Phase and diffusion tensor imaging at ultra-high magnetic field: differences and similarities

Yohan van de Looij[1,2], Rajika Maddage[2], Nicolas Kunz[1,2], Petra S Hüppi[1], Rolf Gruetter[2,3], and Stéphane V Sizonenko[1]

[1]*Division of Child Growth & Development, University of Geneva, Geneva, Switzerland,* [2]*Laboratory for Functional and Metabolic Imaging, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland,* [3]*Department of Radiology, University of Geneva and Lausanne, Geneva and Lausanne, Switzerland*

Introduction:

Diffusion Tensor Imaging (DTI) and Phase Imaging (PI) are two MR techniques used to probe brain microstructure. Through a complete description of water diffusion in the tissue, DTI gives useful information about the white matter (WM) such as fiber direction [1] or integrity [2]. The phase of gradient echo MR images is sensitive to differences in the resonance frequency and, as such, has been used to create anatomical images with excellent contrast between white and grey matter especially at ultra-high magnetic field [3]. Fiber direction, iron and/or myelin are known to influence the phase contrast but, the exact origin of this contrast is not fully understood. Even if the contrast mechanisms of these two techniques are different (i.e spin mobility for diffusion vs. signal phase variation for phase), several similarities such as an influence of myelin and fiber orientation are known [3,4]. The aim of this work was to investigate the potential cross correlations between Diffusion Tensor Imaging and Phase Imaging in the rat brain at ultra-high magnetic field.

Materials and methods:

All MR experiments were performed on an actively-shielded 9.4T/31cm magnet (Varian/Magnex) equipped with 12-cm gradient coils (400mT/m, 120µs) with a quadrature transceive 20-mm surface RF coil. For each rat (n=6), DTI acquisition was performed using a semi-adiabatic double spin-echo sequence [5] with the following parameters: Icosahedral 21 directions diffusion gradient sampling scheme (b = 1000 s.mm^{-2}), FOV = 23 × 15 mm^2, matrix size = 128 × 64 zero-filled to 512 × 340, 9 slices of 0.8 mm thickness in the axial plane, 8 averages with TE/TR = 42/2000 ms. Gradient-echo MR images (TE/TR = 18/900 ms; SW = 30 KHz, FOV = 23×15 mm^2, Matrix size = 512 × 340 and 18 slices of 0.4 mm thickness and 8 repetitions) were acquired for phase imaging.

Data analyses were performed with homemade Matlab software. Diffusion tensor derived parameters: diffusivities (ADC, $D_{//}$ and $D_{\perp}$) and fractional anisotropy (FA) values were derived from the tensor. To remove the effect of large-scale phase shifts across the phase images, ascribed to large-scale B_0 inhomogeneities, a 2D Gaussian high-pass filter with a kernel size of 121 voxels and a width of 10 voxels was applied to all images [3]. Regions of interest (ROIs) were manually delimited in different white matter structures: the corpus callosum (CC), external capsule (EC), anterior commissure (AC), hippocampus (Hp), and caudate putamen (CP). Diffusion tensor derived parameters as well as frequency shifts between white and adjacent grey matter (GM), were averaged in these ROIs. Correlation coefficients were assessed by using Matlab functions.

Results:

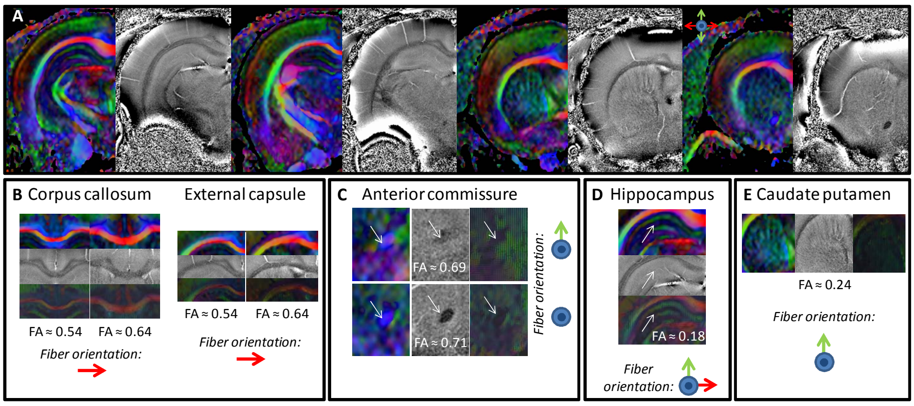

Figure 1: A: Typical DT color maps and phase images at four different image-planes from the genu to the splenium of the corpus callosum. B-E: color maps, phase images and eigenvectors zoomed on different regions of interest: CC and EC (B), AC (C), Hp (D) and CP (E). Below each zoom is displayed the mean FA and the direction of the fibers in the corresponding region. In highly anisotropic regions such as CC (B), the phase contrast is different as a function of the anisotropy degree whereas in AC the contrast changes with the fiber orientation (higher contrast in the anterior part corresponding to marked anteroposterior fiber orientation). In myelinated regions with very low FA such as Hp layers (D, arrows) the contrast is very low on phase images whereas in CP (E) with a mix of fiber directions (up-down and antero-posterior) the contrast seems predominantly related to the up-down fibers.

Figure 1A shows the superb contrast obtained between WM/GM for the two MRI methodologies: DTI and PI. In highly anisotropic regions such as corpus callosum (1B), the phase contrast is different as a function of the anisotropy degree whereas in anterior commissure (1C) the contrast changes with the fiber orientation (higher contrast in the anterior part corresponding to marked anteroposterior fiber orientation). In myelinated regions with very low FA such as hippocampal layers (1D, arrows) the contrast is very low on phase images whereas in caudate-putamen (E) with a mix of fiber directions (up-down and antero-posterior) the contrast seems predominantly related to the up-down fibers. Only in corpus callosum, frequency shift between WM and adjacent GM was inversely correlated (data not shown) to MD (r = -0.41, P = 0.025), $D_{//}$ (r = -0.55, P = 0.002) and FA (r = -0.33, P = 0.05). The correlation with $D_{\perp}$ was positive (r = 0.15) but not significant. Indeed, when looking at the variation in corpus callosum and external capsule through over the different slices the plot of the frequency shift over the slices seems to follow the same trend as $D_{\perp}$ but an opposite to $D_{//}$ and FA (data not shown).

Discussion and conclusion:

This study confirms the excellent contrast obtained on phase images at ultra-high magnetic field [3]. In the principal bundle of fibers (corpus callosum and external caspule) highly anisotropic, this contrast is better. Nevertheless, this excellent contrast in this region is also due to the fact that the main magnetic field, B_0, has a front-rear orientation i.e. perpendicular to these bundles of fibers [3]. In the anterior commissure, the highest contrast was observed at the anterior part corresponding to an area with a marked anteroposterior fiber orientation (dark blue on color maps), confirming the known effect of the fiber orientation.

In myelinated regions with low FA such as the hippocampal layers, contrast between white and grey matter on phase images was extremely low whereas the different layers were clearly visible on color maps. This result suggests also an effect of the fiber organization to the phase contrast.

Through the corpus callosum in the anteroposterior direction, the FA is changing: lower in the body than in the splenium and in the genu. This change is due to the well-known non uniform structure of the CC, with larger axons in the body than in the extremities [6]. It has been shown that the FA decrease in the body is due to a twofold phenomenon: increase of radial diffusivity and decrease of axial diffusivity [6]. According to the variation of frequency shift through over the CC and the correlations observed with the diffusivities, one can imagine an effect of the axonal compaction/axonal diameter on the phase contrast. Further experiments are in progress to quantify more accurately these results by an assessment of the correlations between DTI and susceptibility maps.

References: [1] Basser PJ. et al. MRM 2000. [2] van de Looij Y. et al. NMR in Biomed 2011. [3] Marques JP et al. Neuroimage 2009. [4] Lodygensky G. et al. Neuroimage 2012. [5] van de Looij Y. et al. MRM 2011. [6] Barazany D. et al. Brain 2009.

Supported by the FNS N°31003A-135581, the CIBM of UNIL, UNIGE, HUG, CHUV, EPFL, Leenards-Jeantet foundation.