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Research Interests: Mesoscopic MRI

Magnetic resonance imaging (MRI) is indispensable for today's medicine and physiology. It provides anatomical maps of living tissues using the magnetic resonance signal from nuclear spins, typically those of protons in water, abundant within tissues.

With all its capabilities, however, MRI cannot directly visualize cells, the fundamental structural units of living organisms, as the signal from each cell is too low due to stringent physical and physiological limits on the measurements. Hence, the "mesoscopic" cell size, typically of the order of a micrometer, is just too fine for the clinical MRI, with its 1000x coarser "macroscopic" resolution, of about a millimeter. Consequently, the signal acquired with such a coarse resolution is a result of a massive averaging over contributions from millions of cells with their individual sizes, shapes, arrangement, membrane permeabilities and other physical and physiological properties. The mesoscopic MRI aims at obtaining quantitative information about these properties in vivo using various MRI modalities at the typical resolution of clinical scanners. An example is the Vessel Size Imaging, a method developed for clinical applications in our group to evaluate the mean size of capillaries in a voxel, which is of the order of 10 micrometers, by combining gradient echo and spin echo signals, both acquired over 2-3 mm voxels.

Obviously, not all cellular features survive such a massive averaging. In fact, most of the structural information about tissues at the cellular scale is lost. It is the aim of the mesoscopic MRI to establish which tissue properties can be "recovered" from the MR signal, and how to quantify them, with the ultimate goal of providing objective biomarkers for pathophysiology. This requires a new level of understanding how the measured MR signal originates at a cellular level, and how the mesoscopic structural features evolve upon averaging over a macroscopic voxel. Methods of modern theoretical physics, which have been originally developed within statistical and condensed matter physics to characterize complex media, prove invaluable in addressing this challenge.

I believe that the mesoscopic MRI approach holds tremendous promise for development of MRI towards quantifying tissue structure far below the nominal MRI resolution. Its applications will help address fundamental problems in tissue physiology, as well as will be instrumental in early detection and diagnosis of tumors, stroke and neurodegenerative diseases.

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Projects

- Effective Medium Theory for MRI Signal
- Applications of Effective Medium Theory: From in Vitro Blood Spectroscopy to in Vivo MRI
- Bolus-Tracking Perfusion and Vessel Size Imaging in the Brain
- Blood Transport and Exchange between Tissue Compartments
- Fiber Tracking

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Publications

Publications in PubMed

Earlier publications in SLAC data base (high energy physics)

A textbook in quantum field theory

Selected articles in MRI physics

- M. Reisert, I. Mader, C. Anastasopoulos, M. Weigel, S. Schnell, V. Kiselev. Global fiber reconstruction becomes practical. Neuroimage vol. 54 (2011) 955-62
- D.S. Novikov, V.G. Kiselev. Effective medium theory of a diffusion-weighted signal. NMR in Biomedicine 23(2010)682-697
- D.S. Novikov, V.G. Kiselev. Transverse NMR relaxation in magnetically heterogeneous media. Journal of Magnetic Resonance vol. 195 (2008) 33-39
- V.G. Kiselev, R. Strecker, S. Ziyeh, O. Speck and J. Hennig. Vessel Sise Imaging in Humans. Magn. Reson. Med. 53 (2005) 553-563.
- V.G. Kiselev. On the theoretical basis of perfusion measurements by dynamic susceptibility contrast MRI. Magnetic Resonance in Medicine 46 (2001) 1113-1122.
- V.G. Kiselev, S.Posse. Analytical model of susceptibility induced MR signal dephasing: Effect of diffusion in a microvascular network. Magn. Reson. Med. 41 (1999) 499-509
- V.G. Kiselev, S.Posse. Analytical theory of susceptibility induced NMR signal dephasing in a cerebrovascular network. Phys. Rev. Lett. 81 (1998) 5696-5699

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