Magnetic Field Simulations for SPIOns

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Introduction: we studied the susceptibility effects of iron oxide (SPIONs) functionalized with triethylenglycol (TREG) and Polyethylen Glycol (PEG), those nanoparticles have the necessary properties to be used in the clinic as contrast media in imaging by MRI. We are considering the behavior of the magnetic field as plane wave to explain the electrical and magnetic field produced by SPIONs.

Methods: Images were acquired on a 1.5T imager (Philips Intera-Achieva, Philips Healthcare, Best, Netherlands), with a maximum gradient amplitude of 80 mT/m and a slew rate of 120 mT/m/ms. An 8 channel SENSE head coil was used for data acquisition. Images were acquired mFFE Sequence with the following parameters: TR/TE=230/46ms, slice thickness 5mm, and NEX=2, flip angle = 18. Three glass capillary tubes with a) TREG (10nm) concentration of 300 µg/ml(T), and b) PEGCOOH 6000 (10nm) with 300 µg/ml (P), and 2% agarosa (G).

Magnetic field simulations were calculated in Matlab (Mathworks, Natick, MA,USA). The plane wave that comes in contact with a sphere of radius a, an propagation constant k1, and it is in an homogeneous space k2. We consider that the electric field is linearly polarized on x-direction, with a propagation on z-positive-axis. The expansion of the field vector on spherical coordinates,

$$E_i = a_x E_0 e^{ik_2 z - i\omega t} = E_0 e^{-i\omega t} \sum_{n=1}^{\infty} i^n \frac{2n+1}{n(n+1)} (m_{0\,1n}^1 - i n_{e\,1n}^1) \text{............}(1)$$

$$H_i = a_y \frac{K_2}{\mu_2 \omega} E_0 e^{ik_2 z - i\omega t} = -\frac{K_2}{\mu_2 \omega} E_0 e^{-i\omega t} \sum_{n=1}^{\infty} i^n \frac{2n+1}{n(n+1)} (m_{e\,1n}^1 + i n_{0\,1n}^1) \text{.......}(2)$$

$$m_{\substack{0\\e}n1}^1 = \pm \frac{1}{\sin\theta} j_n(k_2 R) P_n^1(\cos\theta)_{\sin}^{\cos} \varphi i_2 - j_n(k_2 R) \frac{\partial P_n^1}{\partial\theta}{}_{\cos}^{\sin} \varphi i_3 \text{.........}(4)$$

$$n_{\substack{0\\e}n1}^1 = \frac{n(n+1)}{k_2 R} j_n(k_2 R) P_n^1(\cos\theta)_{\sin}^{\cos} \varphi i_2 + \frac{1}{k_2 R} [k_2 R j_n(k_2 R)]' \frac{\partial P_n^1}{\partial\theta}{}_{\cos}^{\sin} \varphi i_2 \pm \frac{1}{k_2 R \sin\theta} [k_2 R j_n(k_2 R)]' P_n^1(\cos\theta)_{\sin}^{\cos} \varphi i_3 \text{.............}(5)$$

The secondary induced field can be explained from the interior of the sphere and valid exterior points. The referred waves are transmitted and reflected, this is valid only when the wavelength is smaller than the radius of the sphere.

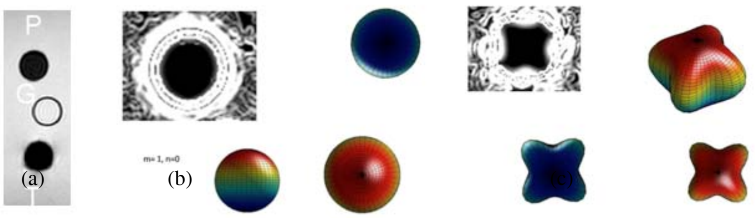

Figure 1. (a) mFFE image of the three phantoms. (b)Magnetic field simulated projection with vibration mode with m=1 and n=0. (c)Projection of the magnetic field and vibration mode of the electrical field inside the sphere.

It can be deduced two equations not homogeneous for the

$$\sum_{n=1}^{\infty} i^n \frac{2n+1}{n(n+1)} (a_n^r m_{0\,1n}^3 - i b_n^r n_{e\,1n}^3) \text{...........}(7)$$

$$H_r = -\frac{n_2}{\mu_2 \omega} E_0 e^{-i\omega t} \sum_{n=1}^{\infty} i^n \frac{2n+1}{n(n+1)} (b_n^r m_{e\,1n}^3 + i a_n^r n_{0\,1n}^3) \text{.....}(8)$$

expansion of the coefficientes where R=a. The system has solution for the coefficientes of the external field:

$$a_n^r = -\frac{\mu_1 j_n(N\rho)[\rho j_n(\rho)]' - \mu_2 j_n(\rho)[N\rho j_n(N\rho)]'}{\mu_1 j_n(N\rho)[\rho h_n^1(\rho)]' - \mu_2 h_n^1(\rho)[N\rho j_n(N\rho)]'} \text{........} \quad (9)$$

$$b_n^r = -\frac{\mu_1 j_n(\rho)[N\rho j_n(N\rho)]' - \mu_2 N^2 j_n(N\rho)[\rho j_n(\rho)]'}{\mu_1 h_n^1(\rho)[N\rho j_n(N\rho)]' - \mu_2 N^2 j_n(N\rho)[\rho h_n^1(\rho)]'} \text{...} \quad (10)$$

Results and Discussion

Figura 1b shows the magnetic field produced by TREG-SPIONs. The secondary radiation of the sphere is elliptically polarized, there are two directions when $\varphi=0$, $Er_\varphi=0$ and $\varphi=\pi/2$, $E_{r\theta}=0$. We observe that the vibrational mode showed on figure 1b is an answer of the electrical oscillation and this is projection of the disturbed magnetic field. TREG-SPIONs produce more serious susceptibility artefacts compared to PEG-SPIONs. Figure 1c shows the disturbed magnetic field produced by the PEGCOOH-SPIONs. The vibrational mode for the behavior is for m=4 and n=4. This study is promissory due to the concordance of the results of the simulations and the inhomogeneities showed in the MR images.

References

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