Towards Whole Body Magnetic Resonance Imaging at Ultra-Low Fields

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Introduction

The development of ultra-low field (1μT - 100mT) magnetic resonance imaging (MRI) has opened up an entire new regime in the field of MRI[1,2]. Although the image resolution does not yet compare to that which is obtained using high field MRI, this unique imaging methodology may provide a complementary resource to traditional MRI, as well as a tool for situations where high field MRI is extremely difficult or impossible to achieve. The continued research and development of this technique is of paramount importance in order to fully realize its potential impact within both the scientific and medical communities.

Background

Nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI) are ubiquitous tools that have been well-established in both science and medicine. NMR provides powerful probes of local and macromolecular chemical structure and dynamics[3,4]. MRI is the tool of choice for tomographic imaging of soft tissue anatomy and for monitoring function based on dynamic physiological processes[5]. The technological trend has been to higher and higher magnetic fields with Larmor precession frequencies (42 MHz/Tesla for protons) of hundreds of MHz. Although high fields enhance magnetic resonance signal strength and many forms of image and spectral contrast, they also preclude or place significant restrictions on many potentially important applications.

Several of these applications become accessible with an ultra-low field (ULF) MRI setup. For example, magnetoencephalography (MEG), a technique that uses sensitive superconducting quantum interference device (SQUID) arrays to localize sources of neural activity within the brain, is incompatible with the high magnetic fields required for traditional MRI. However, MEG measurements are completely compatible with ULF MRI techniques, which also use SQUID arrays[6]. Furthermore, the ULF setup uses simple, inexpensive, and portable coil systems to generate magnetic fields, rather than large superconducting magnets[7,8]. This allows MRI to be more affordable and better suited for operating rooms or field hospital scenarios. In addition, this allows the field strengths and polarities used for imaging to be easily manipulated, facilitating additional scientific investigations within this regime (e.g., systematic studies of relaxation parameters as a function of field strength) as well as possible unique imaging modalities. Finally, T_1-weighted contrast is usually enhanced at low magnetic fields[9], and the increased magnetic relaxation dispersion for tissues at ultra-low fields[10] can be used to selectively enhance T_1-weighted images in this regime. Thus, ULF MRI poses the possibility of enhanced contrast or even new contrast mechanisms for various clinical diagnoses.

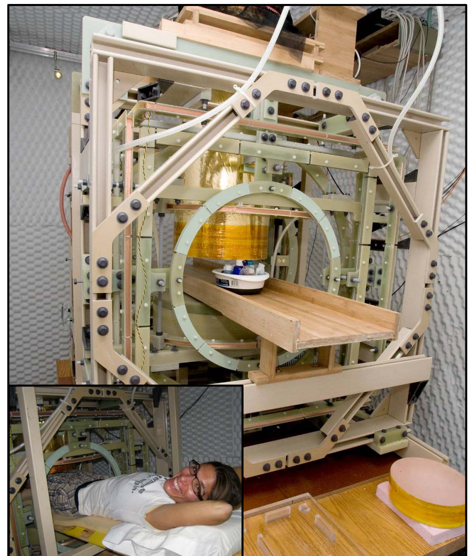

Fig. 1: The custom-built ULF MRI system is capable of imaging any part of the human body for a small adult subject.

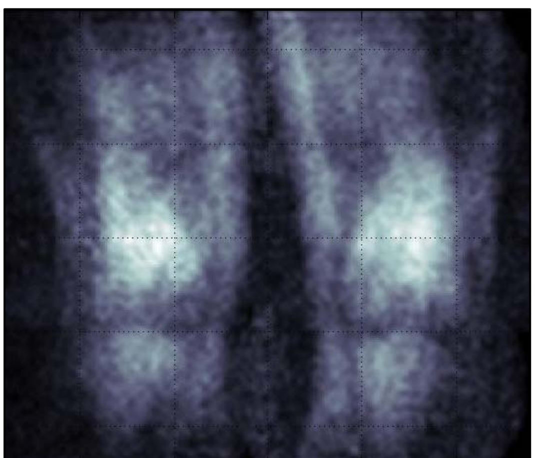

Fig. 2: We obtained ULF magnetic resonance images of several soft tissues, including anterior knee images shown here.

ULF MRI: Towards Whole-Body Imaging

After successfully demonstrating the first ULF magnetic resonance images of a human brain[6], our group has proceeded with the further development of this technology towards achieving whole-body imaging. A new custom-built apparatus was manufactured that is capable of imaging any part of the human body for a small adult subject. As with the previous setup, this system uses a 7-channel SQUID array for the detection of MRI signals due to microTesla fields. The SQUID array sits inside a flat-bottom liquid helium cryostat that was positioned directly over the body part of interest. The entire system is enclosed within a magnetically-shielded room. Although this system does have 3D imaging capability, only 2D images were obtained for this study. The basic imaging sequence used was similar to what has been previously reported[6] without the second phase-encoding gradient. Image analysis and optimization was performed using custom software. A picture of the setup is shown in Fig. 1.

Results

We obtained ULF magnetic resonance images of several soft tissues, including anterior knee images shown in Fig. 2. In addition, we also calculated relaxation times at low field strengths. Specifically, we calculated T_1 times for mT fields and T_2 times for μT fields. In this presentation, these results will be reviewed, along with future directions we plan to take this work.

References

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