

Current Perspectives in Nanotechnology and Nanomedicine

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ABSTRACT

The idea of nanoparticles, nanotechnology, and their applications to medicine could have emerged from the increase in the incidences of malignancies, due to the paucity of safe and effective anti-cancer drugs, and lack of sensitive diagnostic tools. Also, because there is an increase in the treatment failures due to the emergence of multi-drug resistant microbial infections, the medical, scientific and the research fraternity had started to look for better and efficient alternatives in the form of nanotechnology. The nanotechnology has a wide spectrum of applications including the fields of engineering, agriculture, and pharmacy. The nanoparticles have a wide array of applications in the field of medicine that includes but not limited to preparation of pharmaceutical drugs and drug delivery vehicles, improve diagnostic capabilities, and regenerative medicine.

Introduction

Nanoparticles measure less than 100 nanometers in size and possess several unique properties like the uniform appearance, stable conductance, and specific optical properties. Hence, make them desirable in the fields of biology and materials science. Nanoparticles are inorganic in nature with a characteristic layer surrounding them¹. Because of the large surface area, nanoparticles can exert their effects on a large area without a significant modification in their surface area. They are synthesized by gas condensation, ion implantation, attrition, pyrolysis, chemical precipitation, and hydrothermal synthesis

Nanoparticles are made up of three layers; the surface layer, shell layer, and the inner core². The properties exerted by nanoparticles are majorly dependent on its size and enhanced diffusion due to the high surface area to volume ratio. This enhanced diffusion of nanoparticles leads to agglomeration (cluster formation).

The unique size, shape, and structure of nanoparticles make

them highly reactive, and tough. The nanoparticles possess varied optical properties (absorption in the visible region), and magnetic properties, etc. These characteristic features of nanoparticles make them suitable for various applications like imaging, medical applications, catalysis, energy-based research, and environmental applications³. The activity or performance of nanoparticles is made accurate, and precise by coating their surface with organic molecules or polymers, which determines their stability, solubility and targeting ability. For biological applications of nanoparticles, their surface is covalently tagged with monoclonal antibodies, and other proteins (streptavidin), and peptides⁴.

Nanotechnology is the technology employed to produce nanoparticles. There are two approaches to produce/synthesize nanoparticles. The constructive or the bottom-up an approach where small molecules are assembled based on their molecular properties to improve their efficacy, and the top-down approach, also called as a destructive approach, where large molecules with stability and high performance are used to build nano-objects^{5,6}.

Nanomedicine is the application of nanotechnology to the field of medicine, where the nanometer scale sized materials are used for various purposes in medicine. The nanomaterials can be easily interfaced with biological molecules or structures because of their similarity in sizes. Hence nanoscale materials can be used in both in vivo and in vitro biomedical research and applications⁷.

The three major areas where the nanomaterials have applications in the medicine include the Imaging, diagnosis, and treatment.

Nanotechnology and diagnostic imaging

The use of nanotechnology in imaging provides functional versatility that is not provided by the traditional small molecule agents. Here, radiolabeled nanoparticles are attached to the probes for Positron Emission Tomography (PET),

Single Photon Emission Computed Tomography (SPECT) scans and the images produced are used in the diagnosis of conditions like the inflammation, atherosclerosis, angiogenesis, ischemia, blood pool imaging etc.,

Ischemia is a condition that results in the improper functioning of the heart muscles due to low or no oxygen supply. Radiolabeled nanoparticles are used in imaging the site of ischemia. Recently, the nanoparticles are used as antioxidants to reduce the tissue oxidative stress. They are also used to deliver the drugs to the ischemic region, and to image complicated ischemic repercussions at the tissues using the contrasts produced by nanoparticles⁸.

Blood pool agents are magnetic resonance particles used in angiography. These agents are large sized with high molecular weight. This causes them to stay in the vascular system for longer duration and result in gastrointestinal bleeding. They can be used to visualize vasculature around certain tumors, detect endovascular leaks, and help in measuring tissue blood volume and levels of perfusion^{9, 10}. Nanoparticles used as blood pool agents include multimodal dendrimers for SPECT/CT, multimodal cross-linked dextran iron oxide agents for PET/CT and PET/ MR and core-shell star copolymers for PET¹¹.

Radiolabeled nanoparticles are used to detect microvessels formed by angiogenesis. The clinical use of this angiogenesis imaging is to detect the ischemia - induced angiogenesis and intraplaque angiogenesis that leads to plaque rupture, and also helps in the detection of tumor angiogenesis¹².

Radiolabeled lipoprotein nanoparticles i.e., high-density lipoprotein (HDL), low-density lipoprotein (LDL) are used to monitor lipoprotein circulation and lipid uptake in atheromatous lesions¹³. Synthetic lipoprotein shells are designed for multimodal imaging and therapeutic delivery¹⁴. Radiolabeled nanoparticles also help in locating intra-plaque inflammation which helps in initiating therapy before rupturing of the plaque.

Inflammation is the response of the body's immunity against injury or pathogen invasion. It is associated with the pathogenesis of many diseases. There are various nano probes used to diagnose inflammation, in conjugation with PET, MRI, and CT¹⁵. The poor penetration of nano probes into deep tissues limits nanoprobe use as inflammatory markers. To overcome this, self-illuminating nanoparticles are used to detect inflammation as well as in tumor therapy¹⁶.

Nanotechnology and its applications in disease diagnosis

Nanotechnology-based diagnostics help in rapid testing, allowing the accurate disease diagnosis and facilitate early treatment almost at the first visit to doctors. This may help in stopping the progression of the disease and minimizing the morbidity and mortality among the patients. The short circulation time and large size of dyes, chemicals, drugs used in routine imaging of cancer stages can be overcome by the use of nanotechnology-based microbubbles (1-5micrometer). The microbubbles with a half-life of one minute are used to detect and stage the cases of prostate cancer. The tumor tissue shows overexpression of epithelial cells, which can be a hindrance in the cancer diagnosis. This can also be eliminated by the use of nanotechnology^{17, 18}.

Nano sized exosomes are used to diagnose pancreatic cancer¹⁹. Nanowires based sensor detects bladder and prostate cancer in the urine samples²⁰. Gold nanoparticles are used to diagnose flu virus²¹.

Gold nanoparticles with fluorescent protein are used in the diagnosis of the specific type of cancers. Quantum dots, a type of nanoparticles, are used to locate tumors. Nano roughened glass plates are being used to understand the extent of spread of cancers. Carbon nanotubes and gold nanoparticles have been applied to detect proteins that are in turn used to diagnose oral cancer.

Magnetic nanoparticles attached to the micro vessels have been used to detect brain cancer cells and the nanopore sensors are used for the purpose of increasing the sensitivity of viral infection diagnosis^{22, 23}.

Nanotechnology and therapeutic applications

Nanotechnology-based drugs, due to their small size and enhanced diffusion capabilities have several advantages over the traditional drugs²⁴. The benefits of nano drugs include minimal hepatic damage reduced renal excretion which prolongs its circulation time, less accumulation of the drugs in healthy tissue, and site specific drug delivery increases the concentration of the drug at the pathological site thereby improves therapeutic index.

Because of their site specific drug delivery, nano pharmaceutical drugs may be effective in the treatment of solid tumors. The mechanism underlying the treatment of solid tumors with nano drugs is due to their accumulation at leaky blood vessels and regulating the functions of lymphatic vessels.

The enhanced permeability and retention properties of nano drugs make them more effective and have been used selectively in the treatment of diseases like cancer, rheumatoid

arthritis, atherosclerosis etc.,²⁵. Nano preparations are also being considered as potential alternatives to traditional antimicrobial drugs, especially against the multi-drug resistant microorganisms²⁶.

Conclusion and future perspectives

The technology which combines engineering and science at the nanoscale (1-100nm) is called nanotechnology. This technology has a wide spectrum of applications, including medicine. Its role in the medical fields of surgery, drug delivery, diagnostic strategies, are time-saving, and without/minimal side effects. Nanotechnology could also be used to fix gene damage or gene alterations. The drawbacks of nanotechnology may include unemployment, owing to its fast and efficient function. Nanoparticles may become an environmental threat, because of the byproducts they release. Although the nanotechnology can be applied to manufacture atomic weapons, which is a boon to the country, if it falls in the hands of psychopaths/terrorists, may lead to destruction and unnecessary loss of lives. Thus, in conclusion, the nanotechnology has more benefits than disadvantages, and if used with caution, will definitely benefit the medical fraternity.

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