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The development of NMR imaging applications for nano- and micrometric porous systems in the presence of non-uniform magnetic field gradients

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Abstract

The dissertation concerns the application of nuclear magnetic resonance (NMR) for nano- and micrometric studies of porous systems in a magnetic field whose gradient is non-uniform due to hardware imperfections and/or inhomogeneous magnetic properties of the sample. The major goal of this research is to improve existing and find new NMR imaging applications in microstructural studies of porous systems found in biology, medicine, geology and material engineering. For this purpose, NMR techniques were used to measure relaxation and diffusion, and correction methods such as "B-matrix Spatial Distribution" (BSD) were implemented in diffusion tensor imaging (DTI).

The research work focused on overcoming the barriers encountered in the characterization of the microstructure: i) scale, ii) amount of research material, iii) chemical composition of the sample, iv) image artifacts, v) measurement errors (systematic and random). As part of the dissertation, for a more accurate description of the microgeometry of biological systems *in vitro*, it was first proposed to use the method of measuring the time-dependent diffusion coefficient on a single-sided NMR MoUSE scanner, operating in a constant, very strong magnetic field gradient. The methodology developed on model cells of baker's yeast was transferred to the mesenchymal stem cells and enabled the characterization of their biophysical properties and microstructure, including mainly the detection of a component in the signal coming from the cell nucleus. This indicated the possibility of distinguishing two mechanisms of cell death (necrosis and apoptosis). In these research works, the scale and amount of research material barriers were overcome.

The dissertation also presents approaches and clinical advantages of a more accurate description of the microstructure of biological systems *in vivo*-tissues. The focus was on the skeletal muscles of the lower leg in ischemic disease. The effect of mesenchymal stem cell treatment was investigated in a double-blind randomized clinical trial, through the analysis of changes in muscles microstructure. Proper analysis and diagnosis require the elimination of systematic errors, in this case using the BSD method.

The last area of microstructure research were natural porous systems- samples of rock cores. NMR measurements of relaxation processes in a low magnetic field have been proposed as a method to distinguish between "bedded" and "nodular" cherts only on the basis of the features of the pore microstructure in the entire scale range (from nano- to macro-), including surface effects. Principal component analysis was proposed as an auxiliary method. Accurate analysis of NMR data was possible due to the high correlation of samples with natural silica systems (zeolites) and correction for chemical composition. A step forward in rock microstructure characterization was the use of diffusion tensor imaging (DTI), which was possible with carbonate samples. The method of interpreting the DTI results was shown, and on their basis a number of geophysical parameters were determined, including one new metric that could reflect the permeability.

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