Characterization of MRI properties of human body tissues at microTesla magnetic fields

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Abstract

Ultra-Low Field MRI (ULFMRI) by SQUID-detected direct magnetometry (*1*) is a novel approach with the potential to obviate many of the most important limitations of conventional imaging, such as the challenges of cost, safety, siting, portability and patient acceptance. Even if these practical advantages are realized, however, it is unlikely that the instruments will gain significant acceptance if they are unable to achieve clinical image quality comparable to the current generation of commercial devices. Here we present the results of our investigations into the signal properties of human *in vivo* images acquired at 170 μT (7.3 kHz) and higher fields.

Methods

Our prototype ULFMRI instrument is shown schematically in Fig. 1. It consists of a polarization coil that generates a field of up to 100 mT, a set of X, Y and Z gradients wound on approximately 1 meter square formers, a 25 cm induction excitation coil and a superconducting quantum interference device (SQUID) coupled magnetically to the sample volume by a 23 mm diameter and 32 mm baseline second order superconducting gradiometer pickup coil. The entire instrument, including the low noise helium dewar and all supporting electronics, weighs approximately 340 kg. The 140 dB rejection efficiency of the pickup coil, and the low operating frequency, allow us to operate the system in an unshielded environment.

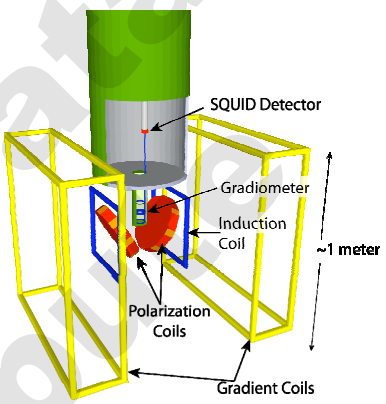

Fig 1. Schematic of ULFMRI imager

In the ULFMRI experiments reported here, we studied the longitudinal and transverse relaxation times in the human forearm as follows. We used a 3D encoding scheme with 8 partitions and a readout duration of 56 ms. For T1 mapping at our imaging field we pre-polarized the sample at 80 mT collecting images at a series of fixed delays, Td, of 0, 30, 60 and 90 msec removing the polarizing field was removed. We determined T1 by fitting the signal intensity (SI) to the function: $SI = ke^{-Td/T1}$. We studied transverse decay rates by measuring the signal intensity in gradient echo and CPMG sequences (using a series of 12 pi pulses) as a function of TE. For comparison purposes we also measured T1 at our polarizing field of 80 mT by varying the polarization time from 100 to 600 ms and we studied T1, T2, T2* and T2d (defined as the apparent relaxation time using a Hahn echo experiment) at 1.5 and 3 Tesla. T1 was determined using FLASH images at varying flip angles, T2* by gradient echo scanning at varied TE, and T2 by CPMG methods.

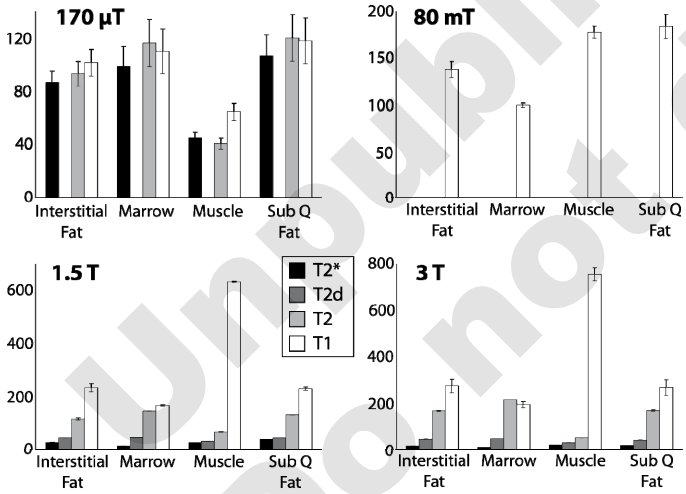

Fig 2. T1 and T2 +/- sem as a function of tissue type and field strength. Sub Q Fat = Sub-cutaneous fat

Results

As shown in Fig. 2, at 170 μT the transverse and longitudinal relaxation times were strikingly similar for the lipid containing tissues in the forearm, whereas the dispersion increased rapidly as a function of field strength. Note that there was little or no difference between the gradient echo and CPMG transverse relaxation times at 170 μT. T1 approximately doubled for all tissues at 80 mT.

Discussion

It is known that T1 and T2 will converge as the product of the Larmor frequency and correlation time becomes small. Little attention has been paid to the contrast behavior of images in this regime, though several investigators have noted that the contrast of T1rho images is similar to that of T2 weighted scans. Our data lend support to these findings: Note for example that the T1 and T2 of muscle are shorter than that of fat. We note also that despite the very low measurement field there is considerable contrast between body tissues.

As noted in a separate abstract (*2*) we believe that it is possible and practical to build a clinical ULFMRI system with signal to noise ratio and resolution comparable to high field instruments. The present data help to define ideal operating parameters for such an instrument by setting practical boundary conditions on readout bandwidth and requisite polarization times. In these tissues for example, near maximum signal will be obtained with a polarization time of 350 ms and a readout of about 150 ms. The fact that such short TR's may be used for spin density experiments implies an additional gain in SNR efficiency over conventional high field instruments.

1. R. McDermott *et al.*, *Journal of Low Temperature Physics* **135**, 793 (2004).
2. B.H Eom, *et al*., "An Ultra-Low Field imaging instrument and analysis of its SNR and scaling properties," *these proceedings*.