WIMP: Self-Navigating Magnetization Transfer Pool Mapping with Stimulated Echoes

R. Newbould[1], C. Liu[1], S. Ropele[2], R. Bammer[1]

[1]Radiology, Stanford University, Stanford, CA, United States, [2]MR Institute, Medical University Graz, Graz, Austria

Introduction: Magnetization transfer (MT) provides information on the rate of exchange as well as relative amount of bound macromolecules present in tissue. MT has been shown useful in detecting early white matter degeneration, such as with multiple sclerosis [6]. However, quantitative MT sequences require complex multi-parametric fits. Therefore, sequences were normally only combined with simple on or off-resonant pre-pulses, from which semi-quantitative parameters, such as MTR, can be computed. However, these variants of MT sequences do not map pure bio-physical parameters and can be confounded by several factors. Transfer rate and relative fraction sizes of bound and free water pools are expected to provide more quantitative information on tissue composition [4] but presently require complicated multi-parametric models and prohibitively long imaging times [3-5]. Recently, Ropele et al. [1] introduced a novel method that provides direct measurement of bound macromolecular water content, which is based on a stimulated echo (STE) preparation scheme that modulates the phase distribution of water spins. These labeled spins are then used as an intrinsic indicator, which dilutes due to magnetization exchange with macromolecular protons. Currently, this method is limited to single-shot acquisitions due to the application of small magnetic field gradients in the preparation phase of the sequence that renders the sequence sensitive to bulk physiologic motion. In this work, we will capitalize on the self-navigating capabilities of variable density spiral trajectories [2] to accurately compensate for motion and phase accumulation, which in turn allows a more accurate BPF calculation and higher spatial resolution.

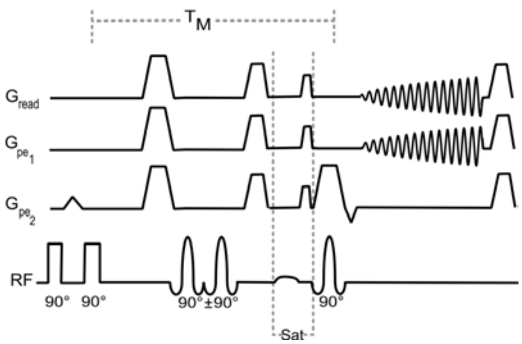

Figure 1 – Spiral-WIMP. A STE prep of length T_M containing a composite pair of refocusing pulses is followed by chemical (fat) saturation and spiral readout. The second pulse of the composite pair is chopped to form composite 180º or 0º pulses.

Methods: To measure the <u>wh</u>i<u>t</u>e <u>m</u>atter <u>p</u>ool (WIMP) size a pair of non-selective $\pi/2$ RF pulses was followed by a composite refocusing pulse. This composite pulse is built from two abutted 2.4 ms $\pi/2$ pulses (Fig. 1). The phase of the second pulse can be modulated, resulting in a total composite flip angle of 0º or 180º. A third, slice-selective $\pi/2$ pulse, at a mixing time T_M (200ms) from the second pulse completes the STE preparation. A chemically-selective RF pulse and gradient spoiling immediately precedes this third RF pulse to perform fat saturation. Spiral or variable-density (VD) spiral readouts then followed this BPF-mapping STE preparation. Acquisitions in phantoms and on two volunteers were performed on a GE Signa 1.5T scanner (GEHC, Waukesha, WI) with 50mT/m gradients using the standard quadrature head coil. Scan parameters were: FOV=24cm, matrix=256^2, TR=3s, TE=20ms, T_M=200ms, NEX=20, thickness=5mm for both spiral waveforms. The WIMP labeling gradients were 15 mT/m and lasted 250 µsec. The variable density spiral used 12 interleaves with pitch factor 2.5, while the constant density spiral used 4 interleaves to minimize shot-to-shot variations. In order to calculate the relative bound pool size (S_{WIMP}) and the bound pool fraction (BPF_{WIMP}), the sequence is run with a composite refocus of 0º and 180º. The calculated signal is:

$$S_{WIMP} = \frac{S_{0^0\,ref} - S_{180^0\,ref}}{S_{0^0\,ref} + S_{180^0\,ref}}\text{, and BPF is defined by } BPF_{WIMP} = \frac{S_{WIMP}}{S_{WIMP}+1}.$$

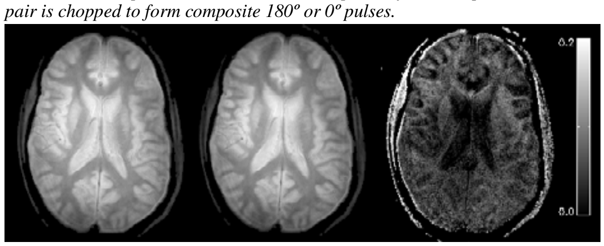

Figure 2 – Spiral acquisition WIMP. (Left) shows a WIMP acquisition with a 0º composite refocus, (Center) used a 180º composite refocus, and (Right) shows the calculated WIMP signal.

Results: Fig. 2 shows the acquired WIMP images using spiral readouts with a composite refocusing pulse totaling 0º and 180º. BPF values in frontal white matter in each slice varied from .10 to 0.13, which is in agreement with previous data [3-5]. Although image quality is excellent, the S_{WIMP} signal is corrupted in the posterior regions of the brain. Increased immunity against motion can be added by using a navigated variable-density spiral trajectory. Phase correction based on a recently proposed [8] algorithm was applied to all data. No motion artifacts were apparent in the raw images and facilitated the computation of high SNR WIMP maps. In the right frontal brain hyperintensities were seen (Fig. 3) and can be attributed to off-resonant spins that affect the 0º and 180º variant differently and is due mostly to the large spacing of the composite pulse.

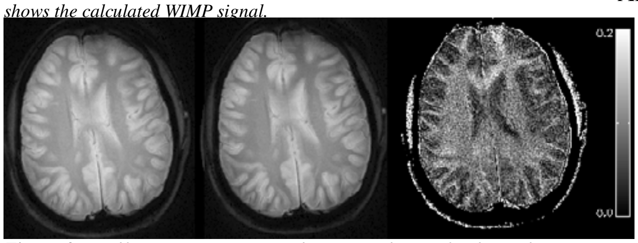

Figure 3 – Self-navigating WIMP with VD spirals. (Left) shows the acquisition with a 0º composite refocus, (Center) used a 180º refocus, and (Right) shows the calculated BPF. All images are shown after self-navigated motion correction.

Discussion: In this study, it has been demonstrated that interleaved variable density spiral imaging is an effective method to measure the bound pool fraction in white matter with high resolution. Single-shot methods suffer from low resolution, geometric distortions and T2* decay during the readout, however phase correction and navigation is necessary in order to use a multi-shot readout to overcome these obstacles. The ability to use gradient instead of RF refocusing [7] for the image readout is of great advantage since MT measurements with FSE readouts are often frustrated by cross-talk and adjacent slice MT saturation as well as high SAR. The latter is of particular interest for high field, especially in conjunction with the lack of MT preparation pulses in this sequence. The variable density spiral approach allows for an efficient use of non-linear phase correction to address phase errors that would otherwise confound the BPF calculation. One possible drawback to the VD spiral method is the resultant noise coloration from oversampling the low spatial frequencies. While the noise coloration may not be bothersome to a human observer, in performing quantitation these noise properties become more evident and noise decoloration, as described in a forthcoming abstract, during gridding reconstruction might be required.

References: [1] Ropele, et al. MRM (49),864-871,2003. [2] Liu, et al. MRM (52),1388-1396,2004. [3] Sled et al. MRM (46),923-931,2001. [4] Henkelman, MRM (29),759-766,1993. [5] Yarnykh, MRM (47),929-939,2002. [6] Tozer et al. MRM 5:83-91, 2003. [7] Ramani, MRI, 20(10), 721-31, 2002. [8] Liu, MRM (54), 2005. **Acknowledgements:** Work was supported in part by the NIH (1R01EB002771), Center of Advanced MR Technology at Stanford (P41RR09784), Lucas and Oak Foundations.