Challenges in Ultrashort Echo Time Relaxometry of the Human Brain

Ece Ercan[1], Peter Börnert[2], Maarten Versluis[1], Tom Geraedts[3], Andrew Webb[1], and Itamar Ronen[1]
[1]C.J. Gorter Center for High Field MRI, Department of Radiology, Leiden University Medical Center, Leiden, Netherlands, [2]Philips Research Laboratories, Hamburg, Germany, [3]Philips Healthcare, Best, Netherlands

Target Audience: Researchers and clinicians interested in new contrast methods for myelin imaging, ultrashort echo time (UTE) imaging of the human brain or relaxometry in the ultrashort and short echo time ranges.

Purpose: **(1)** To investigate the challenges in UTE relaxometry of the human brain, and in particular the possibility of mapping the UTE-MRI signal in brain white matter, potentially generated by the immobile protons in the myelin backbone, with phantom experiments and human data. **(2)** to examine the efficiency of various strategies of improvements of the suppression of the long-T_2 components on such experiments.

Methods: All imaging experiments were performed on a 3T scanner (Achieva TX, Philips HealthCare) equipped with a 32 channel receive coil array. *Phantom Experiments:* The phantom consisted of 3 tubes filled with water and 4 tubes containing manganese chloride ($MnCl_2$) solutions at different concentrations resulting in T_2^* values of (i) 0.19, (ii) 0.94, (iii) 8.64 and (iv) 30 ms. Relaxometric data was acquired using a 3D stack of radial UTE acquisitions[1] at 11 different logarithmically-spaced echo times between 0.1 ms and 14 ms. Scan parameters: resolution: 2.5×2.5×2.5 mm^3, flip angle: 10^0, TR = 20 ms, and SENSE factor = 3. Suppression of the long T_2 components was achieved by means of a 90^0 sinc-gauss pulse of 10 ms duration followed by a crusher. The scan with the shortest TE was repeated without the suppression pulse for normalization. The protocol was repeated for Turbo Field Echo (TFE) factors (number of excitations per set of prepulses) 1, 5 and 17. The data were acquired with two different acquisition schemes: (1) without and (2) with changes aimed at improving suppression of the long-T_2 components including: (a) phase cycling of the magnetization preparation pulse; (b) three-fold increase in crusher gradient amplitude following the UTE encoding; (c) added crusher gradients at the end of the magnetization preparation.

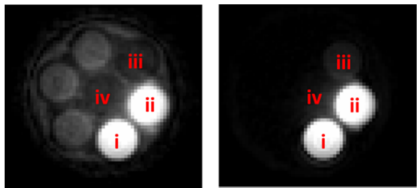

Figure 1: Phantom scans without (left) and with (right) changes to increase the efficiency of long T_2 suppression. Suppression of the signal from the water tubes and the tube with T_2* of 30 ms (iv) is improved with scheme 2.

Human Data: Scans with similar scanning parameters were performed on 2 healthy volunteers (both females, mean age: 22.5 ± 0.7 years). Fat suppression with spectral presaturation by inversion recovery (SPIR) was added. Radial FIDs were sampled in the sagittal plane. The protocol was repeated applying acquisition scheme (2) described above for TFE = 1 and TFE = 5. All further analysis was done with MATLAB®.

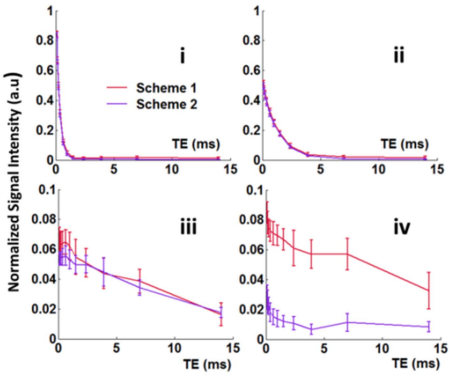

Figure 2: Averaged normalized signal acquired with TFE = 1 from the tubes with T_2* values of (i) 0.19, (ii) 0.94, (iii) 8.64 and (iv) 30.00 ms. The acquisition with the scheme 2 resulted with a lower signal intensity for the solution with a T_2* of 30 ms, thus improves the suppression of such T_2* range. Non-exponential behavior observed for the case (iv).

Results and Discussion: Figure 1 shows the phantom scans with TFE=1 for the acquisition schemes (1) and (2), respectively. The changes to the pulse sequence show a clear improvement in long T_2 suppression. In Fig. 2, the average signal (within an ROI of 15x15mm^2 chosen inside each tube of different T_2* values) is plotted as a function of TE for schemes (1) and (2) for TFE = 1. The signal from each voxel is normalized to the acquisition without any long T_2 suppression. The scheme (2) improves the suppression of the signal from the solution with a T_2* value of 30 ms (Figure 2. (iv)). The improved sequence was then used to acquire relaxometric data with different TFE factors. As expected, an increase in TFE resulted in higher signal for all TE values, as shown in Fig. 3 for the solutions with longer T_2*s (iii and iv). However, a loss of monoexponentiality is observed, giving rise to an artifactual ultrashort T_2 component and a pseudo-oscillatory behavior, clearly seen for both TFE values. Figure 4 shows an axial UTE image of the brain with TE = 0.1ms and TFE = 5. An ROI of 50x25mm^2 is selected from parietal white matter (as shown in red) for relaxometric data for both TFE values. The signal is again normalized with the non-suppressed scan. Signal decay shows a similar behavior for both TFE = 1 and TFE = 5, and a higher signal amplitude for the latter case (Fig.5). A non-exponential behavior is observed in the signal decay around TE = 2.4ms for TFE = 5 and around TE = 4ms for TFE = 1, similarly to our observations on the phantom data as well as the signal decay shown for the knee cartilage by Qian et al.[2] which has a free water component with a T_2* of 12 – 35 ms. We suspect that this behavior is due to the contribution of a small component of non-suppressed signal from the tissue constituents in the T_2 range of 10-30 ms and does not represent a genuine UTE signal from e.g. the myelin backbone.

Conclusion: We have shown significantly improved long T_2 suppression in UTE experiments. Non-exponential decay observed in both phantom and the human brain tissue indicates a possible contamination of the signal in the ultrashort echo times due to the non-fully suppressed longer T_2 tissue constituents such as myelin water (reported[3] to possess a T_2 of 20 ms), which appears to generate a pseudo-UT_2 component which must be considered in the quantification and measurement of the true UTE signal from myelin.

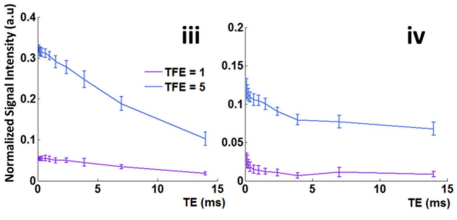

Figure 3: Normalized signal acquired with the scheme 2 from the tubes with T_2* of 8.64 ms (iii) and 30 ms (iv) with TFE = 1 (purple) and TFE = 5 (blue). Greater suppression is observed with TFE =1.

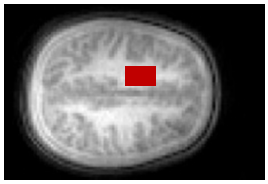

Figure 4: UTE brain images acquired with TFE = 5 at TE = 0.1 ms. A WM ROI (red) is chosen to calculate average signal intensity from voxels in this region.

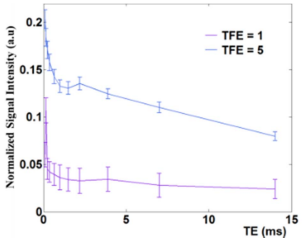

Figure 5: Average signal intensity in the chosen ROI from UTE brain images acquired with TFE = 1 and TFE = 5 with scheme 2. Non-exponential behavior is observed for both cases.

References: 1. Qian Y, et al., MRM (2008). 2. Qian Y, et al., MRM (2012). 3. Meyers S.M. et al., MRI (2009).