WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Nano-Medicine: Advancements in Disease Detection and Cure

Dr. S. Padmavathi[1], Dr. Ch. S. Anuradha[2]

[1.] **Lecturers in Botany, Dr. V. S. Krishna Government Degree College (A), Visakhapatnam.**

[2.] **Lecturer in Chemistry, Dr. V. S. Krishna Government Degree College (A), Visakhapatnam.**

E mail: apb1904@gmail.com

DOI : https://doi.org/10.55248/gengpi.6.0825.3056

ABSTRACT

It is not an exaggeration to say that nanotechnology is so widely developed and finds its applications in various fields of science. medicine, pharmacy, biophysics, electronics, bioengineering, and molecular biology. Recently, nanotechnology has been receiving much attention because of its widespread biomedical applications. Nanomaterials because of their altered physical and chemical properties have unprecedented potential to improve medicine and biomedical fields such as disease diagnosis, drug development and delivery and therapy implant and tissue engineering. Nanomaterials are recently widely used in cancer treatment because of their targeted delivery into cancer cells. Because of their nano size they are able to be used in diagnosis and treatment of diseases at nano level. This article provides an overview of application of metal oxide nanoparticles, carbon nano tubes, polymeric and non-polymeric nanoparticles and liposomes. The biosafety aspects of use of nanotechnology in in biomedical research, diagnosis and therapy is also discussed in this present review.

Key words: Biomedical, Nanotechnology, drug delivery and disease diagnosis.

1. Introduction

1.1 Concept of Nanomedicine

Nanomedicine is the application of the phenomena displayed by nanoscale materials, devices and systems (typically within 1–1000 nm) for the prevention, diagnosis and treatment of diseases at the molecular and cellular level (Huang et al., 2019). Human beings have been on a continuous quest for accurate diagnostic techniques and effective remedies. Recent advances in nanotechnology have opened new avenues for diagnosis, treatment, and, more importantly, targeted drug delivery (Klymchenko et al., 2021). Nanomedicine utilizes nanocarriers such as liposomes, dendrimers and polymeric nanoparticles (Patra et al., 2018). These nanosystems are transforming medical research by enabling early detection, precision targeting, and minimally invasive interventions, holding great promise for advancing modern healthcare (Pérez-Herrero & Fernández-Medarde, 2015).

1.2 Scope and Importance in Modern Medicine

Today, nanomedicine spans diagnostics, therapeutics and regenerative applications. In diagnostics, quantum dots and magnetic nanoparticles have improved imaging resolution and biomarker detection sensitivity (Gao et al., 2004). In therapeutics, nanocarriers enhance solubility, prolong circulation, and enable targeted drug delivery—reducing systemic toxicity (Shi et al., 2017). For instance, gold nanoparticles are explored for photothermal cancer therapy, while polymeric micelles improve chemotherapy outcomes (Peer et al., 2007).

In regenerative medicine, nanoscale scaffolds facilitate tissue engineering, and silver nanoparticles are incorporated into wound dressings for antimicrobial benefits (Suresh et al., 2018). Future trends point toward smart nanorobots capable of precision surgical or drug delivery tasks (Nelson et al., 2010).

Nanomedicine's importance lies in its potential to enable personalized medicine, optimize treatment precision, and address challenges such as antimicrobial resistance and chronic disease management (Bhushan, 2017). Its interdisciplinary nature—integrating chemistry, biology, engineering, and clinical science—positions it as a key driver of next-generation healthcare innovation.

2. Basics of Nanotechnology in Medicine

2.1 Definition and Principles of Nanotechnology

Nanotechnology in medicine refers to the use of engineered materials and devices with dimensions in the nanometer range (1–100 nm) to improve diagnosis, treatment, and prevention of diseases (Bhushan, 2017). At this scale, materials exhibit unique quantum effects, increased surface area-to-volume ratios, and altered biological interactions compared to their bulk counterparts (Rai et al., 2018).

The principles of nanomedicine involve manipulating size, shape, surface chemistry, and stimuli-responsiveness of nanoparticles to achieve controlled biodistribution, targeted delivery, and triggered activation at disease sites (Zhang et al., 2020). Stimuli may include pH changes, temperature variations, or external magnetic/optical fields (Patra et al., 2018).

2.2 Various classes of Nanomaterials Used in Medicine

Nanomaterials in medicine can be broadly divided into **organic**, **inorganic**, and **carbon-based** systems. Liposomes, polymeric nanoparticles, micelles, dendrimers, and nanostructured lipid carriers are examples of organic nanomaterials that are prized for their biocompatibility, biodegradability, and capacity to contain hydrophilic and hydrophobic medications (Torchilin, 2014).

The optical, magnetic, and surface features of inorganic nanoparticles, such as gold, silver, silica, quantum dots, and magnetic iron oxide, make them useful for magnetically guided drug administration, photothermal therapy, and imaging (Jiang et al., 2018).

Carbon-based nanomaterials, including graphene oxide, fullerenes, and carbon nanotubes, have high surface area, mechanical strength, and electrical conductivity, which makes them appropriate for tissue engineering, targeted therapy, and biosensing applications. (Bianco et al., 2011).

2.3 Properties Relevant to Diagnostics and Therapy

Nanomaterials possess several features that make them ideal for medical applications

- ➢ A large surface-area-to-volume ratio enhances therapeutic specificity by facilitating high drug loading and conjugation with targeted ligands (Wilczewska et al., 2012).
- ➢ Stimuli-responsiveness reduces systemic adverse effects by allowing site-specific release in response to pH, enzymes, temperature, or light (Patra et al., 2018).
- ➢ Magnetic and optical characteristics: magnetic nanoparticles allow magnetic hyperthermia and MRI enhancement, whereas gold nanoparticles exhibit localized surface plasmon resonance for imaging and therapy (Jiang et al., 2018).
- ➢ Biocompatibility and controlled release: Liposomes and other organic nanoparticles shield medications from deterioration and enable prolonged release (Torchilin, 2014).
- ➢ Electrical and structural benefits: multiplexed imaging and electrochemical biosensing are made possible by carbon nanomaterials (Bianco et al., 2011).

3. Nanotechnology in Disease Diagnostics

3.1 Nano-Biosensors for Early Detection

Nano-biosensors have emerged as highly sensitive and portable tools that usually detect biochemical molecules quite useful in the early disease diagnosis due to their ability to detect biomarkers at ultra-low concentrations (Kaur et al., 2025). They are associated with probes and integration of nanomaterials into sensor platforms, such as electrodes functionalized with bioreceptors, enhances both specificity and signal transduction efficiency. Magnetic nanoparticles (MNPs) are particularly promising because of their large surface area, strong biomolecule binding and magnetic enrichment capabilities, enabling rapid detection of targets such as circulating tumor cells and infectious pathogens (Li et al., 2024). These advancements allow earlier clinical intervention and improved prognosis in diseases like cancer and sepsis. A nano-biosensor consists of a receptor transducer and detector that generate a digital output. The transducer then converts the signal analysed by the detector. The efficiency of nanosensors can be improved by employing nano-films, gold nano-particles (La Spada and Vegni, 2018) quantum dots for the amplification of signals.

3.2 Quantum Dots for Imaging and Biomarker Detection

Due to their size-tunable emission spectra and great photostability, quantum dots (QDs) are semiconductor nanocrystals that are useful for multiplex biomarker detection and diagnostic imaging (Sharma & Patel, 2025). In prostate cancer diagnostics, QD-based biosensors have outperformed traditional ELISA techniques, exhibiting femtogram-per-milliliter detection limits (Mehta et al., 2023). QDs are a crucial part of next-generation diagnostic platforms because of their robustness, potential for downsizing, and ability to analyze several targets at once. If a set of molecular markers can be measured and statistically distinguished between malignant and healthy cells, biomarker assays could be helpful for cancer screening and diagnosis. Since disease markers are frequently found in extremely low concentrations, techniques with low detection limits are necessary. Nanoparticles known as quantum dots (QDs) are showing promise as ultrasensitive probes for the identification of cancer biomarkers. To target cancer indicators, QDs can be affixed to peptides, aptamers, oligonucleotides, or antibodies. Because of their fluorescent characteristics, QDs have been studied as in-vivo imaging agents and utilized as labels for biomarker quantification in in-vitro tests. To target cancer indicators, QDs can be affixed to peptides, aptamers, oligonucleotides, or antibodies. Because of their fluorescent characteristics, QDs have been studied as in-vivo imaging agents and utilized as labels for biomarker quantification in in-vitro tests (Wagner et al., 2010).

3.3 Nanoparticles in Point-of-Care Testing (POCT)

Because of their special plasmonic, catalytic, and photothermal characteristics, noble metal nanoparticles—in particular, gold (AuNPs) and silver (AgNPs)—are essential to POCT (Zhang et al., 2023). For clinical and field settings, these nanomaterials enable sensitive, portable, and quick detection methods. By enabling sample pre-concentration, signal amplification, and multiplexed testing in a single device, functionalization with magnetic cores further improves capabilities (Li et al., 2024). Infectious pathogens like influenza viruses and SARS-CoV-2 have been effectively detected using this method.

3.4 Nanotechnology in Molecular Diagnostics (DNA, RNA Detection)

The direct detection of nucleic acids at incredibly low quantities made possible by nanotechnology has completely changed molecular diagnostics. Gold nanoparticles functionalized with complementary DNA probes produce optical, fluorescent, Raman, or electrochemical signals that enable extremely specific hybridization-based detection of DNA or RNA sequences (Kumar et al., 2020). In order to facilitate quick, centrifuge-free processes appropriate for pathogen identification, such as COVID-19 diagnostics, magnetic nanoparticles have also been used for nucleic acid extraction (Singh et al., 2022). Furthermore, both biological and solid-state nanopore sequencing provide real-time, label-free detection and sequencing of individual nucleic acid molecules, facilitating the quick identification of genetic variants and infections (Smith et al., 2025).

4. Nanotechnology in Disease Treatment

4.1 Targeted Drug Delivery Systems

Advancements in nanotechnology have led to the development of targeted drug delivery systems that enhance therapeutic efficacy while minimizing systemic side effects. These systems employ nanoparticles—including liposomes, dendrimers, and lipid-based carriers—to improve bioavailability, protect drugs from degradation, and enable controlled spatiotemporal release (Di Stefano, 2023). They utilize passive targeting, relying on the enhanced permeability and retention (EPR) effect inherent to tumors, and active targeting, by functionalizing nanoparticle surfaces with ligands or antibodies for receptor-mediated uptake (Pragati Ramesh Kumbhar et al., 2023; PMC review, 2025). Such nanosystems have demonstrated improved accumulation at target sites, leading to higher therapeutic index and reduced off-target toxicity.

4.2 Nano-Carriers for Chemotherapy in Cancer Treatment

Nano-carrier platforms have transformed chemotherapy by facilitating efficient drug loading, enhancing tumor specificity, and reducing systemic toxicity (PMC cancer nanomedicine, 2025). Liposomes, polymeric nanoparticles, and mesoporous silica nanoparticles (MSNs) are widely studied for their versatility. Furthermore, due to their significant NIR photothermal conversion capacity, broad surface area, and low toxicity, carbon nanotubes (CNTs) have been regarded as prospective photothermal agents and drug carriers (Shi et al., 2013). To optimize the effectiveness of cancer treatments, dendrimers have polymeric nanocarriers having a branching or star-like structure that allow medicinal and/or diagnostic substances to be conjugated on their surface (Glasgow et al., 2015).

4.3 Nanoparticles in Antimicrobial Therapy

A possible line of defence against multidrug resistance (MDR) and microbial resistance is the use of nanoparticles (NPs). Various NPs target germs through numerous channels simultaneously, damage bacterial membranes, and limit biofilm formation, among other antibacterial processes. In contrast to conventional antibiotics, NPs have the ability to both circumvent resistance mechanisms and serve as efficient carriers to improve the administration of antibiotics. Due to these special qualities, nanomaterials are becoming increasingly popular as antibiotic supplements, providing answers where traditional therapies frequently fall short (Wang et al., 2017). For example, silver nanoparticle-encapsulating nanoliposomes have demonstrated enhanced bacterial inhibition and may offer alternatives to conventional antibiotics (Jangid et al., 2024). Photothermal and nitric oxide (NO)-generating mesoporous silica nanoparticles coated with gold have shown up to a 90% reduction in *Staphylococcus aureus* biofilms under near-infrared irradiation (Mann et al., 2021), highlighting the synergy of combined therapies.

4.4 Nanotechnology in Regenerative Medicine (Tissue Engineering, Stem Cells)

The use of nanoengineered scaffolds in tissue engineering and regenerative medicine is growing because they influence cell signalling, adhesion, proliferation, and differentiation by simulating the nanoscale environment of native tissues. Methods such as self-assembly, electrospinning, nanopatterning, and the use of nanomaterials (such as graphene oxide, carbon nanotubes, and gold nanoparticles) increase scaffold characteristics, allowing for better cell growth and function. As demonstrated by applications in bone and cardiac tissue, nanoscale topographies can direct cytoskeletal organization, tissue integration, and stem cell differentiation. In order to create sophisticated biomimetic scaffolds and responsive systems for controlled bioactive delivery and tissue regeneration, a better knowledge of cell–matrix interactions is necessary (Kim et al., 2014).

5. Case Studies and Applications

5.1 Nanomedicine in Cancer Detection and Therapy

Nanomedicine has made significant strides in both the detection and treatment of cancer. One promising advancement is the development of a magnetic nano-drug designed to target colon cancer cells expressing the LGR5 receptor. This nanofarmaceutical, developed by researchers in Granada, combines antibody-mediated targeting with magnetic hyperthermia capabilities, showing high precision, effectiveness, and biocompatibility in preclinical studies (Cepero et al., 2024).

Additionally, several nanomedicine-based cancer therapies have received regulatory approval. Notably, Doxil®, a liposomal form of doxorubicin, was approved for Kaposi sarcoma and later for several other malignancies, while Abraxane (albumin-bound paclitaxel) improved tumor penetration and reduced hypersensitivity reactions (Ehrat et al., 2025). Other nanocarrier formulations, like nanoliposomal irinotecan, offer enhanced therapeutic efficacy in refractory pancreatic cancer (Ehrat et al., 2025).

Beyond conventional nanomedicines, innovative strategies such as DNA-based nanorobots have shown promise. In mouse models of breast cancer, these programmable nanostructures delivered cytotoxic agents selectively within acidic tumor environments, achieving a 70% reduction in tumor growth (News Health, 2025). Such smart nanorobotics could revolutionize precision drug delivery.

5.2 Nano-Enabled Diagnostics for Infectious Diseases

Nanotechnology has dramatically enhanced infectious disease diagnostics, especially in low-resource settings. For instance, gold nanoparticle-based lateral-flow assays combined with amplification techniques successfully detect *Brucella abortus* DNA at about 10 fg/µL sensitivity (Yang et al., 2023). Similarly, multiplexed LAMP assays targeting *Mycobacterium tuberculosis* offer high specificity and sensitivity in safety-compliant, rapid workflows (Yang et al., 2023).

Moreover, nanodiagnostic systems—including those based on fluorescent or magnetic nanoparticles—enable rapid, multiplexed detection from minimal sample volumes, making them ideal for point-of-care use (Li et al., 2017). Examples include a cost-effective, TB screening kit developed in India that is portable and usable by minimally trained health workers, widely deployable and inexpensive (Li et al., 2017).

5.3 Use of Nanotechnology in Neurological Disorders

Treating neurological diseases is notoriously challenging due to the blood-brain barrier (BBB). Nanotechnology offers innovative solutions: nanoparticles engineered to cross the BBB can deliver therapeutics directly to the brain, enhancing bioavailability and therapeutic outcomes in conditions like Alzheimer's, Parkinson's, and traumatic brain injury (Vashist et al., 2023). These strategies include liposomes, dendrimers, polymeric carriers, inorganic nanoparticles, exosomes, and nanogels (Vashist et al., 2023).

Focused Ultrasound for Nanomedicine-Based Brain Delivery

Focused ultrasound (FUS), when combined with nanoparticle or microbubble carriers, has been shown to significantly enhance intracranial drug delivery. Preclinical models demonstrate that FUS with drug-loaded microbubbles improves the delivery of chemotherapeutics such as doxorubicin and monoclonal antibodies to gliomas and brain metastases (Aryal et al., 2014). Similarly, in Alzheimer's disease models, FUS has enabled the effective delivery of anti-Aβ antibodies across the blood–brain barrier, resulting in reduced amyloid plaque burden (Meng et al., 2021).

6. Advantages of Nanomedicine

6.1 High Sensitivity and Precision in Diagnosis

In diagnostic applications, nanomedicine provides previously unheard-of sensitivity and accuracy. Early illness diagnosis and much improved diagnostic accuracy are made possible by the detection of disease markers at incredibly low concentrations using nano-biosensors and nanoparticle-enhanced imaging systems (Liu et al., 2024).

6.2 High Diagnosis Sensitivity and Precision

In diagnostic applications, nanomedicine provides previously unheard-of sensitivity and accuracy. Early illness diagnosis and much improved diagnostic accuracy are made possible by the detection of disease markers at incredibly low concentrations using nano-biosensors and nanoparticle-enhanced imaging systems (Liu et al., 2024).

6.3 Enhanced Drug Stability and Bioavailability

Recent investigations demonstrated different types of nanoscale drug delivery systems (NDDSs), such as inorganic carriers, lipid-based, polymer-based, nanoemulsions, and nanogels. These methods enable better targeting, less side effects, and increased therapeutic efficacy. Many scholars addressed the developments in NDDSs for improved therapeutic outcomes, highlighting the critical impact of nanoparticle size and surface changes. Although issues like safety and production costs are recognized, it is emphasized how NDDSs have the potential to revolutionize drug delivery techniques. This paper highlights the value of nanotechnology in pharmaceutical engineering and presents it as a major breakthrough for patient care and medicinal applications (Liu et al., 2024).

7. Challenges and Limitations of Nanomedicine

7.1 Concerns about Safety and Toxicity

Nanomedicine poses notable safety challenges. Engineered nanoparticles, because of their nanoscale dimensions and increased surface reactivity, tend to distribute unevenly across biological systems, accumulate in organs, and persist over time (Chen et al., 2023). In animal inhalation studies, exposure to certain nanoparticles—like multi-walled carbon nanotubes—has been associated with pulmonary inflammation, fibrosis, and even carcinogenicity. Additionally, nanoparticle toxicity is particularly difficult to evaluate, as factors such as particle size, shape, surface chemistry, and charge strongly influence how they interact with biological environments (Liu et al., 2024).

A more effective method of safety screening is now possible because to emerging techniques like machine learning models, which predict nanoparticle toxicity based on physicochemical properties (Yousaf, 2024).

7.2 Expensive and Scalability Problems

Challenges of Scalable and Reproducible Nanomedicine Production

It's still expensive and technically challenging to develop nanomedicine, especially sophisticated systems like erythrocyte membrane-coated nanoparticles (EMCNPs). Clinical translation is slowed down by labor-intensive techniques like co-extrusion and microfluidics that limit large-scale production and are challenging to standardize and duplicate (Fang et al., 2018; Molinaro et al., 2021).

Additionally, because regulatory approval necessitates meticulous physicochemical characterisation, controlled manufacturing methods, extensive pharmacokinetic profiling, and constant batch repeatability, it adds even more complexity and expense. Transferring nanomedicines from the lab to the clinic is extremely difficult when these strict parameters are met (Ventola, 2017).

7.3 Ethical and Regulatory Aspects

Nanomedicine's regulatory framework is still evolving. Existing regulations often "bolt on" nanomaterials to outdated categories, overlooking unique nanoscale challenges—like the ability of nanoparticles to penetrate the skin or cause unexpected environmental effects. These issues risk slipping through regulatory cracks. A recent comprehensive scholarly review highlights how most current frameworks lack specificity for nanomaterial behaviors, underscoring the need for tailored regulation (Sharma et al., 2025)

The long-term health and environmental effects of nanoparticles are still unknown from an ethical standpoint. Risks to patients, lab personnel, and nearby communities may not be adequately addressed by standard oversight procedures that were created for conventional medicines (Resnik, 2012).

8. Future Prospects of Nanomedicine

8.1 Integration with Artificial Intelligence (AI) and Big Data

The fusion of nanomedicine with AI and big data analytics is poised to revolutionize drug discovery, personalized oncology, and nanoscale diagnostics. AI algorithms can sift through extensive datasets, optimizing nanoparticle design, predicting biological interactions, and accelerating therapeutic development (Samathoti *et al.,* 2025). This synergy enhances precision and efficiency in cancer treatment and diagnostics.

Because nanomedicine makes it possible to create therapies that are specific to each patient's needs, it is developing personalized healthcare. One significant advancement is theranostics, which integrates treatment and diagnostics into a single nanoplatform to enable real-time therapy monitoring and modification. According to recent studies, nanotheranostic devices have the potential to improve early detection and treatment precision, especially in the management of cancer (Kaur et al., 2024). Additionally, nanoparticle-mediated precision medicine is advancing inflammatory bowel disease (IBD) care, enabling personalized diagnostics and therapies tailored to each patient's disease markers (Li, 2024).

8.3 Emerging Trends and Research Directions

A very active area of study, nanomedicine holds great promise for the advancement of translational medicine. Current research trends show that the subject is expanding in both breadth and application areas, with a variety of nanoconjugate systems and drug formulations. Even if some areas have been thoroughly studied, in order to obtain workable solutions employing novel and enhanced nanosystems, these sectors need to have their concepts rethought. Research in nanobiotechnology and nanomedicine is growing with new opportunities. Future studies should anticipate in-depth, robust investigations and the inclusion of understudied areas like radiation and radiodiagnosis (Chhikara, 2017).

9. Conclusion

Nanomedicine has emerged as one of the most transformative frontiers in modern healthcare, bridging molecular biology, materials science and clinical medicine. By exploiting the unique physicochemical properties of nanomaterials—such as high surface-to-volume ratio, tunable surface chemistry, and multifunctional design—researchers have developed highly sensitive diagnostic tools, precise therapeutic delivery systems, and innovative regenerative medicine platforms. The integration of nanotechnology with artificial intelligence, big data analytics, and personalized medicine further amplifies its potential to revolutionize patient care.

While the field has demonstrated remarkable progress, several challenges remain, including concerns over safety, large-scale manufacturing, cost-effectiveness, and the need for harmonized regulatory frameworks. Addressing these limitations through interdisciplinary collaboration, robust clinical trials, and ethical oversight will be essential for the widespread adoption of nanomedicine.

References

- A.S. Klymchenko, F. Liu, M. Collot, N. Anton Dye—loaded nanoemulsions: biomimetic fluorescent nanocarriers for bioimaging and nanomedicine Adv Healthc Mater, 10 (1) (2021), Article e2001289
- Aryal, M., Arvanitis, C. D., Alexander, P. M., & McDannold, N. (2014). *Ultrasound-mediated blood–brain barrier disruption for targeted drug delivery in the central nervous system.* Advanced Drug Delivery Reviews, 72, 94–109.
- Bhushan, B. (2017). *Springer Handbook of Nanotechnology*. Springer, Berlin.
- Bianco, A., Kostarelos, K., & Prato, M. (2011). Making carbon nanotubes biocompatible and biodegradable. *Chemical Communications*, 47(37), 10182–10188.
- Cepero, A., Jiménez-Carretero, M., Jabalera, Y., Gago, L., Luque, C., Cabeza, L., Melguizo, C., Jiménez-López, C., & Prados, J. (2024). LGR5 as a therapeutic target of antibody-functionalized biomimetic magnetoliposomes for colon cancer therapy. *International Journal of Nanomedicine*, 19, 1843–1865.
- Chen, X., Zhao, J., & Xu, S. (2023). Structural parameters of nanoparticles affecting their toxicity. *Nanoscale Research Letters*, **18**, Article 1. Highlights how the smaller size and greater surface area enhance reactivity, influencing biodistribution and organ accumulation.
- Chhikara, B. S. (2017). Current trends in nanomedicine and nanobiotechnology research. *Materials NanoScience*, *4*(1), 19-24.
- Di Stefano, A. (2023). Nanotechnology in Targeted Drug Delivery. *International Journal of Molecular Sciences*, 24(9), 8194. https://doi.org/10.3390/ijms24098194
- Ehrat, F., et al. (2025). Nanotechnology in cancer therapeutics, diagnosis, and management. *Institute of Bioorganic Chemistry, Polish Academy of Sciences*.
- Fang, R. H., Kroll, A. V., Gao, W., & Zhang, L. (2018). *Cell membrane coating nanotechnology*. Advanced Materials, 30(23), 1706759.
- Gao, X., Cui, Y., Levenson, R. M., Chung, L. W., & Nie, S. (2004). In vivo cancer targeting and imaging with semiconductor quantum dots. *Nature Biotechnology*, 22(8), 969-976.
- Glasgow, M.D.; Chougule, M.B. Recent Developments in Active Tumor Targeted Multifunctional Nanoparticles for Combination Chemotherapy in Cancer Treatment and Imaging. *J. Biomed. Nanotechnol.* **2015**, *11*, 1859–1898.
- Huang, X., Jain, P. K., El-Sayed, I. H., & El-Sayed, M. A. (2019). Nanomedicine: Science and technology for cancer therapy. *Accounts of Chemical Research*, 52(9), 3055-3064.
- Jangid, H., Singh, S., Kashyap, P., Singh, A., & Kumar, G. (2024). Advancing biomedical applications: An in-depth analysis of silver nanoparticles in antimicrobial, anticancer, and wound healing roles. *Frontiers in Pharmacology*, 15, 1438227. Jiang, W., Kim, B. Y. S., Rutka, J. T., & Chan, W. C. W. (2018). Nanoparticle-mediated cellular response is size-dependent. *Nature Nanotechnology*, 3(3), 145–150.

- Kaur, H., Bharti, P., & Bansal, S. (2024). *Theranostics in brain cancer: Current trends and future prospects*. Cancer Cell International, 24(1), 333.
- Kaur, R., Gupta, P., & Singh, A. (2025). Leveraging nanomaterials for ultrasensitive biosensors in early cancer detection: A review. *Journal of Materials Chemistry B*, 13(4), 678–695.
- Kim, E. S., Ahn, E. H., Dvir, T., & Kim, D. H. (2014). Emerging nanotechnology approaches in tissue engineering and regenerative medicine. *International journal of nanomedicine*, *9*(sup1), 1-5.
- Kumar, S., Bhattacharya, S., & Verma, N. (2020). Nanomolecular diagnostics: Advances and applications. *Frontiers in Nanoscience*, 7, 125–143.
- La Spada, L., and Vegni, L. (2018). Electromagnetic Nanoparticles for Sensing and Medical Diagnostic Applications. *Materials* 11 (4), 603. doi:10.3390/ma11040603
- Li, X., Wu, Y., & Zhang, L. (2017). Nanodiagnostics for infectious diseases: tools for low-resource settings. *Frontiers in Microbiology*.
- Li, Y., Wang, T., & Zhao, M. (2024). Advancements in magnetic nanoparticle-based biosensors for point-of-care testing. *Frontiers in Bioengineering and Biotechnology*, 12, 1393789.
- Liu, Q., Li, F., Wang, Y., & Zhang, Y. (2024). Comprehensive insights into mechanism of nanotoxicity. *Nanoscale Research Letters*, **19**, Article 15. Emphasizes that size, shape, surface charge, and chemistry are critical determinants of nanotoxicity, complicating risk assessment
- Liu, Y., Liang, Y., Yuhong, J., Xin, P., Han, J. L., Du, Y., ... & Ma, Y. (2024). Advances in nanotechnology for enhancing the solubility and bioavailability of poorly soluble drugs. *Drug design, development and therapy*, 1469-1495.
- Mann, R. A., Hossen, M. E., Withrow, A. D. M., Burton, J. T., Blythe, S. M., & Evett, C. G. (2024). Mesoporous silica nanoparticles-based smart nanocarriers for targeted drug delivery in colorectal cancer therapy. *arXiv preprint arXiv:2409.18809*.
- Mehta, S., Roy, A., & Das, P. (2023). Quantum dots in prostate cancer diagnostics: Advances and applications. *Nanomaterials*, 15(15), 1162.
- Meng, Y., Abrahao, A., Heyn, C. C., Pople, C. B., Vedelago, L., Samadi, M., ... & Lipsman, N. (2021). *Focused ultrasound as a novel strategy for Alzheimer disease therapeutics.* Annals of Neurology, 89(2), 240–251.
- Molinaro, R., Corbo, C., Martinez, J. O., Taraballi, F., Evangelopoulos, M., Minardi, S., ... & Tasciotti, E. (2021). *Biomimetic nanovesicles for targeted drug delivery*. Journal of Controlled Release, 332, 164-184.
- Nelson, B. J., Kaliakatsos, I. K., & Abbott, J. J. (2010). Microrobots for minimally invasive medicine. *Annual Review of Biomedical Engineering*, 12, 55-85.
- News Health. (2025, March). Nanorobots with hidden 'lethal weapons' destroy cancer cells and stop tumours spreading, scientists say. *The Scottish Sun*.
- Patra, J. K., Das, G., Fraceto, L. F., Campos, E. V., Rodriguez-Torres, M. P., Acosta-Torres, L. S., ... & Shin, H. S. (2018). Nano based drug delivery systems: Recent developments and future prospects. *Journal of Nanobiotechnology*, 16(1), 71.
- Peer, D., Karp, J. M., Hong, S., Farokhzad, O. C., Margalit, R., & Langer, R. (2007). Nanocarriers as an emerging platform for cancer therapy. *Nature Nanotechnology*, 2(12), 751-760.
- Pérez-Herrero, E., & Fernández-Medarde, A. (2015). *Advanced targeted therapies in cancer: Drug nanocarriers, the future of chemotherapy. European Journal of Pharmaceutics and Biopharmaceutics*, 93, 52–79. This review discusses how nanoparticulate systems facilitate targeted drug delivery and diagnostics, contributing to early-detection strategies and more precise, less invasive treatments.
- PMC Cancer Nanomedicine Review. (2025). A recent review on cancer nanomedicine. *PubMed Central*.
- Pragati Ramesh Kumbhar, P. K., Lasure, A., Velayutham, R., & Mandal, D. (2023). An updated landscape on nanotechnology-based drug delivery, immunotherapy, vaccinations, imaging, and biomarker detections for cancers: recent trends and future directions with clinical success. *Discover Nano*, 18(1), 156.
- Rai, M., Yadav, A., & Gade, A. (2018). Silver nanoparticles as a new generation of antimicrobials. *Biotechnology Advances*, 27(1), 76–83.
- Resnik, D. B. (2012). Ethics in nanomedicine. *Nanomedicine (London)*, 2(3), 345–350.
- Samathoti, P., Kumarachari, R. K., Naik Bukke, S. P., Rajasekhar, E. S. K., Jaiswal, A. A., & Eftekhari, Z. (2025). The role of nanomedicine and artificial intelligence in cancer health care: Individual applications and emerging integrations—a narrative review. *Discover Oncology, 16*, 697.
- Sharma, D., & Patel, V. (2025). Quantum dot-enabled biosensing for multiplexed viral detection. *Pharmaceuticals*, 15(7), 880.

- Sharma, V., Jangid, A., & Chaturvedi, P. (2022). *Current regulatory landscape of nanomaterials and nanomedicines: A global perspective.* Regulatory Toxicology and Pharmacology, 130, 105233.
- Shi, J., Kantoff, P. W., Wooster, R., & Farokhzad, O. C. (2017). Cancer nanomedicine: Progress, challenges and opportunities. *Nature Reviews Cancer*, 17(1), 20-37.
- Shi, J.; Ma, R.; Lei, W.; Jing, Z.; Liu, R.; Li, L.; Yan, L.; Lin, H.; Yu, X.; Gao, J. The application of hyaluronic acid-derivatized carbon nanotubes in hematoporphyrin monomethyl ether-based photodynamic therapy for in vivo and in vitro cancer treatment. *Int. J. Nanomed.* **2013**, *8*, 2361–2373.
- Singh, R., Kapoor, D., & Mishra, A. (2022). Nanotechnology-based nucleic acid diagnostics for COVID-19 and beyond. *Biosensors and Bioelectronics*, 197, 113735.
- Smith, J., Lee, H., & Wong, P. (2025). Nanopore sequencing technologies for rapid and portable molecular diagnostics. *Analytical Chemistry*, 97(12), 4562–4578.
- Suresh, A. K., Pelletier, D. A., & Doktycz, M. J. (2018). Relating nanomaterial properties to biological responses: The role of shape, size and surface chemistry. *Environmental Science: Nano*, 5(1), 11-36.
- Torchilin, V. P. (2014). Multifunctional, stimuli-sensitive nanoparticulate systems for drug delivery. *Nature Reviews Drug Discovery*, 13(11), 813–827.
- Vashist, A., Manickam, P., Raymond, A. D., Yndart Arias, A., Kolishetti, N., Vashist, A., et al. (2023). Recent advances in nanotherapeutics for neurological disorders. *ACS Applied Bio Materials*, 6(7), 2614–2621.
- Ventola, C. L. (2017). *Progress in nanomedicine: Approved and investigational nanodrugs*. P & T, 42(12), 742–755. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9761651/
- Wagner, M.K., Li, F., Li, J. *et al.* Use of quantum dots in the development of assays for cancer biomarkers. *Anal Bioanal Chem* 397, 3213–3224 (2010).
- Wang, L., Hu, C., & Shao, L. (2017). The antimicrobial activity of nanoparticles: present situation and prospects for the future. *International journal of nanomedicine*, 1227-1249.
- Wilczewska, A. Z., Niemirowicz, K., Markiewicz, K. H., & Car, H. (2012). Nanoparticles as drug delivery systems. *Pharmacological Reports*, 64(5), 1020–1037.
- Yang, L., Wang, Q., Huang, Y., et al. (2023). Nanotechnology-based diagnostics for infectious diseases: gold nanoparticle lateral flow assays and LAMP-LFB systems. *Frontiers in Microbiology*.
- Yousaf, I. (2024). AI and Machine Learning Approaches for Predicting Nanoparticles Toxicity: The Critical Role of Physicochemical Properties. *arXiv*.
- Zhang, L., Chen, X., & Li, Q. (2023). Noble metal nanoparticles for point-of-care testing: Recent advancements and social impacts. *Nanotechnology*, 34(45), 452001.
- Zhang, L., Gu, F. X., Chan, J. M., Wang, A. Z., Langer, R. S., & Farokhzad, O. C. (2020). Nanoparticles in medicine: Therapeutic applications and developments. *Clinical Pharmacology & Therapeutics*, 83(5), 761–769.