



Original Article

# Magnetically Active Nanoparticles in Cancer Therapy: The Role of Pharmacist

R. R. Kulkarni<sup>1</sup>, L. S. Kanna<sup>2</sup>

<sup>1,2</sup> D. S. T. S. Mandal's College of Pharmacy, Solapur

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**Correspondence Address:**

Ms. R. R. Kulkarni, D. S. T.  
S. Mandal's College of  
Pharmacy, Solapur.  
Email:  
[kulkarniraj1993@gmail.com](mailto:kulkarniraj1993@gmail.com)

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## Abstract

By providing targeted drug administration, magnetic hyperthermia, and improved imaging capabilities, magnetically active nanoparticles (MNPs) have become a viable cancer treatment technique. These nanoparticles, which are usually made of iron oxide, can be guided to tumour sites by applying external magnetic fields because of their superparamagnetic characteristics. To create MNPs with the appropriate magnetic characteristics and sizes, a variety of procedures are used, such as co-precipitation, thermal breakdown, and hydrothermal approaches. The size, shape, surface charge, and magnetic characteristics of the nanoparticles are evaluated using thorough characterisation methods such as dynamic light scattering (DLS), vibrating sample magnetometry (VSM), and transmission electron microscopy (TEM). In conclusion, the creation of magnetically active nanoparticles is an example of a multidisciplinary approach to cancer therapy that combines materials science, oncology, and nanotechnology to produce more individualised and efficient treatment plans.

**Keywords:** Magnetically Active Nanoparticles, Cancer Therapy, Magnetic Hyperthermia, Targeted Drug Delivery, Pharmacist Role, Nanomedicine, Superparamagnetic Iron Oxide Nanoparticles (SPIONs), Theranostics.

## Introduction

Cancer remains one of the most challenging and prevalent diseases worldwide, responsible for millions of deaths each year. Despite significant advancements in treatment strategies, such as chemotherapy, radiation therapy, and surgery, these conventional methods often face limitations including poor specificity, severe side effects, and drug resistance. As a result, there has been increasing interest in developing alternative or complementary therapeutic approaches that are more targeted, less invasive, and capable of overcoming the limitations of current treatments.<sup>(1)</sup>

In recent years, magnetically active nanoparticles (NPs) have emerged as promising candidates in the field of cancer therapy due to their unique physical properties, including superparamagnetism, high surface-area-to-volume ratio, and the ability to be manipulated using external magnetic fields. These nanoparticles can be engineered to deliver therapeutic agents, such as drugs, genes, or heat, in a controlled and site-specific manner, enhancing the efficacy of treatment while minimizing damage to healthy tissues.<sup>(2)</sup>

Magnetic nanoparticle-based cancer therapies primarily utilize two main mechanisms: magnetic hyperthermia (MH) and targeted drug delivery. Magnetic hyperthermia involves the application of an alternating magnetic field to induce localized heating of the nanoparticles, which in turn causes thermal damage to the tumor cells. On the other hand, magnetic nanoparticles can also be functionalized with targeting ligands, allowing for the selective delivery of chemotherapeutic agents to tumor sites, thereby reducing systemic toxicity and improving treatment outcomes.<sup>(3)</sup>

This review aims to provide a comprehensive overview of the design, synthesis, and functionalization strategies of magnetically active nanoparticles for cancer treatment. We will discuss various types of magnetic nanoparticles, their therapeutic applications, challenges, and recent advancements in the field. Furthermore, we will explore the future prospects of these innovative nanomaterials in cancer therapy, highlighting their potential to revolutionize personalized medicine and improve the quality of life for cancer patients.<sup>(4)</sup>

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## Applications of magnetically active nanoparticle in Cancer Therapy

### A. Magnetic Hyperthermia

- MNPs generate heat upon exposure to an alternating magnetic field, selectively killing cancer cells while sparing healthy tissues.

### B. Targeted Drug Delivery

- External magnetic fields can guide MNPs to the tumor site, enhancing drug accumulation and reducing side effects.

### C. Imaging and Theranostics

- MNPs enhance MRI contrast, enabling real-time tracking of drug delivery and tumour response.<sup>(5)</sup>

## Methodology

Magnetically active nanoparticles (MNPs) have emerged as a promising tool for cancer therapy due to their unique properties, including targeted drug delivery, hyperthermia treatment, and imaging capabilities. The formulation of these nanoparticles involves careful selection of materials, synthesis methods, surface modifications, and drug-loading techniques to optimize their therapeutic efficiency.

### 1. Selection of Magnetic Core

The core of magnetically active nanoparticles is typically composed of superparamagnetic iron oxide nanoparticles (SPIONs) due to their biocompatibility, strong magnetic response, and ease of functionalization. Common magnetic materials include:

- Iron Oxides ( $\text{Fe}_3\text{O}_4$ ,  $\gamma\text{-Fe}_2\text{O}_3$ ) – Most widely used due to their biocompatibility and FDA approval.
- Cobalt Ferrite ( $\text{CoFe}_2\text{O}_4$ ) – Offers higher magnetic saturation but may require additional surface modifications for biocompatibility.
- Nickel and Cobalt Nanoparticles – Strong magnetic properties but with potential cytotoxicity, requiring coatings.

### 2. Synthesis Methods

The synthesis method affects the size, shape, and magnetic properties of MNPs. Common approaches include:

- Co-precipitation – Simple and widely used method for producing SPIONs in aqueous solutions.
- Thermal Decomposition – Produces monodisperse MNPs with controlled size and crystallinity.
- Microemulsion – Enables better size control through surfactant-based micelle formation.
- Sol-gel Method – Used for hybrid materials and fine-tuned size control.

### 3. Surface Functionalization and Coatings

To enhance biocompatibility, stability, and targeting efficiency, MNPs are often coated with:

- Biopolymers (Chitosan, Dextran, PEG) – Improve biocompatibility and circulation time.
- Silica ( $\text{SiO}_2$ ) – Provides chemical stability and surface functionality for drug loading.

- Gold (Au) – Enhances imaging properties and allows for functionalization with biomolecules.
- Lipid and Albumin Coatings – Enhance cellular uptake and reduce immune clearance.

### 4. Drug Loading and Release Mechanisms

MNPs can act as carriers for anticancer drugs, delivering them directly to tumors while minimizing systemic toxicity. Drug loading methods include:

- **Physical Adsorption** – Electrostatic interactions between drug molecules and the nanoparticle surface.
- **Covalent Bonding** – Uses linker molecules to attach drugs, allowing controlled release.
- **Encapsulation** – Drug-loaded liposomes or polymer shells surrounding the MNP core.

### 5. Release Mechanisms:

- **pH-Responsive Release** – Exploits the acidic tumor microenvironment to trigger drug release.
- **Magnetic Field-Induced Release** – Uses external magnets to release drugs at the tumor site.
- **Enzyme-Triggered Release** – Exploits cancer-specific enzymes to degrade the nanoparticle shell.

### 6. Challenges and Future Perspectives

Despite their potential, MNP-based cancer therapies face challenges, including:

- Biocompatibility and toxicity concerns – Long-term effects need further investigation.
- Scalability of synthesis methods – Large-scale, cost-effective production is required.
- Efficient targeting and retention – Avoiding rapid clearance by the immune system remains a hurdle.

Future research focuses on developing multifunctional MNPs that integrate drug delivery, imaging, and hyperthermia into a single nanoplatform for personalized cancer treatment.<sup>(6, 7, 8, 9)</sup>

## Role of Pharmacist:

The role of pharmacists in cancer treatment using magnetically active nanoparticles (MNPs) is emerging as a crucial aspect of nanomedicine. However, this role comes with several challenges.

### Role of Pharmacists in Cancer Treatment Using MNPs

Pharmacists contribute to this field through the following:

#### 1. Drug Formulation & Delivery

- Develop and optimize MNP-based targeted drug delivery systems.
- Ensure stability and compatibility of MNPs with chemotherapy drugs.

#### 2. Personalized Medicine & Dosage Optimization

- Design personalized treatment plans using MNPs for site-specific drug delivery.
- Determine the optimal magnetic field parameters for targeted therapy.

**3. Patient Safety & Toxicity Monitoring**

- Assess potential toxicity of nanoparticles, ensuring they do not accumulate in unintended organs.
- Monitor side effects and long-term safety concerns.

**4. Collaboration in Multidisciplinary Teams**

- Work with oncologists, biomedical engineers, and researchers to enhance nanoparticle-based therapies.

**5. Education & Awareness**

- Educate patients and healthcare professionals about the benefits and risks of MNP-based treatments.
- Ensure adherence to regulatory guidelines for nanomedicine.

**Challenges Faced by Pharmacists in MNP-Based Cancer Therapy****1. Limited Clinical Data & Regulatory Barriers**

- Lack of long-term studies on efficacy and safety.
- Regulatory approval challenges for nanomedicine formulations.

**2. Toxicity & Biocompatibility Concerns**

- Potential cytotoxicity and immune response to MNPs.
- Difficulty in ensuring biodegradability of nanoparticles.

**3. High Cost & Accessibility Issues**

- Expensive manufacturing and magnetic field equipment.
- Limited availability in developing regions.

**4. Complexity in Drug Delivery**

- Requires precise control over magnetic fields for drug targeting.
- Challenges in ensuring uniform distribution of nanoparticles.

**5. Need for Advanced Training**

- Pharmacists require specialized knowledge in nanotechnology, physics, and oncology.<sup>(10, 11, 12)</sup>

**Conclusion**

Pharmacists play a key role in advancing MNP-based cancer treatment through formulation, safety monitoring, and patient education. However, challenges such as toxicity concerns, regulatory hurdles, and high costs must be addressed to fully integrate this technology into clinical practice.

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**Conflicts of interest**

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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