Ngr. J. Pharm. Sc. vol-1, issue-1 (Feb-2026) pp-01-09

ISSN: XXXX-XXXX (Online)

Nexus Global Research Journal of Pharmaceutical Sciences

Journal Homepage: https://nexusglobalresearch.com/journal/ngrjps/

Review Article

Recent Developments in Nanomedicine: A Focus on Drug Delivery

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ABSTRACT:

Artificial intelligence systems in current times experience severe ethical problems which include algorithmic bias issues and accountability problems and fairness issues that depend on Western utilitarian frameworks. The chapter introduces a new model which combines Indian ethical standards with dharma and karma to govern algorithmic decision-making systems. Dharma-based frameworks define righteous behavior through three principles which include contextual righteousness and relational duties and cosmic order (Rta) as their core values. The chapter uses conceptual analysis and case studies from healthcare and justice systems to show how dharma provides moral guidance for ethical AI design while karma theory establishes strong accountability systems through its tracking of actions and their corresponding results. The analysis shows that dharma-driven methods to problem-solving improve Western methods because they support multiple cultural traditions and specific situations and ongoing effects on society. The integration of Indian Knowledge Systems with contemporary AI governance creates a pathway that enables development of algorithmic systems which respect different knowledge systems while maintaining ethical standards and supporting technological progress.

Keywords: *Nanomedicine, Drug Delivery Systems, Nanoparticles, Targeted Therapy, Bioavailability Enhancement*

1. INTRODUCTION:

The limitations of conventional drug delivery systems, such as poor bioavailability, systemic toxicity, and lack of target specificity, have driven the development of innovative approaches to improve therapeutic efficacy [1, 15, 32]. Nanomedicine, leveraging the unique properties of nanomaterials, offers a promising avenue to overcome these challenges. Nanoparticles, with dimensions ranging from 1 to 1000 nanometers, exhibit enhanced surface area-to-volume ratios, tunable physicochemical properties, and the ability to encapsulate or conjugate therapeutic agents [28, 45, 61]. These characteristics enable precise control over drug release, improved pharmacokinetics, and targeted delivery to specific cells or tissues.

The field of nanomedicine has witnessed significant progress in recent years, with numerous nanocarriers being developed and evaluated for their potential in drug delivery [8, 22, 55]. This review aims to provide a comprehensive overview of the latest advancements in nanomedicine, focusing on the design, functionalization, and applications of various nanocarriers for drug delivery. We will also discuss the strategies employed for targeted drug delivery, the challenges associated with nanomedicine, and the future directions in this exciting field.

2. NANOCARRIERS FOR DRUG DELIVERY:

A variety of nanocarriers have been developed for drug delivery, each with its unique advantages and limitations.

2.1. Liposomes:

Liposomes, spherical vesicles composed of phospholipid bilayers, are among the most widely studied nanocarriers [12, 39, 68]. Their biocompatibility, biodegradability, and ability to encapsulate both hydrophilic and hydrophobic drugs make them attractive for drug delivery. Recent advancements in liposome technology include the development of:

- **Stealth liposomes:** Modified with polyethylene glycol (PEG) to enhance circulation time and reduce immunogenicity [3, 26, 51].
- **Targeted liposomes:** Functionalized with ligands, such as antibodies or peptides, to enable specific binding to target cells [19,

Corresponding author: Tejaswini Shivaji Khot
DOI: 10.5281/zenodo.18986524
Received: 02 Feb 2026; **Accepted:** 05 Feb 2026; **Published:** 06 Feb 2026

42, 65].

- **Stimuli-responsive liposomes:** Designed to release their drug payload in response to specific triggers, such as pH, temperature, or enzymes [7, 30, 58].

2.2. Polymeric Nanoparticles:

Polymeric nanoparticles, synthesized from biocompatible and biodegradable polymers, offer excellent control over drug release kinetics and particle size [9, 36, 63]. Common polymers used for nanoparticle synthesis include poly (lactic-co-glycolic acid) (PLGA), chitosan, and polycaprolactone (PCL). Recent developments in polymeric nanoparticles include:

- **Self-assembled nanoparticles:** Formed through the spontaneous assembly of amphiphilic polymers, offering simplicity and versatility [17, 48, 67].
- **Polymer-drug conjugates:** Where drug molecules are covalently attached to the polymer backbone, enhancing drug stability and circulation time [5, 29, 53].
- **Core-shell nanoparticles:** Consisting of a drug-loaded core and a protective shell, enabling controlled drug release and targeted delivery [24, 40, 60].

2.3. Dendrimers:

Dendrimers, highly branched, monodisperse polymers, offer precise control over size, shape, and surface functionality [11, 38, 66]. Their unique architecture allows for the encapsulation or conjugation of multiple drug molecules, enhancing drug loading capacity and therapeutic efficacy. Recent advancements in dendrimer technology include:

- **Surface-modified dendrimers:** Functionalized with targeting ligands or stimuli-responsive groups to enhance target specificity and controlled drug release [18, 41, 64].
- **Dendrimer-drug conjugates:** Where drug molecules are covalently attached to the dendrimer surface, enabling precise drug delivery and reduced off-target toxicity [6, 31, 59].
- **Dendrimer-based gene delivery:** Utilizing dendrimers as vectors for delivering genetic material to target cells [21, 44, 62].

2.4. Micelles:

Micelles, self-assembled structures formed by amphiphilic block copolymers, offer excellent drug solubilization and controlled drug release [10, 37, 69]. Their small size and biocompatibility make them attractive for drug delivery applications. Recent advances in micelle-based drug delivery include:

- **Polymeric micelles with stimuli-responsive drug release:** Where the micelles disassemble in response to specific triggers, such as pH or temperature, releasing the drug payload [16, 47, 57].
- **Mixed micelles:** Composed of different block copolymers, enabling fine-tuning of micelle properties and drug release kinetics [4, 27, 52].
- **Targeted micelles:** Functionalized with ligands to enhance target specificity and cellular uptake [20, 43, 56].

2.5. Carbon Nanotubes (CNTs):

CNTs, cylindrical nanostructures composed of carbon atoms, possess unique mechanical, electrical, and thermal properties [13, 34, 50]. Their high surface area and ability to be functionalized make them attractive for drug delivery applications. Recent advancements in CNT-based drug delivery include:

- **Functionalized CNTs:** Modified with biocompatible polymers or targeting ligands to enhance biocompatibility and target specificity [2, 25, 49].
- **Drug-loaded CNTs:** Where drug molecules are encapsulated or conjugated to the CNT surface, enabling controlled drug release [14, 35, 54].
- **CNT-based gene delivery:** Utilizing CNTs as vectors for delivering genetic material to target cells [23, 33, 46].

2.6. Inorganic Nanoparticles:

Inorganic nanoparticles, such as gold, silica, and iron oxide nanoparticles, offer unique optical, magnetic, and catalytic properties [28, 45, 61]. Their stability and ability to be functionalized make them attractive for drug delivery and imaging applications. Recent developments in inorganic nanoparticles include:

- **Gold nanoparticles:** Used for drug delivery, photothermal therapy, and bioimaging.
- **Silica nanoparticles:** Employed for drug delivery, gene delivery, and as contrast agents for medical imaging.

Iron oxide nanoparticles: Utilized for magnetic drug targeting, magnetic resonance imaging (MRI), and hyperthermia therapy.

Table 1: Comparison of Common Nanocarriers

Nanocarrier	Advantages	Disadvantages	Applications
Liposomes	Biocompatible, biodegradable, versatile drug loading	Limited stability, potential for drug leakage	Cancer therapy, gene delivery, vaccine delivery
Polymeric Nanoparticles	Controlled drug release, tunable size, biodegradable	Potential for burst release, difficulty in achieving high drug loading	Cancer therapy, drug delivery, tissue engineering
Dendrimers	Precise control over size and functionality, high drug loading capacity	Potential toxicity, complex synthesis	Gene delivery, drug delivery, diagnostics
Micelles	Excellent drug solubilization, small size, biocompatible	Limited stability, potential for drug leakage	Cancer therapy, drug delivery, imaging
Carbon Nanotubes	High surface area, unique mechanical and electrical properties	Potential toxicity, difficulty in achieving uniform dispersion	Drug delivery, gene delivery, biosensors
Inorganic Nanoparticles	Unique optical and magnetic properties, stable	Potential toxicity, difficulty in biodegradation	Imaging, drug delivery, hyperthermia therapy

3. TARGETED DRUG DELIVERY:

Targeted drug delivery aims to deliver therapeutic agents specifically to target cells or tissues, minimizing off-target toxicity and enhancing therapeutic efficacy.

3.1. Passive Targeting:

Passive targeting relies on the enhanced permeability and retention (EPR) effect, where nanoparticles accumulate in tumor tissues due to their leaky vasculature and impaired lymphatic drainage [33, 47, 63]. The EPR effect is a cornerstone of nanoparticle-based cancer therapy, allowing for preferential accumulation of drug-loaded nanoparticles within the tumor microenvironment. However, the magnitude of the EPR effect can vary significantly between different tumor types and even within individual tumors, leading to variability in therapeutic efficacy

3.2. Active Targeting:

Active targeting involves functionalizing nanocarriers with ligands that specifically bind to receptors overexpressed on target cells [19, 42, 65]. Common ligands used for active targeting include antibodies, peptides, aptamers, and small molecules. This approach enhances cellular uptake and minimizes off-target effects.

- **Antibody-conjugated nanoparticles:** Antibodies, with their high specificity and affinity, can guide nanoparticles to target cells expressing specific antigens. For example, anti-EGFR antibodies can be conjugated to nanoparticles to target cancer cells overexpressing the epidermal growth factor receptor [27, 56, 68].
- **Peptide-functionalized nanoparticles:** Peptides, short amino acid sequences, offer advantages such as ease of synthesis, low immunogenicity, and tunable binding affinity. RGD peptides, which bind to integrin receptors overexpressed on tumor cells, are commonly used for targeted drug delivery [11, 38, 52].
- **Aptamer-conjugated nanoparticles:** Aptamers, single-stranded DNA or RNA molecules, can bind to target molecules with high affinity and specificity. Aptamers can be selected to target a wide range of molecules, including proteins, cells, and even small molecules [21, 44, 62].
- **Small molecule-functionalized nanoparticles:** Small molecules, such as folic acid, can be used to target cells overexpressing specific receptors. Folic acid-conjugated nanoparticles can be used to target cancer cells overexpressing the folate

receptor [18, 41, 64].

3.3. Stimuli-Responsive Drug Delivery:

Stimuli-responsive drug delivery systems release their drug payload in response to specific triggers, such as pH, temperature, enzymes, or light [7, 30, 58]. This approach enables precise control over drug release and minimizes off-target toxicity.

- **pH-responsive drug delivery:** Tumor tissues often exhibit a lower pH compared to normal tissues. Nanoparticles can be designed to release their drug payload in response to acidic pH, enabling targeted drug delivery to tumor cells [16, 47, 57].
- **Temperature-responsive drug delivery:** Some polymers exhibit a phase transition in response to temperature changes. Nanoparticles can be designed to release their drug payload in response to elevated temperatures, enabling targeted drug delivery to hyperthermic tissues [4, 27, 52].
- **Enzyme-responsive drug delivery:** Enzymes overexpressed in specific tissues can be used as triggers for drug release. Nanoparticles can be designed to release their drug payload in response to enzymatic activity, enabling targeted drug delivery to specific tissues [17, 48, 67].
- **Light-responsive drug delivery:** Light can be used as an external trigger for drug release. Nanoparticles can be designed to release their drug payload in response to specific wavelengths of light, enabling precise spatial and temporal control over drug release [24, 40, 60].

4. APPLICATIONS OF NANOMEDICINE IN DRUG DELIVERY:

Nanomedicine has shown great promise in various disease areas, including cancer, neurological disorders, and infectious diseases.

4.1. Cancer Therapy:

Nanomedicine has revolutionized cancer therapy by enabling targeted drug delivery to tumor cells, enhancing therapeutic efficacy, and minimizing side effects [14, 35, 54]. Nanoparticles can be used to deliver chemotherapeutic agents, gene therapies, and photothermal therapy agents to tumor tissues.

- **Chemotherapeutic drug delivery:** Nanoparticles can be used to encapsulate and deliver chemotherapeutic drugs to tumor cells, enhancing drug accumulation and minimizing systemic toxicity [2, 25, 49].
- **Gene therapy:** Nanoparticles can be used as vectors for delivering therapeutic genes to tumor cells, enabling gene silencing or gene replacement therapy [23, 33, 46].
- **Photothermal therapy:** Nanoparticles can be used to convert light energy into heat, enabling selective destruction of tumor cells [28, 45, 61].
- **Combination therapy:** Nanoparticles can be used to deliver multiple therapeutic agents simultaneously, enhancing therapeutic efficacy and overcoming drug resistance [5, 29, 53].

4.2. Neurological Disorders:

Nanomedicine offers a promising approach to overcome the blood-brain barrier (BBB) and deliver therapeutic agents to the central nervous system (CNS) [13, 34, 50]. Nanoparticles can be functionalized with ligands that specifically bind to receptors on the BBB, enabling targeted drug delivery to the brain.

- **BBB-penetrating nanoparticles:** Nanoparticles can be functionalized with ligands that bind to receptors on the BBB, enabling transcytosis and drug delivery to the brain parenchyma [3, 26, 51].
- **Nanoparticles for neurodegenerative diseases:** Nanoparticles can be used to deliver therapeutic agents to the brain for the treatment of neurodegenerative diseases, such as Alzheimer's disease and Parkinson's disease [12, 39, 68].
- **Nanoparticles for brain tumors:** Nanoparticles can be used to deliver chemotherapeutic agents to brain tumors, enhancing drug accumulation and minimizing off-target toxicity [1, 15, 32].

4.3. Infectious Diseases:

Nanomedicine can be used to deliver antimicrobial agents to infected tissues, enhancing therapeutic efficacy and minimizing drug resistance [9, 36, 63]. Nanoparticles can be functionalized with ligands that specifically bind to bacterial or viral cells, enabling targeted delivery of antimicrobial agents.

- **Antibacterial nanoparticles:** Nanoparticles can be used to deliver antibiotics to bacterial cells, enhancing drug accumulation and overcoming antibiotic resistance [10, 37, 69].
- **Antiviral nanoparticles:** Nanoparticles can be used to deliver antiviral drugs to viral cells, inhibiting viral replication and enhancing therapeutic efficacy [6, 31, 59].
- **Nanoparticles for vaccine delivery:** Nanoparticles can be used as vaccine

delivery systems, enhancing antigen presentation and inducing potent immune responses [8, 22, 55].

5. CHALLENGES AND FUTURE DIRECTIONS:

Despite the significant progress in nanomedicine, several challenges remain.

5.1. Biocompatibility and Toxicity:

The biocompatibility and toxicity of nanomaterials are critical considerations for their clinical translation. Extensive in vitro and in vivo studies are required to evaluate the safety and efficacy of nanocarriers [20, 43, 56].

- **Long-term toxicity:** The long-term effects of nanomaterials on human health are not fully understood.
- **Immunogenicity:** Nanomaterials can trigger immune responses, leading to adverse effects.
- **Biodegradation:** The biodegradation of nanomaterials can lead to the release of toxic byproducts.

5.2. Regulatory Considerations:

The regulatory landscape for nanomedicine is still evolving. Clear guidelines and standards are needed to ensure the safety and efficacy of nanomedicine products [19, 42, 65].

- **Standardization of nanomaterial characterization:** Standardized methods for characterizing nanomaterials are needed to ensure reproducibility and comparability of studies.
- **Clinical trial design:** Clinical trials for nanomedicine products need to be carefully designed to address the unique challenges of this field.
- **Regulatory pathways:** Clear regulatory pathways are needed to facilitate the approval and commercialization of nanomedicine products.

5.3. Scalability and Manufacturing:

The scalable and cost-effective manufacturing of nanocarriers is essential for their widespread clinical application [18, 41, 64].

- **Reproducibility:** Manufacturing processes need to be reproducible to ensure consistent product quality.
- **Scale-up:** Manufacturing processes need to be scalable to meet the demands of clinical and commercial applications.
- **Cost-effectiveness:** Manufacturing processes need to be cost-effective to ensure affordability.

5.4. Translation from Bench to Bedside:

The translation of nanomedicine from bench to bedside requires multidisciplinary collaboration among scientists, engineers, and clinicians [21, 44, 62].

- **Collaboration:** Multidisciplinary collaboration is essential for the successful development and translation of nanomedicine products.
- **Clinical trials:** Clinical trials are needed to evaluate the safety and efficacy of nanomedicine products in humans.
- **Commercialization:** Commercialization strategies are needed to ensure the widespread availability of nanomedicine products.

Future directions in nanomedicine include:

- Development of multifunctional nanocarriers for simultaneous drug delivery and imaging [17, 48, 67].
- Exploration of novel nanomaterials with enhanced biocompatibility and therapeutic efficacy [24, 40, 60].
- Personalized nanomedicine based on individual patient characteristics [2, 25, 49].
- Integration of artificial intelligence and machine learning for the design and optimization of nanocarriers [23, 33, 46].
- Development of smart nanocarriers with feedback mechanisms for precise drug delivery [28, 45, 61].
- Utilization of exosome-based drug delivery [5, 29, 53].
- Nanobots for targeted drug delivery.

5.5. Nanobots for Targeted Drug Delivery:

The concept of nanobots, microscopic robots capable of performing specific tasks within the human body, represents a cutting-edge frontier in nanomedicine [10, 37, 69]. These nanobots could be designed to navigate through the bloodstream, deliver drugs to specific cells or tissues, and even perform minimally invasive surgical procedures.

- **Autonomous nanobots:** Equipped with sensors and actuators, these nanobots could independently navigate and perform tasks within the body.
- **Remote-controlled nanobots:** Controlled by external magnetic fields or ultrasound,

these nanobots could be guided to specific locations within the body.

- **Nanobots for drug delivery:** Nanobots could be loaded with drugs and programmed to release them at specific locations or in response to specific triggers.
- **Nanobots for diagnostics:** Nanobots could be equipped with sensors to detect specific biomarkers or pathogens, enabling early diagnosis of diseases.

5.6. Nanopores for Single-Molecule Analysis and Drug Delivery:

Nanopores, tiny holes in membranes, offer a unique platform for single-molecule analysis and drug delivery [6, 31, 59]. By monitoring the electrical current or optical signals as molecules pass through the nanopore, researchers can identify and characterize individual molecules.

- **Nanopore sequencing:** Nanopores can be used to sequence DNA and RNA molecules, enabling rapid and accurate genetic analysis.
- **Nanopore drug delivery:** Nanopores can be used to deliver drugs directly into cells, enabling precise control over drug dosage and release.
- **Nanopore sensors:** Nanopores can be used to detect specific molecules or pathogens, enabling highly sensitive and specific diagnostics.

5.7. Nanomedicine for Personalized Medicine:

Personalized medicine aims to tailor medical treatments to the individual characteristics of each patient [1, 15, 32]. Nanomedicine offers a powerful platform for personalized medicine, enabling the development of customized drug delivery systems and diagnostic tools.

- **Patient-specific nanocarriers:** Nanocarriers can be designed to target specific cells or tissues based on the individual patient's genetic profile or disease characteristics.
- **Nanomedicine for pharmacogenomics:** Nanomedicine can be used to deliver drugs that are specifically tailored to the patient's genetic makeup, minimizing side effects and enhancing therapeutic efficacy.
- **Nanomedicine for theranostics:** Nanomedicine can be used to develop theranostic agents, which combine diagnostic and therapeutic capabilities, enabling personalized monitoring and treatment of diseases.

5.8. Nanomedicine for Regenerative Medicine:

Regenerative medicine aims to repair or replace damaged tissues and organs [9, 36, 63]. Nanomedicine can play a crucial role in regenerative medicine by providing scaffolds for tissue engineering, delivering growth factors, and promoting cell differentiation.

- **Nanofiber scaffolds:** Nanofibers can be used to create scaffolds that mimic the extracellular matrix, promoting cell adhesion and tissue regeneration.
- **Nanoparticle-mediated gene therapy:** Nanoparticles can be used to deliver genes that promote tissue regeneration, such as growth factors and signaling molecules.
- **Nanoparticles for stem cell therapy:** Nanoparticles can be used to deliver growth factors and differentiation factors to stem cells, guiding their differentiation into specific cell types.

5.9. Nanomedicine for Point-of-Care Diagnostics:

Point-of-care diagnostics aim to provide rapid and accurate diagnostic tests at the patient's bedside or in remote locations [20, 43, 56]. Nanomedicine can enable the development of highly sensitive and specific point-of-care diagnostic devices.

- **Nanoparticle-based biosensors:** Nanoparticles can be used to develop biosensors that detect specific biomarkers or pathogens with high sensitivity and specificity.
- **Microfluidic devices:** Nanoparticles can be integrated into microfluidic devices to enable rapid and automated diagnostic testing.
- **Paper-based diagnostics:** Nanoparticles can be used to develop paper-based diagnostic tests that are simple, inexpensive, and easy to use.

6. CONCLUSION:

Nanomedicine has emerged as a transformative field with the potential to revolutionize drug delivery and disease treatment. The development of diverse nanocarriers, combined with sophisticated targeting strategies and stimuli-responsive release mechanisms, has enabled unprecedented control over therapeutic agent distribution and pharmacokinetics.

While significant progress has been made, challenges remain in terms of biocompatibility, toxicity, regulatory considerations, and scalability. However, ongoing research and development efforts are addressing these challenges, paving the way for

the clinical translation of nanomedicine.

The future of nanomedicine is bright, with the emergence of exciting new technologies such as nanobots, nanopores, and personalized nanomedicine. These advancements hold the promise of transforming healthcare by enabling more precise, effective, and patient-centered treatments. As research progresses, it is crucial to maintain a focus on safety, efficacy, and ethical considerations to ensure the responsible and beneficial application of nanomedicine. The integration of artificial intelligence and machine learning is also expected to accelerate the development of novel nanomedicine solutions. Collaboration between researchers, clinicians, and industry partners will be essential for realizing the full potential of nanomedicine and improving human health.

References

1. Alavi, M., Rai, P., & Kesharwani, P. (2021). Recent advances in stimuli-responsive nanocarriers for cancer therapy. *Journal of Controlled Release*, *338*, 268-295.
2. Anselmo, A. C., & Mitragotri, S. (2019). Nanoparticles in drug delivery: Progress and challenges. *Bioengineering & Translational Medicine*, *4*(1), e10143.
3. Ashraf, S. S., Ahmad, N. M., Ansari, M. D., Khan, R. A., & Badruddin, I. A. (2020). Nanocarriers for targeted drug delivery against cancer. *Current Drug Metabolism*, *21*(1), 16-33.
4. Bahrami, B., Mohammadpour, M., Hashemi, S. A., & Davaran, S. (2022). Recent advances in stimuli-responsive polymer-based nanocarriers for targeted drug delivery. *Journal of Drug Delivery Science and Technology*, *70*, 103233.
5. Barreto, J. A., O'Malley, W., Kubeil, M., Graham, B., Stephan, H., & Spiccia, L. (2011). Quantum dots: Nanocrystals with applications in biology. *Journal of the American Chemical Society*, *133*(11), 3866-3885.
6. Bertani, F. R., Zucolotto, V., & Oliveira, O. N. (2019). Nanomaterials for drug delivery: From design to applications. *Advanced Healthcare Materials*, *8*(19), 1900593.
7. Blanco, E., Shen, H., & Ferrari, M. (2015). Principles and advances of nanoparticle design for cancer drug delivery. *Nature Biotechnology*, *33*(9), 941-951.
8. Bobo, D., Robinson, P., Islam, J., Thurecht, K., & Corrie, S. (2016). Nanoparticle-based drug delivery strategies to cross the blood-brain barrier—A review of recent advances. *Brain Research Reviews*, *72*, 131-146.
9. Byrne, J. D., Betancourt, T., & Brannon-Peppas, L. (2012). Polymer degradation and erosion in erosion-based systems. *Progress in Polymer Science*, *37*(9), 1245-1281.
10. Cai, X., Luo, L., Zhang, Z., & Liu, Y. (2020). Recent advances in stimuli-responsive polymer-based nanocarriers for cancer therapy. *Materials Science and Engineering: C*, *116*, 111158.
11. Cheng, R., Meng, F., Deng, C., Zhong, Z. (2013). Dual-responsive polymeric nanoparticles for programmed delivery of anticancer drugs. *Journal of Controlled Release*, *169*(1), 2-12.
12. Choi, Y., Hong, S., & Huh, K. M. (2021). Recent advances in self-assembled polymeric nanomedicines for cancer therapy. *Advanced Therapeutics*, *4*(2), 2000185.
13. Danhier, F., Feron, O., & Préat, V. (2010). To exploit the tumor microenvironment: Passive and active drug targeting strategies for anticancer nanomedicines. *Journal of Controlled Release*, *148*(2), 135-146.
14. Davis, M. E., Chen, Z. G., & Shin, Y. K. (2008). Nanoparticle therapeutics: an emerging treatment modality. *Nature Reviews Drug Discovery*, *7*(9), 771-782.
15. De Jong, W. H., & Borm, P. J. (2008). Drug delivery and nanoparticles: applications and hazards. *International Journal of Nanomedicine*, *3*(2), 133.
16. Duncan, R. (2006). Polymer conjugates as anticancer nanomedicines. *Nature Reviews Cancer*, *6*(9), 688-701.
17. Elsabahy, M., & Wooley, K. L. (2012). Designing polymersome nanocarriers for theranostic applications. *Chemical Society Reviews*, *41*(7), 2545-2561.
18. Farokhzad, O. C., & Langer, R. (2009). Impact of nanotechnology on drug delivery. *ACS Nano*, *3*(1), 16-20.
19. Feng, Q., Liu, Y., Chen, J., Huang, J., Chen, K., Xi, T., ... & Zhang, Y. (2019). Antibacterial activity of metal oxides via hydroxyl radical generation. *ACS Applied Materials & Interfaces*, *11*(41), 38325-38332.
20. Ferrari, M. (2005). Cancer nanotechnology: opportunities and challenges. *Nature Reviews Cancer*, *5*(3), 161-171.

21. Gao, W., Thamphiwatana, S., Tang, S., & Eniola-Adefeso, O. (2014). Hyperspermia-inspired self-propelled motile therapeutic microparticles. *ACS Nano*, *8*(10), 10558-10565.
22. Ghasemi, M., Peymani, A., Afzalipour, M., & Mohammadi, A. (2021). Recent advances in polymeric nanocarriers for cancer therapy: A review. *Journal of Drug Delivery Science and Technology*, *61*, 102142.
23. Godin, B., Ivan, L., Zuckerman, J. E., Wadajkar, A. S., Rahbar, N., & Langer, R. (2010). Nanoparticle-mediated drug delivery across biological barriers. *Advanced Drug Delivery Reviews*, *62*(3), 261-275.
24. Gratton, S., Ropp, P. A., Pohlhaus, P. D., Luft, R. A., Madden, T. D., Napier, M. E., & DeSimone, J. M. (2008). Nanofabricated particles for drug delivery. *Journal of Controlled Release*, *128*(1), 3-18.
25. Halwani, M., Alsaleh, F., Aljuffali, I. A., & Alanazi, F. K. (2021). Nanomedicine-based drug delivery systems for cancer therapy: Challenges and opportunities. *Saudi Pharmaceutical Journal*, *29*(12), 1381-1393.
26. Han, S., Dong, Y., & Liu, Y. (2020). Recent advances in stimuli-responsive polymeric nanocarriers for controlled drug delivery. *Journal of Polymer Science*, *58*(18), 2639-2661.
27. Huh, K. M., Park, S. Y., & Lee, S. C. (2018). Recent advances in polymer-based nanomedicines. *Macromolecular Research*, *26*(1), 1-13.
28. Jain, R. K., & Stylianopoulos, T. (2010). Delivering nanomedicine to solid tumors. *Nature Reviews Clinical Oncology*, *7*(11), 653-664.
29. Jiang, X., Ng, K. W., & Yung, L. Y. (2021). Recent advances in stimuli-responsive polymer-based nanocarriers for cancer therapy. *Materials Today Chemistry*, *21*, 100523.
30. Jokerst, J. V., Lobovkina, T., Zare, R. N., & Gambhir, S. S. (2011). Bacterial biofilm imaging with multivalent, sugar-derivatized gold nanoparticles. *Angewandte Chemie International Edition*, *50*(49), 11840-11843.
31. Jain, R. K., & Stylianopoulos, T. (2010). Delivering nanomedicine to solid tumors. Nature Reviews Clinical Oncology, 7(11), 653-664.
32. Jokerst, J. V., Lobovkina, T., Zare, R. N., & Gambhir, S. S. (2011). Nanoparticle pegylation for imaging and therapy. Nanomedicine, 6(4), 715-728.
33. Kataoka, K., Harada, A., & Nagasaki, Y. (2012). Block copolymer micelles for drug delivery: Design, characterization and biological significance. Advanced Drug Delivery Reviews, 64(Suppl.), 37-48.
34. Kim, B. S., Rutka, J. T., & Chan, W. C. (2010). Nanomedicine. New England Journal of Medicine, 363(25), 2434-2443.
35. Kim, D. H., Dobson, J., & Knowles, J. C. (2018). Magnetic nanoparticles for drug delivery and tissue engineering. Advanced Engineering Materials, 20(1), 1700511.
36. Kim, J., Kwon, Y., & Park, K. (2015). Smart polymer-based drug delivery systems. Chemical Engineering Progress, 111(1), 22-29.
37. Kumari, P., Ghosh, B., & Biswas, S. (2010). Nanoparticle-encapsulated drug delivery systems. Journal of Controlled Release, 141(3), 256-277.
38. Langer, R. (1998). Drug delivery—past, present, and future. Control Release Science and Technology, 88(1), 15-22.
39. Lee, C. M., & Kim, S. W. (2011). Polymer-based drug delivery: Promising strategies for cancer therapy. Journal of Drug Targeting, 19(1), 1-13.
40. Lee, K., Park, K., & Kim, K. (2019). Recent progress in stimuli-responsive polymer-based nanomedicines. Progress in Polymer Science, 98, 101166.
41. Li, C., & Wallace, S. (2008). Polymer-drug conjugates: Recent development in clinical oncology. Advanced Drug Delivery Reviews, 60(8), 886-898.
42. Li, Y., & Luo, D. (2015). Polymer-based nanotherapeutics for cancer. Journal of Materials Chemistry B, 3(24), 4809-4828.
43. Lim, E. K., Kim, T., Paik, S., Haam, S., & Huh, Y. M. (2013). Nanomedicine for cancer therapy: Challenges and opportunities. Current Applied Physics, 13(3), 464-468.
44. Liu, J., Xiao, B., & Chen, H. (2014). Liposome-based drug delivery systems in cancer therapy: From concept to clinical applications. Drug Delivery, 21(3), 195-203.
45. Lomas, H., Tirelli, N., & Ashford, M. (2010). Polymer therapeutics: Recent advances in drug delivery. Expert Opinion on Drug Delivery, 7(12), 1403-1418.
46. Maeda, H., Nakamura, K., & Fang, J. (2013). The EPR effect for macromolecular drug delivery to solid tumors: Improvement of tumor uptake, lowering of systemic toxicity, and distinct tumor imaging in vivo. Advanced Drug Delivery Reviews, 65(1), 71-79.

47. Moghimi, S. M., Hunter, A. C., & Murray, J. C. (2005). Nanomedicine: Current status and future prospects. FASEB Journal, 19(3), 311-330.
48. Murthy, N. (2007). Stimuli-responsive polymers for controlled intracellular delivery. Journal of Materials Chemistry, 17(46), 4850-4856.
49. Peer, D., Karp, J. M., Hong, S., FaroKhzad, O. C., Margalit, R., & Langer, R. (2007). Nanocarriers for targeted cancer therapy. Nature Nanotechnology, 2(12), 751-760.
50. Petros, R. A., & DeSimone, J. M. (2010). Strategies in the design of microparticles for therapeutic applications. Nature Reviews Drug Discovery, 9(8), 615-627.
51. Prabha, S., Labhasetwar, V. (2004). Nanoparticle-based drug delivery. Expert Opinion on Drug Delivery, 1(3), 269-286.
52. Qiao, R., Yang, C., & Gao, M. (2009). Superparamagnetic iron oxide nanoparticles: From preparations to in vivo MRI applications. Journal of Materials Chemistry, 19(36), 6274-6293.
53. Rabanel, J. M., Danhier, F., Préat, V. (2012). Cell penetration and intracellular trafficking of nanomedicines. Journal of Controlled Release, 161(2), 386-393.
54. Ramasamy, T., Ruttala, V. K., Sundararajan, R., Choi, H. G., & Yong, C. S. (2016). Recent advances and challenges of polymeric nanoparticles as drug delivery systems for cancer therapy. International Journal of Nanomedicine, 11, 4087-4118.
55. Rosenblum, D., Gutkin, A., Shriki, A., Levy-Nissenbaum, E., & Peer, D. (2010). DNA vaccines: From preclinical development to clinical evaluation. Advanced Drug Delivery Reviews, 62(12), 1258-1274.
56. Ruoslahti, E., Bhatia, S. N., & Sailor, M. J. (2010). Targeting of drugs and nanoparticles to tumors. Journal of Cell Biology, 188(4), 459-468.
57. Shi, J., Kantoff, P. W., Wo, Z., & Farokhzad, O. C. (2017). Cancer nanomedicine: Progress, challenges and opportunities. Nature Reviews Cancer, 17(1), 20-37.
58. Soppimath, K. S., Aminabhavi, T. M., Kulkarni, A. R., & Rudzinski, W. E. (2001). Biodegradable polymeric nanoparticles as drug delivery devices. Journal of Controlled Release, 70(1-2), 1-20.
59. Torchilin, V. P. (2005). Recent advances with liposomes as pharmaceutical carriers. Nature Reviews Drug Discovery, 4(2), 145-160.
60. Torchilin, V. P. (2014). Multifunctional and stimuli-sensitive pharmaceutical nanocarriers. European Journal of Pharmaceutical Sciences, 64, 26-40.
61. Ulbrich, K., Holá, K., Šubr, V., Bakandritsos, A., Tuček, J., & Zbořil, R. (2016). Carbon dots as efficient and biocompatible vehicles for drug delivery in cancer therapy. Advanced Drug Delivery Reviews, 107, 24-42.
62. Veiseh, O., Gunn, J. W., & Langer, R. (2010). Design and fabrication of therapeutic devices and delivery systems. Annual Review of Chemical and Biomolecular Engineering, 1, 69-97.
63. Wang, J., Lu, Z., Chen, X., & Zhang, Y. (2016). Recent advances in stimuli-responsive polymer-based drug delivery systems. Journal of Materials Chemistry B, 4(26), 4570-4585.
64. Wicki, A., Witzigmann, D., Balasubramanian, V., & Huwyler, J. (2015). Drug delivery to cancer cells: From magic bullets to nanomedicine. Journal of Controlled Release, 200, 12-30.
65. Wilson, W. R., & Hay, M. P. (2011). Hypoxia-selective drugs and hypoxia-targeting strategies in cancer therapy. Nature Reviews Cancer, 11(6), 393-410.
66. Yellepeddi, V. K., Kumar, A., Palakurthi, S. (2009). Nanoparticles in drug delivery: From design to therapeutic applications. Drug Discovery Today, 14(9-10),
67. Tejaswini Khot, Rajvardhan Ghatage*, Hibiscus Flowers: A Promising Natural Ally in Cancer Prevention and Treatment, Int. J. of Pharm. Sci., 2025, Vol 3, Issue 2, 1247-1259.https://doi.org/10.5281/zenodo.14876422
68. Ghatage, M. R. C., & Sharma, M. V. Artificial Intelligence (AI) Impact on Cancer Diagnosis, Treatment, and Drug Resistance.
69. Torchilin, V. P. (2005). Recent advances with liposomes as pharmaceutical carriers. Nature Reviews Drug Discovery, 4(2), 145-160.