Ultra-Low-Field Magnetic Resonance Imaging

Organizer: John Clarke

Room: # 104

Date and Time: Wednesday, October5 / 08:30-10:30

Recent Advances in Ultra-Low-Field Magnetic Resonance Imaging
In this symposium, seven speakers from five institutions will give a broad overview of recent advances in the technology of Ultra-Low-Field Magnetic Resonance Imaging (ULF MRI) and its applications. The topics will cover:

· the integration of ULF MRI and MEG using a multichannel SQUID system
· the precise elimination of eddy currents due to pre-polarization pulses
· Ultra-low-noise multichannel-SQUID-System for ULF MRI
· neuronal current imaging by ULF MRI
· study of T1 and T2 of protein gels as a function of magnetic field investigating cross-linkage
· T1 and T2 from in vivo images of the human brain and post-mortem pig brain
· portable ULF-MRI system operational without metallic shielding

The level of presentation will be accessible to a broad audience of BIOMAG attendees.

Speakers:

- **Risto Ilmoniemi** (Aalto Univ., Finland)
  "What is the intended breakthrough in MEG–MRI?"

  Hybrid MEG–MRI technology will enable the measurement of both the structure of the head (MRI) and the electrical activity of the brain (MEG) at the same time. This will improve workflow, remove the registration error, and allow new kinds of measurements such as current-density imaging (CDI). Reliable registration and CDI-enabled accurate determination of individual tissue conductivities will, for the first time, allow reliable use of geometric constraints such as the requirement that source currents may reside in gray matter only. With sufficient *a priori* information, the inverse problem will have a unique solution that can be trusted.

- **Koos Zevenhoven** (Aalto Univ., Finland)
  "Software for ULF MRI: managing the various techniques and hardware"

  As ULF MRI matures, more and more sequences and techniques are available for optimized measurements and different forms of imaging such as current-density imaging. To manage the combination of various methods with reasonable convenience while the instrumentation and techniques are changing, a robust software infrastructure is needed with appropriate abstractions and automated adjustments. As an example, it is shown how setting up DynaCan to remove eddy-current artefacts can be incorporated in the software stack as an extension module.

- **Rainer Körber** (PTB, Germany)
  "Ultra-low-noise multichannel-SQUID-System for ULF MRI"

  We discuss the design of our new multichannel-SQUID-system for ULF MRI. It is geared for ultra-low-noise performance and is based on our modular and robust 18-channel-system which was tested in a prototype. There, a central feature is the use of overlapping magnetometer pick-up coils with different dimensions enabling maximum SNR for different source depths. Using software gradiometer we achieved a minimum noise level of 0.5 fT/√Hz. The prototype was successfully deployed for ULF NMR and MEG. As an example, the system was used to detect 1 kHz components of 1 fT peak-peak amplitude in electro-stimulated MEG signals. We will discuss the properties of the prototype and its implication for the ultra-low-noise system to be used for CDI and NCI at ULF.

- **Martin Burghoff** (PTB, Germany)
  "Neuronal current imaging by ULF MRI (NCI)"

  The goal of NCI is to help overcome a long-standing barrier of the inverse problem in MEG localization, mainly the non- uniqueness of the electromagnetic inverse problem. The detection of the influence of the weak neuronal magnetic fields on an MR image contrast does not suffer from this lack of uniqueness. Phantom studies show promising results to apply this technology for long lasting neuronal activities.

- **Hui Dong** (Chinese Academy of Sciences, China)
  "ULF-NMR T1 and T2 of cross-linked proteins: Implications for brain ULF-MRI"

  The slow molecular dynamics of proteins reveals important interactions of tissue surfaces such as proton and molecule exchange mechanisms. Clinical magnetic resonance imaging (MRI) machines operating in static fields B_0 of the order of tesla use the so-called $T_{1\rho}$ technique to acquire this information. This $T_{1\rho}$ method, in which a radiofrequency (RF) spin-lock field is applied with microtesla amplitude, may exceed the specific absorption rate (SAR) limit, putting subjects at risk. Ultra-low-field (ULF) MRI, based on Superconducting QUantum Interference Devices (SQUIDs), directly detects slow motions of protons at B_0 of typically 100 µT. Using our ULF MRI system at Berkeley, we systematically measured the T_1 and T_2 dispersion profiles of rotationally immobilized gels of bovine serum albumin (BSA) with variable static fields ranging from 55 to 240 µT. Comparing the ULF results with $T_{1\rho}$ dispersion obtained at 7 T, we find that the degree of protein immobilization determines the frequency-dependence of both T_1 and $T_{1\rho}$. Furthermore, scans of *ex vivo* pig brain showed similar behavior between cross-linked proteins and brain tissue. This similarity suggests that ULF MRI may be used to image stroke or traumatic brain injury (TBI) with negligible SAR.

- **Seong-min Hwang** (KRISS, Korea)
  "ULF MRI of in vivo human brain and post-mortem pig brain"

  Recent animal studies with high-field MRI showed that $T_{1\rho}$, which exhibits NMR properties at spin-lock fields much lower than the static field B_0, typically several tesla, could be a good indicator of stroke onset time. ULF MRI is an ideal substitute for $T_{1\rho}$ MRI for stroke onset diagnosis since ULF-MRI measures true T_1 and T_2 at ULF rather than $T_{1\rho}$. Furthermore, ULF MRI is free from the specific absorption rate (SAR) issue unavoidable in $T_{1\rho}$ because it requires the application of a strong high-frequency spin-lock field. We have performed ULF MRI of *in vivo* human brain at B_0 between 58 µT and 235 µT using Inversion Recovery to prevent the much longer relaxation signal from cerebrospinal fluid (CSF) from contaminating T_1 and T_2 of brain tissue. We also report ULF-NMR measurements of gray and white matter taken from postmortem pig brains measured in the same B_0 range. Contrary to *in vivo* human brain, postmortem pig brain showed frequency dispersion and, more significantly, divergence of T_1 and T_2. Further studies with rotationally immobilized protein gels and Sephadex beads indicate that the frequency dispersion and the T_1/T_2 divergence may be due to interaction between localized water and surrounding matrix structures.

- **Per Magnelind** (Los Alamos National Laboratory, USA)
  "Fieldable ultra-low-field MRI systems for non-traditional situations and settings"

  Magnetic Resonance Imaging (MRI) is considered the best non-invasive imaging method for soft tissue anatomy and provides extraordinary diagnostic capabilities, saving countless lives each year. However, conventional MRI relies on high strength magnetic fields (> 1.5 T) with parts-per-million homogeneity, requiring very large and costly magnets that are only available in highly controlled settings in well-funded medical centers. Traditional high-field MRI is not available in rural settings, is not deployable to emergency situations or battlefield hospitals, and is too expensive for poor and developing countries. We will present progress toward developing a portable MRI machine based on SQUID (superconducting quantum interference device) sensor technology and ultra-low-field MRI techniques. We will show brain images acquired inside a shielded room and phantom images acquired in an unshielded setting.