Myelin Water-weighted Imaging

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Background/Purpose Image contrast in the white matter of the brain is generated from the multiple water compartments: myelin, axonal, and extracellular water [1]. These multiple water compartments are believed to have different T_2 [1] and T_1 [2] values. The myelin water has been suggested to have a short T_1 (~ 120 ms) and a short T_2 (~20 ms), or T_2^* (~10 ms), whereas the axonal/extracellular water has been shown to have a long T_1 (> 750 ms) and a long T_2 (~70 ms), or T_2^* (~50 ms) [1-2]. Recently, a new myelin water imaging (MWI) method, Direct Visualization of Short Transverse Relaxation Time Component (ViSTa; previously named background-suppressed MWI [4]) has been proposed [3]. This method suppresses the long T_1 signals using double inversion RF pulses with optimized timing parameters so that the myelin water signal dominates the image [3]. In this study, we have designed new double inversion timing to generate a balanced mixture of signals from myelin water and axonal/extracellular water. Different from ViSTa, which saturates most of the long T_1 (> 750 ms) signals, the new sequence, which is referred to as myelin water-weighted imaging (MWwI), leaves approximately 5% unsaturated magnetization at long T_1 (> 750 ms), generating in a mixed signal of approximately 50% myelin water and 50% axonal/extracellular water (Fig. 1). The magnitude and phase characteristics of MWwI are investigated to demonstrate the composition of the MWwI signal. The new MWwI may allow us to acquire myelin water weighted images at early echoes (< 10 ms), and other water signals at late echoes. This may give us certain benefits over conventional MWI (e.g. estimation of long T_2 characteristics) and ViSTa (direct visualization of myelin water signal without any processing).

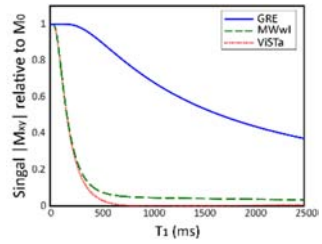

Fig.1: Signal over T_1 in GRE, MWwI and ViSTa

Methods **Data acquisition:** Five subjects were scanned at 3T using GRE, ViSTa and MWwI sequences with the following parameters: single slice, FOV = 220 × 220 mm^2, in-plain resolution = 1.72 × 1.72 mm^2, slice thickness = 5 mm, TR = 1160 ms, TE = 3:2.44:78.64 ms (32 echoes), and flip angle = 90°. The double inversion timing parameters (TI_1/TI_2/TD) for ViSTa were 560/220/380 ms [3] and, for MWwI, were 510/220/430 ms. **Data analysis:** An ROI was manually drawn at the splenium. The mean decay curves were plotted. The T_2^* distributions were estimated by fitting the mean decay curve with multiple exponential T_2^* decay using a nonnegative least square fitting [5]. In the phase images, the nonlocal background phase was estimated by filtering the unwrapped GRE phase image using RESHARP [6]. The background phase of all of the phase images was removed by subtracting the nonlocal background phase estimated in GRE. The mean phase evolution was plotted over the splenium ROI.

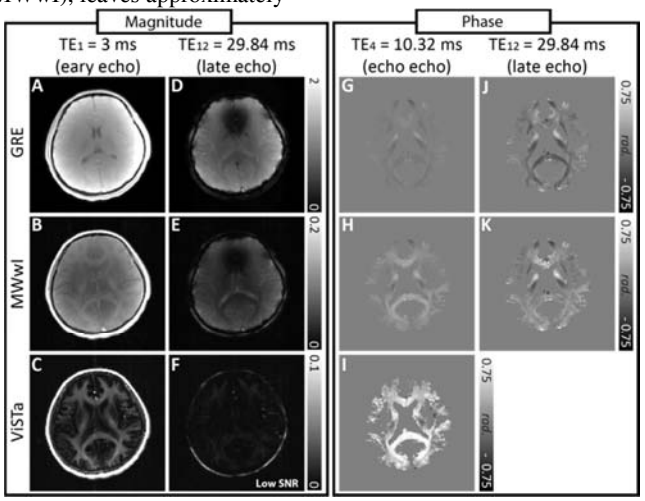

Fig.2: Magnitude and phase images at multiple echoes

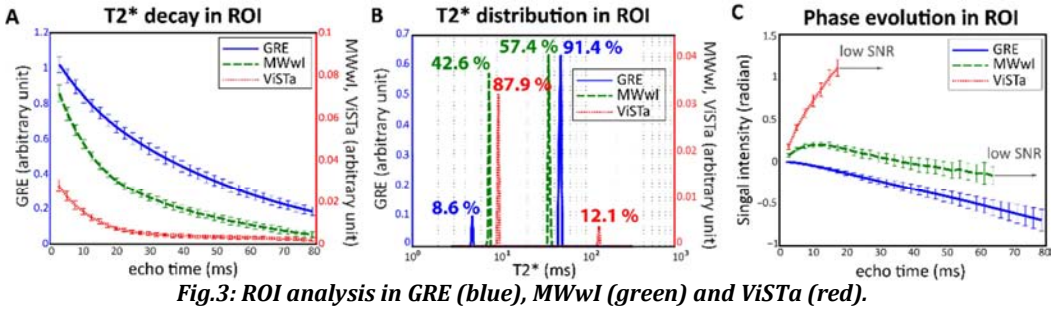

Fig.3: ROI analysis in GRE (blue), MWwI (green) and ViSTa (red).

Results Figure 2 shows the magnitude and phase images of GRE, MWwI and ViSTa at multiple echo times. An early echo (3 ms) MWwI magnitude image (Fig. 2B) shows that the structure of white matter is similar to that in ViSTa (Fig. 2C), and the baseline signal is similar to that in GRE (Fig. 2A). At a late echo (29.84 ms), the MWwI image resembles the GRE image (Fig. 2E and D), losing the short T_2^* myelin water signal. Similarly, the MWwI phase images at an early echo (10 ms) reveal a similar (but reduced) phase contrast to the ViSTa phase image, suggesting the mixture of the ViSTa and GRE phases (Fig. 2G-I). At a late echo (29.84 ms), the MWwI phase shows a similar contrast to that in GRE (Fig. 2J and K). These results are further confirmed in the ROI analysis results (Fig. 3). The magnitude decay curves of ViSTa and MWwI (Fig. 3A) show more rapid signal decays than that of GRE, suggesting a larger contribution of the fast-decaying myelin water signal. This is better illustrated in the T_2^* distribution (Fig. 3B), revealing a larger contribution of the short T_2^* (< 25 ms) myelin water signal (MWwI: short T_2^* = 47.0 ± 10.3% and long T_2^* = 53.0 ± 10.3%; GRE: short T_2^* = 7.5 ± 2.2% and long T_2^* = 92.5 ± 2.2%; ViSTa: short T_2^* = 92.0 ± 5.1% and long T_2^* = 8.0 ± 5.1%; averaged over the five subjects). The GRE phase and ViSTa phase show opposite phase evolutions (Fig. 3C), which agree with the hollow cylinder model [7]. The MWwI phase reveals positive frequency shifts at early echoes, similar to the ViSTa phase. As the myelin water signal decays away (TE = ~10 ms), the MWwI phase follows the pattern of the GRE phase, suggesting that the MWwI signal is a mixture of ViSTa and GRE signals.

Discussion and Conclusion Here, we have demonstrated that the signal contribution of different water pools in white matter can be modified by adjusting the timing in the double inversion sequence. In the new MWwI method, approximately half of the signal is from myelin water and the other half is from axonal/extracellular water. This may provide a directly observable (i.e. no post-processing required) myelin water signal at early echoes and an axonal/extracellular water signal at late echoes. In the case of mixed pathology (e.g. inflammation and demyelination), it may be necessary to estimate the myelin water signal by projecting the long T_2 signals to earlier echoes because both signals may change.

References [1] Mackay, MRM, 1994, 31, 673 [2] Labadie, MRM, 2013, online available [3] Oh, NeuroImage, 2013, 83C, 485 [4] Oh, ISMRM, 2013, #867 [5] Whittall, JMR, 1989, 134 [6] Sun, MRM, 2013, online available [7] Wharton, PNAS, 2012, 109, 18559 [8] Sati, NeuroImage, 2013, 77, 268.