

## Review Article

# Comprehensive Review on Magnetic Drug Delivery Systems: A Novel Approach for Drug Targeting

Mahmood Ahmad\*, Muhammad Usman Minhas, Muhammad Sohail, Muhammad Faisal, Haroon Rashid

Faculty of Pharmacy and Alternative Medicine, the Islamia University of Bahawalpur-63100, Pakistan

\*E-mail of the corresponding author: [ma786\\_786@yahoo.com](mailto:ma786_786@yahoo.com), Tel: +92 300 9682258

Accepted Date: 12 December 2013

### Abstract

Magnetic drug delivery systems have been emerged as a prominent technique for site-specific targeting of various pharmacological agents throughout the last few decades. With the support of a magnetic field, it avoids reticuloendothelial system and directs the drugs to reach the target precisely. Magnetic carriers like nanoparticles, microspheres, liposomes and emulsion have been found advantageous of the fact that they reduces the free drug concentration in the blood and to minimize the adverse effects provoked by these drugs. It has made the most crucial tumor targeting possible without damaging the healthy tissues. In this review, we will summarize the facts about magnetic drug delivery systems comprehensively.

### 1. Introduction

Selective targeting of therapeutics is one of the greatest challenges in designing site-specific drug delivery system in which drugs are required to accrue at the exact location for its pharmacological action (Singh et al., 2011). Increased drug concentration remains a critical concern as drugs are unable to accumulate at the specific receptor, organ or any other part of the body resulting in toxicity to the healthy tissues (Amanda Silva, 2012). To overcome such problems in site-specific targeting, different chemical properties are modified including partition coefficient, attachment of ligands, altered charge density and creation of various biodegradable polymers (Balaita and Popa, 2009). Mononuclear phagocytes of reticuloendothelial system (RES) also creates an apparent obstacle by sequestration of these carriers. Magnetic responsive drug delivery systems are designed for the site specific targeting of drugs without disturbing RES (Salim et al., 2009) in which external magnetic field is applied to increase the drug concentration at tumor site after administration of magnetic particles (Schuth et al., 2007). These carriers are restricted to RES by biophysical means to localize them specifically at the desired site of action. Such system is also titled as “drug delivery polymeric magnetic particles” because different biocompatible and biodegradable polymers are used to envelope magnetic particles along with the drug (Balaita and Popa, 2009). Non-magnetic micro carriers are also used for targeting of drug but due to their clearance by RES, they show poor site-specific action (Torchilin, 2005; Akhtar et al., 2009).

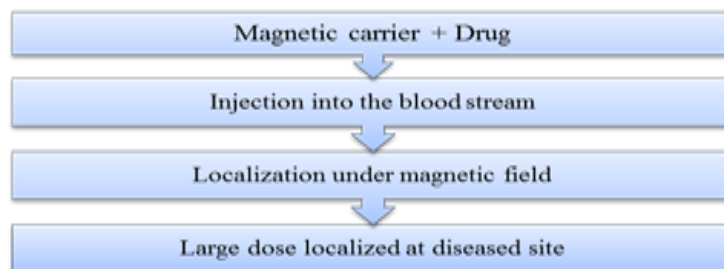


Figure 1: Mechanism of action for magnetic targeted drug delivery systems

## 2. Principle of Magnetic Drug Targeting

Magnetic targeting is one of the productive methods to deliver the drug at diseased site by virtue of a magnetic compound. These drug delivery systems contain magnetic responsiveness being integrated from different substances like magnetite, iron, cobalt, nickel, iron-boron or samarium-cobalt. The drug along with the magnetic compound is injected into the patient's blood circulation system and a magnetic field is applied at the target site to block it. Thus, considerable less amount of drug concentration can be achieved at specific site which minimizes the unwanted effects due to the high drug concentrations of freely circulating drug as shown in Figure 2 (Widder et al., 1979; Gupta and Hung, 1989; Hafeli et al., 1997; Hafeli, 2004; Singh et al., 2011).

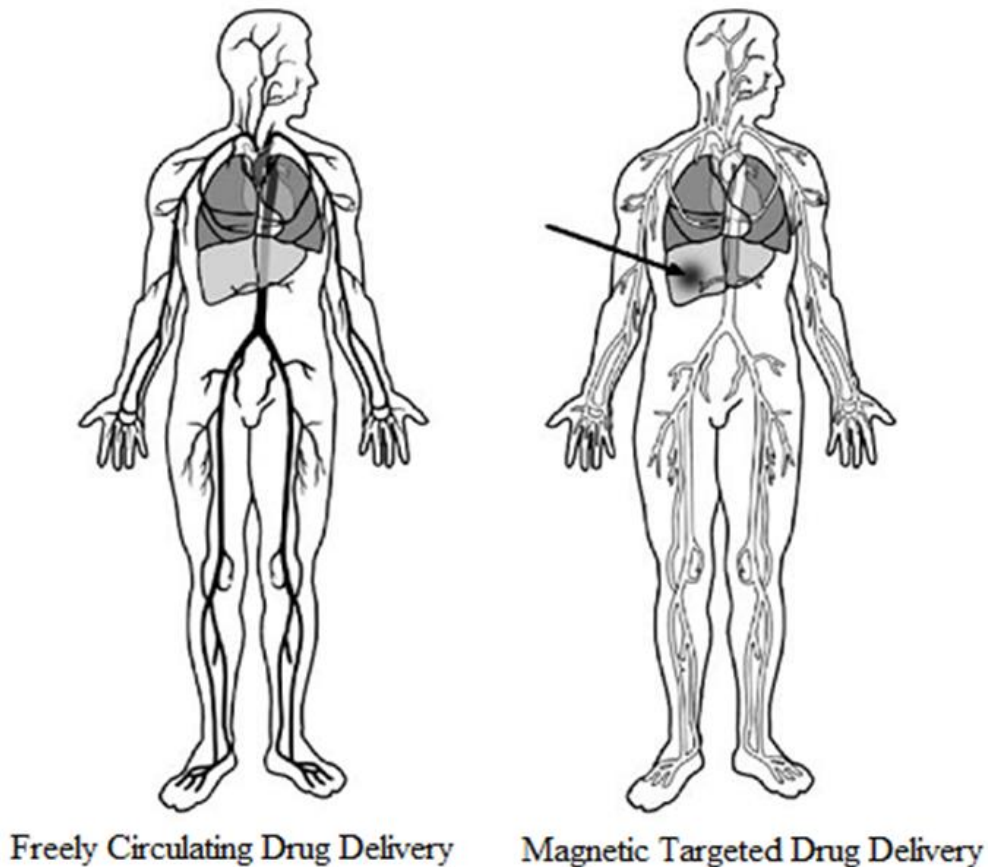


Figure 2: Concept of magnetic drug targeting

## 3. Advantages of Localization of Drugs

Magnetic carriers localize the drug at targeted diseased sites, to accomplish following advantages (Singh et al., 2011):

- Efficient drug delivery to the target tissues (increase up to 60%)
- Reduced toxicity risk
- Minimizes side effects risk
- Free drug concentration in blood stream is reduced by factor of 100
- Decline in normal cell tissue damage rate.

#### 4. Classification of Magnetic Drug Delivery Systems

To achieve controlled and targeted delivery of drug, magnetic carrier drug delivery systems (DDS) can be categorized further into (Akhtar et al., 2009);

4.1 Magnetic nanoparticles

4.2 Magnetic microspheres

4.3 Magnetic liposomes

4.4 Magnetic emulsions

##### 4.1 Magnetic Nanoparticles

Recent decades have shown a vast range of applications in the field of magnetic nanotechnology as it has expanded its scope to oncological, cardiovascular and neurological disorders. They have been under keen investigation in different fields as next generation drug carriers due to their physical properties (Sun et al., 2008). Magnetic nanoparticles have displayed a great potential in drug loading proficiency due to their magnetic core intrinsic capabilities and physico-chemical properties due to the coating efficiency (Chomoucka et al., 2010). These particles having size less than 100 nm, are employed under the influence of magnetic field and manipulated by different materials such as iron, nickel, cobalt (Gupta and Gupta, 2005; Duguet et al., 2006; Gupta et al., 2007; McCarthy et al., 2007). Enhanced performance is delivered below a critical value of their size which is around 10-20 nm. These nanoparticles show super magnetic behavior above blocking temperature and acts like paramagnetic atoms showing less resonance (Shubayev et al., 2009). They can be used in different ways like magnetic resonance imaging, vascular contrasting agents, diagnosing agents (Khan et al., 2012), as theranostic in targeting of cancer treatment (Cole et al., 2011), targeting of genes, tissue engineering, bio separations, cell tracking (Shubayev et al., 2009). However, problems of intrinsic instability can occur over longer period of time as they can easily oxidize in air causing loss of the magnetic property (Khan et al., 2012).

##### 4.1.1 Advantages of Magnetic Nanoparticles

- Excess amount of drug is reduced minimizing unwanted effects
- Frequency of administration is reduced
- Reduced side effects of drugs as compared to conventional dosage forms
- Targeted organ receive prolonged delivery of drug
- Diseased organ receive sustained drug delivery (Indira and Lakshmi, 2010)

##### 4.1.2 Synthesis of Magnetic Nanoparticles

Magnetic nanoparticles have been prepared by using different compounds like cobalt, nickel, iron, ferrous oxides, ferrites like  $MFe_2O_4$  (where M can be Cu, Mg, Mn, Ni etc.) and metal alloys. They can be synthesized using different methods like co-precipitation, thermal decomposition and micro emulsion method (Faraji et al., 2010).

##### (a) Co-precipitation

Co-precipitation is one of the facile, preferred and convenient route for the synthesis of spherical magnetite particles in nanometric size. This method is preferred over other methods due to its lower temperature, time and environment friendly (water as solvent) as compared to other processes. In this method, metal oxides and metal ferrites based magnetic nanoparticles are synthesized from aqueous salt solutions which transform their properties to the latter one. Morphology as well as composition of the nanoparticles depends on the type of salt solution, metals ratio, temperature of the reaction, pH and ionic strength of the medium (Schuth et al., 2007). It is said that particle size generally decrease as the pH and ionic strength increase, illustrating that these two factors can control the size of the particles as a whole. Magnetic nanoparticles can synthesized by this method in two ways in which one uses oxidizing agents to oxidize the metal hydroxides while in the second one, metal hydroxides are mixed together in presence of aqueous media. Finally aggregation occurs within metal hydroxide to form spherical particles (Tartaj et al., 2003)

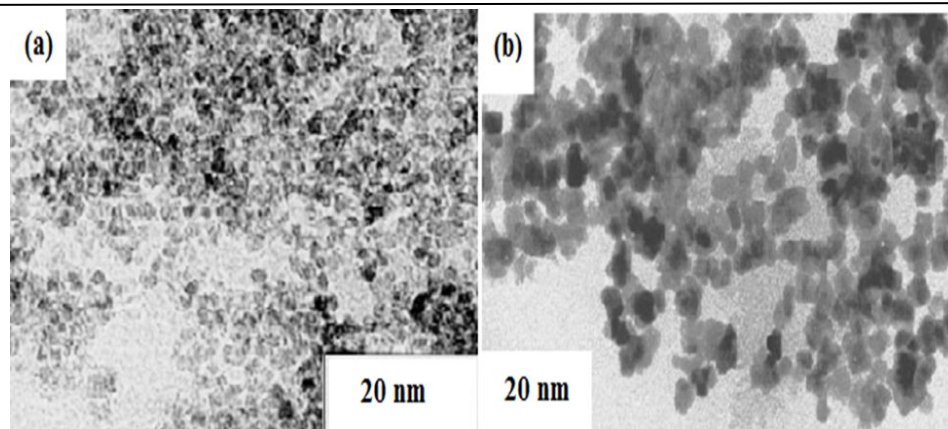


Figure 3: Magnetic nanoparticles prepared by: (a) co-precipitation method (b) microemulsion technique (Tartaj et al. 2003)

#### *(b) Microemulsions*

Microemulsion is widely used technique for formation of uniform particle sized magnetic nanoparticles due to water in oil type emulsion (Perez et al., 1997; Liu et al., 2000). It is an identical thermodynamic scattering of water and oil, stabilized by surfactant molecules which lower the surface tension between the liquids to form a transparent solution (Langevin, 1992). Rapid coalescence takes place resulting in mixing and aggregation of the nano droplets to form magnetic nanoparticles in a spherical shaped water pool. Size of the nanoparticles can be controlled by changing size of the water pool which surrounds the nano droplets (Schuth et al., 2007; Faraji et al., 2010). A precipitate formation can take place in micelles by collision and coalescence of two similar micro emulsions (Gupta and Gupta, 2005).

#### *(c) Thermal Decomposition*

Magnetic nanoparticles by this process are synthesized at high temperature decomposition of organometallic precursors like metal acetylacetonates, metal cupferronates, carbonyls and surfactants like fatty acids, oleic acids and hexadecylamine. Precursors with zerovalent metals forms metallic nanoparticles but if oxidation takes place then mono disperse particles are formed. On the other side, cationic metals decompose directly to metallic oxide nanoparticles (Schuth et al., 2007; Faraji et al., 2010). Ratios of the organometallic precursors, surfactants, organic solvents along with the reaction temperature and reaction time play a vital role in determining the particles morphology and magnitude (Kwon et al., 2007).

#### *4.1.3 Characterization*

- Magnetic nanoparticles can be characterized through following analysis.
- Transmission electron microscopy for determination of size and shape (Hong et al., 2008)
- X-ray diffraction for structural determination (Indira and Lakshmi, 2010)
- Particle size analysis DLC
- Magnetic density by using SJZP-1 Gauss/Tesla-Meter (Zhu et al., 2009)
- Chemical composition by using analytical spectroscopic technique like atomic adsorption spectroscopy (Morais, 2010)
- TGA inductively coupled plasma atomic emission spectrometer for determination of magnetite contents (Hamoudeh et al., 2007)
- Vibrating sample magnetometer to determine its magnetic property (Zhu et al., 2005).

## 4.2 *Magnetic Microspheres*

Magnetic microparticles comprise of different materials, having strong magnetic moment which can successfully deliver non-magnetic substances like cells, antibodies, drugs, nucleic acids and enzymes to the magnetic field (Balaita and Popa, 2009). These are smaller in size i.e. less than 4  $\mu\text{m}$ , which provides an efficient flow rate to pass through capillaries without formation of embolus (Singh et al., 2011). They consist of biocompatible proteins or synthetic polymer to which the drug is bound and are formulated to be used in depot form near targeting site by nearby placing suitable magnet. To avoid unwanted distribution of drug to non target organ help in drug localization and avoid toxicity (Mukherjee and Bandyopadhyay, 2012). It was propounded by Gupta and Hung that magnetic microspheres can cause 16 fold increase in drug concentration, 6 fold increase in drug exposure and 6 fold increase in targeting efficiency of the system (Gupta and Hung, 1989; Vidyavati et al., 2011).

### 4.2.1 *Preparation of Magnetic Microsphere*

Magnetic Microspheres are prepared generally by two methods. One is Phase separation emulsion polymerization method and other is continuous solvent evaporation method. Microspheres prepared by these two techniques are known to be biocompatible with the blood and are stabilized by addition of albumin. Magnetic field having greater field strength is required for a fast moving arterial system (Tarun et al., 2012).

#### (a) *Phase Separation Emulsion Polymerization*

In phase separation emulsion polymerization method, an aqueous suspension is prepared by incorporation of polymer, drug and magnetite into sufficient amount of water. Emulsifying agent is added to the solution for formation of oily phase which is stabilized by heating at appropriate temperature of 100-150°C followed by drop wise addition of cross linking agent with constant stirring that result in formation of magnetic microspheres. Washing procedure is used to separate oil from suspension by subjecting it to freezing temperature at 4°C.

#### (b) *Continuous Solvent Evaporation Method*

Polymer, drug and magnetite solution should be added to the volatile organic solvent at constant stirring to form an auxiliary homogeneous solution at temperature of 22-30°C. Evaporation of the organic solvents takes place to form microspheres followed by centrifugation, freeze drying and storage at 4°C (Akhtar et al., 2009, Singh et al., 2011; Kakar et al., 2013).

### 4.2.2 *Characterization*

Magnetic microspheres are subjected to different tests to verify its morphological structure and different physico-chemical properties. They include particle size analysis (Kakar et al., 2013), scanning electron microscopy (Cao et al., 2006), flow properties through angle of repose and compressibility index, thermal analysis, determination of % age yield, drug content, determination of drug loading, incorporation efficiency of microscopy, determination of solubility and dissolution studies of microspheres (Mukherjee and Bandyopadhyay, 2012).

## 4.3 *Magnetic Liposomes*

Magnetic liposomes consist of bilayered compositional structure in which lipid layer and aqueous layer are designed in alternative patterns. These are biocompatible vesicular shaped structure having nanometric size, being used to encapsulate water soluble and oil soluble therapeutic agents. Water soluble active ingredients are incorporated in aqueous layer of magnetic liposomes and lipid soluble active drugs are incorporated in lipid layer of magnetic liposomes (Martin, 1989). Generally, two kinds of magnetoliposomes exist: one containing metal oxides ion the aqueous layer while other consisting of meta oxides enveloped in lipid layer after being stabilized with laureth.

### 4.3.1 *Method of Preparation*

Magnetic liposomes can be prepared by incorporation of magnetic partices in the phospholipid linkage which acts a nanoreactor while in second method; phosphatidylcholine/ phosphatidylethanolamine are used in the 2:1 ratio covering the magnetic partices, which produces agglomerates of the magnetic particles.

These linkages are stabilized by using pullulan hydrazide. Magnetoliposomes are also advantageous because of the fact that they escape from reticuloendothelial system very easily and their lipid layer is sensitive to the magnetic field (Balaita and Popa, 2009).

#### 4.3.2 Characterization

The internal structure of the magnetoliposomes is observed through time resolved neutron scattering TR-SANS at ILL-D22 and time resolved electron microscopy TR-EM using a stopped-flow mixing device (Nowroth et al., 2003).

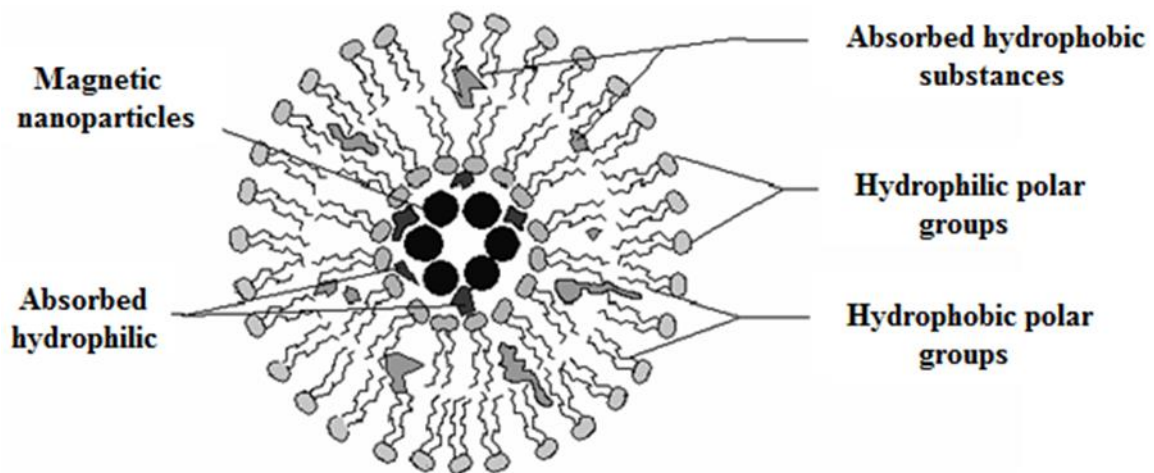


Figure 4: Structure of magnetic liposome

#### 4.4 Magnetic Emulsion

Emulsion is a colloidal system consisting of two immiscible liquids (water and organic solvent) and being stabilized by polymers or surfactants known as emulsifying agents. Water compose oil in water type emulsion when it is based as continuous external phase while as internal dispersed phase, it constitutes reverse water in oil type emulsion. Magnetic emulsion is an emulsion type in which ferrofluids, containing the stable dispersion of magnetic nanoparticles, constitutes the internal phase.

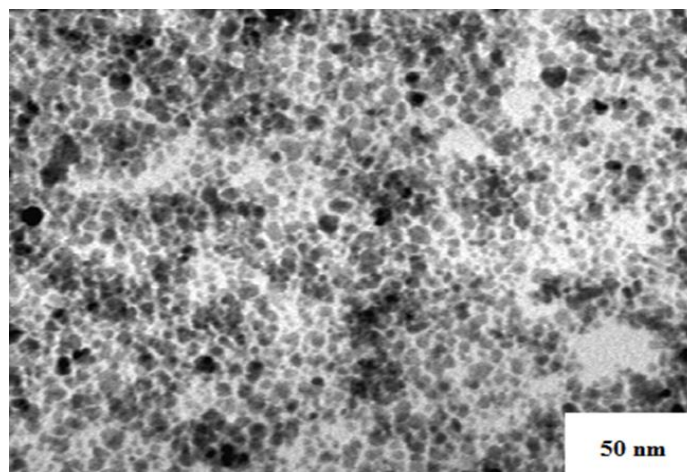


Figure 5: Transmission electron micrograph of the ferrofluids

#### 4.4.1 Characterization

- Magnetic emulsions can be analyzed through following tests:
- Infrared spectroscopy to evaluate the adsorption of surfactants on magnetic particles.
- Elemental analysis to evaluate the ferrofluids and magnetic particles.
- X-ray diffraction to investigate the crystallographic structure of the iron oxides and magnetic particles size distribution.
- Thermogravimetric analysis of the ferrofluids in dried state.
- Transmission electron microscopy.
- Freeze fracture to investigate the internal structure of the ferrofluids.
- Gas chromatography to determine the octane concentration in the magnetic emulsion (Montagne et al., 2002).

### 5. Applications

Magnetic drug delivery system since its origination has shown tremendous applications in biomedical and biophysical fields of science. We will discuss here some of its main contributions towards modern drug delivery.

#### 5.1 Treatment of Tumors

Magnetic microspheres can be used in chemotherapy of anti-cancer drugs in their delivery to tumors e.g. doxorubicin. For such kind of site-specific targeting, magnetically modulated drug targeting systems have been successfully applied (Kas HS, 1990). Magnetic field in such cases is applied to concentrate the drug at tumor site thus eliminating systemic side effects (Batra et al., 2012). Different rats suffering from sarcoma were assessed after giving both free doxorubicin and doxorubicin with magnetic microspheres. It was evaluated that rats treated with free doxorubicin had increased tumor size while those treated with magnetic microspheres showed a significant 83 % decrease in the tumor size (Widder KJ and Senyei AE, 1984).

#### 5.2 Targeting of Radioactive Compounds

Radioisotopes in therapeutic range can be delivered under magnetic field to target tissues. Dose can be increased rendering damage to the normal tissues with improved anti-tumor activity (Singh et al., 2011). Selective radiation of the targeted tissues is carried out with the help of magnetic particles being coupled with different isotopes and an external magnetic field is applied to bind them (Balaita and Popa, 2009). In recent years, radio labeling with isotopes such as <sup>188</sup>Re; <sup>90</sup>Y, <sup>111</sup>In and <sup>125</sup>I have been successfully employed (Hyndavi et al., 2011).

#### 5.3 Magnetic Hyperthermia

Magnetic hyperthermia has been established to destroy the diseased tissues with the help of elevated temperature as they are more sensitive to the temperature compared to the healthy tissues (Mikhaylova et al., 2004; Kim et al., 2006). The other advantage is its restriction to the diseased tissues only (Green 2005). Recently liposomal nanoparticles have been established according to this mechanism as successful approach to the cancer therapy (Akbarzadeh et al., 2012). Magnetic liposomes have also been prepared and studied for hyperthermia treatment of cancer through magnetic particles coated with phospholipids (Vidyavati et al., 2011).

#### 5.4 Diagnostic Applications

One of the modern and useful applications of magnetic delivery system is its diagnostic applications which involves;

#### 5.5 In-vivo Applications

With the development of NMR imaging technique, a new pharmaceutical class known as magnetopharmaceuticals has been established, providing following advantages (Akbarzadeh et al., 2012):

- Improvement in distinguishing of diseased to normal tissue
- To determine normal function of organ

### 5.6 *In-vitro Applications*

Magnetic solid phase extraction method is used in isolation and determination of components and impurities from testing samples in large volume as compared to conventional extraction processes which are more time consuming (Dubertret et al. 2002; Pellegrino et al., 2004; Akbarzadeh et al., 2012).

## 6. Conclusion

Over the years, despite of a defect that magnetic drug delivery carriers constitute of a strong magnetic field, it has still proved to be an efficient drug delivery system by successfully achieving the selective targeting and controlled drug delivery. It's challenging future demands an extensive research area to combat the most chronic diseases of modern ages.

## References

- A.K. Gupta, M. Gupta. (2005), "Synthesis and Surface Engineering of Iron Oxide Nanoparticles for Biomedical Applications", *Biomaterials* 26(18): 3995–4021.
- Akbarzadeh A, Samiei M, and Davaran S. (2012), "Magnetic Nanoparticles: Preparation, Physical Properties, and Applications in Biomedicine", *Nanoscale Research Letters* 7(1): 144.
- Akhtar J, Chaturvedi R, Sharma J, Mittal D and Pardhan P. (2009), "Magnetized Carrier as Novel Drug Delivery System", *International Journal of Drug Delivery Technology* 1(1): 28-35.
- Balaita L and Popa M. (2009), "Polymer Magnetic Particles in Biomedical Applications", *Revue Roumaine de Chimie* 54(3), 185-199.
- Batra D, Kakar S, Singh R and Nautiyal U. (2012), "Magnetic Microspheres as a Targeted Drug Delivery System: An Overview", *Journal of Drug Delivery Research* 1(3): 10-17.
- Cao Y, Bai G, Chen J, Tian W, Wang S and Yang W. (2006), "Preparation and Characterization of Magnetic Microspheres for the Purification of Interferon  $\alpha$ -2b", *Journal of Chromatography B* 833: 236–244.
- Chomoucka J, Drbohlavova J, Huska D, Adam V, Kizek R and Hubalek J. (2010), "Magnetic Nanoparticles and Targeted Drug Delivering", *Pharmacological Research* 62: 144–149.
- Cole AJ, Yang VC and David AE. (2011), "Cancer Theranostics: The Rise of Targeted Magnetic Nanoparticles", *Trends in Biotechnology* 29(7), 323-332.
- Dubertret B, Skourides P, Norris DJ, Noireaux V, Brivanlou AH. (2002), "In-Vivo Imaging of Quantum Dots Encapsulated in Phospholipid Micelles", *Science* 298 (5599): 1759–1762.
- Duguet E, Vasseur S, Mornet S and Devoisselle JM. (2006), "Magnetic Nanoparticles and their Applications in Medicine", *Nanomedicine* 1 (2): 157–168.
- Faraji M, Yamini Y and Rezaee M. (2010), "Magnetic Nanoparticles: Synthesis, Stabilization, Functionalization, Characterization and Applications", *Journal of the Iranian Chemical Society* 7(1): 1-37.
- Green M. (2005), "Organometallic Based Strategies for Metal Nanocrystal Synthesis", *Chemical Communications* 24: 3002–3011.
- Gupta AK, Naregalkar RR, Vaidya VD and Gupta M. (2007), "Recent Advances on Surface Engineering of Magnetic Iron Oxide Nanoparticles and their Biomedical Applications", *Nanomedicine* 2(1), 23–39.
- Gupta PK and Hung CT. (1989), "Magnetically controlled targeted micro-carrier systems", *Life Science* 44, 175–186
- Häfeli U, Schütt W, Teller J, Zborowski M. (1997), "Scientific and Clinical Applications of Magnetic Carriers", First ed. Plenum Press, New York.
- Hamoudeh M, Al Faraj A, Canet-Soulas E, Bessueille F, Léonard D, Fessi H. (2007), "Elaboration of PLLA-Based Superparamagnetic Nanoparticles: Characterization, Magnetic Behaviour Study and In-vitro Relaxivity Evaluation", *International Journal of Pharmaceutics* 338(1-2): 248-57.



- Hong RY, Zhang SZ, Di GQ, Li HZ, Zheng Y, Ding J and Wei DG. (2008), "Preparation, Characterization and Application of Fe<sub>3</sub>O<sub>4</sub>/ZnO Core/Shell Magnetic Nanoparticles", *Materials Research Bulletin* 43 (8-9): 2457-2468.
- Hyndavi m, Badarinath AV, Nirosha M, Kumar PA, Prasad K, Naveen N and Shankar BR. (2011), "Magnetic Carriers: A Novel Approach for the Targeted Drug Delivery", *International Journal of Review in Life Sciences* 1(4): 221-225.
- Indira Tk and Lakshmi PK. (2010), "Magnetic Nanoparticles: A Review", *International Journal of Pharmaceutical sciences and nanotechnology* 3(3): 1035-1042.
- Kakar S, Batra D, Singh R and Nautiyal U. (2013), "Magnetic Microspheres as Magical Novel Drug Delivery System: A Review", *Journal of Acute Disease*, 1-12.
- Kas HS. 1990, "Magnetically Targeted Microspheres: A Review", *Pharmacia* 30(2): 77-97.
- Khan S, Tiwari T, Rao N, Joshi A, Dubey BK. (2012), "Microspheres: A Review", *World Journal of Pharmacy and Pharmaceutical Sciences* 1(1): 125-145.
- Kim J, Park S, Lee JE, Jin SM, Lee JH. (2006), "Designed Fabrication Of Multifunctional Magnetic Gold Nanoshells And their Application to Magnetic Resonance Imaging and Photothermal Therapy", *Angewandte Chemie International Edition* 45(46):7754–7758.
- Kwon SG, Piao Y, Park J, Angaappane S, Jo Y, Hwang NM, Park JG and Hyeon T. (2007), "Kinetics of Monodisperse Iron Oxide Nanocrystal Formation by "Heating-Up" Process", *Journal of the American Chemical Society*, 129(41): 12571-84.
- Langevin D. (1992), "Micelles and Microemulsions", *Annual Review of Physical Chemistry* 43: 341-369.
- Liu C, Zou B, Rondinone AJ and Zhang ZJ. (2000), "Reverse Micelle Synthesis and Characterization of Superparamagnetic MnFe<sub>2</sub>O<sub>4</sub> Spinel Ferrite Nanocrystallites", *The Journal of Physical Chemistry B* 104(6): 1141-1145.
- Martin FJ. (1989), "Liposomes: From Biophysics to Therapeutics", *Journal of Pharmaceutical Sciences* 78(2): 181-182.
- McCarthy JR, Kelly KA, Sun EY and Weissleder R. (2007), "Targeted Delivery of Multifunctional Magnetic Nanoparticles", *Nanomedicine* 2 (2): 153–167.
- Mikhaylova M, Kim DK, Bobrysheva N, Osmolowsky M, Semenov V. 2004, "Super Paramagnetism of Magnetite Nanoparticles: Dependence on Surface Modification", *Langmuir* 20(6): 2472–2477.
- Montagne F, Mondain-Monval O, Pichot C, Mozzanega H and Elaissari A. (2002), "Preparation and Characterization of Narrow Sized (O/W) Magnetic Emulsion", *Journal of Magnetism and Magnetic Materials* 250: 302–312.
- Morais PC. (2010), "Nanoparticulated Magnetic Drug Delivery Systems: Preparation and Magnetic Characterization", *Journal of Physics: Conference Series* 217 : 012091.
- Mukerjee S and Bandyopadhyay P. (2012), "Magnetic Microspheres: A Latest Approach In Drug Delivery System", *Journal of Pharmaceutical and Scientific Innovation* 1(5): 21-25.
- Nawroth T, Rusp M and May RP. (2003), "Magnetic Liposomes and Entrapping – Hollow Nanoparticles for Biomedical Applications", *GDCh Annual Conference, München* 11.10.2003.
- Pedro Tartaj P, Morales MDP, Veintemillas-Verdaguer S, Gonzalez-Carreno T and Serna CJ. (2003), "The Preparation Of Magnetic Nanoparticles For Applications In Biomedicine", *Journal of Physics D: Applied Physics* 36: R182–R197.

This academic article was published by The International Institute for Science, Technology and Education (IISTE). The IISTE is a pioneer in the Open Access Publishing service based in the U.S. and Europe. The aim of the institute is Accelerating Global Knowledge Sharing.

More information about the publisher can be found in the IISTE's homepage:

<http://www.iiste.org>

## CALL FOR JOURNAL PAPERS

The IISTE is currently hosting more than 30 peer-reviewed academic journals and collaborating with academic institutions around the world. There's no deadline for submission. **Prospective authors of IISTE journals can find the submission instruction on the following page:** <http://www.iiste.org/journals/> The IISTE editorial team promises to review and publish all the qualified submissions in a **fast** manner. All the journals articles are available online to the readers all over the world without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. Printed version of the journals is also available upon request of readers and authors.

## MORE RESOURCES

Book publication information: <http://www.iiste.org/book/>

Recent conferences: <http://www.iiste.org/conference/>

## IISTE Knowledge Sharing Partners

EBSCO, Index Copernicus, Ulrich's Periodicals Directory, JournalTOCS, PKP Open Archives Harvester, Bielefeld Academic Search Engine, Elektronische Zeitschriftenbibliothek EZB, Open J-Gate, OCLC WorldCat, Universe Digital Library, NewJour, Google Scholar

