Whole-Brain Tissue-Based Assessment of the Ultrashort T2 Component Using 3D UTE MRI Relaxometry

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Introduction: Ultrashort echo time (UTE) MRI is used to probe signals from tissue components with T_2 relaxation times in the sub-millisecond range [1], typically generated by quasi-solid macromolecular structures. UTE MRI has been recently suggested as a promising method to measure directly the myelin content of nerves [2] and as a potential probe for myelin in brain white matter [3]. In this work we present a whole-brain tissue-based characterization of the ultrashort T_2 components using 3D UTE MRI. Initial results show clearly distinct distributions of ultrashort relaxation rates in gray and white matter.

Materials and Methods: 3D UTE was performed on a 3T scanner (Achieva TX, Philips HealthCare) equipped with a 32 channel receive coil array in 5 healthy volunteers (28 ± 4 years). A stack of radials UTE sequence (similar to [4]) was used sampling radial FIDs in the sagittal plane, phase encoding in the left-right direction (FOV: 240×240×159mm³,voxel: 1×1×3mm³, flip angle: 10°, TR = 20ms, pixel BW = 0.434 kHz, TFE=17). Magnetization preparation was employed to suppress long-T_2 components (by applying a 90° sinc-gauss pulse (10ms) followed by a crusher) and to suppress fat signal (using SPIR (spectral presaturation by inversion recovery)). The reconstruction was based on Roemer's scheme [5]. Different echo times were used: 0.12, 0.14, 0.17, 0.20, 0.24, 0.30, 0.38, 0.45, 0.70, 2.00, 5.00 and 16.00 ms, for a total scan time of about 50 minutes. In Fig. 1, images from one subject obtained at two different echo times are shown. All UTE images from the same subject were co-registered to the first UTE image (TE = 0.12ms) using the FSL FLIRT software package [6]. Tissue-based probabilistic tissue maps were computed based on the high resolution T1-weighted image using the FSL-FAST software package [7]. The probabilistic maps were then registered to the first UTE volume such that they had the same resolution and orientation as the UTE images. A conservative threshold of 90% was applied to the probabilistic maps in order to obtain gray matter and white matter tissue masks. For each voxel, a bi-exponential fit was computed based on the signal intensity at different echo times, using a multivariate constrained nonlinear optimization method, and which yielded voxel-wise fractions and T_2 values for the ultrashort T_2 component and the remaining, "long" T_2 component. All analyses were performed using MATLAB ® (Mathworks, Natick, MA).

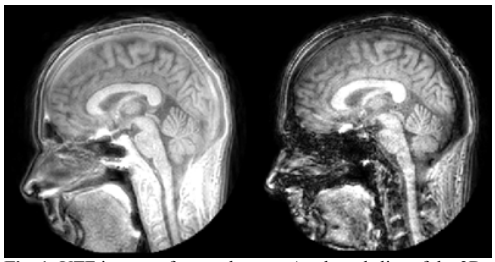

Fig. 1: UTE images of one volunteer. A selected slice of the 3D data is shown at (left) TE = 0.12ms and (right) TE = 5ms.

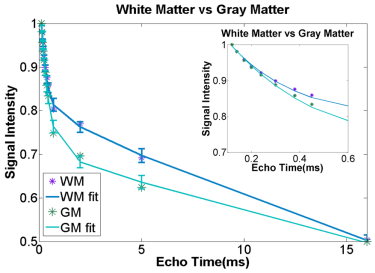

Fig. 2: Bi-exponential fit to the mean signal decay in white and gray matter for all subjects. The small error bars indicate the consistency of the estimated values in between subjects.

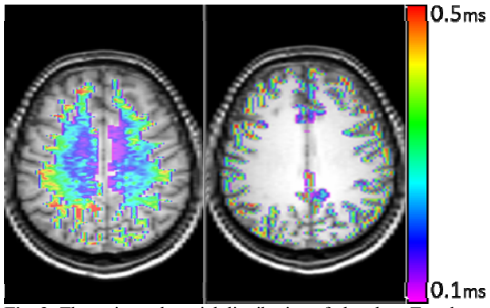

Fig. 3: The estimated spatial distribution of ultrashort T_2 values of white and gray matter in the parietal region.

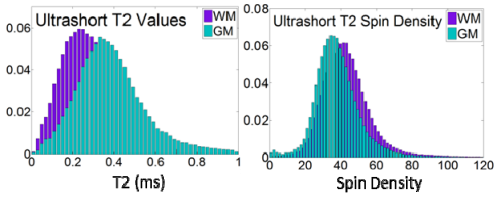

Fig. 4: Estimated ultrashort T_2 and spin density distribution. Significant difference is seen for WM and GM T_2.

Results: In Fig. 2, the mean signal intensities of white and gray matter for all subjects are plotted for each echo time. The fits for white and gray matter are drawn based on the estimated parameters. The mean ultrashort T_2 values across subjects in white and gray matter are estimated to be 0.26±0.02ms and 0.38±0.02ms respectively, and the FWHM of the T_2 distributions are 0.16ms and 0.19ms, respectively. Fig. 3 shows tissue-based maps of the ultrashort T_2 values. Normalized histograms of these values and spin densities in gray and white matter (Fig. 4) show significant difference in the ultrashort-T_2 values in white matter compared to gray matter, but not in the spin densities of the ultrashort T_2 component.

Discussion and Conclusion: The histograms in Fig. 4 strongly suggest two distinct distributions of ultrashort T_2 values for gray and white matter. The ultrashort T_2 component in gray matter is robust and reproducible across subjects, especially given the conservative constraints on tissue probability set for the definition of gray matter pixels. This component may be attributed to a host of macromolecular structures present in gray matter, and is likely to contain a significant contribution from protons in phospholipids in cell membranes. The estimated mean and distribution of the ultrashort T_2 value for white matter is consistent with data previously obtained from 2D UTE studies [8]. This component is likely to contain contributions from cell membranes as well as from myelin, which is much more ubiquitous in white matter than in gray matter. This implies that the actual ultrashort T_2 value of myelin protons may be even shorter than the mean value found here and in previous works. Further work is needed to corroborate the link between the ultrashort T_2 components with the macromolecular content of both tissue types, and in particular the white matter ultrashort T_2 component with myelin density. For that purpose, correlations with other imaging modalities that indirectly reflect myelin concentrations are being carried out, as well as correlation of the spatial patterns of the ultrashort T2 value and spin density with histology. Emphasis is also being put on devising a more efficient estimation (and possibly removal) of the residual "long" T_2 components, which affect the estimate of the spin density of the ultrashort T_2 component, as well as on an efficient data collection strategy that will shorten the scans to a more clinically-relevant scan time.

References: [1] Waldman A, et al., Neurorad 45:887-892 (2003). [2] Horch RA, et al., MRM 66:24-31 (2011). [3] Du J, et al., Proc. ISMRM, 2007, P3368. [4] Qian Y, et al., MRM 60(1):135-45 (2008). [5] Roemer P, et al., MRM 16(2):192-225 (1990). [6] Jenkinson M, et al., Med. Img. An. 5(2):143-156, 2001. [7] Zhang Y, et al. IEEE Trans. on Med. Img. 20(1):45-57 (2001). [8] Nayak KS, et al., Proc ISMRM, 2000, P509.