A Review of Nanoferrites: Synthesis and Application in Hyperthermia

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Abstract
The use of magnetic particles for the hyperthermia treatment of cancer is discussed in this paper due to their unique magnetic properties and excellent biocompatibility as well as multi-purpose biomedical potential. Iron oxide nano particles are attracting increasing attention in both medical as well as industrial purpose. In this review, the limitations and recent advances in the development of superparamagnetic iron oxide nanoparticles for hyperthermia are presented. So that motivation for this work and a discussion of the advantages of the present method is delineated.

Keywords: Hyperthermia, cancer therapy, nanoferrite, transition temperature, drug delivery etc.

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1. Hyperthermia
Inducing a high temperature fever into a patient seems like an unusual way to treat a disease, but cancerous cells have been found to be especially susceptible to high temperatures. Although uncomfortable for the patient, normal cells can survive at higher temperatures of 46°C [1-2]. This technique is termed hyperthermia and works because tumors are not effectively cooled by blood flow since their vascular and nervous systems are not well developed. The history of hyperthermia dates back to about 3,000 years B.C., when Egyptian pundits tried to burn out superficial tumors [3-6]. Thus, the concept of hyperthermia is to heat a region of the body affected by cancer to temperatures between 43°C to 45°C. At these temperatures, the growth of cancerous cells can be halted. Since cancers originate from alterations in biological processes at

The molecular or nanoscale level, nanotechnology based strategies are an emerging and promising approach with a great potential to facilitate the diagnosis and treatment of cancer [7-10]. Nanoparticle (NP) therapeutics can offer solutions to the current obstacles in cancer therapies, because of unique characteristics such as the high surface area to volume ratio, and controllable optical, electronic, magnetic, and biologic properties. By involving nanotechnology,
We can achieve several objectives including, diagnostic agents through biological barriers, obtain targeted delivery of drugs and develop innovative diagnostic tools. With the advances of nanomedicine and the understanding of properties and physical characteristics of materials in the nano-range, several distinct therapeutic systems have been approved or entered clinical development for medical applications [11,12]. Meanwhile, many nonmaterial’s are being studied in clinical trials or have been approved by the Food and Drug Administration (FDA) for use in humans, and several are in the proof-of concept stage in research laboratories [13-15]. Depending upon the method of preparation, many types of nanoparticles (NPs) such as polymeric nanospheres and nanocapsules can be obtained. Today the SPION (superparamagnetic iron oxide nanoparticle) are interesting material due to their rich physical properties. Such as ferrofluids, inter-body drug delivery, Magnetic resonance imaging for tumor therapy or cardiovascular diseases etc. in particular due to their specific properties, such as superparamagnetism [16-19]. There are several magnetic nonmaterial that have been used in hyperthermia applications including SPIONs (Fe₃O₄ and γ Fe₂O₃), iron–palladium and cobalt, ferrimagnetic spinels, cobalt ferrite, Mn–Zn and Mn–Zn–Gd ferrite particles, copper–nickel, ferromagnetic perovskites LaSrMnO₃, NiCr, gadolinium, calcium, and lanthanum complexes, and ferrimagnetic SrFe₁₂O₁₉/γ-Fe₂O₃ composites, LaAgMnO₃ and LaNaMnO₃ etc. In the present work we are going to be focusing on biocompatibility Curie temperature of the material, controlling the coercivity, remanence and, consequently, the shape of the hysteresis loop, multiphase materials have been designed such as those composites shows the different magnetic properties from each phase[20].

2. Literature survey

Won li Choiet al. (2012) was studied the effect of mechanical properties of iron oxide nanoparticle loaded functional nano-carrier on tumor targeting and imaging, and they conclude that the mechanical properties of chitosan-functionalized, Pluronic based nano-carrier were systematically varied by loading different amounts of IONPs, but still keeping the same size, shape, surface charge, and release profile of the loaded IONP. Overall, very good tumor targeting and accumulation of IONP were achieved by using the functional nano-carrier, thus, this could serve as an enhanced MRI contrast agent. P.A. Desai et al.(2011) were studied on Silver doped lanthanum chromites by microwave combustion method and found that LaCrO₃ and silver doped lanthanum chromite nanoparticles have been syntheses by microwave combustion route. Pure phase products are obtained at microwave power of 0.56 kW, irradiation time of 10 min and fuel to oxidizer ratio of 1. Average size of LaCrO₃ particles is 57 nm, while the silver doped samples have a finer particle size of 7–8 and 20–26, respectively, for A site and B site doping. Increase in coercivity and saturation magnetization values of doped samples is attributed to non magnetic nature of silver. Hasan Mukhtar et al.(2013) also studied on Nanoformulation of natural products for prevention and therapy of prostate cancer and they conclude that the use of naturally occurring products, such as dietary nontoxic phytochemicals, has emerged as one important approach to fight this disease, which may be appropriated for high-risk patients, especially those with isolated HG-PIN, elevated PSA, and negative biopsy. Silvio Dutz et al. (2009) were studied on Ferrofluids of magnetic multi core nanoparticles for biomedical applications and they found that the peak position from XRD data was used to distinguish between the magnetic phase’s maghemite and magnetite. The diffractogram show a relatively broad single peak between the theoretical angles for maghemite and magnetite. This means that the resulting particles presumably consist of solid solutions of both phases (one resulting peak). However, it is also
possible that particles consist of a mix of maghemite and magnetite particles (two separated peaks). In principle, a differentiation between these both cases is feasible, but due to the peak broadening of the small particles, a superposition of both peaks is possible. Pol-Edern Le Renard et al. (2011) studied on magnetic and in vitro heating properties of SPIONs and they found that the superparamagnetic properties of magnetic silica composite microparticles embedding nanoscale maghemite iron oxides are preserved in the injectable formulations for the whole range of concentrations that allow syringeability. These properties also remain preserved in the implants formed in situ. The magnetic properties as well as the heating capacity, which improved with increase in particle fraction, can be extrapolated from the concentration of magnetic microparticles. With these AMF parameters, a straightforward determination of the dissipated heat is now possible. In association with the previous in vivo studies, this further allows for the modeling of tissue heating in vitro and in vivo, and this improves our understanding of the heated livery through formulations intended for magnetically mediated hyperthermia in the treatment of solid tumors. Ahmad Gholami et al. (2015) studied on Lipoamino Acid Coated Superparamagnetic Iron Oxide Nanoparticles Concentration and Time Dependent Enhanced Growth of Human Hepatocarcinoma Cell Line. And they found that the cytotoxic effects of naked and some surface coated SPION on hepatocarcinoma cells revealed that SPION at lower concentrations can be beneficial for these cells because of their nutrient effect. However, at concentrations higher than 50 micro gram/mL the trend was reversed and the cell viability was decreased. Generally, it was concluded that SPION have dual impact on Hep-G2: cell growth promotion and toxicity. In the initial phase (at concentrations from 1 to 50 micro gram/mL), the dominant mechanism is the former one; however, by increasing nanoparticles concentration, cytotoxic effect progressively rises and eventually becomes the main mechanism, if aggregation or sedimentation of particles did not happen. Surface modification of SPION especially the ones coated with LAA’s can maintain growth-enhancing effect. The reason may be the controlled release of ionic iron into the cells. Biocompatible LAA coated SPION can be used as targeted delivery of materials for diagnostic and therapeutic purposes. Alexander L. Kovarski et al. (2006) studied on ESR of thermal demagnetization processes in ferromagnetic nanoparticles and the results comes out that ESR data indicate that the process of thermal demagnetization of the tested particles is very complex, and some magnetic ordering remains in the particles even above the Curie temperature, measured by static magnetic measurements. Processes of thermal demagnetization in the vicinity of the Curie temperature in the alloys and manganites are significantly different. Further studies of the thermal demagnetization processes in ferromagnetic nanoparticles and deeper understanding of their mechanisms are crucial for developing effective mediator particles for magnetic fluid hyperthermia with parametric feedback for biological applications [21-22].

3. Methodological Review

To prepare an IONP-loaded nano-carrier with different mechanical characteristics, an IONP solution was added into the nano-carrier with three different amounts (IONP nano-carrier) 1:20 (5 wt.%), 1:6.7 (15 wt.%), and 1:2.5 (40 wt.%) and was subsequently incubated at 4°C for over 12 h, which induced the spontaneous loading of IONP into the nano carrier. The encapsulation efficiency (over 95%) and the amount of IONP loaded inside the nano-carrier were determined by separating the unloaded IONP by spin filtration at 11,000 rpm for 10 min at 37°C and were calculated as reported previously. The hydrodynamic diameters and surface charges of IONP or IONP-loaded nano-carriers in de-ionized water were analyzed at 37°C by using an electrophoretic light scattering spectrophotometer (ELS-Z2). The morphologies of IONP or
IONP loaded nano-carriers were also observed by using a TEM (JEM-2100, JEOL, Japan). To quantitatively compare the mechanical strengths of the nano-carrier with different IONP loadings, highly concentrated nano-carrier solutions (40 wt.% based on the amount of the nano-carrier) in de-ionized water, which formed weak physical gel states at 37 °C (above the critical concentration and temperature of Pluronic), were prepared, and the module of the hydro gels were measured by using a rheometer (Gemini, Malvern Instrument, England) equipped with a temperature controller at 37 °C and a solvent trap. Samples were analyzed with a sandblast parallel plate geometry and a 300 μm gap thickness (the volume of sample: 60 μL) under 1 rad/s angular frequency and 0.1% strain. The obtained modulus was converted into the Young’s modulus. All measurements were carried out in triplicates: by Won li Choi et al.(2012)The salt precursors, i.e. lanthanum nitrate (La(NO₃)₃·6H₂O), chromium nitrate (Cr(NO₃)₉H₂O) and urea (NH₂CONH₂) as fuel were from Loba Chemie, India, while silver nitrate (AgNO₃) was from Qualigens, India. Lanthanum chromite was synthesized by initially mixing the precursor salts together in stoichiometric amounts, i.e. 1:1 equimolar ratio followed by the addition of urea as fuel (0.4 M), and to this was added 50 ml of double distilled water. The stoichiometric composition of the mixture: by P.A. Desai et al.(2011) Several methods for chemical synthesis of SPIONs have been described. The most commonly used methods amongst these methods, coprecipitation of Fe²⁺ and Fe³⁺ ions in a basic aqueous media (e.g. NaOH or NH₄OH solutions) is the simplest way, but usually nanoparticles are poly dispersed and poorly crystallized [23-25]. To avoid these disadvantages, thermal decomposition methods have been employed to produce SPIONs with mono dispersity and uniform crystalline [26-27]. Subsequently, the hydrophobic iron oxide nanoparticles can be coated with phospholipids, silica, or amphiphilic polymers as shells to display good solubility and biocompatibility in vivo: by Sophie Laurent.

4. Parameter under Consideration

By the literature survey its reveals that the characterize for mechanical properties affect the long-term circulation of the nano carriers, the MRI study was performed at several time [28-30] and for finding the crystal size and phase transformations with the help XRD data, since many of the researcher they are focusing on particle size because it play a very important role for specific rate of absorption and some other physical properties. Keep it in mind that the magnetic material should be biocompatible therefore researcher also focuses on non toxicity and PH value of material. And the Vibrating Sample Magnetometer was used to perform magnetic measurements of material and gives the idea about hysteresis loop [31]. While The FTIR spectrum reveals the characteristic metal oxygen bands for stretching and TGA analysis of the samples shows stable behavior of the product.

5. Disclosure

From the various literature surveys we arrived to the conclusion that the Iron Oxide based nano particle is widely used in the applications of hyperthermia for cancer treatment [32-34]. Since Iron oxide nanoparticle (IONP)-loaded, functional nano-carrier with different loading contents to modulate the mechanical properties of the material, and compared the characteristics of tumor targeting and imaging in terms of loading contents of IONP. Also it is found from the literature the microwave combustion technique is the one of the promising technique for preparation of sample with the possibility of utilizing cheap precursors, short reaction time and nanocrystalline products. For very small particles (typically 10 nm) the barriers for magnetization reversal come into the order of magnitude of thermal energy and superparamagnetic relaxation effects cause vanishing of remanence, coercivity as well as hysteresis losses [35-36]. When the barriers for magnetization reversal are much larger than thermal energy remarkable hysteresis losses may be
found in the single domain regime. VSM measurements with immobilized particles reveal a thermally blocked behavior of the particles. The clusters of different mean diameters show coercivity depending on the size of the clusters. This implies that in this case the magnetic behavior is mainly determined by the cluster size and not by the constant size of the primary cores as the coercivity (HC) correlates linear with the relative remanence. Hence, the applied fractionation method allows the adaption of the relative remanence of the ferrofluid to optimal values for applications based on magnetic attraction, e.g. cell separation or drug targeting. Hyperthermia is currently under study in many clinical trials to improve and better understanding this promising technique. Future areas of challenge and opportunity for hyperthermia include improving understanding from thermal and biological point of view and technologies for delivery and monitoring of heat treatments in patients. Since in the present work, our attention is to improve the material up to the level of biocompatible in human body by controlling pH [37-38]. The Iron Oxide based material should be design as multiphase composite such that it shows the different magnetic properties from each phase. The Curie temperature is in between 40 - 500°C so that it can be easily demagnetized. It should be single spin domain so that it is easily oriented by external applied field.

References

1. Won Choi, Ja-Young Kim, Seon U. Heo, Yong Yeon Jeong, and Young Ha Kim, Giyoong Tae: The effect of mechanical properties of iron oxide nanoparticle-loaded functional Nano-carrier on tumor targeting and imaging: Journal of Controlled Release 162, 267–275, 2012
9. Ahmad Gholami, Sara Rasoul-amini: Lipoamino Acid Coated Superparamagnetic Iron Oxide Nanoparticles Concentration and Time Dependently Enhanced Growth of Human


12. Ahmed Bettaieb, Paulina K. Wrzal and Diana A. Averill-Bates Hyperthermia: Cancer Treatment and Beyond http://dx.doi.org/10.5772/55795


18. L. Gál1, I. Mohai: synthesis of nanosized zinc ferrites in rf thermal plasma reactor, Poh Lin Leng1 Synthesis and Characterization of Ni-Zn Ferrite Nanoparticles (Ni0.25Zn0.75Fe2O4) by Thermal Treatment Method: Advances in Nanoparticles, 2, 378-383, 2013


