Content available at: https://www.ipinnovative.com/open-access-journals

IP Journal of Diagnostic Pathology and Oncology

Journal homepage: https://www.jdpo.org/

Review Article

Exploring nanomedicine in cancer: Diagnosis, treatment and its potential applications

Jameel Ahmed S. Mulla[1]*, **Mukesh Vinod Kapse**[1]

[1]*Dept.of Pharmaceutics, Shree Santkrupa College of Pharmacy, Ghogaon, Maharashtra, India*

ARTICLE INFO

Article history:
Received 05-07-2024
Accepted 20-07-2024
Available online 01-08-2024

Keywords:
Nanomedicine
Nanoparticles
Oncology
Diagnosis
Treatment
Targeted Delivery

ABSTRACT

This review explores the various applications of nanomedicine in cancer characterization, diagnosis, treatment and targeted therapy. Both active and passive strategies are used by nanoparticles to target cancer cells. Nanoparticles can be engineered to carry imaging agents that permit for the visualization of tumors at the molecular and mobile tiers. Techniques inclusive of magnetic resonance imaging (MRI), computed tomography (CT), and positron emission tomography (PET) can be greater the use of nanoparticle evaluation sellers, providing unique records about the tumor's length, form, and location. Moreover, nanoparticles can facilitate the controlled release of drugs and increase drug release efficiency with fewer side effects. Nanomaterials such as microbubbles are used as molecular imaging agents for ultrasound imaging. A greater surface area, a higher volume proportion, and improved targeting skills are just a few of the remarkable characteristics of nanoparticles. Furthermore, because they don't harm healthy cells as much, they can functionally enter tissues and epithelium, increasing their bioavailability and half-life. Many medications are now offered or coated with nanoparticles to directly target tumors or damaged organs without endangering healthy tissues or cells. Numerous nanoparticle kinds, including dendrimers, graphene, fullerene, metallic, magnetic, polymeric, metal oxide, quantum dots, liposomes, carbon nanotubes, and graphene, may find use in the detection and therapy of cancer. Because of their antioxidant properties, nanoparticles have been shown in numerous studies to exhibit intrinsic anticancer activity and to suppress the growth of malignancies. Nanomedicine has emerged as a transformative approach in cancer treatment and diagnosis. This review covers the latest diagnostic procedures, therapeutic treatment and potential applications of nanomedices.

1. Introduction

One of the biggest causes of death worldwide and a major health burden is cancer. By 2018, it was estimated that there will be 9.6 million cancer-related deaths and 18.1 million new cancer diagnoses.[1] Uncontrolled cell growth that spreads from an original focal point to various areas of the body and ultimately results in death is what defines cancer. These factors make early cancer diagnosis and treatment essential for limiting the disease's spread and lowering death rates. The field of nanotechnology is one of the approaches now being used widely in cancer research. Nanotechnology has shown promising advances in cancer detection and therapy, including medication delivery.[2] Nanoparticles are a suitable material for biological applications because of their large surface area and variety of sizes from 10 nm to 100 nm. The targeted tissues may be effectively penetrated by the nanoparticles, which can then move throughout the body's organs. In diagnostic applications, therapeutic substances can be delivered to diseased tissues, such as cancer cells, using nanoparticles. Nanoparticles are around the same size as DNA and smaller than blood cells.[3] The quick

* *Corresponding author*.
E-mail address: jameelahmed5@gmail.com (J. A. S. Mulla).

https://doi.org/10.18231/j.jdpo.2024.017

growth of nanotechnology has resulted in the creation of nanomedicine agents, which might greatly enhance cancer treatment protocols. A growing field called "nanomedicine" uses nanotechnology to identify, treat, and prevent cancer.[4]

Products in the nanomedicine field provide the opportunity to create multifunctionality and enhanced targeting. According to the International Union of Pure and Applied Chemistry (IUPAC), nanoparticles (NPs) are tiny particles with sizes ranging from one to one hundred nanometers. These particles are a great option for materials and biology study because of their special physical properties, which include conductivity, stability, and optical attributes.[5] Because of their low toxicity, bioavailability, and capacity to target specific areas of the body, nanomedicines are gaining popularity. Nanoparticles employ both active and passive methods to target cancer cells. Numerous nanotherapeutics have been created since the FDA approved Doxil®, some of which have been approved for use as cancer therapies. In addition to liposomes, polymeric nanoparticles, solid lipid nanoparticles, and nanoemulsions, extracellular vehicles (EVs) and thermal nanoparticles are being investigated & applied in novel ways.[6]

1.1. Origin and History of Cancer Nanomedicine

Cancer nanomedicine has emerged as a potential area of study and development during the last decade.[4] It solves some of the disadvantages of conventional cancer therapy, including fewer side effects and more precise medicine administration procedures. Nanotechnology-based therapies have demonstrated considerable promise for enhancing cancer therapy safety and effectiveness.[7] Furthermore, the introduction of nano vectors, such as nanoparticles, has enabled the precise delivery of medications and imaging agents to tumors.[4] These nanoparticles may be precisely targeted to cancer cells and loaded with drugs or imaging chemicals to increase therapeutic efficacy while minimizing injury to healthy cells (Figure 1).

1.1.1. Early Beginnings (1959s)

Since Richard Feynman's 1959 Caltech presentation, which created the concept of nanotechnology, nanomedicine as it exists now has been considered as a possibility, "There is plenty of room at the bottom". He said that the atoms may be arranged any way that would be wanted. Nanotechnology used to medical and pharmaceutical particles with sizes ranging from 1 to 100 nm is known as nanomedicine.[8]

1.1.2. Later (1970s-1990s)

The notion of employing nanoparticles for drug delivery dates back to the 1970s and 1980s, when liposomes were initially proposed as possible drug carriers.[9] Drugs can be encased in liposomes, which are lipid-based nanoparticles, and administered to particular areas of the body. In the 1990s, the discovery of polymer-based nanoparticles increased the potential for targeted drug delivery.[10]

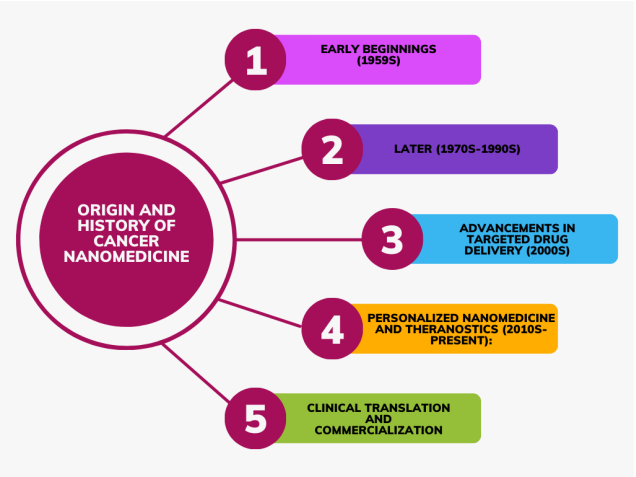

Figure 1: Origin and history of cancer nanomedicine

1.1.3. Advances in targeted drug delivery (2000s)

The creation and production of targeted nanoparticles for cancer treatment advanced significantly in the 2000s.[11] Scientists began focusing on developing nanoparticles which could accurately targeted cancerous cells without causing the least amount of damage to healthy tissues. This resulted in the creation of nanoparticles functionalized with targeted ligands such as antibodies, peptides, and aptamers, which improved their selectivity and effectiveness.[12]

1.1.4. Personalized nanomedicine and theranostics (2010s-Present)

Personalized medicine and theranostics have received increased attention in cancer nanomedicine in recent years.[13] The word "theranostics" refers to the integration of therapeutic and diagnostic characteristics on a single platform, allowing for actual time therapeutic efficacy monitoring and personalized therapy changes. Nanotechnology advancements have allowed the production of multifunctional nanoparticles that can carry medications, diagnostic agents, and gene therapies all at the same time.[14]

1.1.5. Clinical translation and commercialization

As the science of cancer nanomedicine advances, there is a rising emphasis on moving these innovations from the laboratory to clinical practice.[15] Several nanoparticle-based cancer medicines have begun clinical trials, and several have achieved regulatory clearance for clinical use, highlighting nanomedicine's potential to transform cancer therapy.[16]

2. Cancer Diagnosis with Nanotechnology

Nanoparticles and nanomedicines have demonstrated promising results in the early identification of cancer using different imaging and diagnostic approaches. Nanoparticles and nanomedicines provide novel methods for early cancer diagnosis, including improved imaging tools, sensitive biosensors, and tailored therapies (Figure 2). Ongoing research in this field has significant potential for improving early detection rates, enabling prompt treatment, and, eventually, improved the results for patients in cancer care.

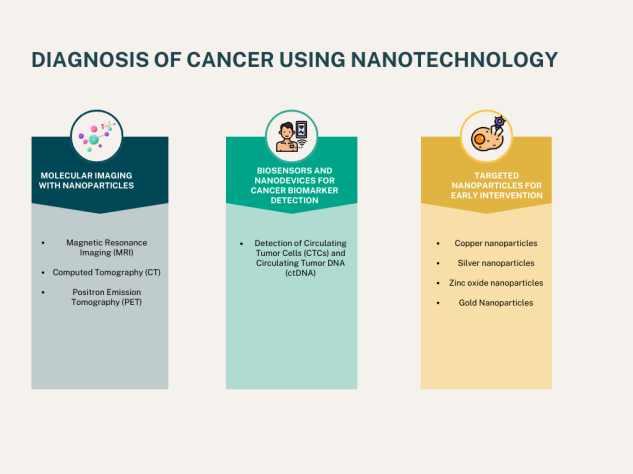

Figure 2: Diagnosis of cancer using Nanotechnology

2.1. Molecular Imaging with Nanoparticles

1. Magnetic Resonance Imaging (MRI): The sensitivity and specificity of MRI for tumor detection can be increased by nanoparticles.[17] MRI is an extremely flexible and robust imaging technique that uses radio frequency (RF) pulses and a magnetic field to produce high-resolution three-dimensional pictures. Proton relaxation times, which are present in lipids, proteins, and water, are measured by MRI, which generates high spatial resolutions and strong endogenous contrast without the need of radioisotopes or ionizing radiation.[18] MRI has become a vital and noninvasive technique for cancer detection and treatment because it generates remarkably accurate and comprehensive anatomical and functional images of soft tissues.[19]
2. Computed Tomography (CT): When evaluating X-ray absorption with high-atomic-number (HA) content material, CT is the gold standard for diagnosing cancer because it increases the sensitivity of the CT picture to specific contrast agents. This modality offers a number of benefits, including as precise signal quantification, very high spatial resolution, quick scan times, and low cost.[20] Contrast agents based on nanoparticles can improve the visibility of metastatic lesions and malignancies in CT scans.[21] Coencapsulated two commercially available FDA-approved agents, indocyanine green (ICG) and iohexol, to develop CF800, a novel lipid-based nanoliposomal imaging agent for Near Infrared (NIR) fluorescence and CT imaging.[22] To show efficient accumulation and imaging in these solid tumors, CF800 was used to animal cancer models in mice (breast, ovarian malignancies) and rabbits (lung, head, and neck malignancies).[23]
3. Positron Emission Tomography (PET): Due to its ability to offer quantitative imaging, PET is a widely used technique for the diagnosis of cellular and molecular abnormalities.[24] High-specificity radiopharmaceutical activity is used to provide pictures that are useful for diagnosis. As PET imaging agents, radiolabeled nanoparticles can be used to detect cancer and monitor its progression.[25] While PET has excellent sensitivity and specificity for tracking biological processes, its expensive cost limits its clinical use. When it comes to cancer therapy and follow-up monitoring, nanoparticles might prove to be a very useful tool in the soon-to-be era of increasingly customized cancer therapies.[26]

2.2. Biosensors and Nanodevices for Cancer Biomarker Detection

Circulating tumor DNA (ctDNA) and Circulating Tumor Cells (CTCs) detection: A biosensor is a tool used to identify biological analytes that come from within the human body or from the environment. An electrical signal that may be amplified, displayed, and assessed is created from information such as the presence and concentration of the analyte. Analytes consist of nucleic acids, proteins (such as enzymes, antibodies, and antigens), and other biological or metabolic elements (such as glucose). Biosensors can be used in medicine to identify viruses, monitor blood glucose levels in diabetics, and diagnose and treat cancer.[27] Nanoparticle-based biosensors can extract and analyze CTCs and ctDNA from blood samples, allowing for early cancer identification and surveillance.[28]

2.3. Targeted nanoparticles for early intervention

Metal nanoparticles targeted at cancer cells are a useful tool for cancer detection and treatment. Recent research on the topic consists of the following:[29]

1. Copper nanoparticles: Recently, copper nanoparticles have attracted attention as possible anticancer therapeutics due to their capacity to create oxidative stress in cancer cells. Reactive oxygen species (ROS), are produced by copper nanoparticles and lead to cell death. It has been demonstrated that they selectively target cancer cells, leaving healthy cells

unharmed.[30] Additionally, it has been shown that copper nanoparticles increase the responsiveness of cancer cells to radiation therapy, hence promoting tumor remission.[31]

2. Silver nanoparticles: These particles are being researched as a potential cancer therapy. Researchers have demonstrated that by attaching to proteins on the surface of cancer cells and releasing ROS that kill cells, silver nanoparticles may be able to selectively target cancer cells.[32] Because of their excellent optical qualities, silver nanoparticles have been investigated as imaging agents for cancer diagnostics.[33]
3. Zinc oxide nanoparticles: Because they may cause cancer cells to undergo apoptosis, these particles are being studied as a potential anticancer treatment. It has been demonstrated that by activating caspases and obstructing anti-apoptotic proteins, zinc oxide nanoparticles may specifically target cancer cells and cause cell death.[34]

Furthermore, it has been shown that zinc oxide nanoparticles can help cancer cells overcome drug resistance, which increases the efficacy of chemotherapy treatments. The sensitivity and precision of early detection techniques can be increased by functionalizing Nanoparticles with targeted ligands that bind specifically to cancer cells or biomarkers.[35]

3. Nanotechnology Advances in Targeted Cancer Treatment

Nanotechnology has altered the field of targeted cancer therapy by enabling the precise delivery of therapeutic drugs directly to cancer cells. Drugs can be encapsulated and given directly to tumors using nanoparticles, reducing harm to healthy tissues.[36] These nanoparticles may be tailored to target specific receptors or markers on cancer cells, allowing for greater effectiveness and fewer adverse effects than standard chemotherapy (Figure 3).[37]

Furthermore, nanotechnology allows for the simultaneous administration of various medications or therapeutic agents, resulting in synergistic effects that can enhance treatment outcomes.[38] The capacity to create nanoparticles with distinct traits such as regulated release mechanisms or stimuli-responsive behavior expands their potential in targeted cancer therapy. Overall, nanotechnology has created new opportunities for individualized and effective therapies in oncology.[39]

3.1. Both Active and Passive Targeting

Stimuli-Responsive Nano medicine: - Over the past 10 years, polymeric micelles have been thoroughly investigated as nanocarriers for the delivery of common anticancer medications. Due to their higher permeability and retention, these nanoparticles have several important advantages

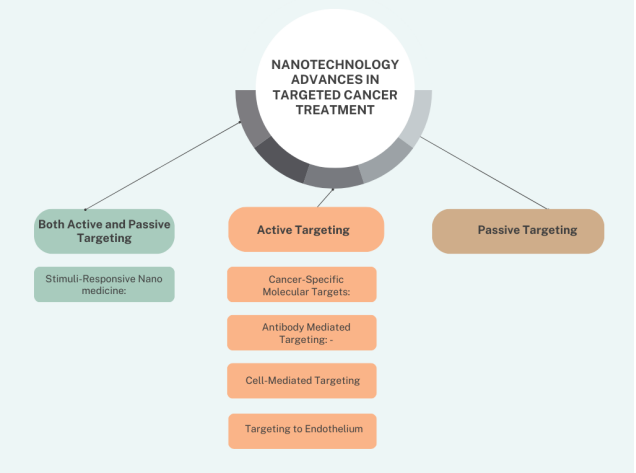

Figure 3: Nanotechnology advances in targeted cancer treatment

for drugs, such as enhanced solubility, extended in vivo circulation, and preferential accumulation at tumor locations.[40] To improve medicine administration, stimuli-responsive cross-linked micelles (SCMs) were developed.[41] SCMs can latch onto medications better and are more stable in blood circulation. SCMs can be made responsive to one or more external stimuli and the milieu of the tumor site or inside tumor cells by using environmentally sensitive crosslinkers or assembly units.[42] Breakdown of intra-micellar crosslinking or dissolution of the stimuli-responsive micelles release drugs only at the target spot.[43]

3.2. Active targeting

Active targeting is a supplementary method to passive targeting that aims to improve accumulation selectivity and prolong intratumoral drug retention.[44] Active targeting targets cancer cells precisely by engaging with ligands and receptors directly. The ligands on the surface of NPs are chosen to target molecules that are overexpressed on the surfaces of cancer cells in order to discriminate between targeted and healthy cells.[45] Internalized NPs can effectively release therapeutic drugs through a process known as receptor-mediated endocytosis, which is started when ligands on NPs bind with receptors on the surfaces of cancer cells.[46] This is why macromolecular drugs like proteins and siRNAs are particularly well-suited for active targeting.

1. Cancer-Specific Molecular Targets: Selecting the appropriate target is critical for accurately targeting a tumor. A target molecule must be either absent in normal tissues or overexpressed on the surface of malignant cells compared to normal cells. It is also important to consider the possible use of tumor stroma-associated targets.[44]

2. Folate Receptor: Many neoplastic cells excessively express folate receptors, making them a target for a variety of anticancer therapies. Researchers are attempting to build folic acid onto the surface of nanoparticles. In four mouse tumor models, the effectiveness of folic acid as a targeting agent for pHPMA conjugated daunomycin delivery was examined by Russell-Jones et al. Folic acid-targeted daunomycin HPMA conjugates have been shown to prolong life periods and enhance the proportion of survivors in tumor-bearing mice. The findings demonstrate that folic acid can significantly boost the potency of several polymer-bound cytotoxins.[47] Another study examined folate-linked methotrexate dendrimers in female immunodeficient athymic nude mice (Kukowska-Latalloto et al.). Twice a week, the mice received an injection of the nanoconjugates through a lateral tail vein.[48] The results showed that conjugated methotrexate in dendrimers dramatically decreased toxicity and boosted efficacy by a factor of ten at a same cumulative dosage. The mice's survival was lengthened as a result. Treatment for cancer using doxorubicin aggregates tailored to the folate receptor at the nanoscale was tried.[49]
3. Receptor for Transferrin: - Transferrin is one kind of serum glycoprotein that aids in the uptake of iron by cells. In most solid tumor cells, transferrin receptor expression is overexpressed, whereas it is modest in normal cells. Consequently, transferrin-conjugated NPs are employed as an active targeting technique to deliver medications for cancer therapy. Comparing transferrin-modified NPs to unmodified NPs, it has been shown that the former had better intracellular drug delivery and higher cellular absorption efficiency. Furthermore, data suggest that transferrin-conjugated polymeric nanoparticles are important in beating back chemotherapy that is resistant to drugs.[50] It was also demonstrated that, although it does not have the same effect on normal cells, this formulation may effectively kill T47D cancer cells and induce over 80% apoptotic cell death in around 10 minutes. Therefore, in the paradigm of athymic mice, the intravenous delivery of Tf-lytic peptide greatly prevented the growth of tumors.[49]
4. Targeting mediated by antibodies: Because tumor antigens are seen as own cells, they cause weakened immune responses Monoclonal antibodies (mAbs) with high specificity are utilized to boost the immune system's anticancer activity and immunological response. These antibodies specifically target proteins required for the development of neoplastic cells but overexpressed in them. To deliver drugs in a tailored way, antibodies against certain tumor antigens are coupled with nanoparticles. The majority of mAbs are made from a single cloned hybridoma cell. A myeloma that makes antibodies and a normal plasma cell that has been induced to attach selectively to antigens on tumor cells combine to form the hybridoma cell. mAbs can destroy cancer cells in a number of ways after attaching to tumor antigens, such as by directly triggering apoptosis, obstructing growth factor receptors, and generating anti-idiotypes.
   They can obliterate cancer cells indirectly by starting complement-mediated cellular cytotoxicity and antibody-dependent cell-mediated cytotoxicity.[49]
5. Cell-Mediated Orientation: Longer half-life, controlled and progressive release, decreased immunogenicity and cytotoxicity, and active delivery of the loaded drug to the desired site are just a few of the special advantages that come with this technique. Some cell types can enter a tumor even when there is a tumor stroma present and the interstitial pressure is high. Gradients of growth factors like VEGF, the growth factor TGF, and fibroblast growth factor FGF-2, as well as pro-inflammatory cytokines like macrophage colony-stimulating factor (CSF1) and chemokines recognized by the CXCR4/CXCL12 receptor system and the MCP-1 monocyte chemotactic protein, can be used as cell attractants. Numerous cell types have been studied as potential drug transporters thus far. Thus, malignancies at this site were successfully attacked by naïve T-cells that were tropic to lymph nodes. For tumors with different localizations, primed T-cells specific to a single tumor cell surface antigen may be used. Antitumor drugs have been effectively delivered by monocytes and neutrophils, macrophages, neural stem cells, and mesenchymal stem cells derived from bone marrow and cord blood, among other cell types.[44]
6. Targeting to Endothelium: Rather of going straight after cancer cells, certain NPs have an impact on angiogenesis, which is an alternative mode of cancer treatment. The process of vascularization is largely dependent on the interaction between VEGF and VEGF receptors (VEGFRs).[51] Moreover, it has been shown that liposomes that target VEGFR-2 and VEGFR-3, the two primary VEGF receptors, simultaneously increase therapeutic efficacy. Tumor cell migration and invasion are significantly influenced by extracellular matrix protein receptors on the cell surface called integrins.[50]

3.3. Targeting passively

Using the differences between healthy and cancerous tissue is the goal of passive targeting. Medication can have therapeutic effects if it is delivered to the target spot with efficiency. We call this kind of targeting passive. High cancer cell proliferation causes neovascularization, and

big vascular wall pores exacerbate the tumor vasculature' perm selectivity in comparison to normal.[50] Via passive targeting, nanoparticles can also target cancer. When malignant cells cease to undergo apoptosis, they continue to improperly absorb nutrients through blood vessels, causing angiogenesis to cause the blood vessels around the cells to enlarge and leak. Abnormalities in the basement membrane and a reduction in the number of pericytes lining rapidly growing endothelial cells lead to the formation of leaky blood vessels. As a result, there is an increase in the permeability of molecules to enter the interstitial space around tumor cells via the vessel wall. Leaky endothelial cells have holes that range in size from 100 to 780 nm. Nanoparticles smaller than that can therefore readily flow through the holes.[49]

4. Characterization of Nanomedicines

The characterization of nanomedicine in cancer is crucial for understanding its effectiveness and safety in the treatment of cancer. Characterization involves the study and analysis of various properties of nanomedicine, including its physical and chemical attributes, stability, drug release kinetics, targeting efficiency, biodistribution, and toxicity. This information allows researchers and clinicians to evaluate the performance of nanomedicine in terms of its therapeutic efficacy, pharmacokinetics, and potential side effects.[52] This information is essential for assessing the performance and potential drawbacks of nanomedicine in cancer therapy. Furthermore, characterization plays a vital role in optimizing and improving nanomedicine formulations, helping researchers identify potential issues and make necessary modifications to enhance their effectiveness. By characterizing nanomedicine in cancer, researchers can assess its performance in terms of therapeutic efficacy, pharmacokinetics, and toxicity.[53,54]

5. Applications of Nanomedicines in Cancer Diagnosis

Nanomedicine, the application of nanotechnology in medicine, holds immense promise for the diagnosis and treatment of cancer. By utilizing nanoscale materials and devices, nanomedicine offers innovative approaches to detect cancer at its earliest stages and deliver targeted therapies directly to tumors. These advancements in nanomedicine have the potential to revolutionize cancer diagnostics and treatment by improving accuracy, reducing side effects, and increasing patient outcomes. Furthermore, nanomedicine allows for the development of theragnostic methods, which combine diagnostic and therapeutic capabilities in a single treatment approach.[55] In addition, nanoparticles can be precisely engineered to carry therapeutic agents, such as drugs or gene therapies, directly to cancer cells. This targeted delivery system not only enhances the efficacy of the treatment but also minimizes damage to healthy cells, resulting in reduced side effects for patients. Overall, the applications of nanomedicines in cancer offer a promising avenue for personalized and more effective cancer care. Nanomedicines in cancer have the potential to revolutionize the field by improving accuracy, reducing side effects, and increasing patient outcomes. Furthermore, nanomedicine can also play a crucial role in noninvasive cancer detection by identifying circulating tumor cells. Overall, nanomedicine in cancer has the potential to revolutionize the field by improving accuracy, reducing side effects, increasing patient outcomes.[56]

5.1. Near infrared (NIR Quantum Dots (QDs)

The use of visible spectrum imaging is limited by its inability to penetrate things. To get around this issue, quantum dots that release fluorescence in the 700–1000 nanometer range, or the near-infrared spectrum, have been developed. This makes them more appropriate for imaging diseases such as lymphoma, liver, pancreatic, and colorectal cancers. To help with cancer imaging, a second NIR window (NIR-ii, 900-1700 nm) has also been created with better tissue penetration depth and improved spatial and temporal resolution. Additionally, it has been reported that the creation of Ag_2Te QDs rich in silver and including a sulfur source enables the observation of superior spatial resolution pictures throughout a broad infrared range.[57]

5.2. Carbon nanotubes (CNTs)

Based on their diameter and structure, CNTs may be classified into two groups: single-walled CNTs (SWNTs) and multiwalled CNTs (MWNTs). The MWNTs are composed of concentrated graphene, whereas the SWNTs are formed of monolithic cylindrical graphene. Carbon nanotubes are a promising contender for a wide range of biological applications because of their unique physical and chemical characteristics, including their surface area, mechanical strength, metal properties, electrical conductivity, and thermal conductivity.[57] Moreover, carbon nanotubes can target these cells because to their thermal impact, which causes tumor cells to warm up by absorbing light in the NIR spectrum.[58] Naturally occurring carbon nanotubes are believed to be incredibly efficient delivery systems for many medicinal substances into living cells, as well as promoting the noninvasive penetration of biofilms. Because carbon nanotubes are so suitable, medications like paclitaxel are combined with them and given to patients both in vivo and in vitro to treat cancer.[59]

5.3. Dendrimers

The spherical polymer core of the dendrimers, which are nanocarriers, is branched at regular intervals. There is a tendency for the dendritic macromolecule to lean towards a spherical form as its diameter rises. Many studies have

been conducted on dendrimers as potential antibacterial, antiviral, and anticancer drugs. The primary application of dendrimers as anticancer medicines is in photodynamic treatment (PDT). They are built around a light-harvesting core (a porphyrin) in one method. Poly (ethylene glycol)-b-poly (aspartic acid) micelles are used to encapsulate these dendrimers in order to decrease their toxicity in non-irradiative circumstances, also known as dark toxicity. These micelles are stable under physiological conditions.[56]

5.4. Micelles made of polymers

Developments relating to a solid micelle with a particle size range of 10-1000 nm are known as polymeric nanoparticles (PNPs). The first polymers for drug delivery systems that were found were PNPs. They are also referred to as nanoparticles, polymer micelles, nanospheres, and nanocapsules. Because the amphiphilic polymers contain both a hydrophilic and a hydrophobic block, PNPs have the potential to self-assemble quickly in an aqueous solution due to hydrophobic interactions. PNPs can form a covalent connection or interact with hydrophobic medications through their hydrophobic core. To transfer hydrophilic charged molecules like proteins, peptides, and nucleic acids, these blocks are therefore swapped to allow interactions in the core and neutralize the charge.[53] Natural and manmade polymers like PLGA and polyhydroxyalkanoates (PHAs), have been studied for use in combination with anticancer medications including doxorubicin, cisplatin, and paclitaxel in targeted drug delivery applications. These studies were tested in vivo and there are some that have been used in preclinical trials on mice.[60]

5.5. Gold nanoparticles

The creation of a colloidal gold nanoparticle vector that focuses the delivery of tumor necrosis factor (TNF) to a solid tumor developing in mice was initially described by Paciotti et al. in 2004.[56] Aptamers are utilized in the detection and treatment of cancer when paired with gold and magnetic nanoparticles. Anti-cancer drugs are well-suited to be delivered using gold nanoparticles as carrier molecules. Gold nanoparticles have also been utilized to provide targeted drug delivery. By combining targeting ligands with nanoparticles, one possible way to deliver nanotherapeutics preferentially to the locations of interest while minimizing unwanted side effects elsewhere is to create spatially controlled drug delivery systems. Covalent or noncovalent interactions can be used to load therapeutic substances onto gold nanoparticles. The anticancer medication paclitaxel has been covalently attached to 2 nm-sized gold nanoparticles by Gibson et al. According to research by Stern, J. M. et al., human prostate cancer cells can be ablated in vitro by gold nanoshells stimulated by a laser. This technique of nanoparticles is a promising therapeutic agent for targeted tumor ablation.[61]

6. Conclusion

Nanomedicine holds significant promise in revolutionizing the field of cancer diagnosis and treatment. The integration of nanotechnology in oncology has led to the development of advanced diagnostic tools and therapeutic approaches that offer enhanced specificity, sensitivity, and efficacy. In conclusion, nanomedicine represents a transformative approach in the fight against cancer, offering unprecedented opportunities for improving patient outcomes. Continued research and innovation in this field are essential to fully realize its potential and to bring these cutting-edge technologies from the laboratory to the clinic, ultimately enhancing the quality of life for cancer patients worldwide.

7. Abbreviations

NPs - Nanoparticles, RF - Radio frequency, MRI - Magnetic Resonance Imaging, CT - Computed Tomography, NIR - Near Infrared, PET - Positron Emission Tomography (PET), ctDNA - Circulating tumor DNA, CTCs - irculating Tumor Cells, ROS - Reactive oxygen species, SCMs - Stimuli-responsive cross-linked micelles, mAbs - Monoclonal antibodies, HPMA - Hydroxy propyl methacrylamide/methacrylic acid, VEGF - Vascular endothelial growth factor, VEGFRs - Vascular endothelial growth factor receptors, TGF - The growth factor, MCP - Monocyte chemotactic protein, QDs - Quantum Dots, SWNTs - Single-walled CNTs, MWNTs - Multiwalled CNTs, PDT - Photodynamic treatment, PNPs - Polymeric nanoparticles, PLGA - Poly Lactic-co-Glycolic Acid, PHAs – Polyhydroxyalkanoates, TNF - Tumor necrosis factor.

8. Source of Funding

None

9. Conflict of Interest

None

References

1. Bray F, Ferlay J, Soerjomataram I, Siegel R, Torre L, Jemal A, et al. Global cancer statistics: Globocan estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA Cancer J Clin*. 2018;68:394–424.
2. Meyers JD, Doane T, Burda C, Basilion JP. Nanoparticles for imaging and treating brain cancer. *Nanomedicine*. 2013;8(1):123–43.
3. Noor A, Khan F, Ebtesam A, Elaissari A. Nanotechnology in Cancer Diagnosis and Treatment. *Pharmaceutics*. 2023;15(3):1025. doi:10.3390/pharmaceutics15031025.
4. Deshpande G. Cancer Nanotechnology: The Recent Developments in the Cancer Therapy. *Glob J Nano*. 2016;1(1):555551. doi:10.19080/gjn.2016.01.555551.
5. Nirmala MJ, Kizhuveetil U, Johnson A, Balaji G, Vignesh M, Nagarajan R, et al. Cancer nanomedicine: a review of nano-therapeutics and challenges ahead. *RSC Adv*. 2023;13(13):8606–29.

6. Aghebati-Maleki A, Dolati S, Ahmadi M, Baghbanzhadeh A, Asadi M, Fotouh A, et al. Nanoparticles and cancer therapy: Perspectives for application of nanoparticles in the treatment of cancers. *J Cell Physiol*. 2019;235(3):1962–72.
7. Wicki A, Witzigmann D, Balasubramanian V, Huwyler J. Nanomedicine in cancer therapy: Challenges, opportunities, and clinical applications. *J Controlled Release*. 2015;200:138–57. doi:10.1016/j.jconrel.2014.12.030.
8. Bodunde O, Ikumapayi M, Akinlabi E, Oladapo N. A futuristic insight into a "nano-doctor": A clinical review on medical diagnosis and devices using nanotechnology. *Mater Today Proc*. 2021;44(1):1144–53.
9. Gregoriadis G. Liposomes in drug delivery. *Drug Alcohol Depend*. 1976;1(1):1–2.
10. Langer R. New methods of drug delivery. *Science*. 1990;249(4976):1527–33.
11. Davis ME, Chen G, Shin D. Nanoparticle therapeutics: an emerging treatment modality for cancer. *Nat Rev Drug Dis*. 2008;7(9):771–82.
12. Peer D, Karp J, Hong S, Farokhza OC, Margalit R, Langer R, et al. Nanocarriers as an emerging platform for cancer therapy. *Nat Nanotechnol*. 2007;2(12):751–60.
13. Jokerst J, Gambhir S. Molecular imaging with theranostic nanoparticles. *Acc Chem Res*. 2011;44(10):1050–60.
14. Shi J, Kantoff P, Wooster R, Farokhzad O. Cancer nanomedicine: progress. challenges and opportunities. *Nat Rev Cancer*. 2017;17(1):20–37.
15. Wilhelm S, Tavares AJ, Dai Q, Ohta S, Audet J, Dvorak HF, et al. Analysis of nanoparticle delivery to tumours. *Nat Rev Mater*. 2016;p. 16014. doi:10.1038/natrevmats.2016.14.
16. Anselmo AC, Mitragotri S. Nanoparticles in the clinic. *Bioeng Transl Med*. 2016;1(1):10–29.
17. Jokerst V, Gambhir S. Molecular imaging with theranostic nanoparticles. *Accounts Chem Res*. 2011;44(10):1050–60.
18. Fatima H, Kim K. Iron-based magnetic nanoparticles for magnetic resonance imaging. *Adv Powder Technol*. 2018;29:2678–2685.
19. Nguyen V, Lee B. Protein corona: A new approach for nanomedicine design. *Int J Nanomedicine*. 2017;(12):3137–51. doi:10.2147/IJN.S129300.
20. Zheng C, Allen S, Serra D, Vines M, Charron, Jaffray D, et al. Liposome contrast agent for CT-based detection and localization of neoplastic and inflammatory lesions in rabbits: Validation with FDG-PET and histology. *Contrast Media Mol Imaging*. 2010;5(3):147–54.
21. Mulder WJ, Strijkers GJ, Van Tilborg G, Griffioen AW, Nicolay K. Lipid-based nanoparticles for contrast-enhanced MRI and molecular imaging. *NMR Biomed*. 2006;19(1):142–64.
22. Zheng J, Muhanna N, Souza RD, Wada H, Chan H, Akens MK, et al. A multimodal nano agent for image-guided cancer surgery. *Biomaterials*. 2015;67:160–8. doi:10.1016/j.biomaterials.2015.07.010.
23. Mukherjee S, Ray S, Thakur RS. Solid Lipid Nanoparticles: A Modern Formulation Approach in Drug Delivery System. *Indian J Pharm Sci*. 2009;71(4):349–58.
24. Basu B, Alavi A. PET-Based Personalized Management in Clinical Oncology: An Unavoidable Path for the Foreseeable Future. *PET Clinics*. 2016;11(3):203–7.
25. Liu X, Law WC, Jeon M, Wang X, Liu M, Kim C, et al. Cu2-x Se nanocrystals with localized surface plasmon resonance as sensitive contrast agents for in vivo photoacoustic imaging: demonstration of sentinel lymph node mapping. *Adv Healthc Mater* . 2013;2(7):952–7. doi:10.1002/adhm.201200388.
26. Aghanejad A, Jalilian A, Ardaneh K, Bolourinovin F, Yousefnia H, Samani A, et al. Preparation and Quality Control of 68Ga-Citrate for PET Applications. *Asia Ocean J Nucl Med Biol*. 2015;3(2):99–106.
27. Bohunicky B, Mousa S. Biosensors: the new wave in cancer diagnosis. *Nanotechnol Sci Appl*. 2011;4:1–10. doi:10.2147/NSA.S13465.
28. Karabacak NM, Spuhler PS, Fachin F, Lim EJ, Pai V, Ozkumur E, et al. Microfluidic, marker-free isolation of circulating tumor cells from blood samples. *Nat Protocols*. 2014;9(3):694–710.
29. Baranwal J, Barse B, Petrillo AD, Gatto G, Luca P, Kumar A, et al. Nanoparticles in Cancer Diagnosis and Treatment. *Materials (Basel)*. 2023;16(15):5354. doi:10.3390/ma16155354.
30. Das M, Duan W, Sahoo SK. Multifunctional nanoparticle-EpCAM aptamer bioconjugates: a paradigm for targeted drug delivery and imaging in cancer therapy. *Nanomedicine*. 2015;11(2):379–89.
31. Jiang YW, Gao G, Jia HR, Zhang X, Zhao J, Ma N, et al. Copper Oxide Nanoparticles Induce Enhanced Radiosensitizing Effect via Destructive Autophagy. *ACS Biomater Sci Eng*. 2019;5(3):1569–79.
32. Tai WC, Zhang J, Guo J, Zhu Y, Ling QD, Gu F, et al. Silver nanoparticles selectively induce human oncogenic γ-herpesvirus-related cancer cell death through reactivating viral lytic replication. *Cell Death Dis*. 2019;10(6):392. doi:10.1038/s41419-019-1624-z.
33. Lee JU, Kim WH, Lee HS, Park KH, Sim SJ. Quantitative and Specific Detection of Exosomal miRNAs for Accurate Diagnosis of Breast Cancer Using a Surface-Enhanced Raman Scattering Sensor Based on Plasmonic Head-Flocked Gold Nanopillars. *Small*. 2019;15(17). doi:10.1002/smll.201804968.
34. Akhtar MJ, Ahamed M, Kumar S, Khan MM, Ahmad J, Alrokayan SA, et al. Zinc oxide nanoparticles selectively induce apoptosis in human cancer cells through reactive oxygen species. *Int J Nanomed*. 2012;7:845–57. doi:10.2147/IJN.S29129.
35. Zhang Y, Zhang B, Liu F, Luo J, Bai Y, Wang J, et al. Biofunctionalized nanoparticles for targeted imaging and therapy of cancer. *Adv Mater*. 2016;28(29):5255–81.
36. Malhotra V. Biomedical Nanotechnology: Current Status and Future Prospects in Disease Diagnosis and Therapy. *J Biomed Syst Emerg Technol*. 2023;10(3):1–2.
37. Chehelgerdi M, Allela O, Cosme D, Jayasankar J, Rao D. Progressing nanotechnology to improve targeted cancer treatment: overcoming hurdles in its clinical implementation. *Molecular Cancer*. 2023;22(169):1–103.
38. Dessale M, Mengistu G, Mengist HM. Nanotechnology: A Promising Approach for Cancer Diagnosis. Therapeutics and Theragnosis. *Int J Nanomed*. 2022;17:3735–49. doi:10.2147/IJN.S378074.
39. Wang T, Cao C, Gavahi M, Sadri M, Rongn X. Using Nanotechnology for Diagnosis and Treatment of Breast Cancer: A Review. *Indian J Pharm Sci*. 2022;84(2):237–45.
40. Lindner A, Landon LC, Park J, Simnick A, Dreher ME. Overcoming Limitations in Nanoparticle Drug Delivery: Triggered. Intravascular Release to Improve Drug Penetration into Tumors. *Cancer Res*. 2012;72(21):5566–75.
41. Popescu M, Tsitsilianis C, Papadakis C, Adelsberger J, Balog S, Busch P, et al. Stimuli-Responsive Amphiphilic Polyelectrolyte Heptablock Copolymer Physical Hydrogels: An Unusual pH-Response. *Macromolecules*. 2012;45:3523–30.
42. Meng F, Zhong Z, Feijen J. Stimuli-responsive polymersomes for programmed drug delivery. *Biomacromolecules*. 2009;10(2):197–209.
43. Li Y, Xiao K, Zhu W, Deng W, Lam KS. Stimuli-responsive cross-linked micelles for on-demand drug delivery against cancers. *Adv Drug Del Rev*. 2014;66:58–73. doi:10.1016/j.addr.2013.09.008.
44. Kutova O, Guryev E, Sokolova E, Alzeibak R, Balalaeva I. Targeted Delivery to Tumors: Multidirectional Strategies to Improve Treatment Efficiency. *Cancers*. 2023;11(1):68. doi:10.3390/cancers11010068.
45. Shi J, Xiao Z, Kamaly N, Farokhzad OC. Self-assembled targeted nanoparticles: evolution of technologies and bench to bedside translation. *ACC Chem Res*. 2023;44(10):1123–34.
46. Farokhzad O, Langer R. Impact of nanotechnology on drug delivery. *ACS Nano*. 2009;3(1):16–20.
47. Russell-Jones K, Tavish M, Mcewan B, Thurmond B. Increasing the Tumoricidal Activity of Daunomycin-pHPMA Conjugates Using Vitamin B12 as a Targeting Agent. *J Cancer Res Updates*. 2012;1(2):203–11.
48. Kukowska-Latallo JF, Candido KA, Cao Z, Nigavekar SS, Majoros IJ, Thomas TP, et al. Nanoparticle targeting of anticancer drug improves therapeutic response in animal model of human epithelial cancer. *Cancer Res*. 2005;65(12):5317–24.
49. Sutradhar B, Amin M. Nanotechnology in Cancer Drug Delivery and Selective Targeting. *ISRN Nanotechnol*. 2014;p. 1–12. doi:10.1155/2014/939378.

50. Yao Y, Zhou Y, Liu L, Xu Y, Chen Q, Wang Y, et al. Nanoparticle-Based Drug Delivery in Cancer Therapy and Its Role in Overcoming Drug Resistance. *Front Mol Biosci*. 2020;7:193. doi:10.3389/fmolb.2020.00193.
51. Apte RS, Chen DS, Ferrara N. VEGF in Signaling and Disease: Beyond Discovery and Development. *Cell*. 2019;176(6):1248–64.
52. Babu A, Templeton AK, Munshi A, Ramesh R. Nanoparticle-Based Drug Delivery for Therapy of Lung Cancer: Progress and Challenges. *J Nanomaterials*. 2013;p. 1–11. doi:10.1155/2013/863951.
53. Wang JC, Oppong-Gyebi K, Hu A, J. Application of Nanotechnology in Cancer Diagnosis and Therapy a Mini Review. *Int J Med Sci*. 2020;17(18):2964–73.
54. Dawidczyk C, Russell L, Searson C. Nanomedicines for cancer therapy: state-of-the-art and limitations to pre-clinical studies that hinder future developments. *Front Chem*. 2014;2(69):69. doi:10.3389/fchem.2014.00069.
55. Misra R, Acharya S, Sahoo SK. Cancer nanotechnology: application of nanotechnology in cancer therapy. *Drug Discovery Today*. 2010;15(19-20):842–50.
56. Svenson S, Tomalia D. Dendrimers in biomedical applications-reflections on the field. *Adv Drug Deliv Rev*. 2005;57(15):2106–29.
57. Gao X, Cui Y, Levenson RM, Chung LW, Nie S. In vivo cancer targeting and imaging with semiconductor quantum dots. *Nat Biotechnol*. 2004;22(8):969–76.
58. Burlaka A, Lukin S, Prylutska S, Remeniak O, Prylutskyy Y, Shuba M, et al. Hyperthermic effect of multi-walled carbon nanotubes stimulated with near infrared irradiation for anticancer therapy: in vitro studies. *Exp Oncol*. 2010;32(1):48–50.
59. Bianco A, Kostarelos K, Prato M. Applications of carbon nanotubes in drug delivery. *Curr Opin Chem Biol*. 2005;9(6):674–9.
60. Sell M, Lopes AR, Escudeiro M, Esteves B, Monteiro AR, Trindade T, et al. Application of Nanoparticles in Cancer Treatment: A Concise Review. *Nanomaterials*. 2023;13(21):2887. doi:10.3390/nano13212887.
61. Mulla JAS. Drug Delivery and Therapeutic Approaches to Prostate Cancer. *Indian J Novel Drug Del*. 2018;10(3):98–109.

Author biography

Jameel Ahmed S. Mulla, Professor https://orcid.org/0000-0002-1042-7134

Mukesh Vinod Kapse, Research Scholar https://orcid.org/0009-0002-3960-6934

Cite this article: Mulla JAS, Kapse MV. Exploring nanomedicine in cancer: Diagnosis, treatment and its potential applications. *IP J Diagn Pathol Oncol* 2024;9(2):86-94.