High-Field MRI of Brain Cortical Substructure Based on Signal Phase

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INTRODUCTION

The spatial resolution of clinical brain MRI is limited to about 1 mm^3 (1 μl), which is not optimal for measuring the fine-scale differences in cortical morphology across functional regions or between normal and pathological tissue. Although recent developments in high field MRI technology and array detectors have allowed a reduction of the voxel volume to below 0.1 μl [1], the generation of strong cortical contrast has proven challenging. Recently, susceptibility contrast was used to improve detection of venous structures and iron rich brain regions such as the substantia nigra and the globus pallidus [2]. Here, we investigate whether susceptibility contrast at high field allows improved measurement of cortical morphology.

METHODS

MRI experiments were performed on a 7.0 T GE Signa MRI scanner, receiving signals from 16 channels of a 24-channel receive-only detector array. Six normal volunteers (3 male, 3 female) in the age range of 25-52 years were scanned under an IRB approved protocol. Axial gradient echo (GRE) acquisitions were performed with TE=28-31 ms, TR=500-800 ms, flip angle 30-50 degrees (adjusted at center of brain), slice thickness 1 mm, field of view 240×180 mm^2, matrix size 1024×768, bandwidth 32 kHz, and first order flow compensation on all imaging gradients. The total scan time was 6.5 – 10 minutes. Multiple slices were acquired throughout the brain with varying inter-slice gap. For comparison, 3D MPRAGE scans were performed with TE=5.4 ms, TR=11.3 ms, flip angle 14, slice thickness 1 mm, field of view 240×180 mm^2, matrix size 512×384, bandwidth 62.5 kHz, TI=1.2 s, overall TR=3 s, scan time 20 minutes. Prior to the anatomical scans, higher (second) order B_0 shims were adjusted to minimize macroscopic susceptibility effects. In addition, during each scan, real time higher order shimming was performed to compensate for B_0 fluctuations related to the respiratory cycle [3]. Images were reconstructed using phase sensitive combina of the individual coil data [4] using the separately acquired coil sensitivity reference data. Susceptibility images were derived from the GRE phase data after removal of macroscopic phase variation with eight-order 2D polynomial fitting.

RESULTS AND DISUSSION

A dramatic contrast was observed in the GRE phase data, indicating frequency differences of up to 5 Hz between cortical grey matter (GM) and underlying white matter (WM) (Figs. 1-2). CSF phase was similar to that of WM. Similar GM-WM differences were seen in all subjects. In motor cortex parallel to B_0, the frequency difference ranged from 3-5 Hz in the central layers, corresponding to a susceptibility difference of 0.01-0.02 ppm. At 5 Hz frequency difference, the estimated *CNR* gain over magnitude data was about 9-fold. *CNR* values in peripheral and central regions for MPRAGE were around 1.5:1 and 8:1 respectively, compared to 3:1 and 20:1 for GRE phase data. When taking into account the 2-3 times longer scan time and 4 times lower resolution, the inherent *CNR* of MPRAGE data was 10-12 fold lower than that of GRE phase data. Interestingly, in many cortical regions including the motor cortex and visual cortex, phase variations across the cortical thickness were observed, suggesting a layer-specific contrast (Fig. 2). The hypo-intensity seen in the primary visual cortex is suggestive of the line of Gennari, a feature that has been observed previously with T_1-weighted MRI [5,6] at lower resolution. These results indicate that high field MRI combined with multi-channel detection and phase-based contrast allows *in-vivo* brain imaging with unprecedented *CNR* and resolution.

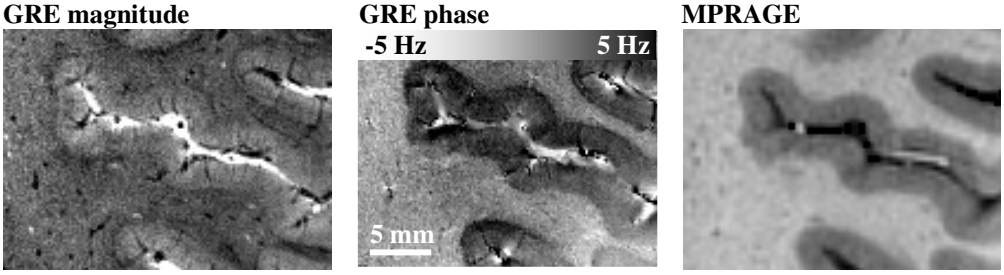

Figure 1

The susceptibility related phase effects observed in this work could originate from a variety of sources, including variations in iron content, myelin content, and deoxy-hemoglobin. Post-mortem iron and myelin stains and histochemistry on the same tissue might elucidate the relative contributions of these mechanisms.

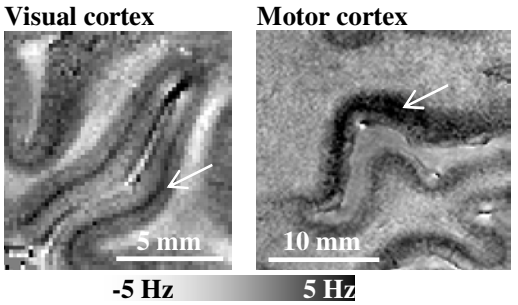

Figure 2

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