# Could We Characterize Fine Structures in Human Brain Using High-resolution Magnitude and Phase image at 7 Tesla In Vivo?

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**[Introduction]** The high-field scanner (≥ 7T) has potential advantages of high SNR, CNR, and spatial-resolution in human brain imaging. MR magnitude and phase image at 7T shown the unprecedented high T2*-weighted contrast in deoxygenated vessels [1, 2] and iron-deposit region such as basal ganglia or deep brain nucleus [3]. While the magnitude signal is determined by T2* relaxation time, proton-density, and water contents, the phase is affected mainly by the local field inhomogeneity [4]. These two different characteristics can be utilized to characterize the signal source of brain structures, particularly the fine hair-like structures in human brain such as vessels or neuronal fibers. In this study, the high-resolution brain anatomy images were obtained in the cortex through deep brain using the developed reconstruction algorithm at 7T equipped with multi-channel RF coil [5].

**[Methods]** All scans were performed on Trio7T scanner (Siemens Medical Solutions, Erlangen, Germany) with 9-channel RF coil (1 volume transceiver + 8 surface receivers). Three normal volunteers consented to the study approved by the IRB of the university. Dual-echo 2D GRE sequence was used to get the T2*-weighted MR images [5]. As a comparison study, the typical True-FISP image was acquired to get the heavily water-weighted image in cerebral-spinal-fluid for one case. For the vessel simulation, the infinite-long cylindrical model [6] was used to calculate the inhomogeneous field in the neighboring space at 7T; susceptibility difference between blood and tissue $1.0\times10^{-6}$, hematocrit concentration 0.4, fractional oxygen saturation of hemoglobin 0.55 during rest period, and cylinder radius 150 μm (Fig. 1A). The direction of cylinder was changed with two rotation angles (α & β for *x*- and *y*-axis). The phase was converted from the calculated inhomogeneity field by $\phi = -\gamma \cdot \Delta B_z \cdot TE$, where γ is gyromagnetic ratio and TE is echo time 20 ms. The spin density assumed to be same in tissue and blood for the simplicity. The magnetization at the center of vessel was integrated over 2 mm-thick slice in axial, coronal, and sagittal image in complex domain (Figs. 1B – D) with different orientation of cylinder. The visual cortex, basal ganglia, and pons were selected for the detail analysis of anatomy using reconstructed magnitude and phase images. Particularly, the fine hair-like structures were focused to understand the anatomical source of intensity based on our simulation.

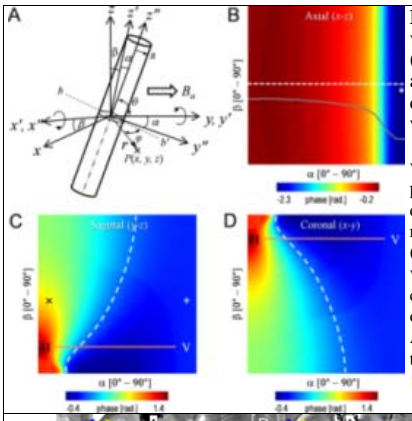

**Fig. 1 (**A) Cylindrical model for the blood-vessel simulation, and the phase distribution in (B) axial (*x*-*z* plane), (C) sagittal (*y*-*z* plane), and (D) coronal view (*x*-*y* plane). White-dashed traces represent the direction of vessels with zero phase values in C and D. 'H' – horizontally, and 'V' – vertically oriented vessel. The voxel phase had the maximum negative polarity for the cylinder lying in the magnetic field $\vec{B}_0$ direction (asterisk in B), but it didn't change over a relatively broad range of tilting angle toward $\vec{B}_0$ field (e.g., 0° - ~65°) (gray-trace in B). In sagittal view, the voxel phase is negative with a parallel direction of cylinder to $\vec{B}_0$ field, while positive with the orthogonal direction of cylinder to magnet field $\vec{B}_0$. At these zero phase points in C, the angle $\vec{B}$ between the axis of cylinder and magnet field $\vec{B}_0$ ranges from 100° to 130° in this simulation.

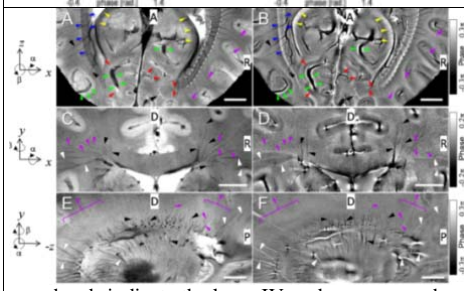

**Fig. 2** Image intensity change depending on the vessel orientation and imaging slice. (Left panels) Magnitude and (Right panels) phase images; axial (A & B), oblique coronal (C & D), and sagittal view (E & F) from top to bottom. Black-arrowheads indicate same polarity of vessel, and white-arrowheads represent the opposite polarity of vessel in magnitude and phase image. Magenta-arrowheads indicate those nullified at phase image while dark in magnitude image. Red-arrowheads indicate the layer IV, and green-arrowheads for susceptibility effect at boundary of vessel. Magnitude images are displayed in arbitrary unit. Scale bar 10 mm. The coordinate axis is same as Fig. 1A. Abbreviation; A – anterior, R – right, D – dorsal, and P – posterior. Same abbreviations are applied to following figures.

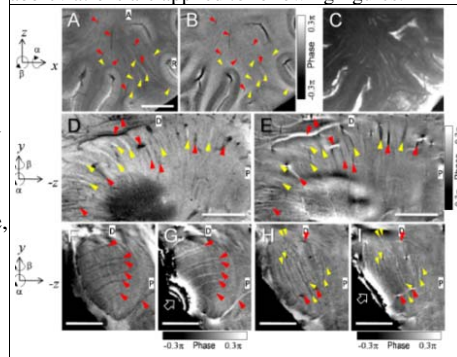

**Fig. 3** Unknown fine structures in 7T MR image. (A – C), Axial magnitude and phase images, and True-fisp image. Red-arrowheads indicate the dark-intensity vessels, and yellow-arrowheads represent the white-intensity in magnitude but nullified in phase image. (D and E), Magnitude and phase image in midbrain region. Yellow-arrowheads indicate the unknown fiber-structure with white- but dark-intensity in magnitude and phase image, respectively. (F and G), Magnitude and phase image in pons and stem. (H and I), Magnitude and phase image in deeper pons. Yellow-arrowheads indicate the unknown fiber-structure with dark- but white-intensity in magnitude and phase image, respectively. White arrows indicate the susceptibility artifacts. Scale bar 10 mm. The coordinate axis is same as Fig. 1A.

**[Results and Conclusions]** In the vessels, the results of simulation and MR images were well correlated. That is, the phase in axial view was always negative under paramagnetic susceptibility condition ($\Delta\chi > 0$) (Figs. 1B & 2B); positive with diamagnetic condition ($\Delta\chi < 0$). In sagittal (coronal) view, the polarity of phase changes from negative to positive when the cylinder is in parallel to orthogonal to $\vec{B}_0$ field (Figs. 1C & D and 2D & F); there are the transient points where the phase becomes zero (white-trace in Fig. 1C and magenta-arrowheads or -brackets in Figs. 2D & F). Some micro-structures showed the different characteristics from the deoxygenated vessels filled with paramagnetic susceptibility blood (Fig. 3). The hyperintense (nullified) vessel-like fine structure in magnitude (phase) image at the parietotemporal visual cortex was proved to be the CSF around artery by comparison of magnitude, phase, and True-FISP images (see yellow-arrowheads in Figs. 3A - C). In the midbrain, dark lines are supposed to be vessels in magnitude image, and the corresponding phase values are well matched with simulation (i.e., horizontal – bright & vertical – dark) (red-arrowheads in Figs. 3D & E), but the white lines in magnitude didn't show the consistent phase values (yellow-arrowheads). Another interesting thing was the micro-stripe structures in sagittal image (Figs. 3F - I). Based on simulation results, the horizontal lines are vessels (red-arrowheads in Figs. 3F & G) and the vertical lines are not the deoxygenated vessels, but possibly the corticospinal cord (yellow-arrowheads in Figs. 3H & I). In conclusion, the fine structures in human brain can be characterized using high-resolution magnitude and phase images acquired at high-field magnet 7T. **[Reference]** 1. Hammond et al. *Neuroimage*, 2007. 2. Duyn et al., *PNSA*, 2007. 3. Abduljalil et al., *JMRI*, 2003. 4. Haccke et al., *JMRI*, 2007. 5. Moon et al., *ISMRM*, 2009, *submitted*. 6. Ogawa et al., *PNAS*, 1990. **Acknowledgements]** We thank Dr. Z.H. Cho for the support of a 7T multi-channel head RF coil.