High Resolution Multispectral qMRI Protocol: PD, T1, T2, T2*, ADC, MT

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Purpose: The purpose of this study was to develop a high-resolution, multi-spectral, quantitative magnetic resonance imaging (qMRI) pulse sequence protocol to interrogate T1, T2, T2*, proton density (PD), diffusion coefficient, and magnetization transfer parameters at ultra-high field (11.7T) MRI.

Methods: Imaging experiments were performed using 11.7T MRI. All pulse sequences were implemented in the axial plane, with the following common geometry parameters: voxel dimensions = 100x100x600 µm³ and matrix = 256x256.

We implemented a dual sequence version of the mixed-TSE sequence, termed here as tandem-mixed-TSE with the following parameters: pulse sequence 1, dual-echo RARE; TE1 = 14ms, TE2 = 27ms, TR = 4000; pulse sequence 2, dual-echo RARE with inversion recovery pulse; TE1 = 14ms, TE2 = 27ms, TI = 400ms, TR = 4400ms (Figure 1) (1). Images acquired with these two sequences were used to calculate parametric PD, T1, and T2 maps. A tri-echo gradient echo (FLASH) with the following parameters was implemented: TE1 = 4.5ms, TE2 = 6.8ms, TE3 = 9.0ms, TR = 140ms, flip angle = 30° (Figure 2). Directly acquired images were used to construct parametric T2* maps (Figure 2). For diffusion weighted MRI (DWI), a multi-slice spin echo image pulsed field gradient (PFG) acquisition (TE = 10ms, TR = 2000ms) was utilized with b-values of 21, 301, and 601 s/mm² for constructing parametric ADC maps (Figure 3). For the quantitative magnetization transfer (qMT) experiments, we used a single 15ms Gaussian pulse with 13 frequency offsets ranging from ranging from 435Hz to 50kHz (logarithmic spacing). A single magnetization transfer pulse power was used (16uT). A two-dimensional spoiled gradient echo sequence (FLASH) was used with the magnetization transfer pre-pulse for image acquisition with the following parameters: TE = 4ms, TR = 260ms, flip angle = 30° (Figure 4). An additional reference dataset with the identical parameters was also acquired without a magnetization transfer pulse.

This multi-spectral qMRI pulse sequence was applied to a qMRI phantom containing water, agarose gels, sucrose solutions, and olive oil. Also, the protocol was applied to ex vivo liver imaging of a murine model of steatohepatitis as well as ex vivo murine brain imaging; all tissue imaging was carried out at 23.5°C using an internal reference vial containing phosphate buffered saline (PBS) and olive oil. T1 relaxation time determination using the tandem-mixed-TSE sequence was validated using an accepted, well established qMRI sequence using multiple inversion times.

Results: Excellent directly-acquired and qMRI map image quality was obtained for all of the MRI parameters at 11.7T (Figures 1-4). Excellent agreement between the tandem-mixed-TSE and the multi-IR sequence was found for the phantom materials/internal references within the tissue samples: T1_water = 430ms, T1_agarose = 1767ms, T1_PBS = 2054ms, T1_water = 2054ms. The diffusion coefficient for the water was determined to be 2.4cm²/sec, in excellent agreement with known values at 23.5°C (2). Magnetization transfer experiments generated expected results with varying agarose gel concentration in the phantom imaging experiments.

Conclusion: We have developed a comprehensive, multi-spectral qMRI protocol affording high-resolution imaging at 11.7T MRI. We envision myriad applications for a complete, multi-spectral qMRI protocol such as we have successfully implemented.

References