Understanding the orientation dependent T2* contrast of the cingulum in ultra high fields

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Introduction:

It was shown recently that high resolution T2*-weighted images, acquired at ultra high field, display T2* heterogeneity in white matter [1], and an unexpected signal dependence in the cingulum bundles on head orientation to the main magnetic field [2]. The orientation dependence was not been observed in ex-vivo samples at lower field strength [3]. Because the effect of susceptibility variations increases with field strength, the orientation dependence might thus only be observable at higher fields [2], and/or in-vivo [4]. The signal change with orientation is still poorly explained. Here we used, in addition, phase images arising from high resolution spoiled gradient echo sequences, because such images are more sensitive to susceptibility effects [5]. We also obtained TSE images to determine whether the orientation dependence of the signal appears in that sequence as well. We also compared the measurements with simulations of simple model using the forward field calculation [6].

Methods:

Images were acquired with a whole body 7T scanner (MAGNETOM, Siemens Medical Solutions, Erlangen, Germany) using an 8 channel phased array coil (Rapid, Rimpar, Germany). The subject was firstly positioned supine in the magnet, and 40 coronal slices using a 2D fully flow-compensated spoiled gradient echo sequence (TR/TE=1400/23 ms, bw=130 Hz/pixel; voxel=0.6x0.6x1mm³) were acquired. TSE images were acquired with TR/TE=5910/22 ms, turbo factor 8, flip angle 60°. Then subjects were asked to tilt their heads backwards (hyper-extended), which results in an angle of about 27 degrees compared to the first position. The same scanning parameters were used. The slices were repositioned to cover the same area of the head.

Field perturbations due to a susceptibility distribution $\chi(\mathbf{r})$ in a magnetic field B_0 applied in the z-direction were evaluated by inverse 3D Fourier transformation (FT) of $B_0\mathrm{X}(\mathbf{k})(1/3\text{-}\cos^2\beta)$, where $\mathrm{X}(\mathbf{k})$ is the 3DFT of $\chi(\mathbf{r})$ and β is the angle between **k** and the k_z-axis [6]. This approach has the advantage of naturally including the effect of the sphere of Lorentz so that multiplication of the calculated field, offset by the magnetogyric ratio γ yields the NMR frequency offset [6]. Field changes due to object rotation may also be easily evaluated. Simulations were carried out in which the cingulum bundles and the corpus callosum were represented by simple tubes (6 voxels diameter), placed in a 3D matrix size of 128^3. Susceptibility values were chosen as -9.4 ppm for the tubes and -9.5 ppm for the surrounding volume.

Both the measured phase data and simulated field-shifts were high-pass filtered so as to remove phase variations occurring on a large length scale. This was accomplished by dividing the original complex data by a low-pass filtered version of the data, formed via Gaussian Fourier filtering (15 pixels FWHM).

Results and discussion:

As shown in Figure 1, in the cingulum both the magnitude (b,f) and the phase data (c,g) of the T2*-weighted images show an orientation dependence with respect to the main magnetic field. For comparison: A signal change of 12 % for the magnitude and a change in field-shift of about 2.2 Hz using the phase information (Table1). By contrast, there is almost no signal change in the magnitude and only 1.4 Hz change in the phase in the corpus callosum (see also Table1). Both fibre bundles are perpendicular to the B0 field in the supine head position. The relative orientation of the cingulum fibres to the B0 field is changed when the head is in the hyper-extended position, whereas the bundles in the corpus callosum are still perpendicular. The TSE images (Fig.1 d,h) do not show any signal change in these areas (Table1). Field-shift simulations predict a field change of 0.007 ppm (2.1 Hz at 7T) for the "cingulum" and 0.0029 ppm (0.9 Hz at 7T) for the "corpus callosum". This approximate agreement with a simple model suggests that a change in demagnetizing factor of the cingulum with orientation may explain the effect.

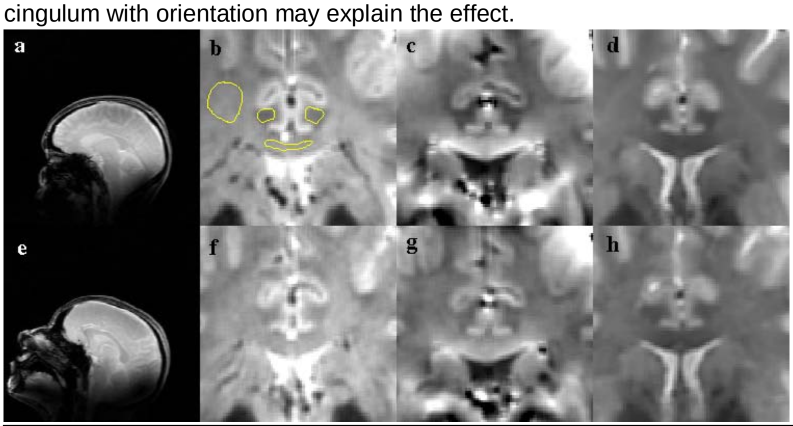

Figure1: The magnitude (b), phase image (c) and TSE (d) acquired at the supine position (a) and the magnitude (f), phase image (g) and TSE (h) at the hyper-extended position (e). The yellow areas in (b) display the regions for the Cingulum, Corpus Callosum and the control region.

	Left Cingulum	Right Cingulum	Corp. Callos.
Magnitude	0.84 ± 0.01	0.92 ± 0.01	1.12 ± 0.01
Fieldshift [Hz]	-2.32 ± 0.09	-1.91 ± 0.08	4.2 ± 0.5
TSE	0.83 ± 0.01	0.82 ± 0.01	0.78 ± 0.01

	Left Cingulum	Right Cingulum	Corp. Callos.
Magnitude	0.94 ± 0.01	1.04 ± 0.01	1.12 ± 0.01
Fieldshift [Hz]	-0.25 ± 0.02	-0.4 ± 0.03	2.8 ± 0.1
TSE	0.81 ± 0.01	0.82 ± 0.01	0.75 ± 0.01

Table1: The normalized values (S/Scontrol for magnitude and TSE, $\varphi\text{-}\varphi_{control}$ for field-shift) for the normal head position (top) and hyper-extended head position (bottom).

References:

[1] Li *et al*. NeuroImage 32:1032-1040 (2006) ; [2] Wiggins *et al*. Proc ISMRM 16:237 (2008) ; [3] Henkelmann *et al*. MRM 32:592-601 (1994) ; [4] Wiggins *et al*. Proc OHBM 14:650 M-PM (2008) ; [5] Duyn *et al*. PNAS 104 (26):11796-11801 (2007) ; [6] Salomir *et al*. Conc. MR 19B: 26-34, (2003)