Phase Imaging of the Human Brain at 7T

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Introduction: The increased susceptibility effects and high signal-to-noise ratio at 7T enable anatomical neuroimaging using the phase of the MR signal. Developing consistent phase contrast requires long echo times over which low-frequency field variations (caused by metallic objects in the bore and the patient bulk susceptibility effects) introduce phase wraps. After correction for these low-frequency distributions the remaining phase may be ascribed to differences in chemical content of the voxel and the presence of iron-containing compounds. This study presents methodology for creating phase images using a multichannel coil and phase unwrapping. The resulting images highlight venous vessels, provide added gray/white matter contrast and significantly improve contrast in the basal ganglia.

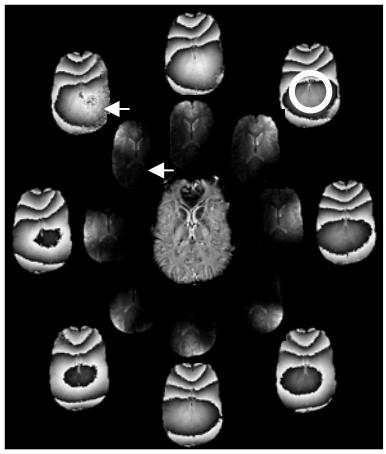

Figure 1: Phase (outer ring) and magnitude (inner ring) data for the phase contrast image (center). A central ROI (circle) was used to align the channel phases. Notice the poor phase estimate where coil sensitivity is low (arrow).

Methods: High resolution gradient echo images of ten volunteers giving informed consent were acquired at 7T. Three subjects received a repeat scan at 7T and 3T to evaluate reproducibility. The 7T and 3T whole-body MR scanners (GE Healthcare, Milwaukee, WI) were equipped with 8-channel receive phased array coils (from Nova Medical, Wilmington, MA at 7T and In Vivo, Miami, FL at 3T). Excitation was done using a head transmitter coil with active detuning at 7T and the body transmitter at 3T. Parameters for the 2D gradient echo scan were 512x512 matrix, 18cm FOV, NEX 3, TE/TR 11.4/250ms, flip 20°, 2mm/6mm slice/gap, and scan time 6.5min.

Data Analysis:

(1) The individual channel phases were aligned to get the same mean phase over a central ROI (circle, Fig 1).

(2) Coil sensitivity profiles (S_n) were estimated by smoothing the coil magnitude images.

(3) A multichannel phase image was created by weighting confidence in each channel's aligned phase by the sensitivity profiles. This minimizes noise by preferentially weighting the phase estimate from coils with higher sensitivity and hence lower phase noise.

(4) The resulting image was unwrapped using PRELUDE[1] and high-pass filtered for viewing. Data processing took <3 minutes on a Sun Microsystems SunBlade 1500.

The noise estimate for the contrast-to-noise ratio (CNR) was taken as the standard deviation of the difference between two consecutive scans of the same patient.

Results: The high-resolution 7T phase images show excellent anatomical detail in the microvasculature, gray and white matter, basal ganglia and white matter tracts of the occipital cortex (Fig 2). Phase CNR was shown to be reproducible across scans and, in the basal ganglia, superior to magnitude CNR (Table 1). The 3T phase images had poor gray/white matter contrast (CNR 0.8±1.2) and contrast in the basal ganglia was comparable to magnitude contrast (CNR 3.0 ±1.4).

On average the vessel width was 34% narrower on phase than magnitude images ($P < 0.001$, Wilcoxon signed rank test) and had similar continuous vessel length ($P > 0.3$, Wilcoxon signed rank test). In the periventricular microvasculature, vessels were 52% narrower on phase images.

Region	Comparing	CNR	
		Magnitude	Phase
Cortex	Gray to white matter	4.8 ± 1.3	2.1 ± 0.8
Cortex	Vessels to adjacent tissue	3.9 ± 1.8	7.1 ± 2.4
Brainstem	Red nucleus to pars dorsalis	4.7 ± 0.8	3.1 ± 0.9
Basal ganglia	Caudate to internal capsule	2.9 ± 1.2	6.8 ± 1.5

Table 1 (above). Contrast-to-noise comparison

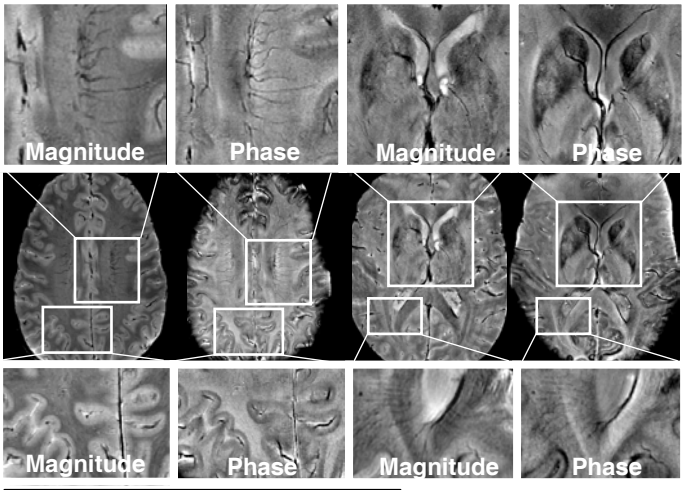

Figure 2 (top): High resolution anatomical images.

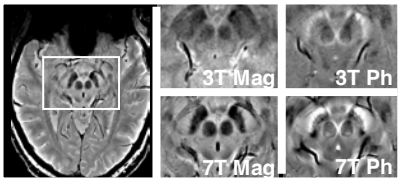

Figure 3 (left): The brainstem imaged by magnitude and phase at 3T and 7T.

Discussion: The expected field shifts in iron-laden tissues[2] and vasculature are confirmed by the phase data. Vasculature has narrower apparent widths on phase than magnitude images because the susceptibility of deoxygenated bloods shifts the field in opposite directions within and adjacent to the vessel. Therefore magnitude has signal dropout both within and adjacent to the vessel while phase is high bright adjacent to and dark within the vessel.

The additional information that phase provides could be used to improve anatomical segmentation or quantitatively analyze the presence of susceptibility-shifted tissues and fluids. The strong contrast within the basal ganglia, for example, could be applied to studies of neurodegenerative disorders such as Alzheimer's. Other potential applications include bi-variate gray-white matter segmentation using magnitude and phase, studies of iron accumulation in aging and studies of the microvasculature.

Conclusion: Phase imaging at 7T and preliminary results at 3T are shown to provide novel contrast to magnitude without requiring an additional scan. Phase imaging is demonstrated to feasibly and reproducibly highlight iron-laden tissues and microvasculature.

References: (1) Jenkinson. *MRM* 49:193-197 (2003). (2) Hallgren *et al. J Neurochem* 3:41-51; 1958.

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