Quantitative Magnetization Transfer Bound Pool Mapping at 3T

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Introduction: While magnetization transfer (MT) is useful in detecting subtle changes in white matter diseases, its use at high field strengths has been limited by SAR concerns [1]. Most MT sequences use SAR-intensive RF pulses, or use complex parametric models requiring large datasets from RF-spoiled gradient-echo (GRE) acquisitions. White matter pool (WIMP) mapping uses a stimulated echo (STE) method by Ropele et al. [2] combined with a variable density (VD) spiral readout [3] that directly measures the bound proton fraction (BPF). However, WIMP uses the difference between two similar-contrast STE images, which results in low signal (and thus SNR) in the computed BPF images. In experiments at 1.5T, an average of only <3% difference between the images was noted. While several averages are simple solution to increase SNR, with excessive averaging motion becomes an increasing issue. Both additional signal and signal difference may be possible via the use of higher field strength, e.g. 3T. Ropele's method is particularly interesting for high field applications since, aside from exceptionally low SAR, it requires neither the use of MT RF pulses nor the knowledge of underlying the T1 or T2 values. This method is therefore both feasible and practical at high field strength.

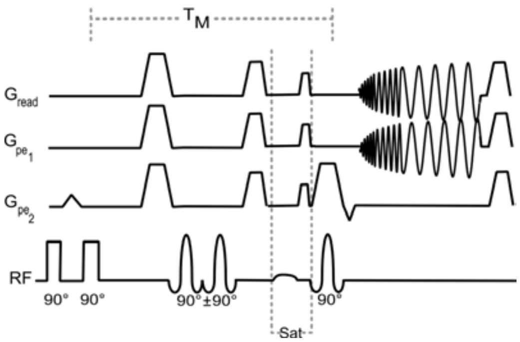

Figure 1 – VD Spiral-WIMP. A STE prep of length T_M containing a composite pair of refocusing pulses is followed by fat saturation and a spiral readout. The second pulse of the composite pair is chopped to form a composite 180º or 0º pulse.

Methods: A WIMP sequence is similar to a stimulated echo preparation, with three $\pi/2$ RF pulses. The second and third pulses are separated by a time TM, which includes a composite refocusing pulse of two abutted 2.4 ms $\pi/2$ pulses. The phase of the second pulse can be modulated, resulting in a total composite flip angle of 0º or 180º. A chemically-selective RF pulse and gradient spoiling immediately precede the final RF pulse to perform fat saturation, as in Fig. 1. VD spiral readouts then follow this BPF-mapping WIMP preparation. Acquisitions in a volunteer were performed on a GE Signa 3.0T scanner (GEHC, Waukesha, WI) with 40mT/m gradients using the standard quadrature birdcage head coil, and an 8 channel phased array head coil (MRI Devices, Milwaukee, WI). Scan parameters are: FOV =24cm, matrix=256x256, TR=3s, TE=6ms, T_M=200ms, NEX=10, thickness=5mm for both examinations. The WIMP labeling gradients were 15 mT/m and lasted 250 μsec. The variable density spiral used 16 interleaves with pitch factor 2.5. In order to calculate the relative bound pool size (S_{WIMP}) and the bound pool fraction (BPF_{WIMP}), the sequence is run twice.

Results: BPF images attained with the quadrature head coil are presented in the top row of Fig. 2; while those acquired with the receive-only phased-array coil are in the bottom row. As the quadrature head coil is used for B1 transmission, rather than the body coil for the receive-only coil, its smaller diameter, even at 3T, gives a more marked B1 variation across the volume of interest. The residual B1 artifacts are evident in the final quantitative BPF maps on the top right in Fig. 2. The more even excitation profile of the body coil aids the image quality in the bottom right of Fig. 2. Despite the image apodization from the B1 field, image quality is remarkable, showing excellent grey/white contrast. BPF values in white matter are consistent with those previously reported [4-6].

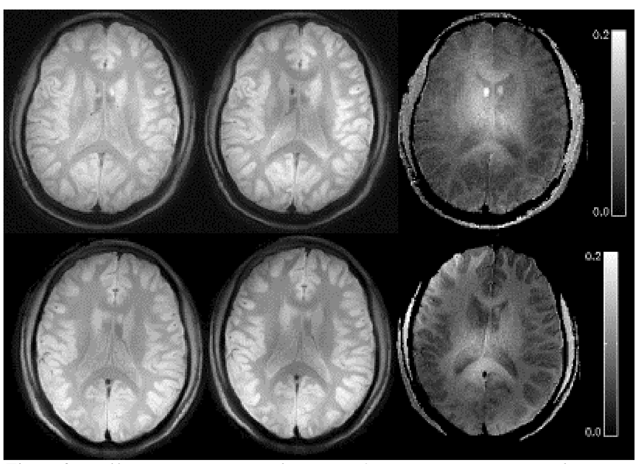

Figure 2 – Self-navigating VD Spiral WIMP at 3T using a (Top Row) quadrature birdcage coil and (Bottom Row) receive only phased array coil. (Left) shows the acquisition with a 0º composite refocus, (Center) used a 180º refocus, and (Right) shows the calculated BPF.

Discussion: This method can quantify the BPF without high SAR, making it suitable for high field. Further, a self-navigating spiral readout has allowed both high resolution, as well as the ability to navigate patient motion and correct cumulative phase differences from both the labeling gradients as well as off-resonances, necessary for multi-shot acquisition. However, in moving to higher field, variation in the applied B1 field has left residual artifacts. The use of hard RF pulses with a small diameter transmit coil produces an inhomogeneous B1 field. The use of body coil excitation with a receive-only coil will alleviate this problem to some extent. The composite refocusing RF pulse is another source of possible artifacts. This pulse is built from two abutted 90º pulses. If we use the center of each RF pulse as the time of application, there is a gap of one RF pulse width, here 2.4ms, between them. Any spins off-resonant will precess during this time and can result in artifact. A variation in B1 will change the 180 refocusing composite pulse's effective flip angle, additionally saturating the longitudinal magnetization and modulating the resultant signal intensity. The WIMP signal will therefore be artificially increased, as is seen in the images. The use of a simple 180º (non-composite) and no RF pulse for the 0º refocus is unfortunately not a solution. Differences between the images from the MT effect are confounded and overwhelmed by differences resulting from using two disparate RF pulses for the longitudinal spin refocusing in each image. Thus the use of identical pulses is necessary. A more optimized set of pulses is being explored, or this method could be combined with a B1 mapping process. Current work is exploring alternate RF pulses, such as binomial pulses, to remove the residual B1 sensitivity. One potential solution is the use of transmit SENSE for a more homogenous B1 field. In the bottom-left and center images of Fig. 2, using the receive-only coil at 3T, a clear differentiation between grey matter, which is expected to exhibit less of an MT effect, and the white matter is clearly discernible. Thus, the goal in moving to higher field strength—a pronounced signal attributable to MT with excellent SNR—was achieved. This method is therefore both viable and preferable at higher field strengths.

References: [1] Lin, MRM (50), 1, 114-121, 2003 [2] Ropele, et al. MRM (49), 864-871, 2003. [3] Liu, et al. MRM (52), 1388-1396, 2004. [4] Sled and Pike. MRM (46), 923-931, 2001. [5] Henkelman, MRM (29),759-766,1993. [6] Yarnykh, MRM (47), 929-939, 2002. **Acknowledgements:** This work was supported in part by the NIH (1R01EB002771), Center of Advanced MR Technology at Stanford (P41RR09784), Lucas and Oak Foundations.