Experimental investigation of the relationship between phase contrast and orientation of white-matter fiber orientation

F. Schweser[1], B. W. Lehr[1], A. Deistung[1], J. R. Reichenbach[1], and D. Güllmar[1]
[1]Medical Physics Group, Department of Diagnostic and Interventional Radiology, Jena University Hospital, Jena, Germany

Introduction

Recently, a theoretical framework was published which allows quantitative description of phase contrast and corresponding frequency shifts and is based on the concept of a generalized Lorentzian approximation [1]. This framework takes into account both tissue architecture and its (sub-)cellular orientation with respect to the external magnetic field and predicts a correlation between the orientations of white matter fibers with respect to the external magnetic field and phase contrast. This correlation was experimentally observed by Hernandez et al. [2]. However, based on the presented theoretical framework, we intended to repeat this experimental investigation with different orientations of the white matter structure to the external magnetic field.

Materials and Methods

High-resolution whole-brain data of a healthy volunteer were acquired using the ToF-SWI sequence [3] (isotropic voxel size of 0.6 mm³, 75% PF in phase and slice encoding direction and TE1/TE2/TR/FA/BW1/BW2=3.38ms/22ms/30ms/20°/271Hz/px/93Hz/px). Furthermore, an EPI-DTI sequence were applied (TE/TR/b-value/nDiffDirections=91ms/6900ms/1000 s mm-2/76, voxel size 2.5×2.5×2.5 mm³). ToF-SWI data as well as DTI data were acquired at four different orientations of the head with respect to the main magnetic field. The head was tilted approx. 50°, 4°, -17°, and -35° about x-axis (left-right-axis) with respect to the magnetic field orientation. All MR acquisitions were performed on a 3T MR-scanner (Tim Trio, Siemens Medical Solutions) using a 12-channel head-matrix coil. Multi-channel phase images were combined using uniform sensitivity reconstruction [4] and 3D phase unwrapping [5] was applied to resolve phase aliasing. Background field contributions were removed utilizing the harmonic-function mean-value property [6]. A mask removing unreliable phase values (unwrapping artifacts and low SNR) was generated based on automatic evaluation of magnitude and phase data. DTI-tensor maps were reconstructed and the angles between the first Eigenvector (principal fiber orientation) and the external magnetic field were computed. Brain voxels exceeding a fractional anisotropy threshold of 0.3 and having reliable phase values were selected for further comparison in order to consider only white matter compartments. Phase values were grouped for fiber orientations with respect to B_0 from 5 to 85 degrees in 3 degree steps and averaged.

Results

Fig. 1 shows sagittal views of the phase data and the corresponding angle data, which reflect the angle between white matter fiber orientation in each voxel and the B_0 field during acquisition. A slice position was selected cutting the Cingular bundle longitudinal to illustrate the contrast in both data modalities. Fig. 2 shows the relationship between orientation of the white matter fiber and corresponding phase values for four different conditions. As can be seen from the graph the plots follow an almost cosine function except the data for the data set with a tilt angle of -35°. The cosine-shape of the plots correlate to the angular factor $-(\cos^2\vartheta - 1/3)$ ([1]). In the case of $\vartheta = 54.74°$ (magic angle) the theoretical framework predicts a mean phase value that only depends on the susceptibility of white matter, since the angular factor becomes zero.

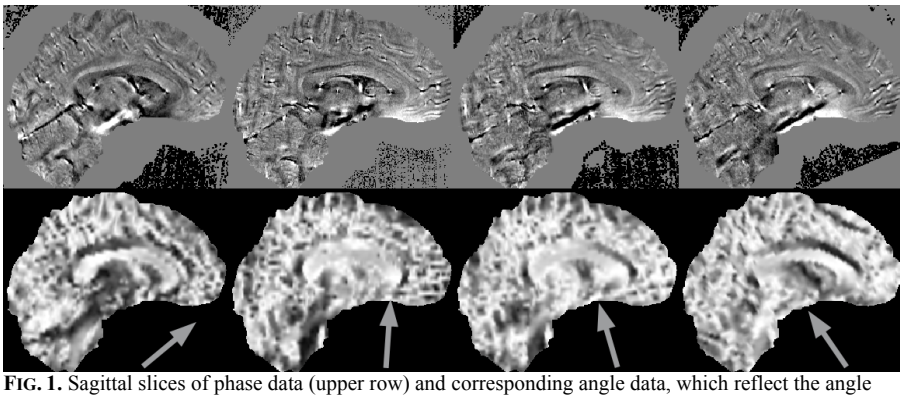

Fig. 1. Sagittal slices of phase data (upper row) and corresponding angle data, which reflect the angle between the white matter fiber orientation and the B_0 field (lower row). The arrows in the lower row indicate the orientation of the B_0 field during the acquisition, respectively.

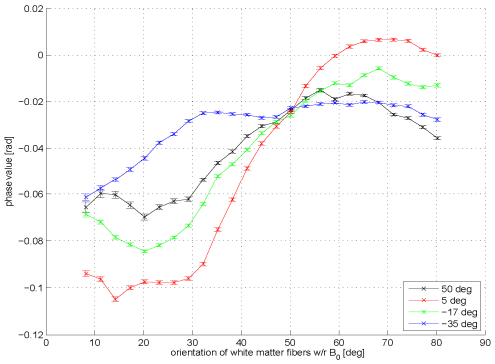

Fig. 2. Phase values vs. orientation of white matter fibers with respect to B_0 plotted for four different positions in the MR scanner

Discussion

The presented results indicate that the relation between orientation of white-matter fibers and phase not only depends on the angle with respect to the main magnetic field. This confirms one part of the recently published theoretical correlation between orientation of white-matter fibers and the external magnetic field.

References

[1] He X and Yablonskiy DA. *Proc Natl Acad Sci U S A*. 106(32):13558-63, 2009. [2] Hernandez E. et al. *ISMRM*, p953, 2009. [3] Deistung A et al. *J Magn Reson Imag*, 29(6): 1478-84, 2009. [4] Ros C et al. *ISMRM*, p1265, 2008. [5] Abdul-Rahman HS et al. *Appl Optics*, 46(26):6623-35, 2007. [6] Schweser F et al. *ISMRM*, 2010 (submitted).