Simulation of Nuclear Magnetic Relaxation Induced by Superparamagnetic Nanoparticles trapped in a biological tissue

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Superparamagnetic nanoparticles are generally small bids of iron oxides and notably have a high magnetization when submitted to a high external field, and no remnant magnetization in zero field. Those properties make them suitable to be used as contrast agents in nuclear magnetic resonance, where they can accumulate in a tissue, affect its relaxation time, and therefore make it appear clearly in contrast to other surrounding tissues.

There is a variety of theoretical models which try to quantitatively explain the relaxation induced by those types of nanoparticles: it appears to be caused by the diffusion of the water molecules in the magnetic inhomogeneities that the nanoparticles produce in the sample [1].

The diffusion coefficient of water molecules therefore is an important parameter in these models. However, they only focus on relaxation in a homogeneous medium, whereas in a biological tissue, the diffusion of the water molecules is strongly constrained by the presence of a network of cells in which water diffuses. In particular, cellular membranes affect the water molecule movement through their permeability. Those constraints on diffusion affect the relaxation times [2].

This work aims at simulating by using Monte Carlo techniques the relaxation of water molecules in a tissue loaded with superparamagnetic nanoparticles. The cell network is modeled as a periodic layout of semi-permeable membranes.

It is shown that, when all the cells are identically loaded by the nanoparticles, the simulated relaxation times do not differ from the relaxation in a homogeneous medium and do not depend on the cell permeability. However, if the cells are not all loaded in the same way, that is to say, the nanoparticle load in the tissue is inhomogeneous, the relaxation can greatly vary and will depend on the cell permeability, and the spatial distribution of the nanoparticles. This effect should thus be taken into account for the iron quantification by MRI in vivo.

References

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[2] A. Szafer, J. Zhong, et J. C. Gore, « Theoretical Model for Water Diffusion in Tissues », *Magn. Reson. Med.*, vol. 33, nº 5, p. 697-712, mai 1995.