Effective Heating of Magnetic Nanoparticles for In Vivo Nano-Theranostic Hyperthermia in MRI

The nano-theranostic system of combined hyperthermia/MRI has been proposed to simultaneously diagnose and treat cancers. However, the promising possibilities of this pre-clinical or clinical application can only be realized if the physical and magnetic properties of the nanoparticles are precisely controlled to optimize their heating efficiency, which is critical to focusing the energy onto tumor cells and avoiding damaging healthy tissue. For this purpose, we have established a novel model to evaluate and optimize the system’s in vivo heating efficiency, based on three major findings: (i) Magnetic nanoparticles are interacting in the colloidal suspension. (ii) Magnetic susceptibility and magnetic field amplitude are nonlinearly related. (iii) Relaxation times due to the Brownian or Néel relaxation mechanisms depend on the amplitude of the applied magnetic field.

In order to assess the accuracy of our in vivo theoretical model’s consideration of aggregation, the nonlinear response of the magnetic susceptibility, and the magnetic field effects on relaxations times, predictions made by our model for previously published experimental data were compared with predictions made by the previously proposed models. The comparisons showed that our proposed model predicted the experimental values with a significantly higher degree of accuracy than the conventional models. Our calculations based on the data led us to conclude that magnetic nanoparticles should be coated with a surface material sufficiently thick to avoid particle aggregation, as the heating efficiency can be significantly reduced when aggregate forms. We further noted that the nonlinear regime induces an additional heating effect, but that saturated magnetization in the presence of MRI will have a negative impact on heating efficiency. In the interest of effective heating of magnetic nanoparticles for nanotheranostic hyperthermia in the clinical MRI environment, we proposed to heat either large magnetic nanoparticles using a low frequency-driven alternating magnetic field, where the Brownian relaxation is the dominant relaxation mechanism, or small magnetic nanoparticles using a high frequency-driven alternating magnetic field, where the Neel relaxation is the dominant relaxation mechanism.

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