e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:05/Issue:02/February-2023 Impact Factor- 6.752 www.irjmets.com

CANCER DIAGNOSIS AND TREATMENT USING MAGNETIC NANOPARTICLES: A BRIEF REVIEW

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DOI : https://www.doi.org/10.56726/IRJMETS33498

ABSTRACT

Cancer is a set of over a hundred diseases characterized by uncontrolled, incontinent cell division that develops as the body's rudimentary reproductive system loses the ability to make dangerous immature cells, in contrast to normal cells. In recent years, advances and explorations in nanosystems, particularly magnetic nanoparticles, have been made with a focus on tumor targeting in oncology to combat the uncontrollable development of replicating cells. The magnetic nanoparticles are a class of intelligent, highly functionalized, biocompatible coated nanostructures with intrinsic magnetic properties of ferromagnetism and super paramagnetism in vivo at a specific site under the employed alternating external magnetic field, making them the most promising tool and design with reduced the probability of resistance that provides multimodal and functional platform for. This review clarified the different uses of magnetic nanoparticles, such as their significance in cancer research, diagnostics, and treatment, as well as their potential for growth and difficulties in the future.

Keywords: Cancer Diagnosis; Cancer Treatment, Magnetic Nanoparticles.

I. INTRODUCTION

Despite tremendous efforts over the last 50 years, cancer mortality has declined only slightly, but not significantly. Nanomedicine is proving to be a game-changer in future cancer prevention, diagnosis, and treatment, as estimated by the National Cancer Institute. Nanotechnology may play an important role in cancer diagnosis by enabling early visualization of cancer cells. Magnetic nanoparticles (MNPs) are a very important group of nanomaterials with the potential to revolutionize current clinical therapeutic and diagnostic techniques. The application of magnet-based nanoparticles in medical applications is a new and highly interdisciplinary field, offering great potential for in vitro and in vivo therapeutic and diagnostic testing. Early medical applications used iron powder or magnetite directly in therapeutics. Recently, magnetic nanoparticles have become highly visible tools in cancer therapy. Nanoparticles containing nickel, cobalt, and iron can pass through magnetic fields due to their ferromagnetism. Iron oxide nanoparticles are mainly used in biomedicine. There are now nanoparticles successfully used to diagnose cancer, allowing healthcare physicians to image specific areas of the body where cancer is located. For example, using magnetic particles together with MRI scans has significantly improved image contrast. Contrast leads to detection of a variety of small cancerous metastases that are otherwise undetectable. Nanoparticles are also used in the physical process of tumor tissue destruction by magnetic nanoparticles hyperthermia. Nanoparticles have been found to have multiple applications in the diagnosis and treatment of different types of cancer. This technique uses a magnetic field to vibrate iron oxide magnetic nanoparticles and generate heat [1].

II. MAGNETIC NANOPARTICLES

Magnetic nanoparticles are one of the most intensively studied nanomaterials due to their potential use in various research fields. The magnetic nanoparticles have been used for cancer detection and molecular imaging by localizing sentinel nodes. The magnetic nanoparticles are being intensively studied for use in a variety of industrial and scientific fields, from mass data storage to catalysis. The concept of cancer therapy using magnetic nanoparticles to target human tumor cells was first proposed in the late 1970s. The magnetic nanoparticles can be used to heat and kill tumor cells. This is because tumor cells are more sensitive to increased temperature than healthy cells. Cancer cells are damaged by taking magnetic nanoparticles into tumors and releasing energy as heat when exposed to alternating magnetic fields. These magnetic nanomaterials are ferromagnetic (example: cobalt, nickel, iron, etc.), paramagnetic (example: magnesium, lithium, tantalum, gadolinium, etc.), diamagnetic (example: silver, copper, gold, and most known elements, etc.),

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which are classified into five main types of antiferromagnets. (example: CoO, MnO, $CuCl_2$ and NiO) and ferrimagnetic materials (such as maghemite-Fe_2O_3 and magnetite-Fe_3O_4). The chemical and physical properties of magnetic nanoparticles are highly dependent on their size, shape, crystal structure, and chemical composition. In addition, magnetic nanoparticles possess special magnetic properties such as low Curie temperature, superparamagnetism and large susceptibility. Magnetic susceptibility is the ratio of magnetization to applied magnetic field and indicates how strongly nanoparticles are attracted or repelled by a magnetic field. The basic idea behind magnetic nanoparticles was to attach conventional anticancer drugs to small magnetic beads externally before administering them to the human body. When injected into the bloodstream, a strong external magnetic field collects the drug-laden nanoparticles in the tumor tissue. This method is expected to significantly reduce drug load. This prevents unwanted side effects associated with the systematic distribution of chemotherapy drugs, such as hair loss, nausea, and a weakened immune system. Although not yet in full clinical use, nanomedicine has come a long way from these original concepts and is advancing at an astounding rate. Iron oxide MNPs are the most advantageous nanomaterials in medical science due to their properties such as biocompatibility, stability in aqueous solution, low toxicity, and excellent physicochemical properties such as superparamagnetism. The widespread use of iron oxide magnetic nanoparticles has also been attributed to their ability to manipulate particle motion, induce energy dissipation, and provide image contrast when exposed to an external magnetic field. The magnetic response of iron oxide is stable due to its low sensitivity to oxidation. In addition, iron oxide magnetic nanoparticles are superior to alternative metal nanoparticles with size control, specific interactions and dispersion, and avoidance of aggregation by coating and penetrating cell and tissue barriers. Overall, magnetic nanoparticles are receiving more and more attention due to their unique behavioral, structural, and diverse applicability. For example, their well-defined magnetic properties and tunable size, functionalize surface with different molecules, biocompatibility with different cell types, high chemical stability due to increased surface area, induced magnetic moment, high magnetization. rate, and superparamagnetism. Superparamagnetic and biocompatible nanoparticles can be instantly injected into tumor tissue where they can be manipulated by an external magnetic field to generate heat as a result of Brownian and Neel relaxation processes.

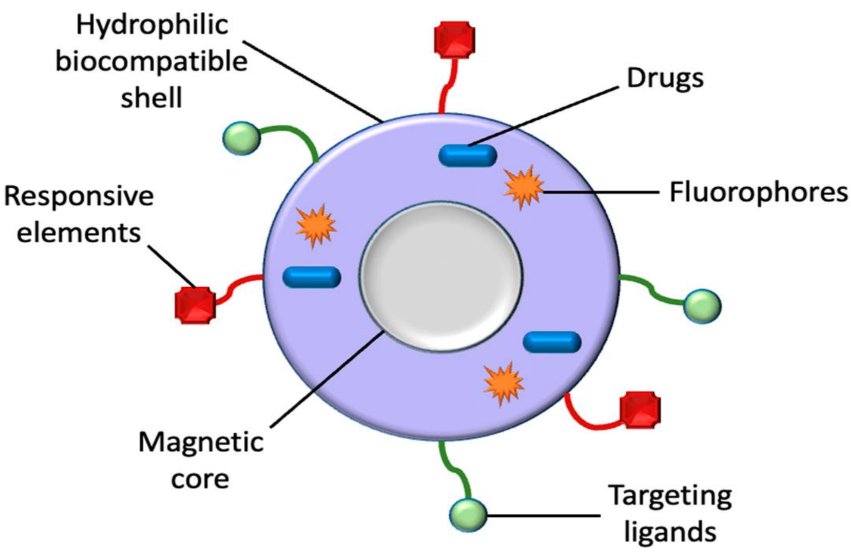

Figure 1. A pictorial representation of a magnetic nanoparticle structure.

Although there have been many developments in the field of nanomedicine in recent years, there are still many shortcomings. For example, the long-term toxicity of some nanoparticles is not well known due to the novelty of this research area. Moreover, while nanomedicine is not yet in full clinical use, it has made great strides and is advancing at an astounding rate. The aim of this study was to investigate the application of magnetic nanoparticles for cancer diagnosis and therapy. Various aspects of magnetic nanoparticles are investigated in this review to support this investigation. Synthetic techniques and functionalization approaches for magnetic nanoparticles are described. Clinical and toxicology studies on magnetic nanoparticles are also reviewed [2].

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III. USE OF MAGNETIC NANOPARTICLES CANCER THERAPY

3.1. Magnetic Nanoparticles Application in vivo Imaging

Magnetic resonance imaging (MRI) is the most valuable technique for cancer diagnosis, capable of reconstructing 2D and 3D images of internal structures in vivo. Gadolinium (III)-based MNPs were the first clinically investigated nano-based structures as contrast agents. Numerous magnetic nanoparticles-based candidates have been used as contrast agents (CA), including lanthanide ions and iron oxide nanoparticles. The purpose of injecting CA is to alter the relaxation rate of NMR-active hydrogen atoms around labeled cells, causing a quantified change in signal intensity between normal cells and particle-loaded tissue. The resulting signal differences allow MRI to distinguish between benign/malignant contrast-enhanced tissue and normal tissue. Contrast agents used in MRI can be classified as non-specific and tissue-specific based on their final biodistribution in vivo. Magnetic resonance imaging was originally used as a screening tool for breast cancer using, a gadolinium-based contrast agent that efficiently and rapidly accumulates in the breast cancer stroma. Leading breast cancer MRI protocols include T1-weighted acquisition of pre- and post-contrast accumulations at target sites and various large-scale multicenter studies of germline mutations.

3.2. Magnetic Nanoparticles (MNPs) Application

Many MNPs can be functionalized and other drug release designs are navigated by techniques such as magnetic drug targeting (MDT), where drug delivery is used to treat cancer and therapeutics are used directly. can develop in response to remote and internal stimuli. It is connected to an external magnetic field powered magnetic nanoparticle drug delivery vehicle. Such strategies could improve the consistency of controlled release and reduce side effects to unaffected organs caused by antitumor systemic treatments. Quantum dots are being used as a tool to detect cancer cells in the blood of lung cancer patients. Iron oxide-based superparamagnetic nanoimmunoliposomes demonstrate enhanced in vivo targeting and uptake capabilities in human cancer cells. Chemotherapeutic agents are being investigated in the loading and delivery of anticancer agents such as paclitaxel and fluorouracil, TMZ (temozolomide), doxorubicin with MNPs.

3.3. MNPs Application in Radiotherapeutics

MNP has advantages over current conventional radiotherapy techniques due to its low injury rate to non-target tissues through passive and active targeting and generation of ROS (reactive oxygen species). efficacy required to cause damage to immature cells. The enhancement in vivo radiotherapy studied for tumor cell sensitization through higher ROS concentrations in cells using iron oxide-based MNPs. Researchers conducted a study and proposed that MNPs including neutron-activated Pt- and Ho-166-based chemotherapy could be effective chemotherapeutic therapies for lung cancer. in which platinum derivatives act as radionuclides to improve tumor sensitivity to radiation therapy). Some researchers have also suggested that modified Zn-doped iron oxide MNPs act synergistically as a radioimmunotherapy agent for the treatment of gliomas [3].

3.4. MNPs Application in Biotherapeutics

The origin of malignancy can be the result of dysfunctional genes in a cell. Thus, gene drugs have a promising potential to interfere with tumor origin in cancer therapy. But a major challenge in genomics is the lack of suitable and efficient vectors that can introduce a genetic entity into the mutant gene. But biologic therapy involves delivering bioactive molecules such as DNA, small interfering RNA, peptides, or proteins. And magnetization is a method in which the targeted transfection of cells with MNP-conjugated nucleic acids is guided by a magnetic field. Qi et al. used iron oxide-based MNPs to deliver siRNA directly into tumor cells and showed much better transgene efficiency with other transformation reagents [4].

3.5. MNPs Application in Immunotherapeutics

Cancer immunotherapy involves a number of therapies that explore the body's immune system to detect, block, and even attack cancer cells directly. Several strategies have been considered to achieve therapeutic immune responses, such as the introduction of resistance checkpoint molecules CTLA-4/anti-PD1/anti-PD-L1, vaccine dendritic cell-based method, cell transfer method, and a combination of the above methods. Combining cancer immunotherapeutic strategies with MNPs leads to various advantages of targeted vehicles fine-tuned with the size and surface characteristics required to maximize the efficiency of magnetic field delivery. Aid in navigation and enhance treatment effect on specific target sites. Several immunotherapeutic formulations of MNPs have been exploited both as fluorescent probes and as MRI contrast agents in vivo [5].

IV. MAGNETIC NANOPARTICLES AGAINST CANCER DRUG RESISTANCE

Nanotechnology allows the combination of a wide variety of substances and their mechanisms of action, as well as their intended uses. The magnetic nanoparticles are coated with biocompatible materials and functionalized with one or more different active ingredients. Therefore, it is possible to use different therapeutic mechanisms simultaneously in the same place, greatly reducing the possibility of drug resistance. For example, Tang et al. used magnetic nanoparticles with cores of manganese, zinc, and iron oxide, as well as human albumin, folic acid, cisplatin, and 188 rhenium radionuclides. In this way, the triple effect of radiation, chemotherapy and hyperthermia can be achieved. They tested the pharmacokinetics and biodistribution in vivo in a naked mouse model of a tumor. Another possibility is to increase the concentration of the anticancer drug to the point where no malignant cells survive. A magnetic field for tissue-specific enrichment of magnetic nanoparticles and the accompanying drug is of great value for this purpose. For example, this strategy is used in MDT, as described previously. Even tumors that are already resistant to treatment can be more effectively accessed with magnetic nanoparticles. For example, one strategy is to combine an anticancer drug and a drug that targets the resistance mechanism. With this approach, Cheng et al. successfully used magnetic nanoparticles loaded with chemotherapeutic agents and ABC transporter inhibitors. By testing the cytotoxic potential of doxorubicin on K562/A02 cells (human chronic myeloid leukemia cell line) in vitro, they found a significantly enhanced effect on these cells. cells versus nanoparticle-bound antineoplastic agents without ABC transporter inhibitors Substances can be used that are unaffected by the resistance mechanism involved or that directly target it (example: antibodies against the ABC transporter). In addition to its biocompatible core and coating, in an ideal case, a functionalized nanoparticle should have four components to perform different tasks:

1. Anti-tumor effects

This effect is obtained by a combination of substances that act directly on the tumor tumor, such as chemotherapeutic agents, nucleic acids, radionuclides, etc. This heading also covers induction of hyperthermia using an alternating magnetic field.

2. Overcoming cancer drug resistance

Substances that aim to provide effective therapy by blocking tumor resistance are incorporated with nanoparticles. Here ABC transporter inhibitors or antibodies are considered.

3. Diagnostic and imaging tests

Functional nanoparticles must include a substance used for diagnostic purposes. This will allow to combine treatment and diagnostic investigation into “therapy”. magnetic nanoparticles (MNP) were used as contrast agents in magnetic resonance imaging (MRI).

4. Enhancement at Target Site

To focus the nanoparticles to the desired area and treat the tumor in a targeted way, it is possible to combine them with tumor-specific binding antibodies [6-9].

V. CONCLUSION

The range of magnetic nanoparticles has been expansively considered in the past years, and most recently oriented for nano-theranostics application. The less in size, manageable inherent physico-chemical characteristics, externally applied magnetic field response and multi-surface functionalization create attractive facets that make magnetic nanoparticles beneficial nanoscale systems for targeting, imaging and drug delivery, in the theranostic field. The foremost purpose and concern in this field trust on the development of nano-systems that gather stability in biological surroundings, controlled drug delivery, good sensitivity for diagnosis, and low-toxicity. Hence, the expansion of specific guidance and cataloguing systems is an imperative stage to most competently characterize and parametrize magnetic nanoparticles. The snowballing outlay in research related to this creates the optimistic technological development in the nano-theranostic field regarding magnetic nanoparticles. Cancer nano-theranostics is a presently continuous developing area with great potential regarding biomedical applications, which comprises the novel approaches to resolve the diagnosis and therapeutics requirements.

IRJMETS

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ACKNOWLEDGEMENTS

Authors are very much thankful to Principal, Smt. Radhabai Sarda Arts, Commerce & Science College, Anjangaon Surji, Dist. Amravati, Maharashtra – 444705 for providing necessary academic help.

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