Triple-Quantum-Filtered Sodium MRI of the Human Brain at 4.7T

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Background and Purpose: In vivo imaging of sodium, a key metabolic marker of ionic homeostasis, may complement ^{1}H imaging for the evaluation of different neurological disorders. In particular, imaging of intracellular sodium may provide more insight into the state of cellular impairment. Triple-quantum-filtering (TQF) can yield signal selectively from sodium nuclei exhibiting biexponential relaxation, which in biological tissue is presumed to occur to a greater extent in intra-cellular spaces[1-2]. Standard single quantum sodium MRI is difficult enough due to poor signal, but this issue is compounded by the <10% yield of a triple quantum filter. There has only ever been one published paper on TQF sodium MRI of in vivo human brain which was acquired with 3D twisted projection imaging at 3T in 20 min[3]. However, anatomical structures within the brain were difficult to appreciate given the low resolution which may limit its utility in patient populations. The purpose of this abstract is to demonstrate that improved in vivo TQF human brain sodium images can be acquired in a reasonable 11 min by using 3D twisted projection imaging with sampling density weighted apodization at the higher magnetic field strength of 4.7T.

Methods: All sodium MRI was performed on a Varian Inova 4.7T whole-body MRI scanner with a single-tuned 53 MHz head RF coil. Phantom Study - A phantom was built with an inner compartment (16.5 cm diameter) filled with 5% agar (70 mM Na) and an outer compartment (0.6 cm thickness) with saline (60 mM Na). A four-pulse TQF sodium sequence with 3D twisted projection readout acquisition was used with TR = 100 ms, τ = 7 ms, δ = 0.6 ms, TE = 5.3 ms, FOV = 23.5 cm, resolution = 8.4 x 8.4 x 8.4 mm^3, 90^o flip angle (rectangular pulse width = 500 µs) was used for the three RF excitation pulses and a 180^o flip angle (pulse width = 1000 µs) was used to refocus B_0 inhomogeneity in between the first and third 90^o RF pulses, one average, 4.1 min acquisition time. The phase φ was stepped through 30^o, 90^o, 150^o, 210^o, 270^o, and 330^o and the receiver phase alternated between 0^o and 180^o. Single-quantum sodium images (90^o flip angle, pulse width = 500 µs, TR = 130 ms, TE = 0.4 ms, resolution = 8.4 x 8.4 x 8.4 mm^3, 1 min acquisition time) were obtained to verify that sodium signal is observed in both compartments of the phantom. In Vivo Study - A healthy volunteer was imaged with a three-pulse TQF sequence using 3D twisted projection imaging acquisition[4-5] with TR = 100 ms, τ = 7 ms, δ = 1.1 ms, TE = 6 ms, resolution = 8.4 x 8.4 x 8.4 mm^3, 90^o flip angle (pulse width = 1900 µs) for the three RF excitation pulses, 370 number of projections, twist p = 0.14, readout time – 12.4 ms, 3 averages, 11 min acquisition time. The three-pulse implementation without the 180^o refocusing pulse was used for the human study to minimize specific absorption rate.

Results and Discussion: Figure 1 shows that sodium signal in the agar (inner compartment) is present in both the single-quantum and triple-quantum images whereas the sodium signal in saline (outer compartment) is absent in the triple-quantum images, as expected. The phantom study confirms that the TQF sodium MRI sequence is filtering out the mono-exponentially relaxing sodium signal. In vivo TQF sodium brain images of the volunteer were feasible in 11 min at 4.7T and demonstrate clear demarcation of the ventricles (Figure 2). Sodium in CSF does not exhibit biexponential relaxation and thus does not pass through the triple quantum filter. In order to accommodate for the very low yield of TQF, the voxel size of 593 mm^3 is much larger than that often obtained (~50 mm^3) in single quantum sodium MRI of the brain[4]. Nonetheless, this lower resolution may be adequate to examine large lesions in the brain (e.g. stroke, tumors). The resolution of the previous TQF sodium MRI of the brain was not reported but the ventricles were not readily visible in that study at a lower field strength of 3T and twice the scan time[3]. Our study built upon theirs by also using 3D twisted projection imaging, but with the added advantages of a stronger static field of 4.7T and sampling density weighted apodization[5]. Our results are encouraging and suggest that TQF sodium MRI has the scan time and resolution to make it feasible for clinical patients and that it will progress even further given the proliferation of even higher field MRI scanners.

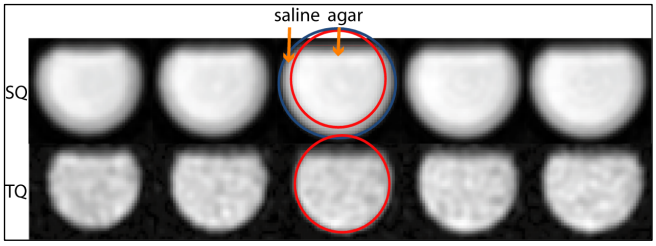

Figure 1 –Single-quantum (SQ) and triple-quantum (TQ) sodium images of the phantom. Note the lack of sodium signal in the saline on the TQ filtered image. The red line depicts the boundary between the two compartments in the phantom.

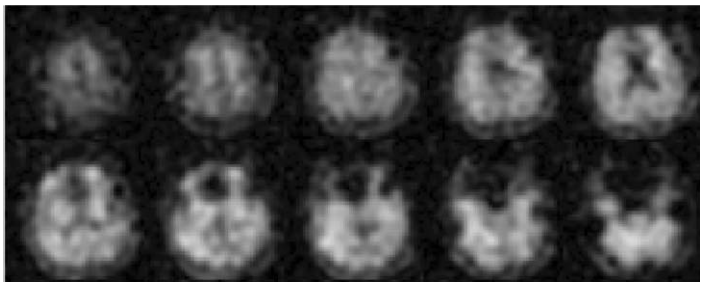

Figure 2 – Axial TQF sodium images of a healthy volunteer acquired in 11 min at 4.7T showing signal from the brain (SNR = 21) and lack of signal from the ventricles.

References: [1] G. Jaccard, et al., *J Chem Phys*, 85(11):6282(1986). [2] J. Pekar, et al., *J Magn Res*, 72:159(1987). [3] I. Hancu, et al., *Magn Res Med*, 42:1146(1999). [4] R. Stobbe, et al., *Magn Res Med*, 59:345(2008). [5] R. Stobbe, et al., *Magn Res Med*, 60:981(2008).