Exploring Orientation Dependence of T2* in White Matter by Extreme Rotation of the Human Head at 7 Tesla

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Introduction: T2* weighted gradient echo scans at 7T have revealed surprising variation in image intensity in white matter [1]. Various mechanisms have been proposed, including differences in iron concentration or myelin density in various white matter fiber bundles or variation in density and orientation of venous micro-vascular elements [1]. The dependence of white matter contrast variation on orientation relative to the main magnetic field was clearly demonstrated in high field animal brain T_2^* imaging [2]. Although the effect is smaller at lower field, it has been evaluated in 3T human brain imaging, where it is suggested that T2* varies according to $1 / (R2 + k\,sin^2(\theta_z))$ where θ_z is the angle between the fiber orientation and B_0[3]. Studies using fixed ex-vivo brain samples have failed to find any orientation dependence [7], suggesting that the fixation process changes the tissue in a way that eliminates this contrast mechanism. We image the human brain in vivo in positions which vary the angle relative to B_0 by close to 90 degrees in order to study the orientation dependence of T2* in white matter.

Methods: We have constructed a coil system at 7T which allows the head to be rotated by greater than 90 degrees to further investigate this phenomenon. It is described in more detail in a separate abstract by Zhang et.al. We use traveling waves excited by a patch antenna for RF excitation [4], and a six-element U-shaped receive-only coil which wraps over the crown of the head. This allows the subject to lie on a custom cushion on the patient table rails in a sphinx position, with the face pointing towards the service end of the bore. Data obtained in this way are compared to data on the same subject in the regular head-first supine position using a 24 element receive array with volume coil transmit (Nova Medical, Wilmington MA)

When using traveling wave excitation, the required RF pulse voltage was calibrated with a 2D GRE sequence at a number of RF pulse amplitudes (TR/TE=1000ms/19.3ms, Slice=5mm, BW=30.0, 64×64 matrix, FOV=192×192, RF amplitudes from 50 to 350v). Multi-echo gradient echo images were then acquired using the appropriate RF voltage for a nominal 45° flip angle (TR=700ms, TE = 12.24, 23.45, 34.67, 45.89 ms, Slice=1.5 mm, BW=190.0Hz/pixel, 640×640 matrix, FOV=200 mm × 200 mm). T2* maps were calculated on a voxel-by-voxel basis by fitting a straight line to the logarithmic signal decay as a function of TE.

Results: With the subject in the sphinx position the orientation of the brain relative to B_0 is 80° different from when in the supine position (Fig. 1, top). Contrast variations are clearly visible in the magnitude T2* images (Fig. 1, bottom). The local T2* values for axial and coronal slices are mapped in Figure 2. Regions of interest are depicted in Figure 3, with mean T2* values for the various ROIs are listed in Table 1. It is clear that T2* values are essentially inverted between regions by the change of orientation in these ROIs, except in the Corpus Callosum. The nerve fibers of the Corpus Callosum are oriented such that they transverse the brain from left to right, which means that they do not change their orientation to the applied field appreciably between the two head positions.

ROI	Supine	Sphinx
Corpus Callosum	28	24
Cingulum Right	24	35
Cingulum Left	25	36.5
Centrum Semiovale Right	38	23.5
Centrum Semiovale Left	37	23.5
Centrum Semiovale Medial	22	36
Centrum Semiovale Lateral	31	24

Table 1: Mean T2* values in the ROIs depicted in Figure 5. There is little change in the Corpus Callosum, whose fibers are perpendicular in both orientations, but substantial changes elsewhere

Discussion: The ability to perform in-vivo measurements of MR properties at UHF at very different tissue orientations should help to elucidate the mechanisms involved. The behavior observed here and in previous studies shows a shorter relaxation time if the fiber bundle is oriented perpendicular to the applied magnetic field, which is different from the Magic Angle behavior that has been observed in peripheral nerves [5] and tendons. For a full understanding of the phenomenon, it will clearly be important to characterize individual brain areas at a number of intermediate orientations, which this apparatus makes possible.

[1] Li T, NeuroImage 32 (2006) 1032 [2] Wiggins CJ, et al, ProcISMRM 2008 p237 [3] Bender B, et al, NMR Biomed, p1071-11076, 2010 [4] D.O. Brunner et al. Proc. ISMRM 2008 [5] Chappel et al. AJNR 25:431-440 (2004)

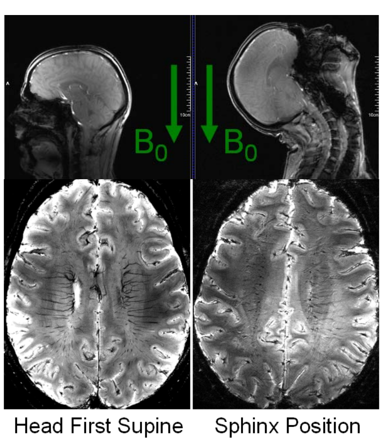

Fig. 1 Sagittal GREs (top) in scanner coordinates showing head rotation and corresponding T2* weighted GREs

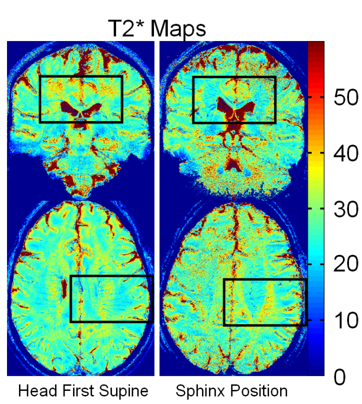

Fig. 2. T2* maps measured in Supine (left) and Sphinx (right) positions

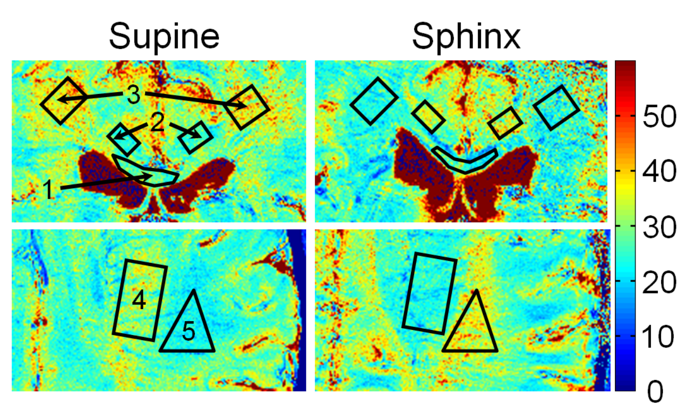

Fig. 3. Regions of interest in the T2* maps: 1) Corpus Callosum, 2) Cingulum, 3) Centrum Semiovale, 4) C. Semiovale Medial. 5) C. Semiovale Lateral. T2* values clearly reversed except in 1)