Measurement and theoretical description of spin-echo T2 anisotropy in the human brain

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Introduction: In this work we demonstrate spin-echo T_2 anisotropy in the human brain, and present a theoretical framework for its description in biophysical terms. The work is motivated by the sensitivity of T_2 to many aspects of tissue microstructure, physiology and pathology, such that deeper understanding of T_2 can provide detailed information on tissue state not apparent by visual inspection of weighted images.

Methods: Volunteers were scanned at 3 T with an MPRAGE, multi-contrast spin-echo (TE = 12:12:144 ms) and 60-direction DTI sequence (b = 1000 mm^2/s) , these being repeated with the subject's head tilted at 3 different orientations relative to the main magnetic field. T_2 maps were computed by a voxel-wise mono-exponential fit. Diffusion tensors were fitted using fsl. The T_2 dependence on the angle between the principle eigenvector of the diffusion tensor and B_0 (θ_{FB}) as well as fractional anisotropy (FA) was extracted by bin-ranging θ_{FB} and FA, then averaging the corresponding T_2 observations. 15 minutes measurement time were used per orientation.

Theory: T_2 is anisotropic if its value is dependent on the orientation of the voxel under observation with respect to the applied magnetic field[1]. Our model for this is based on intramolecular proton dipolar couplings. We assume that water molecules bind an oriented structure reversibly (in fast exchange), such that a particular set of dipole tensor orientations are preferred, making T_2 anisotropic. In the bound state(s), Gaussian axial fluctuation[2] (GAF) dynamics are assumed. The effective spin-echo T_2 is then

$R_2(\Omega) = (1 - f^{Aniso}) R_2^I + f^{Aniso} R_2^A(\Omega)$ Where R_2^I is the isotropic R_2, $R_2^A(\Omega)$ is the (orientation-dependent) anisotropic R_2 at orientation Ω, f^{Aniso} is the fraction of anisotropic water (or other observable spins). Representation of anisotropy is through the spectral density function, calculable in an arbitrary frame from the principle axis system (PAS) of the dipole tensor with

$J_q(\omega,\Omega) = \sum_{nn'=-2}^{2} D_{qn}^{(2)}(\Omega) D_{qn'}^{(2)*}(\Omega) J_{nn'}^{D}(\omega)$ where $D^{(2)}$ are 2^{nd}-rank Wigner rotation matrices, J^D is the spectral density function in the dipolar PAS and J the spectral density in the frame of observation. It is calculated from the GAF model. Data fitting and simulation was by bespoke software written in Matlab.

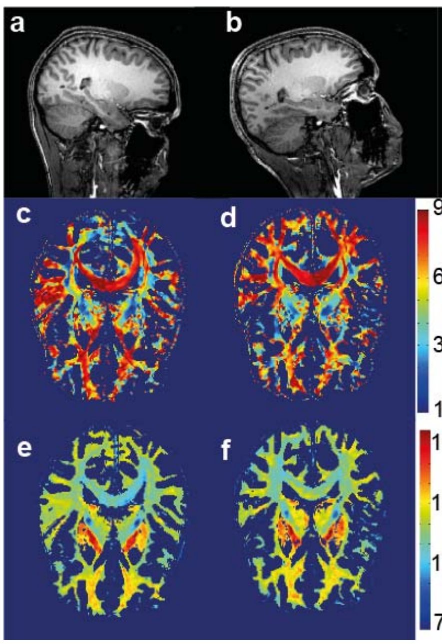

Figure 1. (a-b) MPRAGE images at 2 different subject orientations, (c-d) corresponding θ_{FB} angle maps, (e-f) corresponding R_2 maps. The R_2 scale bar is in s^{-1}

Results: Figure 1 shows T_2 and θ_{FB} maps for 2 subject orientations. T_2 is evidently different once the system is rotated. The dependence of T_2 upon FA and θ_{FB} for a particular subject orientation is given in Figure 2 along with examples of the fit of the dipolar model for particular FA bin ranges. We observe a dependence of T_2 upon θ_{FB} in gray matter (GM) and white matter (WM) but with an inverted form, the dependence in both cases being stronger at higher FA. Thus a higher degree of spatial restriction on translational diffusion correlates with greater T_2 anisotropy. The dipolar model is a very good fit to the data for both GM and WM. By performing the data analysis in this way, regional T_2 anisotropies can be determined without the need for measurements at multiple subject orientations, relying instead on the directional information encoded by DTI.

Conclusions: T_2 anisotropy can be detected by spin-echo measurements both in GM and WM and is consistent with a dipolar model. We expect that measurements of T_2 anisotropy will allow for more detailed assessments of tissue microstructure.

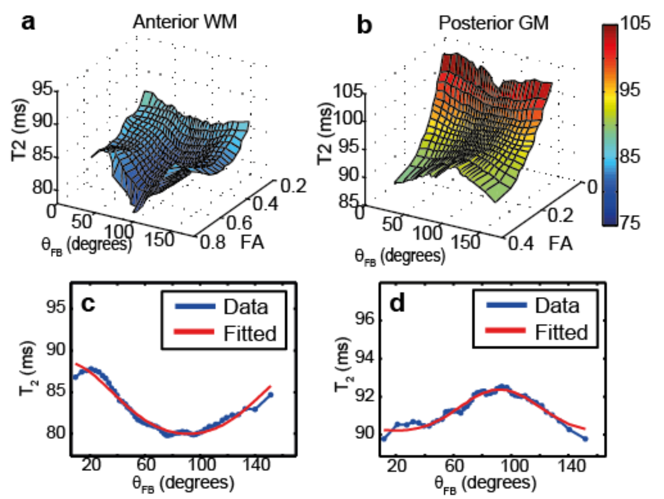

Figure 2. T_2 dependence on θ_{FB} and FA for anterior WM (a) and posterior GM (b). (c) and (d) show the fit of the dipolar model to WM and GM data respectively for particular FA bin ranges.

References:

1. Nicholas *et al.* (2010) Proc. Nucl. Magn. Reson. Spectrosc. 57(2): 111-158

2. Lewandowski *et al.* (2009) J. Am. Chem. Soc. 132(4):1246-1248