding the delivery of therapeutic agents for genetic diseases. Genomics explores genome aspects, while nanotechnology supports gene-editing and stem cell research. Nanomaterials also enhance cell tracking in therapies (Paramasivam et al., 2024).

Applications of Nanomaterials in Cancer Detection and Treatment

Nanotechnology has a major role in cancer management. Gene therapy and drug administration are some of its prominent applications. Nanotechnology has a considerable role in diagnostics, monitoring of biomarkers and tracing, histopathological imaging, and medicines. Gold nanoparticles and quantum dots are widely used at the molecular level to diagnose cancer. Various molecular diagnostic techniques are based on nanoparticles such as biomarker discovery which can properly and rapidly diagnose tumours.

Nanotechnology plays a crucial role in solving complications regarding the diagnosis of diseases. Nanoscale drug delivery specifies the target and thus reduces the complications by increasing the sensitivity. Nanomaterials have active as well as passive targeting mechanisms due to which they are used in the treatment and diagnosis of cancer (Kher and Kumar, 2022).

Nanoparticles in Early Cancer Detection

Nanoparticles are better than currently used conventional techniques which include ultrasonography, X-ray, MRI (magnetic resonance imaging), PET (positron emission tomography), and CT (computed tomography) scan. Certain morphological changes occur in cells or tissues which help detect or confirm cancer. Conventional techniques involve these morphological changes for results but they are detectable only after certain visible changes in tissues or cells have already occurred. It is the time when cancer has started its proliferation and causes metastasis. Conventional techniques are also unable to differentiate benign and malignant tumors. Histopathology and cytology cannot be utilized as independent tests for cancer detection. Nanotechnology provides rapid and more accurate early diagnosis along with an ongoing assessment of cancer patients' care (Kher and Kumar, 2022).

Theranostic Applications of Nanomaterials in Cancer Treatment

Targeted drug delivery systems based on nanomaterials have advanced recently, offering both passive and active targeting options. While passive targeting is accomplished by increased permeability and retention effects, active targeting is accomplished through the use of antibodies or small molecule-conjugated nanoparticles. Active targeting exhibits significant promise and serves as a viable substitute for passive targeting. Its enhanced efficiency and retention have been shown to improve tumor localization in active targeting. Drugs based on nanomaterials have superior loading capacities, longer half-lives, lower cytotoxicity, better specificity, and better bioavailability than conventional chemical therapies (Zhu et al., 2022).

Nanomaterials have the potential to significantly increase the effectiveness of cancer immunotherapy. Cancer vaccines are an important component of cancer immunotherapy. Remarkably, a recent study described the synthesis of a D-enantiomeric supermolecule nanoparticle and the demonstration of its p53-dependent antiproliferative action, which in turn improved antitumor immunity. Nanomaterials can transport tumor antigens, which will be beneficial for immunotherapy, and because of their unique properties, they can also influence the immune response. Notably, the PC7A nanoparticles triggered the pathway that stimulates interferon genes, which strengthens the anti-tumor immune response (Zhu et al., 2022).

Infectious Disease Diagnostics with Nanomaterials

Nanomaterials in the Rapid Detection of Pathogens

Contamination of food by various pathogens is a major problem throughout the world. Therefore, quick detection of these pathogens is very important so that infectious diseases can be controlled. Various techniques have been employed in the past to control pathogens, but these techniques require huge apparatus and are very costly. Recently nanomaterials have grabbed attention because of their small size and large surface area Widely used nanomaterials for the detection of food-borne pathogens are peptide nanotubes, magnetic nanoparticles, gold nanoparticles, and quantum dots. Magnetic nanoparticles are used for efficient detection of *Salmonella typhimurium* because the pre-enrichment and isolation of bacteria is not needed using these nanomaterials. The photothermal effects of these nanomaterials have improved the sensitivity of detection also. Similarly, gold nanoparticles can be used for the on-site detection of *Staphylococcus aureus*. It is so rapid that it can be done within 15 minutes (Shen et al., 2021).

Antimicrobial Nanomaterials for Infectious Disease Management

Metals such as gold and silver were used in the past because of their antimicrobial properties. These metals can prevent the proliferation of gram-positive bacteria, gram-negative bacteria, and viruses on the surfaces. However, the limitation was that these metals could be toxic, and their bioactivity also decreased over time. With the advancement of technology, nanoparticles have been discovered. These nanoparticles are coated on the surface of biomaterials to prevent adhesion of microbes and biofilm formation (Yılmaz et al., 2023). For example, carbon nanodots, because of the properties of photoactivation and surface charge, can inhibit the growth of *Escherichia coli* O157:H7 and *S. typhimurium*. Therefore, carbon nanodots are used in food packaging materials and wound dressings (Huang et al., 2023).

Neurodegenerative Disease Diagnostics with Nanomaterials

Neurodegenerative disorders involve the progressive decline of normal brain functions. Diagnosis of diseases like Alzheimer’s disease and Parkinsons' disease is difficult at an early stage. The new hope for the early diagnosis of neurodegenerative diseases is nanotechnology because it is very sensitive to the detection of biomarkers for neurodegenerative disorders (Hanif et al., 2021). Among nanomaterials, two-dimensional nanomaterials have gained interest because of their ultrathin structure and their ability to cross the blood-brain barrier. Two-dimensional nanomaterials include graphene, transition metal dichalcogenides, transition metal carbide and nitride, and transition metal oxide. Among them, graphene nanomaterials have distinct physical and chemical properties. Graphene not only prevents the accumulation of neural proteins but also helps in their removal. Thus, it helps to prevent Alzheimer’s and Parkinson's disease (Tiwari and Tiwari, 2023).

Challenges and Considerations for the use of Nanomaterials in Molecular Diagnosis

Biocompatibility and Safety Concerns

Nanoparticles in *in vivo* applications raise concerns about potential toxic effects, but this is less significant in *in vitro* diagnostics. The environmental impact of nanoparticle release during manufacturing and naturally occurring nanoparticles in the atmosphere are under investigation. Despite advancements, there are still unanswered questions about nanoparticles' fate in living organisms due to the diverse materials and sizes. Nanoparticles smaller than 20 nm have the potential to penetrate cells, and approval for *in vivo* nanomaterials for human diagnostics may be hindered without clear safety demonstrations (Aziz et al., 2021). Nanoparticles play a crucial role in biomedical applications, such as drug delivery, gene delivery, and biosensors, but their blood compatibility is essential for safe use. In vitro studies show moderate biocompatibility, but no aggregation of blood cells with nanoparticle interaction has been observed. Nanoparticles are unstable and undergo agglomeration and dissolution, impacting biological effects. Researchers modify nanoparticles to reduce toxicity and improve biocompatibility, but concerns remain about the potential loss of original features. Continuous efforts are needed to advance the understanding of nanoparticle toxicity and biocompatibility for safe applications (Joglekar and Gajaralwar, 2021).

Even though nanoparticles are the new hope in the field of medicine, surgery, diagnostics, neurodiagnostic, and food, their drawbacks should not be undermined. Nanoparticles can affect different parts of the body by accumulating in them.

The use of nanoparticles offers a promising diagnosis of Parkinson's disease, but it also acts as a contributing factor in the induction of this disease by damaging dopaminergic neurons in the substantia nigra. Thus, before incorporating the use of nanoparticles in different fields, their harmful effects should be extensively studied (Mohammadipour et al., 2020).

Nanotechnology in medical applications has raised concerns about nanoparticle-mediated toxicity and adverse reactions, particularly in Alzheimer's disease treatment. The size, shape, and surface characteristics of nanoparticles influence pharmacokinetics and biodistribution. The benefit-to-risk ratio depends on nanoparticle dose and dosing frequency. Nanoparticles may hinder P-glycoprotein efflux pumps, induce cell death, and modulate gene expression. Hypersensitivity reactions and complement system activation may also cause adverse reactions. Understanding nanoparticle properties and interactions with biological systems is crucial for developing effective and safe treatments, especially in Alzheimer's disease (Halder et al., 2022). The toxicity of gold nanomaterials is a topic of interest due to their potential biomedical applications. However, safety and toxicology studies are crucial before clinical translation. The uptake of gold nanoparticles is influenced by factors such as size, shape, surface functionality, charge, concentration, and cell type. Surface chemistry, particularly charge, plays a crucial role in nanoparticle-cell interactions. Purity assessment is also essential for effective biomedical applications (Balog et al., 2024). Nanotechnology's production of small particles raises toxicological risks due to increased reactivity. Regulations are inadequate, but each system requires thorough investigation for potential health effects. Public awareness and ethical discussions highlight the need for risk assessments and systematic evaluations (Wang et al., 2022).

Standardization and Regulatory Hurdles

The Food and Drug Administration (FDA) acknowledges nanotechnology's potential and encourages responsible development. It regulates nanotechnology products under existing statutory authorities, tailoring approaches based on legal frameworks. The FDA addresses scientific gaps and collaborates with other agencies to ensure transparent regulatory pathways. The draft guidance is issued for industry applications, and early consultations are encouraged for safety, effectiveness, and regulatory status questions (Dias et al., 2021). Nanomedicines, a key focus in pharmaceutical research, require rapid advancements to address medical needs. Understanding and characterizing these complex nanomedicines is crucial to prevent adverse effects. Collaboration between scientists, regulators, industry, and patient representatives is essential for successful technology development (Halwani, 2022).

Integration with Existing Diagnostic Platforms

Nanotechnology's application in personalized medicine offers unique opportunities for disease treatment. Nanomaterials, with their small sizes, design flexibility, and modifiable surfaces, can be engineered to interact with specific biological components. Understanding nanomaterial interactions is crucial for designing diagnostic imaging and drug delivery (Đorđević et al., 2022).

Ethical consideration in the use of Nanomaterials for Diagnostics

The challenge of balancing scientific advancements with human rights and dignity is posed by the rapid evolution of nanotechnology. To address ethical issues, diversifying tests, defining properties, monitoring risk assessments, and conducting continuous studies on nanoparticle interactions with human organisms are crucial (Srivastava and Manjhi, 2023). The ethical discussion surrounding nanotechnologies is hindered by public hype, unclear definitions, and the early stages of research. The term "nano" is broad and vague, making it difficult to pinpoint ethical issues. To address these challenges, scholars recommend critically examining nanotechnology's social context, traditions, stakeholders, and research activities, challenging the current monolithic visions (Wahab et al., 2023).

Future Perspectives and Emerging Trends for Nanomaterials

Future perspectives and emerging trends in innovative nanomaterials for molecular diagnostics hold immense promise for revolutionizing healthcare. Nanotechnology offers unparalleled opportunities to enhance sensitivity, specificity, and multiplexing capabilities in diagnostic assays.

Nanomaterial-based biosensors offer the promise of rapid and accurate detection of biomolecules at low concentrations, enabling early diagnosis of diseases such as cancer, infectious diseases, and genetic disorders (Iftikhar et al., 2023). Advancements in nanotechnology will facilitate the development of point-of-care devices that are portable, cost-effective, and user-friendly, enabling decentralized testing in resource-limited settings Here are some anticipated trends and perspectives:

Enhanced Sensitivity

Nanomaterials such as quantum dots, gold nanoparticles, and carbon nanotubes possess distinctive optical, electrical, and magnetic properties. Integrating them into diagnostic platforms can significantly enhance sensitivity, enabling the detection of ultra-low concentrations of biomarkers, viruses, or genetic material (Heydari-Bafrooei and Ensafi, 2023).

Multiplexed Assays

The simultaneous detection of multiple analytes within a single sample is critical for comprehensive diagnostics. Nanomaterials facilitate the development of multiplexed assays, where different nanoparticles are functionalized to specifically bind to different targets (Jarockyte et al., 2020).

Point-of-care Testing

Miniaturized devices integrated with nanosensors can provide real-time results, facilitating early disease detection and personalized treatment strategies. These advancements in point-of-care testing reduce the reliance on centralized laboratory facilities, making diagnostic services more accessible and timely, particularly in remote or resource-limited settings (Biswas et al., 2022).

Liquid Biopsy

Liquid biopsy utilizing nanoparticles represents a cutting-edge approach to cancer diagnostics. These tiny particles, engineered for precise targeting, enable non-invasive detection of biomarkers from bodily fluids. Their high specificity and sensitivity offer invaluable insights into disease progression and treatment response, heralding a new era of personalized medicine and improved patient outcomes (Vázquez-Iglesias et al., 2024).

Emerging Trends in the uses of Nanomaterials in Molecular Diagnostics

Functionalized Nanoparticles

Functionalized nanoparticles are engineered particles with tailored surface properties, enabling precise interactions with biological or chemical entities. Through covalent or non-covalent attachment of functional groups, these nanoparticles exhibit enhanced stability, selectivity, and reactivity. Their diverse applications span drug delivery, imaging, sensing, catalysis, and environmental remediation (Khalili et al., 2022).

Nanopore Sequencing

Nanopore-based sequencing technologies offer a promising approach for rapid and cost-effective DNA sequencing. This method involves passing DNA molecules through a nanopore, where changes in electrical conductivity can be monitored, enabling real-time sequencing of nucleic acids. Nanopore sequencing holds great promise for clinical diagnostics, facilitating personalized medicine and the swift identification of genetic mutations (Chen et al., 2023).

Plasmonic Nanomaterials

Plasmonic nanoparticles, such as gold and silver nanoparticles, exhibit localized surface plasmon resonance (LSPR), which can be exploited for label-free detection of biomolecules. LSPR-based biosensors offer high sensitivity and allow for real-time monitoring of molecular interactions, making them invaluable tools for molecular diagnostics (Csáki et al., 2018)

Nanotechnology-enhanced Imaging

Nanotechnology-enhanced imaging leverages innovative nanomaterials to revolutionize medical diagnostics and research. These cutting-edge materials, manipulated at the nanoscale, enhance imaging resolution, sensitivity, and specificity, enabling unprecedented insights into biological structures and functions (Sikkander et al., 2024)

Nanoparticle Engineering

Nanoparticle engineering pioneers the creation of innovative nanomaterials, leveraging meticulous manipulation at the molecular scale. Through precision crafting, it tailors materials with unparalleled properties, revolutionizing industries from medicine to electronics. This interdisciplinary field melds cutting-edge science with engineering prowess, unlocking boundless potential in realms previously unimaginable (Alshangiti et al., 2023).

Bioconjugation Strategies

Innovative bioconjugation techniques are emerging to enable stable coupling of biomolecules with nanomaterials. Methods such as click chemistry, DNA origami, and peptide-mediated conjugation offer efficient and site-specific functionalization, minimizing nonspecific binding and enhancing assay robustness (Dubey and Tripathi, 2021).

Integration of Artificial Intelligence

Utilizing AI algorithms and machine learning techniques can enhance the interpretation of complex molecular data generated by nanomaterial-based diagnostic assays, enabling accurate disease diagnosis and personalized treatment strategies (Kasture and Shende, 2023).

Conclusion

The integration of nanomaterials in molecular diagnostics presents a promising frontier in the field of healthcare and research due to the unique properties of nanomaterials which include a high surface-to-volume ratio. Trends in functionalized nanoparticles, nanopore sequencing, plasmonic nanomaterials, nanotechnology-enhanced imaging, and nanoparticle engineering are emerging nowadays. Overall use of nanomaterials can enhance the sensitivity as well as specificity of diagnostic assays. Still, challenges like standardization, scalability, and safety concerns regarding the use of nanomaterials need to be addressed. Some ethical concerns need to be addressed before using nanomaterials on a commercial scale. With advancements in research, the synergy between nanotechnology and molecular diagnosis is expected to be improved in the future.

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