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Nanoparticles - Based Imaging and Therapy: A Review of Applications in Medicine

Umme Najma[1], Lata Kulkarni[2]

[1]Department of Biotechnology, Maharanis Science College for Women, Mysore - 570005, India
Corresponding Author Email: *najmamaharanis[at]gmail.com*

[2] Department of Electronics, Maharanis Science College for Women, Mysore - 570005, India
Email: *ruchiralata[at]gmail.com*

Abstract: ***Nanoparticles (NPs) have emerged as versatile tools in medicine offering unique properties for both imaging and therapy. This review explores the diverse applications of NP - based approaches in medical imaging and therapy. From diagnosis to treatment, NPs offer precise targeting, enhanced contrast and controlled drug revolutionizing the landscape of medical interventions. We discuss the latest developments, challenges and future prospects in this rapidly evolving field.***

Keywords: Nanoparticles, Imaging, Therapy, Medicine, Drug delivery

1. Introduction

Nanoparticles are defined as particulate dispersions or solid particles with a size in the range of 10 - 1000nm. The drug is dissolved, entrapped, encapsulated or attached to a nanoparticle matrix [1]. The unique property of nanosized material as compared to bulk material is the advantage of more surface to volume ratio [2]. Nanoparticles (NPs) can be synthesized from various organic or inorganic materials such as lipids, proteins, synthetic/natural polymers, and metals [3]. In fact, many functional elements of biological systems are at the nanometer scale. thereby, nanomaterials can be ideally sized to assume some biological functionality at the molecular level. Recent advances in nanotechnology are expected to help solve many key issues in biological disorders. with a NPs size of 2–100 nm exhibit unique electronic, optical, chemical, and magnetic properties distinct from larger particles of the same material. [4]. The benefits of nanoparticles to modern medicine are numerous. Indeed, there are some instances where nanoparticles enable analyses and therapies that simply cannot be performed otherwise. However, nanoparticles also bring with them unique environmental and societal challenges, particularly in regard to toxicity [5].

2. Nanoparticle - Based Imaging

Imaging techniques play an important role in the medical care of all organ systems and better and increased research in medical imaging may be beneficial for the complete health and disease management process [6]. Nanoparticles can provide significant improvements in traditional biological imaging of cells and tissues [7]. Nanoparticles, including fluorescent semiconductor nanocrystals (quantum dots) and magnetic nanoparticles, have proven their excellent properties for *in vivo* imaging techniques in a number of modalities such as magnetic resonance and fluorescence imaging, respectively [6]. Medical imaging covers many different imaging modalities: X - ray - based methods such as radiography and Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Ultrasound (US), Nuclear medicine with Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT), and several optical imaging methods [6].

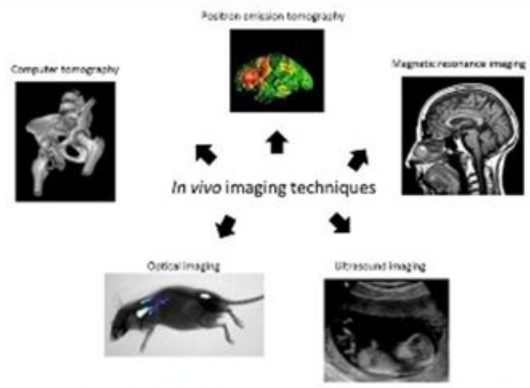

Fig. 1 Medical Imaging techniques adapted from Ryvolova M et al., 2012

2.1 Magnetic Resonance Imaging (MRI)

Magnetic nanoparticles for medical and biological applications are being of great interest due to their unique properties. The switchable magnetic properties of superparamagnetic nanoparticles make these materials useful for magnetic drug targeting, cell tracking, hyperthermia and medical imaging [6]. Use of NPs as contrast agents significantly enhances contrast in MRI and diseases can be potentially detected at an earlier stage.

2.2 Computed Tomography (CT) Imaging

Computed tomography (CT) is an X - ray based whole body imaging technique that is widely used in medicine. A variety of nanoparticle types have been used as contrast agents for CT, such as emulsions, liposomes, micelles, lipoproteins, polymeric nanoparticles, solid metal nanoparticles and so on. Micelles and lipoproteins, which can be regarded as a form of micelle, have yielded excellent results as CT contrast agents [8]. Targeted nanoparticle CT contrast agents can detect the expression of proteins or cell types in tissues, for example detecting the macrophage content of atherosclerotic plaque [8, 9].

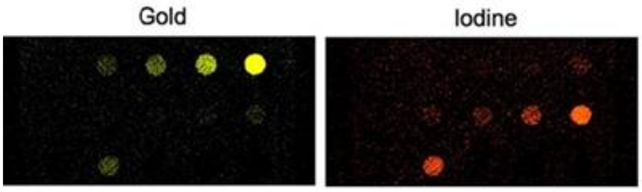

Figure 2: Computed image adapted from cormode et al.,2010

2.3 Optical Imaging

Fluorescence - based techniques such as fluorescence microscopy, flow cytometry and cell sorting fluorescence correlation spectroscopy falls under the roof of optical imaging. Semiconductor quantum dots (QDs) the NPs are employed as fluorescent probes for in vivo bimolecular and cellular imaging. Surface enhanced Raman Scattering (SERS), the plasmonic counterpart of spontaneous Raman spectroscopy, requires placing of the analytes nearby metal nanostructures, whereby a huge enhancement in Raman signals is observed owing to plasmon - assisted scattering of molecules [10]. SERS - based detection and imaging methods is widely used as it renders high sensitivity of image minimal sample preparation.

2.4 Ultrasound Imaging

Ultrasound Imaging has its unique advantage due to its features of real - time, low cost, and high safety making it the ideal candidate for imaging guided cancer therapy. Numerous functional nanomaterials including superparamagnetic iron oxide nanoparticles (SPIOs), CuS nanoparticles, gold nanoparticles (GNPs), gold nanorods (GNRs), gold nanoshell (GNS), graphene oxides (GOs), Prussian blue (PB) nanoparticles, and polypyrrole (PPy) DNA, siRNA have been incorporated to different types of Ultrasound Contrast agents to obtain additional functionalities for cancer diagnosis and therapeutics [11].

3. Nanoparticle - Based Therapy

3.1 Drug Delivery

The aims for nanoparticle entrapment of drugs are either enhanced delivery to, or uptake by, target cells and/or a reduction in the toxicity of the free drug to non - target organs. Both situations will result in an increase of therapeutic index, the margin between the doses resulting in a therapeutic efficacy (eg, tumor cell death) and toxicity to other organ systems [12]. In developing nanocarriers for the delivery of multiple drugs with different chemical properties and functions, it is necessary to consider their physicochemical compatibility and the desired release kinetics of each drug [13]. Three different drugs, salvianolic acid B (Sal B), tanshinone IIA (TS IIA), and panaxnotoginsenoside (PNS) were simultaneously loaded in PLGA NPs for the treatment of brain disease [13]. To facilitate targeted delivery into specific tissues NPs in different formulation were being synthesized forms that mimic the natural extracellular and intracellular trafficking system of the cell (Fig 3.).

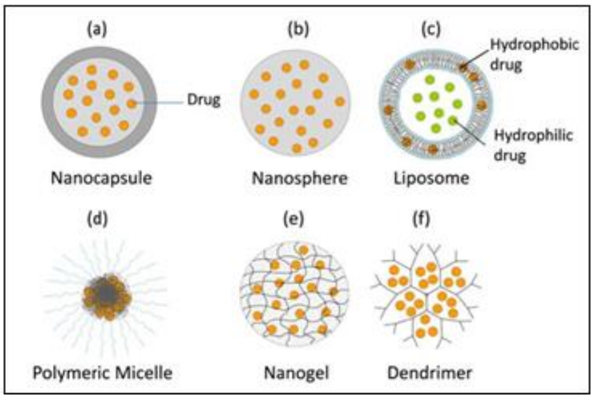

Figure 3: Nanoparticle forms utilized in drug delivery adapted from lee 2015

3.2 Photothermal Therapy (PTT)

Among different therapies PTT is attractive therapeutics in oncology because of its noninvasive and selective therapeutic potential. In general, PTT uses photothermal effects induced by photothermal agents that convert light energy into heat, thus increasing the temperature of surrounding tissue and triggering cell death [14]. Nanosized photothermal agents (NPA) can accumulate in tumors via enhanced permeability and retention (EPR) effects with targeted activity. Metal nanomaterials (platinum and gold), semiconductor nanomaterials (copper), carbon nanomaterials (carbon nanotubes and graphene), and conducting polymers (polyaniline and polypyrrole) are being utilized as NPA in effective cancer treatments [15].

3.3 Photodynamic Therapy Photodynamic Therapy (PDT)

PDT involves the administration of a tumor - localizing photosensitizer (PS) followed by local illumination of the tumor with light of a specific wavelength to activate the PS. The excited PS then transfers its energy to molecular oxygen, thus generating cytotoxic reactive oxygen species (ROS), such as singlet oxygen (1 O2) that can oxidize key cellular macromolecules leading to tumor cell ablation [13, 14]. The application of nanoparticles in the field of PDT is an extremely promising avenue for future technological breakthroughs. Nanoparticles can act as carriers of hydrophobic PSs and transport high PS "payload" to the tumor site via the EPR effect Among the various nanoconstructs, polymeric (synthetic or natural), liposomal or dendrimer nanoparticles are biocompatible and biodegradable, and hence have the added advantage of being enzymatically hydrolyzed and excreted from the body, minimizing long term accumulation [14].

3.4 Gene Therapy

The proton sponge escape occurs when nanoparticles containing amino groups, such as polyethylenimine (PEI) or polyamidoamine (PAMAM) based dendrimers, are protonated during acidification of the endosome, resulting in an increased osmotic pressure due to an influx of chloride ions and consequent swelling of the endosome with nanoparticles release into the cytoplasm [12]. The approach involves a magnetic iron oxide (g - Fe_2O_3 or Fe_3O_4) core with smaller gold nanoparticles (hydrodynamic diameter of 240 nm) immobilized on its surface. The viral component on the nanobioconjugate was an adenovirus. The adenoviral vectors (Ad) are widely used for gene transfer because of their high transduction efficiency [13].

4. Challenges and Future Directions

Research has demonstrated that low - solubility nanoparticles are more hazardous and toxic on a mass by mass basis than larger particles. Other potential risks posed by nanoparticles include explosions and catalytic effects. It is important to note that only specific nanomaterials are considered risky, particularly those with high reactivity and mobility. Until more thorough studies can confirm the hazardous effects of nanomaterials, the mere presence of them in a laboratory setting will not in itself impose a threat to humanity and the environment Potential risks of nanotechnology can be broadly grouped into three areas: Health, environment and society [15].

5. Discussion

Despite the potential benefits of nanoparticles in imaging and therapy, there are still challenges and limitations that need to be addressed. The applications of nanoparticles in imaging and therapy have the potential to impact a wide range of medical fields, including oncology, cardiology, and neurology The use of nanoparticles in imaging and therapy should be approached with caution, as there are still unknown risks and challenges that need to be addressed. The review is limited by the current state of the field, as there is still much to be learned about the use of nanoparticles in imaging and therapy in medicine. The future scope of nanoparticles - based imaging and therapy in medicine is vast, with potential for further development and integration into clinical practice.

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