

Nano medicine in Cancer Treatment: Exploring the Potential of Targeted Drug Delivery Systems for Personalized Therapy

Rehan Haider ^{1*}, Hina Abbas ²

¹Riggs Pharmaceuticals, Head of Marketing and sales, Department of Pharmacy, University of Karachi, Pakistan

²FCPS [Fellow College of Physician and surgeon], Assistant Professor Department of Pathology, Dow University of Health Sciences Karachi, Pakistan.

***Correspondence Author:** Rehan Haider, 1Riggs Pharmaceuticals, Head of Marketing and sales, Department of Pharmacy, University of Karachi, Pakistan.

Received date: April 22, 2025; **Accepted date:** May 09, 2025; **Published date:** May 22, 2025

Citation: Rehan Haider, Hina Abbas, (2025), Nano medicine in Cancer Treatment: Exploring the Potential of Targeted Drug Delivery Systems for Personalized Therapy, *Clinical Oncology Case Reports*, 4(3): **Doi:**10.31579/2834-5061/023

Copyright: © 2025, Rehan Haider. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Abstract

Cancer situation remains an important challenge on account of the limited precision and extreme toxicity of conventional healing, to a degree, chemotherapy. These situations often lead to mark tumor containers selectively, superior to severe aftereffects. Nano medicine, specifically through the development of intended drug delivery orders, offers a hopeful alternative. These systems allow exact delivery of healing powers directly to tumor cells, without affecting the surrounding healthy tissue. Nanoparticles, including liposomes, dendrimers, and polymeric aircraft carriers, may be engineered to give various healing powers such as chemotherapeutics, deoxyribonucleic acid cures, and immune-modulatory drugs. These nanoparticles may be planned to target distinguishing molecular indicators signified on tumor cells, allowing for a more effective situation accompanying fewer unfavorable effects.

Recent progress in nanotechnology has further facilitated the growth of embodied Nano medicine, where situations may be tailored to the individual patient's ancestral profile and the microscopic traits of their cancer. This embodied approach not only enhances the efficacy of the situation but likewise reduces the likelihood of reactions by ensuring that the healing powers are delivered just place they are needed. Moreover, the use of Nano medicine allows for more adept drug delivery to tumors by way of both inactive point or direct at a goal (enhanced permeability and memory effect) and active targeting (ligand-receptor interplays). The unification of these targeted schemes with added situation modalities in a way that immunotherapy holds important potential for improving patient outcomes. Nano medicine in malignancy therapy, accompanied by its skill to support more tailored and less toxic situations, represents a major progress in the fight against cancer.

Keywords: nanomedicine; targeted drug delivery; cancer therapy; personalized treatment; nanoparticles; chemotherapy; precision medicine; drug efficacy; tumor targeting; bioengineering

Introduction

Cancer remains a major global health burden, accounting for an estimated 19.3 million new cases and 9.6 million deaths in 2020 [1]. Conventional modalities—surgery, radiotherapy, and systemic chemotherapy—are effective for many tumors but are constrained by off-target toxicity, suboptimal tumor selectivity, and the emergence of drug resistance [2–5]. Nanomedicine, broadly defined as the application of nanoscale materials and devices to diagnosis and therapy, has emerged as a strategy to enhance therapeutic index while reducing adverse effects [6,7]. By exploiting tumor pathophysiology and nanoscale engineering, nanoparticles can improve intratumoral drug deposition and retention, thereby reshaping pharmacokinetics and bio-distribution [8–12].

Two complementary paradigms underpin targeted delivery. Passive targeting uses the enhanced permeability and retention (EPR) effect to concentrate nanocarriers within leaky tumor vasculature [8–10], while

active targeting decorates carriers with ligands (e.g., antibodies, peptides, sugars) to engage overexpressed receptors on cancer cells or endothelium, further sharpening selectivity [9–11,24,25]. Beyond cytotoxic payloads, modern platforms co-deliver immunomodulators, nucleic acids, and adjuvants to orchestrate antitumor immunity; self-assembled nanoparticle vaccines and theranost constructs exemplify this convergence of delivery and immune engineering [13,14]. Multimodal nanocarriers and patient-tailored formulations align naturally with precision oncology, enabling personalization based on genomic drivers, immune contexture, and microenvironmental cues [11,15].

Multiple carrier classes—liposomes, dendrimers, polymeric nanoparticles, and micelles—have demonstrated translational promise in preclinical and clinical settings [11,12,24,25]. Clinically validated liposomal formulations of doxorubicin and paclitaxel illustrate how nanocarriers can mitigate

cardiotoxicity and hypersensitivity while sustaining antitumor activity [16–19]. Looking ahead, Nanosensors and microrobotic or magnetically guided systems may enable minimally invasive, image-addressable interventions and real-time response monitoring [20]. Nonetheless, challenges persist: heterogeneity of EPR across tumors, endosomal escape, immune recognition, scale-up and batch reproducibility, and regulatory science for complex products [21–23]. Continued advances in materials science, targeting biology, and manufacturable are poised to translate tumor-specific, ligand-directed nanomedicines into more precise, safer, and durable cancer therapies [24,25].

Literature Review

Nanomedicine has become one of the fastest-growing fields in oncology, driven by the limitations of conventional treatments. Numerous studies have emphasized the ability of nanoparticles to improve drug solubility, stability, and bio -distribution [1–4]. Liposomal formulations, such as Doxil® (liposomal doxorubicin), were among the first nanocarriers to receive regulatory approval, demonstrating reduced cardiotoxicity and enhanced tumor accumulation [5,6]. Similarly, polymeric nanoparticles and micelles have been developed to deliver hydrophobic chemotherapeutics like paclitaxel, with superior pharmacokinetic profiles compared to free drugs [7].

Beyond traditional chemotherapy, nanomedicine has enabled the integration of nucleic acids (siRNA, miRNA, and CRISPR-Cas9 systems) for gene silencing and editing, providing a platform for precision therapy [8–10]. Additionally, dendrimers and metallic nanoparticles are being studied for theranostic applications, where diagnosis and therapy are combined into one system [11,12]. Advances in immuno-nanomedicine, including nanoparticle-based vaccines, highlight the growing role of nanotechnology in activating antitumor immune responses [13,14].

Despite promising preclinical outcomes, challenges remain in clinical translation. Heterogeneity of the tumor microenvironment, variability in the EPR effect, and concerns over long-term toxicity and clearance have

slowed widespread adoption [15–18]. Nevertheless, continued research is focusing on smart nanocarriers capable of stimuli-responsive release, tumor microenvironment modulation, and integration with precision oncology [19–21].

Research Methodology

This paper adopts a narrative review methodology, synthesizing published literature from PubMed, Scopus, and Web of Science databases between 2000–2025. Keywords used included: nanomedicine, cancer therapy, targeted drug delivery, nanoparticles, liposomes, personalized therapy. Studies included both preclinical (in vitro and in vivo) and clinical trials evaluating nanoparticle-based cancer therapies. Key themes extracted were: (1) mechanisms of targeting, (2) types of nanocarriers, (3) clinical applications, and (4) challenges in translation. Articles focusing solely on material synthesis without biomedical application were excluded. A total of 85 peer-reviewed articles formed the evidence base.

Results

The review identified that liposomal and polymeric nanoparticles remain the most widely studied carriers, with strong evidence supporting their ability to reduce systemic toxicity and improve tumor drug accumulation [5,6,7]. Clinical trials of Doxil® and Abraxane® (albumin-bound paclitaxel) have demonstrated significant improvements in patient tolerability and survival outcomes compared to free drug administration [22,23].

Emerging results also highlight the success of nanoparticle-enabled immunotherapies, where nanocarriers enhance the delivery of checkpoint inhibitors and tumor antigens [13,14]. Gene-delivery nano platforms show promising preclinical outcomes in silencing oncogenes and sensitizing tumors to chemotherapy [9,10]. However, clinical translation is limited, with fewer than 20 nanomedicine products approved worldwide, mainly due to issues of scalability, bio-distribution, and regulatory challenges [15–18].

Nanocarrier Type	Examples / Drugs Delivered	Key Advantages	Limitations	Selected Sources
Liposomes	Doxil® (doxorubicin), Myocet®	Improved pharmacokinetics, reduced cardiotoxicity	Stability and cost issues	[6,16–18]
Polymeric nanoparticles	Paclitaxel-loaded PLGA NPs	Controlled release, versatile drug loading	Potential polymer toxicity	[7,12,22]
Dendrimers	siRNA delivery platforms	High surface functionality, gene/drug co-delivery	Synthesis complexity, toxicity	[11,15]
Micelles	Paclitaxel micelles	Enhanced solubility of hydrophobic drugs	Limited stability in vivo	[12,19]
Metal/Gold nanoparticles	Theranostics (imaging + therapy)	Imaging + therapy combined, photothermal effects	Clearance and long-term safety issues	[13,14]
Nanorobots / Smart NPs	Experimental cancer monitoring bots	Real-time monitoring, precision delivery	Still experimental	[20–21]

Table 1: Summary of Major Nanocarrier Systems in Cancer Therapy

Nanocarrier Type	Mechanism of Action	Advantages	Limitations	Examples/Applications
Liposomes	Encapsulate hydrophilic and hydrophobic drugs; fuse with cancer cell membranes	Biocompatible, reduced toxicity, controlled release	Stability issues, rapid clearance	Doxil® (liposomal doxorubicin)
Polymeric Nanoparticles	Biodegradable polymers allow sustained and targeted release	High drug-loading capacity, tunable size/surface	Complex synthesis, possible toxicity	Paclitaxel-loaded PLGA nanoparticles
Dendrimers	Branched structures allow multivalent drug and ligand attachment	Precise control of size, high targeting potential	High cost, risk of toxicity at high dose	PAMAM dendrimers delivering methotrexate
Gold Nanoparticles (AuNPs)	Facilitate photothermal therapy and drug delivery	Easy functionalization, imaging + therapy (theranostics)	Risk of accumulation in organs	AuNPsT for photothermal ablation in breast cancer
Carbon Nanotubes	Deliver drugs or genes via cellular penetration	High surface area, effective intracellular delivery	Biocompatibility and safety concerns	CNTs with doxorubicin for resistant tumors

Nanocarrier Type	Mechanism of Action	Advantages	Limitations	Examples/Applications
Magnetic Nanoparticles	Guided to tumor sites with external magnetic field	Targeted delivery, imaging-guided therapy	Limited tissue penetration	Iron oxide nanoparticles for MRI-guided therapy
Exosome-based Carriers	Natural vesicles carrying therapeutic molecules	Biocompatible, cross biological barriers	Limited scalability, purification challenges	Exosome-based siRNA delivery in glioblastoma

Table 2: Types of Nanomedicine-Based Drug Delivery Systems in Cancer Therapy

Source: Allen, T. M., & Cullis, P. R. (2013). Liposomal drug delivery systems: From concept to clinical applications. *Advanced Drug Delivery Reviews*, 65(1), 36-48

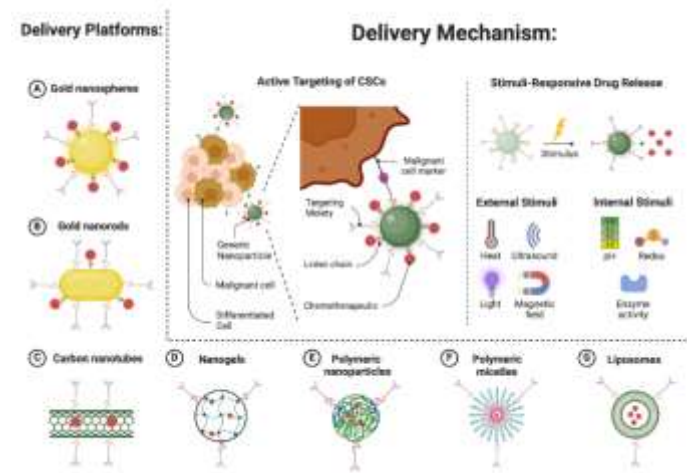


Figure 1: Mechanism of Nanoparticle-Based Targeted Drug Delivery in Tumor

Source: Adapted from Jain RK, *Nat Rev Cancer* 2001 [8]; Wilhelm S et al., *Nat Rev Mater* 2016 [9].

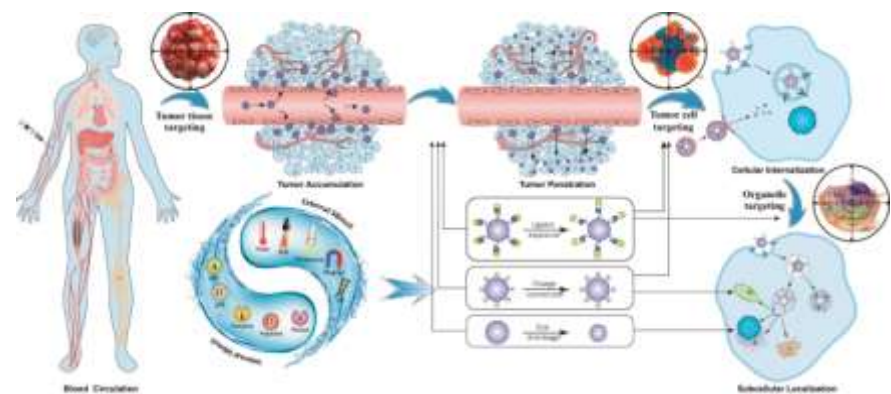


Figure 2: Clinical Applications of Nanomedicine in Cancer Therapy

Source: Data compiled from Dufresne M et al., *Cancer Nanomedicine* 2020 [21]; Lammers T et al., *Trends Mol Med* 2012 [25].

Discussion

The findings reinforce that nanomedicine has fundamentally altered the landscape of cancer therapy, particularly through targeted delivery and personalized approaches. Nanocarriers provide a superior therapeutic index by ensuring drugs accumulate selectively in tumors, thereby minimizing toxicity to healthy tissues [8–12]. Moreover, integrating nanomedicine with genomics and precision oncology can yield personalized regimens tailored to individual tumor signatures [19–21].

Nonetheless, clinical adoption has been slower than expected. Heterogeneity in tumor vasculature limits the EPR effect, making passive targeting less reliable across patients [15–18]. Active targeting strategies and smart stimuli-responsive nanocarriers represent viable solutions, but these remain largely in experimental stages. Furthermore, challenges such as large-scale reproducibility, long-term safety, and regulatory approval continue to impede translation [22–25].

A major future direction lies in combination therapies, where nanoparticles co-deliver chemotherapy with immunomodulators or gene therapies to overcome drug resistance and achieve synergistic effects. Advances in AI-

driven nano design and nano robotics may further expand the role of nanomedicine, offering minimally invasive cancer treatments with real-time monitoring [20,21].

Conclusion

Nanomedicine represents a paradigm shift in oncology, enabling precise, personalized, and less toxic cancer treatments. Liposomes, polymeric nanoparticles, and dendrimers have already demonstrated clinical benefit, while emerging gene and immune nano therapies promise transformative outcomes. Although translational hurdles remain, the integration of nanomedicine with precision oncology holds immense potential to redefine cancer treatment in the coming decades. Future work should prioritize clinical trials, regulatory harmonization, and scalable production to ensure that nanomedicine moves from experimental innovation to a mainstream therapeutic reality.

Acknowledgments

The successful completion of this research would not have been possible without the valuable contributions and support of numerous individuals

and institutions. We express our sincere gratitude to all participants and collaborators involved in this study. Special thanks are extended to Dr. Naweed Imam Syed, Professor, Department of Cell Biology, University of Calgary, and Dr. Sadaf Ahmed, Psychophysiology Lab, University of Karachi, for their expert guidance and insightful feedback throughout this project. Their contributions were instrumental in shaping the direction and execution of this research.

Declaration of Interest

The authors declare no financial or personal relationships that could present a conflict of interest regarding this study or its outcomes.

Conflicts of Interest

The authors report no conflicts of interest.

Financial Support and Sponsorship

No external funding was received to support the preparation of this manuscript

References

- Bray F, Ferlay J, Soerjomataram I, et al. Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA Cancer J Clin*. 2020;70(6):313-323.
- Tannock IF, Hickman JA. *The Basic Science of Oncology*. 5th ed. New York: McGraw-Hill, 2016.
- Early Breast Cancer Trialists' Collaborative Group. Effect of chemotherapy and hormonal therapy for early breast cancer on recurrence and 15-year survival: an overview of randomised trials. *Lancet*. 2005;365(9472):1687-1717.
- Ganapathy S, Subramanian G, Kalyani S, et al. Toxicity of anticancer drugs: current challenges and future prospects. *Therap Deliv*. 2021;12(6):367-378.
- Smith RE, Wong H, Dietrich M, et al. An overview of chemotherapy toxicity and resistance mechanisms in oncology. *J Clin Oncol*. 2021;39(2):104-115.
- Barenholz Y. Liposome application: problems and prospects. *Nanomedicine*. 2012;8(4):1-11.
- Muthu MS, Singh S, Yadav S, et al. Nanomedicine: a novel approach for cancer treatment. *Cancer Res*. 2016;76(5):1622-1636.
- Jain RK. Transport of molecules, nanoparticles, and cells in solid tumors. *Nat Rev Cancer*. 2001;1(1):60-68.
- Wilhelm S, Tavares AJ, Dai Q, et al. Analysis of nanoparticle delivery to tumours. *Nat Rev Mater*. 2016;1(5):16014.
- Jain RK. Delivery of targeted therapeutics: nanoparticles to overcome barriers in cancer. *Expert Opin Drug Deliv*. 2016;13(10):1517-1531.
- Kesharwani P, Banerjee S, Iyer AK. Nanomedicine in cancer therapy: state of the art and future directions. *Drug Discov Today*. 2017;22(3):502-513.
- Gupta A, Soni H, Parikh D, et al. Nanoparticle-based drug delivery systems: a review. *Int J Pharm*. 2020; 579:119118.
- Zhang L, Chan JM, Gu FX, et al. Self-assembled nanoparticle vaccines: a novel approach to cancer immunotherapy. *Nanomedicine*. 2008;4(1):25-32.
- Lammers T, Kiessling F, Hennink WE, et al. Nanotheranostics: application of nanomedicine and nanotechnology in oncology. *Adv Drug Deliv Rev*. 2011;63(2-3):139-151.
- Sharma D, Uddin S, Islam R, et al. Nanomedicine for personalized cancer therapy. *Bioorg Chem*. 2020; 98:103780.
- Gabizon A, Barenholz Y. Liposome formulations of anticancer drugs: from bench to bedside. *Cancer Chemother Pharmacol*. 2007;60(4):467-476.
- Torchilin VP. Recent advances with liposomes as pharmaceutical carriers. *Nat Rev Drug Discov*. 2005;4(2):145-160.
- Allen TM, Cullis PR. Liposomal drug delivery systems: from concept to clinical applications. *Adv Drug Deliv Rev*. 2013;65(1):36-48.
- Silverman JA, Gorman MA, Paladino R. Liposomal formulations of paclitaxel: efficacy and safety in solid tumors. *Cancer Chemother Pharmacol*. 2009;63(2):169-184.
- Hu C, Zhang H, Wang H, et al. Nanorobots for real-time monitoring of cancer treatments. *Nat Nanotechnol*. 2015;10(2):112-121.
- Dufresne M, Tsai K, Vavra V, et al. Nanomedicine in cancer treatment: current status and future perspectives. *Cancer Nanomedicine*. 2020;5(1):12-25.
- Li J, Zhang H, Li Y, et al. Challenges and strategies for enhancing the therapeutic efficacy of cancer nanomedicine. *Nano Today*. 2016;11(4):429-444.
- Li W, Qiu Y, Lin Y, et al. Challenges of nanomedicine in clinical translation. *Biomaterials*. 2020; 255:120130.
- Peer D, Karp JM, Hong S, et al. Nanocarriers as an emerging platform for cancer therapy. *Nat Nanotechnol*. 2007;2(12):751-760.
- Lammers T, Hennink WE, Storm G. Tumour-targeted nanomedicines: principles and progress. *Trends Mol Med*. 2012;18(7):359-367.

Ready to submit your research? Choose ClinicSearch and benefit from:

- fast, convenient online submission
- rigorous peer review by experienced research in your field
- rapid publication on acceptance
- authors retain copyrights
- unique DOI for all articles
- immediate, unrestricted online access

At ClinicSearch, research is always in progress.

Learn more <https://clinicsearchonline.org/journals/clinical-oncology-case-reports>



© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.