Phantom study on the dependency of the MRI phase contrast on the underlying micro structure

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Introduction: Signal phase contrast in gradient echo imaging delineates anatomic brain structures in great detail **(1)**. While the phase contrast in the deep gray matter nuclei has been attributed to iron, the origin of the phase contrast between gray and white matter is not yet fully understood **(2)** and several theories have been proposed. He and Yablonskiy, for example, proposed a Lorentzian cylinder approximation which predicts phase effects due to the (sub-)cellular diffusion anisotropy in the vicinity of myelin bundles **(3)**. Liu et al., on the other hand, found considerable anisotropy of the magnetic susceptibility of myelin-lipids **(4)**. The purpose of this work was to investigate both phenomena more closely using phantom experiments with well-defined magnetic and structural properties.

Materials and Methods: Three 15ml tubes (10cm long and 14mm inner diameter) were immersed in the middle of a spherical phantom holding 4.3 liters saline. The tubes were placed about 4cm apart and oriented perpendicular to the main magnetic field. One tube was filled with a bundle of 750 parallel oriented 10cm long pieces of nylon fishing line (diameter of single string was 200µm). The total volume of the nylon strings was about 2.35ml which occupied a volume fraction of about 15% of the tube. Another tube was filled with the same amount of fishing line but cut into 1-5mm long pieces which were randomly oriented. The third tube was filled with saline only for later adjustment of the influence of the tube wall material. MR phase data of the phantom was acquired using a 3T clinical scanner with double echo gradient echo imaging with TEs=10/40ms, TR=100ms, FA=25°, matrix=128x128, FOV=200x200mm^2.

The magnetic property of the nylon string material was assessed by measuring a single string piece placed across the inside of a 50ml Falcon tube filled with saline, so that the string was oriented perpendicular, and the tube parallel to the main magnetic field of a 7T small animal MR scanner. Double echo gradient echo imaging sequence parameters were: TEs=5/10ms, TR=100ms, FA=10°, matrix=512x512, FOV=25x25mm^2.

Field maps were generated by complex division between the phase images of the two echo times. Macroscopic background field inhomogeneities were minimized by fitting a quadratic correction function to the field map values of the farther surrounding of the investigated objects. To eliminate the influence of the tube wall, the field maps of the different tubes were also subtracted from each other.

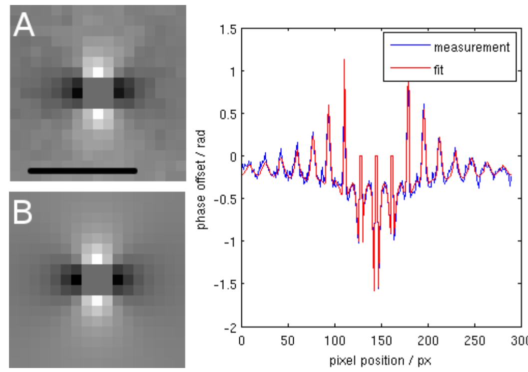

Figure 1: Measured (A) and fitted field map (B) of single string. Black bar indicates 1mm. Main magnetic field penetrates from left to right. The one dimensional plot over all field values in the field map better depicts the similarity between the measured and fitted field maps.

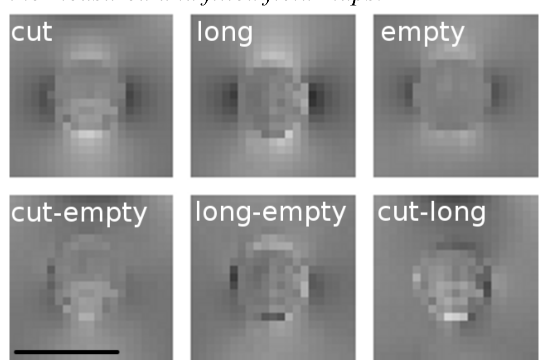

Figure 2: Field maps of phantom tubes filled with cut or long strings or saline only (upper row). Their subtractions with each other eliminates the influence of the tube wall (lower row). Black bar indicates 20mm.

Results: Fitting of the field distortion of the single string with the cylindrical dipole field using the string's 100µm radius as constraint **(5)** yielded a magnetic susceptibility of $\Delta\chi = -0.36$ppm with respect to the surrounding saline (Fig.1). The negative $\Delta\chi$ means that the string material was more diamagnetic than saline. The difference of the field maps of the tubes filled with long and cut string pieces (Fig.2, cut-long) gives an inverted contrast as compared to all other sub pictures of Figure 2. This suggests that the generated local field distribution of the long strings is stronger diamagnetic then that of the cut strings.

Discussion and Conclusion: With the assumption of an isotropic magnetic property of the nylon strings our findings are in agreement with He and Yablonskiy which suggest a stronger field effect of fibers oriented perpendicular to the main magnetic field than non-oriented fibers **(3)**.The heterogeneous appearance inside the tubes filled with cut or long nylon strings is caused by an inhomogeneous distribution of the strings due to settlement. However, this can be easily overcome by preparing the phantom with a higher volume fraction of strings which was relative low (15%) at the time of these measurements. Therefore, the obtained field maps need to be validated using another phantom made with higher string volume fraction. We believe that our experimental setup will, additional to the presented results, help to better understand the origins of the anisotropic phase effect observed in white matter **(3, 4)**.

References: **(1)** Rauscher A et al. AJNR. 2005;26:736-42. **(2)** Langkammer C et al. Neuroimage. 2011 Aug 26 Epub **(3)** He X and Yablonskiy DA. PNAS. 2009;106:13558-63. **(4)** Liu W et al. Neuroimage. 2011 Oct 20 Epub **(5)** Yablonskiy DA and Haacke EM. MRM 1994;32:749-63.