Robust adiabatic T2 preparation for fast whole brain spiral myelin water imaging at 3 Tesla

Thanh D. Nguyen[1], Kofi Deh[1], Ashish Raj[1], Martin Prince[1], Yi Wang[1], and Susan A. Gauthier[2]

[1]*Radiology, Weill Cornell Medical College, New York, NY, United States,* [2]*Neurology and Neuroscience, Weill Cornell Medical College, New York, NY, United States*

Target Audience Researchers and clinicians interested in myelin-related white matter diseases.

PURPOSE Multicomponent T2 relaxometry (1) measures myelin water fraction (MWF) changes in multiple sclerosis (MS), yielding results highly correlated with the myelin loss and regeneration measured by histopathology (2-4). However, the translation into routine clinical MRI has been hindered by the slow acquisition speed of the standard 2D CPMG spin echo sequence (26 min per slice) (5). Recently, a fast T2prep 3D spiral sequence has been developed to shorten whole brain coverage to 24 min at 1.5T (6). Follow-up studies have utilized the SNR advantage at 3T to further reduce scan time or to improve the robustness of MWF extraction. However, the increased field inhomogeneity at 3T may seriously degrade the T2 weighting accuracy of the conventional T2prep module (7), yielding unreliable MWF quantification. Here we propose an adiabatic T2prep design and demonstrate significantly improved MWF maps which can be obtained for the whole brain in only 10 min.

METHODS In the conventional design (Fig.1a), proton magnetization is tipped into the transverse plane where it is refocused by a series of $90_x180_y90_x$ composite pulses (with a fixed inter-pulse interval, typically 5-10 ms) to form spin echoes while undergoing T2 relaxation, then returned to the longitudinal axis for subsequent imaging. In contrast, our T2prep module is based on the modified BIR-4 pulse (8), consisting of a reverse half passage, a full passage and a half passage adiabatic pulses, which are separated by two equal time delays (Fig.1b). T2 weighting is controlled by these variable time delays (TE), in addition to a fixed weighting (ΔTE) introduced by the adiabatic pulse itself (9): $S(TE) = \Sigma\alpha_j \exp(-TE/T2_j)\exp(-\Delta TE/T2_j)$. While the composite design (COMP) requires uniformly accurate refocusing flip angles to prevent contamination from stimulated echoes, the BIR-4 design does not rely on the formation of spin echoes and is much more robust against field inhomogeneities. Since this design does not use multiple refocusing pulses, it is better suited for reducing SAR of multicomponent T2 relaxometry which requires a large number of echoes and long TEs to fully resolve the T2 spectrum.

Bloch simulations and 3T imaging experiments in $MnCl_2$ phantom and volunteers (n=7) were conducted to compare the accuracy of the COMP and BIR-4 T2preps. In addition, relapsing-remitting MS patients (n=7) were imaged with BIR4 T2prep. A T2prep stack-of-spirals sequence was used (2.5s TR, 1.2x1.2x5mm^3 voxel, 28 slices, 7 and 15 non-linear T2prep times for phantoms and humans, respectively, 10 min whole brain scan time, 8-channel brain coil). The 0° BIR-4 pulse had a length of 10 ms (without the inter-pulse delays), a nominal amplitude of 0.21 Gauss and a maximum frequency offset of 9 kHz. MWF maps were obtained from the T2 weighted images using a non-linear, three-pool fitting algorithm.

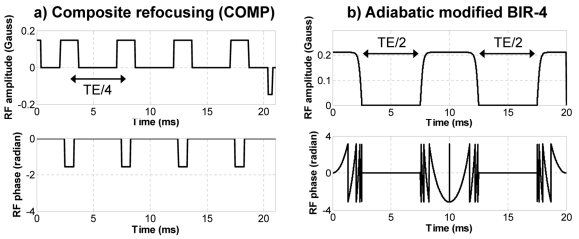

Fig.1. Conventional composite refocusing and proposed adiabatic modified BIR-4 T2prep designs for multicomponent T2 relaxometry.

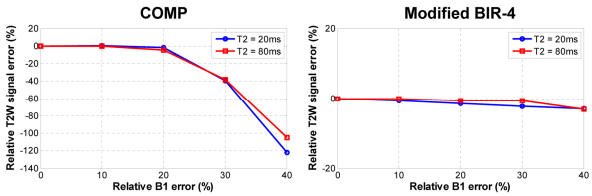

Fig.2. Simulated on-resonance T2 weighting error as a function of B1 error for the T2prep modules shown in Fig.1.

RESULTS Bloch simulations (Fig.2) suggested that the COMP design only provided good T2 weighting within 15% B_1 error, while adiabatic BIR-4 was robust up to 60% B_1 error. Phantom experiments (Fig.3) confirmed these results, showing significantly increased T2 errors for COMP at 20% B_1 error, especially for longer T2 values. On the contrary, BIR-4 yielded consistently accurate T2 estimates (error within 3%). Fig.4 shows an example of spiral images and MWF maps extracted from 3 consecutive slices in a healthy subject, demonstrating severe artifacts in the cortical areas, most likely due to larger B_1 inhomogeneity, in the images obtained with COMP. BIR-4 provided much improved image quality and MWF maps with exquisite details across the whole brain, indicating more robust T2 weighting. In the splenium of the corpus callosum (CC), COMP yielded slightly higher MWF than BIR-4 (17.2 ± 0.9% vs. 16.4 ± 1.2%, P=0.07, n=7) in healthy volunteers, which were both significantly higher than that obtained from MS patients (13.6 ± 1.9%, P<0.01, n=7). Fig.5 shows an example of MWF maps obtained from an MS patient, demonstrating variable MWF reduction within lesions.

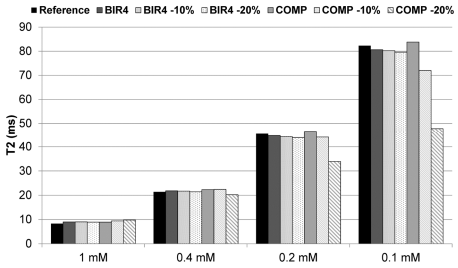

Fig.3. Comparison of phantom T2s obtained with adiabatic BIR-4 and composite (COMP) T2prep at 0%, 10% and 20% B_1 error. Reference T2 values were obtained with CPMG spin echo method.

CONCLUSION Our preliminary results show that the adiabatic BIR-4 T2prep provides more accurate T2 weighting with less SAR than the conventional spin echo based composite refocusing T2prep for multicomponent T2 relaxometry and enables fast whole brain myelin water mapping. Advanced acceleration techniques are being explored to further reduce scan time to allow myelin quantification in routine brain MRI.

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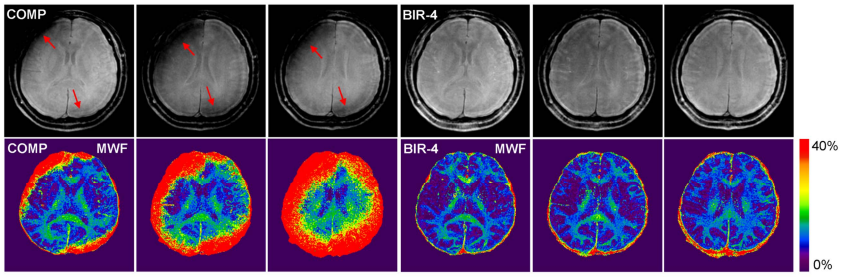

Fig.4. Examples of spiral T2W source images and MWF maps obtained with COMP T2prep showing severe artifacts (arrows). BIR-4 T2prep provides artifact free source images and MWF maps with exquisite details in the cortical areas.

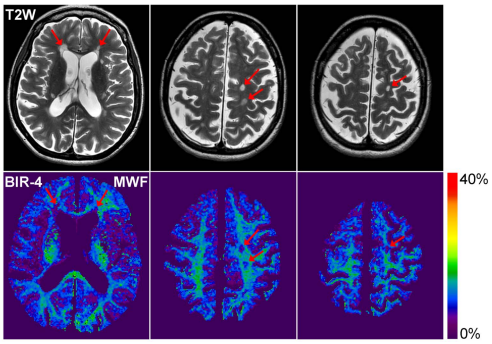

Fig.5. Examples of T2W anatomical images and corresponding MWF maps from an RRMS patient (arrows indicate lesions).