

Role of Nanotechnology in Cancer Treatment

Dr. Sanjay R.Kumavat ^{1*}

¹Assistant Professor, G. H. Raisoni College of Engineering and Management, Jalgaon, Maharashtra.

Abstract

One rapidly developing cutting-edge area with several uses in novel cancer detection platforms is nanotechnology. Nanoparticles are being used to enhance the identification and treatment of a number of disorders, including cancer. Nanotechnology has enabled the use of nanoparticles in cancer therapy, which are capable of passively aggregating at tumour sites, rendering them an ideal alternative to conventional methods. This article reviews studies on the use of nanotechnology to cancer therapy from a variety of sources. From the review it concluded that nanotechnology plays a crucial role in revolutionizing cancer treatment by enhancing diagnosis, drug delivery, and therapy. Nanomedicine offers high sensitivity, specificity, and improved pharmacokinetics, enabling targeted drug delivery with reduced toxicity and enhanced therapeutic efficacy. Various nanoparticles, including polymeric, metallic, and hybrid NPs, provide platforms for combination therapy, overcoming multidrug resistance. Despite challenges in specificity, biodistribution, and clinical efficacy, ongoing research is optimizing “nanoparticle-based drug delivery”. Diagnosis and therapy integration (theragnosis) exhibits significant potential for personalised cancer treatment. With continuous advancements, nanotechnology is transforming oncology, offering innovative solutions for efficient, site-specific, and cost-effective cancer management.

Keywords: Nanotechnology, Nanoparticles, Cancer diagnosis, Tumors, Cancer treatment, Chemotherapeutic, Drug delivery, Nanomedicine, etc.

1 Introduction

Cancer's high death rate and considerable incidence have made it a global problem. For patients with cancer at various stages, surgery, chemotherapy, and radiation therapy have been common first-line

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treatment choices. Most cancer patients are treated with chemotherapy either before to or after surgery [1]. Chemotherapeutic drugs target fast-dividing malignant cells, but they also impact healthy cells that replicate quickly, such those found in the gastrointestinal system, hair follicles, and bone marrow. Chemotherapy damages organs and systems via a variety of ways, including as direct toxicity, indirect toxicity caused by liver metabolites, immune system suppression, decreased oxygen delivery, and inflammation [2]. The systems and organs impacted determine the precise negative consequences and damage manifestation. Chemotherapy dosage is often restricted as a result of these adverse effects, which lowers the effectiveness of the anti-cancer treatment. Current treatments that try to reduce these side effects are insufficient since they have negative side effects of their own [3]. Therefore, in order to continue full-dose chemotherapy, the adverse effects must be reduced. Therefore, creating new, enhanced, safer, and more targeted treatments is crucial for cancer patients. A number of strategies to broaden cancer treatment beyond conventional chemotherapy have surfaced in recent decades [4]. Deciphering molecular markers and discovering new treatment targets are made possible by advanced technology, such as genomic approaches, translation advancements, and protein processing breakthroughs. Models of cancer stem cells aid in the development of methods for comprehending the behaviour, treatment resistance, and tumour heterogeneity of cancer cells [5]. Examined in both in vitro and in vivo research, precisely tailored nanotechnology drug delivery systems transform therapeutic effectiveness by demonstrating adaptability in diagnostics and targeted therapies [6].

Nanotechnology-based drug delivery has great potential for cancer diagnosis and treatment with fewer side effects, as shown by recent advancements in nanomedicine. Although nanoparticles (NPs) are far smaller than cells, they are nevertheless big enough to contain a lot of small-molecule substances. In addition, NPs' vast surface area makes them very capable of functionalising with ligands, such as peptides, small molecules, and DNA or RNA strands [7].

A. Nanoparticles

The term nanoparticles (NPs) refers to particles that have a single dimension of less than 100 nm and unique properties that are often lacking in bulk samples of an identical substance. These may be categorised as 0D, 1D, 2D, or 3D based on the general form of the nanoparticle [8]. A nanoparticle's fundamentally complex composition is made up of its "surface layer, shell layer, and core", which is essentially its central portion and frequently referred to as the NP itself. These materials are very significant in transdisciplinary fields because of their exceptional qualities, which include their "high surface-to-volume ratio, dissimilarity, sub-micron size, and enhanced targeting mechanism" [4].

According to reports, the "enhanced permeability and retention (EPR)" effects of NPs is facilitated by their deep tissue penetration. Additionally, by successfully overcoming epithelial fenestration, the surface properties affect bioavailability and half-life. For example, NPs coated with the hydrophilic polymer polyethylene glycol (PEG) reduce opsonisation and evade immune system clearance [9]. Additionally, by adjusting the properties of particle polymers, the rate of release of the medication or active moiety may be optimised. Overall, the therapeutic impact of NPs in the prevention and therapy of cancer is determined by their distinctive characteristics [10].

B. Application of NPs in cancer diagnosis

In order to successfully treat and control cancer, early diagnosis is essential. There are a number of methods for diagnosing cancer, including physical examination, laboratory testing (such as blood and urine tests), biopsy, and imaging methods (such as X-ray, CT, MRI, and PET) [11]. Cancer identification has become much more accurate and quick because to modern diagnostic techniques, which also improve patient outcomes by enabling prompt treatment commencement. Nonetheless, more precise and non-invasive diagnostic techniques are still required, as is the creation of tailored strategies that take into account the particulars of each patient's malignancy [7].

NPs, like gold NPs in home pregnancy tests, have shown a lot of promise in a variety of medical testing and screening processes. Because NPs are inexpensive and may be used to identify any kind of cancer, they have gained interest in the field of cancer detection. They can capture cancer biomarkers including DNA, circulating tumour antigens, exosomes, and different cell types, including circulating tumour cells [11]. Assays based on NPs exhibit superior selectivity and sensitivity in comparison to current cancer diagnostic methods, resulting in early cancer diagnosis and improved prognostic results. Body fluids including urine and saliva, as well as tissues and blood, contain cancer indicators. The low quantities of biomarkers in bodily fluids, timing, and heterogeneity are only a few of the obstacles that may impede the early identification of biomarkers. NPs may, however, enhance biosensors for selective diagnostics due to their great sensitivity and selectivity in specifically targeting [12].

C. Significant challenges in the clinical application of nanoparticles

Today, the amount of research and data focused on nanoparticles has increased in tandem with the growth of nanotechnology. Few of them, however, really advance to clinical testing. In vitro and in vivo stages are where the majority of them stop. Clinical translation presents unique problems for each specific nano-formulation, however the majority of NPs encounter common issues that may be categorised into biological, technical, and study-design related issues [4].

Lack of routes of administration, reducing biodistribution, NPs' ability to pass through biological barriers, their toxicity, and degradation are examples of biological obstacles. It is difficult to remain and interact with the target region when NPs are administered intravenously because the blood absorbs them. This leads to the use of a high concentration drug that could not provide the desired therapeutic effects. However, this may be avoided since 3D magnetic flies have been used in a number of "in vitro and in vivo" studies to control NP movement in opposition to blood flow. There is still a need for further research on the impact of magnetic fields on human beings, the crosstalk among magnetic fields, and a variety of other nanoparticles [13].

To regulate the biological fate of NPs is a challenging endeavour that necessitates a significant amount of attention. The potential for lung, liver, and kidney harm exists, regardless of whether nanoparticles are made from biosafety materials and are appropriately calibrated to extend their retention period and half-life. Certain variables that influence toxicity include particle shape and size, surface area, solubility, and agglomeration. "Oxidative, cytotoxic, and inflammatory consequences" have been observed in

conjunction with an increase in lung deposition caused by NPs. According to research, the healthy cells are frequently damaged by the free radicals that are generated by NPs. NPs that are derived from more biocompatible materials, including chitosan, and compounds that decompose when exposed to near-infrared light, are potential remedies [14].

2 Literature Review

(Wang et al., 2024) [15] Drugs or gene fragments may be efficiently delivered to tumour tissues by nanoparticles using active or passive targeting techniques, improving therapeutic results while causing the least amount of damage to healthy cells. The treatment effectiveness of malignant tumours may be improved by using nanoparticles in conjunction with photothermal therapy and radiation sensitisation. The use of nanotechnology in both the detection and treatment of malignant tumours is summarised in this review along with an overview of the literature. We examine the latest advancements in nanotechnology applications in relation to oncological illnesses that originate from many bodily systems and combine the pathophysiological characteristics of tumours at several locations. The promises and difficulties of nanotechnology in cancer are finally briefly covered.

(Kemp & Kwon, 2021) [16] Nanotechnology has gradually spread into the fields of imaging, diagnostics, radiation, and cancer treatment, proving its ability to enhance each and improve patient care. Nanomaterials provide a wealth of adaptability, usefulness, and uses for developing robust imaging modalities, improved radiation adjuvants, precisely targeted cancer medication, and precise early-detection tools. This study sheds light on the present preclinical and clinical nanotechnological uses for radiation treatment, imaging, diagnostics, and cancer medication therapy.

(Yu et al., 2021) [17] Nanoparticle technology offers a new way to improve on conventional therapies and diagnostics. However, there aren't many published clinical studies on nanoparticles, and the majority of research on them is being conducted in vitro and in vivo. Initially, this investigation offers a comprehensive examination of the present applications of nanoparticles in the detection and treatment of cancer. Then, using the most recent two years' worth of updated research, we suggest the problems impeding the clinical use of NPs and provide workable remedies. Our thoughts on the potential advancements of NPs in tumour detection and therapy will be presented at the conclusion.

(Alrushaid et al., 2023) [18] Numerous medications are currently available or coated with nanoparticles to ensure that they directly target tumours or damaged organs without compromising healthy tissues or cells. According to several studies, nanoparticles' antioxidant properties and ability to prevent tumour development give them inherent anticancer efficacy. Additionally, medications may be released more efficiently and with fewer adverse effects when nanoparticles are used to allow regulated release. The molecular imaging agents employed in ultrasonography are nanomaterials such as microbubbles. In this investigation, the various types of nanoparticles that are frequently employed in both the identification and treatment of cancer are examined.

(Dessale et al., 2022) [9] Nanotechnology has the potential to be a viable technology for the in vivo imaging and identification of cancer cells and biomarkers, given its extensive spectrum of applications.

The use of nanotechnology in cancer treatment may provide a rapid, secure, economical, and successful approach. Moreover, it offers concurrent cancer diagnosis and therapy via the use of nano-theragnostic particles that promote early identification and cancer cell degeneration. The best cancer diagnostic, therapy, and management alternatives must be chosen based on current and updated talks, and it is crucial to get fresh knowledge about creating efficient protocols. In addition to providing insights for the field's future, this paper discusses the utilisation of nanotechnology in cancer diagnosis, therapy, and prognosis.

(Ganesh et al., 2022) [11] Nanotechnology has enormous potential to transform the way physicians identify and treat cancer patients. Nanotechnology is already significantly influencing patient care, but it also presents significant challenges for the future, such enhancing the engineering and design of materials that target cancer. There has been a lot of work done in the last several years. committed to developing nanotechnology to reduce and enhance the dispersion and toxicity of anticancer therapies in healthy tissues, as well as the transport of anticancer drugs to tumour tissue. Many things have changed. Polymer Carbon, liposomes, dendrimers, nanoparticles, and nanoshells Novel platforms for nanotechnology include nuclei acid-based nanoparticles, superparamagnetic nanoparticles, and nanotubes.

(Zhu et al., 2022) [19] A variety of nanomaterials are used in the treatment of cancer. In order to boost medication capacity and bioavailability while overcoming cytotoxicity and limited selectivity, nanomaterials have been created for cancer therapies. Only a small number of nanodrugs have received approval for clinical use, despite the growing number of related research. Studies on targeted medication delivery using nanocarriers are required to enhance the translation of these materials. It is still necessary to address cytotoxicity, increased permeability and retention effects, and the protein corona's protective function. In this mini-review, novel nanomaterials produced in research and clinical settings are compiled, existing obstacles to their clinical adoption are examined, and the successful use of nanoparticles in cancer therapy is discussed.

(Kumar et al., 2024) [20] Nanotechnology has enabled the introduction of nanoparticles that might passively collect at tumour sites, making them a perfect alternative to conventional cancer treatment techniques. Nanoparticles have advantages such as reduced toxicity and biocompatibility, which make them suitable for targeted drug delivery. The high surface to volume ratio of nanoparticles aids in the binding, absorption, and transportation of small biomolecules, including protein molecules, ribonucleic acid drugs, and deoxyribonucleic acid, to the targeted site, enhancing the effectiveness of therapeutic agents. The aforementioned benefits make them significantly different and more successful than traditional cancer treatment methods. This paper will provide an overview of medication delivery using nanovessels and nanoparticles for cancer diagnosis.

3 Conclusion

With its great sensitivity, specificity, and multifunctionality, nanotechnology is essential to transforming cancer detection and therapy. Despite advancements in nanoparticle (NP) engineering for targeted drug delivery, challenges remain in enhancing selectivity, sensitivity, and optimal pharmacokinetics.

Multidrug resistance (MDR) may be overcome by combination therapy thanks to "NP-based drug delivery systems (DDS)", which provide enhanced biocompatibility, tumour targeting, and stability. Various NPs, including polymeric, metallic, and hybrid types, have shown promising results, yet understanding their toxicity and interaction with biological systems remains critical. Nanomedicine enables theragnosis, integrating diagnosis and treatment into a single platform, improving patient survival rates. Liposomal and protein-based nanomedicine formulations are already in clinical use, with many undergoing advanced trials. Nanocarriers offer site-specific drug delivery, reducing toxicity while enhancing therapeutic efficacy. Personalized cancer therapy benefits from nanotechnology's ability to penetrate and retain within tumors effectively. However, optimizing NP design and engineering remains essential for their full potential in clinical applications. Nanotechnology, with its ongoing developments, has the potential to revolutionise cancer treatment by improving focused therapy, reducing side effects, and increasing patient outcomes in general.

References

- [1]. A. N. Al-Thani, A. G. Jan, M. Abbas, M. Geetha, and K. K. Sadasivuni, "Nanoparticles in cancer theragnosis and drug delivery: A comprehensive review," *Life Sci.*, vol. 352, no. June, p. 122899, 2024, doi: 10.1016/j.lfs.2024.122899.
- [2]. L. Sun *et al.*, "Smart nanoparticles for cancer therapy," *Signal Transduct. Target. Ther.*, vol. 8, no. 1, 2023, doi: 10.1038/s41392-023-01642-x.
- [3]. Z. Cheng, M. Li, R. Dey, and Y. Chen, "Nanomaterials for cancer therapy: current progress and perspectives," *J. Hematol. Oncol.*, vol. 14, no. 1, pp. 1–27, 2021, doi: 10.1186/s13045-021-01096-0.
- [4]. S. Gavas, S. Quazi, and T. M. Karpiński, "Nanoparticles for Cancer Therapy: Current Progress and Challenges," *Nanoscale Res. Lett.*, vol. 16, no. 1, 2021, doi: 10.1186/s11671-021-03628-6.
- [5]. K. Saini and P. Richhariya, "Enhanced Brain Tumor Classification using VGG19 and Data Augmentation Techniques," pp. 18–26, 2023.
- [6]. M. Arif *et al.*, "Nanotechnology-based radiation therapy to cure cancer and the challenges in its clinical applications," *Heliyon*, vol. 9, no. 6, p. e17252, 2023, doi: 10.1016/j.heliyon.2023.e17252.
- [7]. N. Rashidi, M. Davidson, V. Apostolopoulos, and K. Nurgali, "Nanoparticles in cancer diagnosis and treatment: Progress, challenges, and opportunities," *J. Drug Deliv. Sci. Technol.*, vol. 95, no. March, p. 105599, 2024, doi: 10.1016/j.jddst.2024.105599.
- [8]. W. H. Gmeiner and S. Ghosh, "Nanotechnology for cancer treatment," *Physiol. Behav.*, vol. 176, no. 5, pp. 139–148, 2015, doi: 10.1515/ntrev-2013-0013.Nanotechnology.
- [9]. M. Dessale, G. Mengistu, and H. M. Mengist, "Nanotechnology: A Promising Approach for Cancer Diagnosis, Therapeutics and Theragnosis," *Int. J. Nanomedicine*, vol. 17, no. August, pp. 3735–3749, 2022, doi: 10.2147/IJN.S378074.
- [10]. M. Sell *et al.*, "Application of Nanoparticles in Cancer Treatment: A Concise Review," *Naunyn. Schmiedebergs. Arch. Pharmacol.*, 2023, doi: 10.1007/s00210-024-03082-y.

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(Volume-1)*

- [11]. P. Ganesh, K. Jadhav, P. Tambe, S. Salunkhe, and P. Birhade, "NANOTECHNOLOGY'S ROLE IN CANCER TREATMENT A REVIEW," vol. 10, no. 3, pp. 907–919, 2022.
- [12]. Y. Yao *et al.*, "Nanoparticle-Based Drug Delivery in Cancer Therapy and Its Role in Overcoming Drug Resistance," *Front. Mol. Biosci.*, vol. 7, no. August, pp. 1–14, 2020, doi: 10.3389/fmolb.2020.00193.
- [13]. M. J. Nirmala, U. Kizhuveetil, A. Johnson, G. Balaji, R. Nagarajan, and V. Muthuvijayan, "Cancer nanomedicine: a review of nano-therapeutics and challenges ahead," *RSC Adv.*, vol. 13, no. 13, pp. 8606–8629, 2023, doi: 10.1039/d2ra07863e.
- [14]. P. M. Giri, A. Banerjee, and B. Layek, "A Recent Review on Cancer Nanomedicine," *Cancers (Basel)*, vol. 15, no. 8, 2023, doi: 10.3390/cancers15082256.
- [15]. B. Wang *et al.*, "Current advance of nanotechnology in diagnosis and treatment for malignant tumors," *Signal Transduct. Target. Ther.*, vol. 9, no. 1, 2024, doi: 10.1038/s41392-024-01889-y.
- [16]. J. A. Kemp and Y. J. Kwon, "Cancer nanotechnology: current status and perspectives," *Nano Converg.*, vol. 8, no. 1, 2021, doi: 10.1186/s40580-021-00282-7.
- [17]. Z. Yu *et al.*, "Nanoparticles: A New Approach to Upgrade Cancer Diagnosis and Treatment," *Nanoscale Res. Lett.*, vol. 16, no. 1, 2021, doi: 10.1186/s11671-021-03489-z.
- [18]. N. Alrushaid, F. A. Khan, E. A. Al-Suhaimi, and A. Elaissari, "Nanotechnology in Cancer Diagnosis and Treatment," *Pharmaceutics*, vol. 15, no. 3, 2023, doi: 10.3390/pharmaceutics15031025.
- [19]. R. Zhu, F. Zhang, Y. Peng, T. Xie, Y. Wang, and Y. Lan, "Current Progress in Cancer Treatment Using Nanomaterials," *Front. Oncol.*, vol. 12, no. July, pp. 1–9, 2022, doi: 10.3389/fonc.2022.930125.
- [20]. A. Kumar, A. Parmar, R. Singh, and S. Dhiman, "Nanoscience: an overview about nanotheranostics for cancer treatment," *Egypt. J. Basic Appl. Sci.*, vol. 11, no. 1, pp. 55–68, 2024, doi: 10.1080/2314808X.2023.2301281.