AbstractID: 8454 Title: Estimating Temperature from the Magnetic Nanoparticle Magnetization

Purpose: We present a method of non-invasively estimating the temperature of magnetic nanoparticles in vivo. The method has wide application including monitoring magnetic nanoparticle hyperthermia to obtain effective thermal doses.

Methods: The signal from magnetic nanoparticles is generated by applying a pure sinusoidal magnetic field and observing the signal at the harmonic frequencies produced by the nanoparticles. The Langevin function model of the nanoparticle magnetization predicts a balance between the forces induced by the applied magnetic field and thermal motion of the nanoparticles. The ratio of the fifth and third harmonics is uniquely related to the temperature if the saturation magnetization and particle size distribution remain constant. Therefore, when the ratio of the harmonics is known at one calibration temperature, subsequent temperature changes can be assessed from the ratio of the harmonics.

The method was tested using samples of Feridex™ at temperatures between 0°C and 100°C. After the sample reached equilibrium with a water bath of known temperature, the fifth and third harmonics of a 10mT, 9kHz sinusoidal field were measured using a pickup coil and a lockin amplifier. The temperature was estimated numerically using a spline interpolation of the Langevin function with a sinusoidal argument.

Results: The ratio of the fifth to the third harmonics was shown numerically and experimentally to increase monotonically with increasing amplitude of the sinusoid in the Langevin function and the amplitude is inversely related to the temperature, P-value of 0.0053. However, the intercept was not zero as expected, probably an artifact of the size distribution. The error in the calculated temperature estimate depends on the size distribution and temperature range used but the error was small: the standard deviation was 0.44 degrees.

Conclusion: The temperature of magnetic nanoparticles can be estimated in the physiologic range using the ratio of the harmonics.