Intensive Analysis of Core–Shell Silica-Coated Iron-Oxide Nanoparticles for Magnetic Hyperthermia

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We report the synthesis and characterization of silica-coated iron-oxide nanoparticles with a core–shell structure, which can be used for magnetic hyperthermia. The nanoparticles were synthesized by the reverse micelle method. The silica coating was performed simultaneously with the synthesis of the nanoparticles. The nanoparticles were characterized using various analytical tools. X-ray diffraction measurements confirmed their cubic spinel structure. Transmission electron microscopy (TEM) revealed monodisperse nanoparticles of nearly spherical core–shell structures with an average diameter of 17 nm. The bonding of the silica on the surface of the iron-oxide nanoparticles was confirmed by Fourier transform infrared spectrometry (FTIR). The silica-coated iron-oxide nanoparticles exhibited superparamagnetic properties with a saturation magnetization of 48.8 emu/g measured with a vibrating sample magnetometer (VSM). The applicability of the nanoparticles to magnetic hyperthermia was tested by measuring the temperature increase in an aqueous solution of nanoparticles in a 260 kHz alternating magnetic field. An optimum nanoparticle concentration of approximately 2.0 mg/ml achieved a saturation temperature of 42 °C, the target value for magnetic hyperthermia. The dependence of the SAR on the nanoparticle concentration and magnetic field strength was also measured. These results demonstrated the applicability of silica-coated iron-oxide nanoparticles to magnetic hyperthermia.

Keywords: Silica-Coated Iron-Oxide Nanoparticles, Magnetic Hyperthermia, Specific Absorption Rate (SAR).

1. INTRODUCTION

Magnetic nanoparticles have attracted much attention in recent years for their practical application to ferrofluids,1 magnetic recording,2 drug delivery,3 MRI contrast agents,4,6 and magnetic hyperthermia treatment.7 Among the various magnetic nanoparticles available, iron-oxide (magnetite, Fe3O4) nanoparticles are some of the most important spinel-structured ferrites, as their superparamagnetic properties make them useful for biomedical applications, including magnetic hyperthermia. Monodisperse iron-oxide nanoparticles can be obtained in various ways, e.g., using the coprecipitation,4,6 reverse micelle,8 and sonochemical methods.9 Their magnetic moment is relatively large compared to other ferrite nanoparticles,10,11 an advantage in magnetic-related applications.

Hyperthermia treatment is a cancer therapy in which tumor tissue is killed by increasing its temperature up to 42 °C. Tissue can be heated via injected magnetic nanoparticles subjected to an external alternating magnetic field. Heat dissipation in magnetic nanoparticles in an alternating magnetic field is caused mainly by Néel and Brown relaxation losses.12,13 Here, Néel relaxation loss is due to the delay in the relaxation of magnetic-moment reversal over the anisotropy barrier, whereas Brown relaxation loss is caused by the physical relaxation due to the interaction between the particles and the surrounding liquid. The heating ability of magnetic nanoparticles depends on the particle concentration, the duration of exposure to the alternating magnetic field, and tissue characteristics.14,15

Magnetic nanoparticles tend to agglomerate after being injected intravenously, thereby forming clusters in the blood because of their high surface-to-volume ratio and