Three dimensional T2prep spiral imaging with efficient brain coverage for myelin water quantification: Validation at 1.5 Tesla

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INTRODUCTION Quantitative assessment of demyelination in white matter (WM) is important for characterizing tissue damages and evaluating response to therapy in multiple sclerosis. Multi-component T2 relaxometry (1,2) is a promising method to measure myelin water fraction (MWF), which highly correlates with histological myelin measurement in animals (3) and may be useful clinically (4). However, its utility is impeded by time-consuming single-slice 2D fast spin echo (FSE) data acquisition. Multi-slice 2D T2prep spiral imaging has been developed to address this problem, but low SNR efficiency remains a challenge (5). The objective of this study was to develop and optimize an SNR efficient 3D T2prep spiral gradient echo (SPIRAL) sequence for full brain T2 relaxometry and to validate this sequence using 3D FSE as reference standard at 1.5T.

MATERIALS AND METHODS **Fig.1** shows the schematics of the implemented sequence. Five water tubes were doped with $MnCl_2$ to match the range of T2 values for human WM pools and imaged with 3D FSE and SPIRAL (TR=2 sec, 16 TE and T_{PREP} values between 5 and 960 ms, spiral TR=9.1 ms, birdcage coil). The number of the spiral views collected following each T2prep segment (VPS) was varied from 12 to 48. T1 mapping was also obtained. Next, a high-resolution phantom and two healthy volunteers were imaged with 5°, 10°, 15° and 30° spiral flip angles to optimize image quality. Finally, 8 healthy volunteers (6 men, 2 women, 30±7 yo) were scanned with the optimized 3D SPIRAL and FSE in randomized order (axial FOV=30 cm; TR=2.5 sec; 32 TE's =5, 10-310 ms (10 ms step) for FSE; 24 T_{PREP}'s=5, 10-160 ms (10 ms step), 180-300 ms (20 ms step) for SPIRAL; matrix=256x128 with 0.5-0.6 partial phase FOV for FSE and 192x192 for SPIRAL, interpolated to 256x256; slice=5 mm; number of slices=8 for FSE and 28 for SPIRAL; spiral TR=5.9 ms; scan time=32-38 min for FSE and 24 min for SPIRAL, 8-channel receive coil). Phantom T2's were obtained using mono-exponential fitting. T2 spectra were obtained using regularized non-negative least squares fitting (2,6) for 3x3 pixel ROIs placed within matching 6 WM and gray matter (GM) locations on FSE and SPIRAL images. For each voxel, MWF was calculated as the ratio of the sum of spectral peaks under 50 ms and the sum of all peaks. SNR was also measured in the splenium of corpus callosum (CC).

Fig.1. T2 prepared 3D spiral gradient echo sequence consisting of T2prep with variable T_{PREP} to create T2 weighting, followed by segmented k-space stacks-of-spiral data acquisition with a k_z-centric view order and a variable time delay T_{VAR}, and completed by a saturation pulse (SAT) and a fixed time delay T_{FIX} to allow uniform magnetization recovery independent of T_{PREP}.

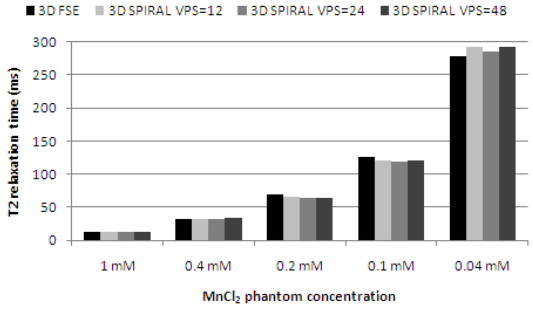

Fig.2. Phantom T2 values obtained with 3D FSE and SPIRAL.

RESULTS Phantom T1 was 125/303/576/910/1487 ms. Compared to FSE, SPIRAL provided T2 values within 1 ms for short T2 phantoms and within 5% for long T2 phantoms, even with a long spiral readout of 48 VPS or ~440 ms (**Fig.2**). High-resolution phantom and human imaging showed that a spiral flip angle of 10° and VPS=24 provided the best compromise between SNR and image blurring along the slice direction due to centric view ordering. Over 8 subjects, the optimized SPIRAL yielded comparable MWF's to that of FSE for all six WM and GM locations (**Table 1** and **Fig.3**). SNR was 471±61 for FSE and 206±18 for SPIRAL.

Table 1. Comparison of myelin water fractions (N=8).

Structure	Myelin water fraction (%)		p value
	3D FSE	**3D SPIRAL**	
Corpus callosum, genu	12.6 ± 1.7	12.8 ± 1.2	0.65
Corpus callosum, splenium	15.7 ± 1.6	15.3 ± 1.7	0.38
Internal capsules	12.7 ± 1.3	12.8 ± 1.2	0.88
Caudate	1.3 ± 0.8	1.5 ± 0.7	0.39
Putamen	1.8 ± 1.2	1.3 ± 0.4	0.20
Thalamus	2.6 ± 1.4	2.9 ± 1.1	0.21

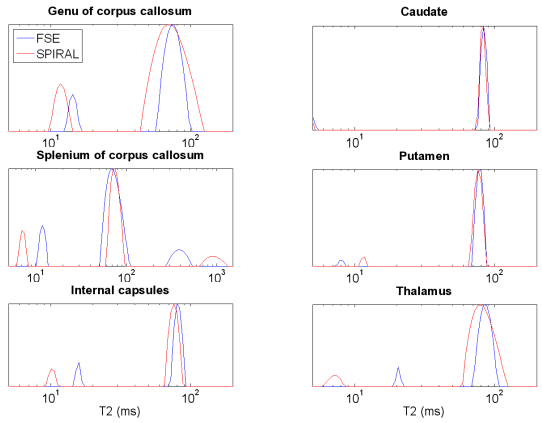

Fig.3. T2 spectra obtained with 3D FSE and SPIRAL in one subject.

DISCUSSION Our preliminary results demonstrated that the developed 3D SPIRAL sequence provided similar T2 on phantom and MWF for WM and GM tissues compared to 3D FSE at 1.5T. To our best knowledge this is the first study to directly compare FSE and spiral T2 relaxometry sequences in the same subjects. Compared to conventional single-slice 2D FSE, 3D SPIRAL provided an order of magnitude improvement in scan efficiency (<1 min vs. 15-25 min per slice) and 2.5-fold higher SNR (206 vs. 80 in CC) (6). While SNR of 3D SPIRAL is lower than that of 3D FSE, it was sufficiently high to provide accurate MWF measurements, even when a reduced number of T2prep times was used to shorten scan time. SPIRAL employs low flip angle data acquisition and is therefore much less intensive than FSE with regards to specific absorption rate (SAR), making it particularly suitable for higher field strength. SPIRAL also offers more flexible control over scan time through the choice of the number of T2prep times. The 3D SPIRAL T2 relaxometry sequence developed in this study represents a major step toward achieving full brain coverage in clinically relevant scan time.

REFERENCES 1. MacKay et al. MRM 1994;31:673. 2. Whittall et al. MRM 1997;37:34-43. 3. Gareau et al. JMRI 2000;11:586. 4. Laule et al. J Neurol 2004;251:284. 5. Oh et al. MRI 2006;24:33. 6. Kolind et al. MRM 2009;62:106.