First Microtesla MRI of the Human Brain

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INTRODUCTION: Magnetic resonance imaging at ultra-low fields (ULF MRI) is a promising new imaging method [1] that uses measurement fields in the microtesla range. In this method, sample magnetization is enhanced by a pre-polarization field substantially larger than the measurement field, and MRI signals are subsequently measured at an ultra-low field using SQUIDs (superconducting quantum interference devices) – the most sensitive detectors of magnetic flux. Imaging at ULF greatly simplifies coil design, and makes it possible to build MRI systems that are simple, inexpensive, portable, open, quiet, and patient-friendly. Improved T_1 contrast at ULF [2] may allow more efficient diagnostics of various medical conditions, including cancer. Unlike conventional imaging, ULF MRI is compatible with SQUID-based techniques for biomagnetic measurements, such as magnetoencephalography (MEG) [3]. This allows development of new instruments for multi-modal imaging, including next-generation MEG systems with ULF MRI capability.

METHOD: Recently, we reported the first multi-channel SQUID system specially designed for both ULF MRI and MEG [4-6]. The system includes seven 37 mm diameter second-order SQUID gradiometers installed inside a flat-bottom liquid helium cryostat. Their magnetic field resolutions are 1.2 to 2.8 fT/√Hz. Five sets of coils generate magnetic fields and gradients for 3D Fourier imaging using pre-polarization. The system was initially used to acquire ULF images of a human hand and record auditory MEG [4]. More recently, it demonstrated benefits of multi-channel imaging at ULF, including imaging acceleration with the sensor array [6].

In this work, we used our system to acquire MR images of the human head at an ultra-low (46 microtesla) measurement field. A human subject was placed inside the system with the right side of the head against the bottom of the cryostat. A pre-polarization field of 30 mT was applied for 1 sec prior to each imaging step. The image was acquired at 46 μT field according to 3D Fourier protocol. The imaging resolution was 3 mm × 3 mm × 6 mm with the 6 mm pixel size for the vertical (Y) dimension. The image matrix size was 81×61×11. A multiple-echo technique was used, and three echoes with echo tops at 65 ms, 137 ms, and 210 ms were recorded.

RESULTS: The first 3D ULF MRI image of the human head is exhibited in Fig. 1. It is a composite seven-channel image with T_2 contrast corresponding to the first echo. It was obtained by averaging images from six consecutive *k* space scans with single-shot acquisition. Only four horizontal layers of the 3D image (out of 11 acquired) are shown in the figure. Imaging SNR decreases with the distance from the cryostat, because of the limited sensitivity depth of the pick-up coils used. The images corresponding to the second and third echoes (not shown) exhibit stronger T_2 contrast. Using the multiple-echo data, we were able to estimate values of the transverse relaxation time T_2 for different parts of the human head at ULF for the first time. Immediately following the ULF MRI experiment, and without removing the human subject from inside the system, we also performed auditory MEG measurements.

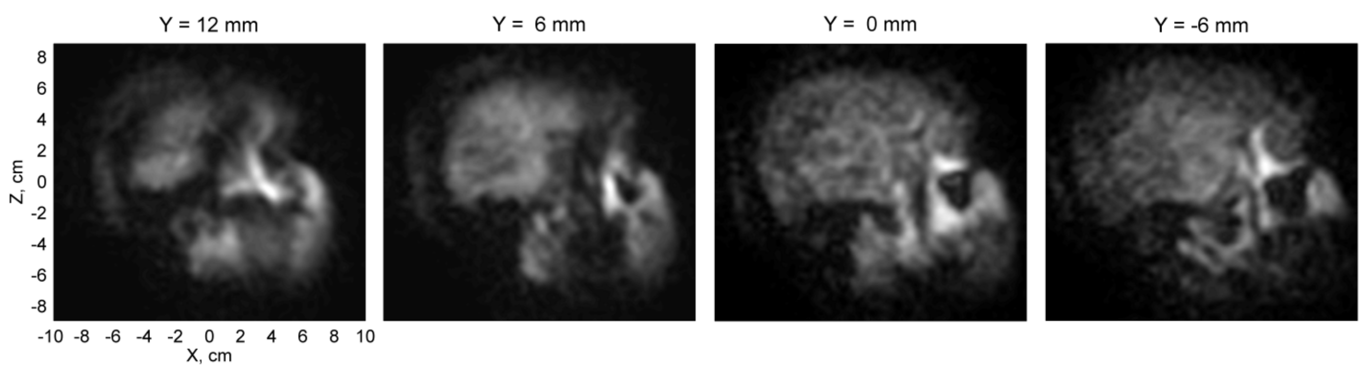

Fig. 1. The first 3D ULF MRI image of the human head acquired at 46 μT measurement field (f =1.9 kHz) with pre-polarization at 30 mT.

CONCLUSION: Our results demonstrate feasibility and potential of the human brain imaging at microtesla magnetic fields. They also suggest that inexpensive and patient-friendly ULF MRI may become an alternative to conventional high-field MRI.

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