Nanotechnology in Cancer Diagnosis and Therapy

Raji P[1], Kalpana Shree[2], Hemlata S[3], Anne Celshia[3], Parthiban Govindarajoo[4]

Corresponding author email id: hemlata.senthil@gmail.com

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ABSTRACT

Cancer is one of the leading causes of mortality worldwide, which is caused by abnormal growth of cells. Prevalence of morbidity is primarily due to late diagnosis and conventional therapeutic approach is time consuming and not effective to all cancer cells. Nanotechnology has emerged as a transformative platform in cancer treatments due to the precise and targeted drug delivery in a particular cell and damaging the cancer cells. Nanomaterials such as metallic nanoparticle, carbon-based nanoparticle, polymeric nanoparticle have the unique property that enhanced imaging sensitivity and controlled drug release. This review highlights the nanomaterials and clinical application in cancer diagnosis and therapy.

[1] Department of Biotechnology, Vel Tech High Tech Dr. Rangarajan Dr Sakunthala Engineering College, Avadi, Chennai – 600062, Tamil Nadu, India.
[2] Department of Biotechnology, Sri Venkateswara College of Engineering, Pennalur-Sriperumbudur Tk, Tamil Nadu-602117, India
[3] Department of Biotechnology, School of Bio and Chemical Engineering, Sathyabama Institute of Science and Technology, Chennai – 600 119, Tamil Nadu, India.
[4] Department of Anatomy, Faculty of Medicine, Manipal University College Malaysia, Jalan Batu Hampar-75150, Melaka

INTRODUCTION

Cancer is one of notorious disease which gives a world-wide threat with nearly 20 million new cases and 10 million deaths in 2020 (Zhang et al., 2022). Conventional treatment like chemotherapy, radiotherapy and surgery often suffers from limitation include lack of specificity, damaging non-cancer cells and systemic toxicity (Guimarães et al., 2013; Atlihan-Gundogdu et al., 2020). To overcome this nanotechnology have emerged as a transformative platform by manipulating the materials at the nanoscale to interact with the cancer cells (Chen et al., 2018; Singh, 2019).

Nanomaterials that are used in cancer application encompass a wide of rang of inorganic, organic and hybrid systems which are lipid-based nanomaterials, polymeric nanomaterial, carbon nanoparticle like carbon nanotubes, carbon dots and graphene oxide and metal nanoparticles like gold nanoparticle, silver nanoparticle with unique property and behavior (Brindhadevi et al., 2023; García-Pinel et al., 2019; Luk and Zhang, 2014; Păduraru et al., 2022).

Nanotechnology in Cancer theranostics

Techniques like MRI, CT, PET etc., are the imaging approaches conventionally used in cancer diagnosis. In order to increase sensitivity of the image, contrast agents are used. Nanoscale contrasting agents are being developed, which are able to target specific sites to help visualization. SPIONs, Gadolinium oxide nanoparticles, Polymer-coated Bi2S3 nanoparticles and gold nanoparticles have proven to act as good contrasting agents (E. Rosen et al., 2011). Similarly, nanomaterials have been used in liquid biopsy to detect tumor cells and extracellular vesicles. Magnetic nanoparticles, graphene, gold and silicon nanoparticles are used in biological detection (Li et al., 2019). On the other hand, nanobiosensors with great sensitivity, specificity and reproducibility are developed to detect cancer in early stages (Sheervalilou et al., 2003). Theranostics aid in the detection of target cells, tracking of the drug movements, and response to the therapy. The nanomaterials are coated with hydrophilic substances which prolong the drug delivery duration, apart from acting as imaging agents (Kashyap et al., 2023).

Nanotechnology In Cancer Therapy

Conventionally used cancer therapy has various adverse effects, and is nonspecific. Whereas nanoformulations overcome these issues, it helps to improve solubility, reduce systemic toxicity and increase targeting ability. Liposomes, dendrimers, nanoemulsions and micelles are commonly used in targeted drug delivery of cancer therapeutics (Tang et al., 2021). Wide range of drugs are conjugated to or are encapsulated into nanocarriers which are then released at specific sites, enabling chemotherapy (Zhao et al., 2018).

Nanoparticles are used as drug delivery agents which are commonly administered through IV, and are used in diagnosis, to learn the progress of treatment using diagnostic and molecular imaging approaches (Norouzi et al., 2020). They also help in early screening by means of rapid nano-optical and high throughput techniques (Zuo et al., 2007). Various formulations of cancer nanomedicines have been approved so far by FDA and EMA. Few of them include, Doxil, Genexol-PM, Onivyde, Vyxeos, and Abraxane (Norouzi et al., 2020).

Advantages Of Nanotechnology In Oncology

Nanotechnology offers significant advantages in cancer diagnosis and therapy by substantially increasing the sensitivity and specificity in cancer diagnostics compared to conventional methods (Zhang et al., 2019). Nanotechnology enables targeted delivery of anticancer agents directly to tumour tissues by exploiting the enhanced permeability and retention (EPR) effects (Ammar et al., 2025) targeting at molecular sites, and enhancing therapeutic efficacy with controlled drug release, higher bioavailability, and reduced systemic toxicity compared to conventional treatments (Venturini et al., 2025). Many studies have reported different forms of nanomaterials such as liposomes, polymers, and antibodies. These nanomaterials used are found to have reduced toxicity and increased efficiency of the drug in cancer studies (Mudra, 2023; Venturini et al., 2025; Bozzuto and Molinari et al., 2015; Jani et al., 2020). Additionally, nanodevices have been designed to respond in specific physiological conditions such as pH and temperature, which enables controlled drug release (Venturini et al., 2025).

Challenges and Limitations

Nanotechnology in cancer diagnosis faces several significant challenges and limitations including the toxicity and biocompatibility issues. Maintaining the uniformity of the nanomaterials size during the scale-up process is a key step in manufacturing as it directly influences the property of the nanomaterial (Zhang et al., 2019; Saripilli et al., 2025; Giri et al., 2023). Standardization of the molecules to tumour specificity, stability studies and dose to efficacy and toxicity profiles should be evaluated for each nanomaterial that is aimed to treat cancer. Additionally, regulatory barriers slow down the translation from research to approved clinical applications, which mounts up the high cost addressing of all these challenges are necessary to implement this wonderful technology to save many suffering lives (Bhatt et al., 2025; Ma et al., 2024; Giri et al., 2023; Chehelgerdi et al., 2023). Thus, nanotechnology has emerged as a powerful and transformative approach in cancer diagnosis which offered a targeted drug delivery and gives a solution to the limitation of conventional treatments. The development of nanomaterials has further advanced the concepts of cancer treatments and despite of all these limitation nanotechnologies have given some solution and in further studies the nanotechnology might be the solution to cancer treatments.

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