Improved Sodium MRI of the Human Knee with Projection Acquisition in the Steady State at 4.7 Tesla

A. Watts[1], R. Stobbe[1], A. Tsang[1], and C. Beaulieu[1]
[1]Biomedical Engineering, University of Alberta, Edmonton, Alberta, Canada

INTRODUCTION: Osteoarthritis is associated with degenerative cartilage in joints that results in pain, swelling, and reduced motion and flexibility. Sodium MRI may be able to detect and quantify cartilage degradation[1], but it suffers from low signal to noise ratio (SNR). This necessitates long scan times (10-30 min) and ideally higher fields, yet still only results in low resolution images in vivo (3.4-14.6 mm^3)[1]-[4]. Sodium MRI studies have typically used a tissue sodium concentration (TSC) approach (long TR, short TE), but it has been shown for the brain that a projection acquisition in the steady state (PASS) approach (lower flip angle, longer RF pulses, shorter TR allowing more averages) can provide a marked increase of SNR in a given scan time within specific absorption rate (SAR) constraints[5]. The purpose of this study is to evaluate the PASS method for improved SNR and resolution of sodium MRI of the human knee, which has higher permissible SAR than the brain.

METHODS: Sodium signal was simulated[5] for a range of combinations of pulse width (proportional to TE) and TR at constant SAR of ~6 W/kg and constant scan time. Relaxation parameters were needed for the simulation: T1=19.9 ms, T2s=15.8 ms, T2f=2.3 ms measured for a 10% (500 mM) agar phantom at 4.7T, and T1=17 ms, T2s=10 ms and T2f=1.5 ms taken from the literature for the human knee at 4.0T[4]. Based on the results of the simulations, 3D twisted projection imaging acquisition parameters were chosen for both PASS (flip angle = 74°, pulse width = 0.25 ms, TE=0.185 ms, TR=30 ms, 3 averages) and TSC (flip angle=89°, pulse width=0.120 ms, TE=0.120 ms, TR = 90 ms, 1 average). Both protocols had the same nominal voxel volume (defined by 1/(2*Kmax)) of 2.56 mm^3, and constant acquisition times of 9 minutes for each TSC or PASS data set. All sodium MRI experiments of the 10% agar phantom and 9 healthy volunteers (25+\-4 years) were performed on a Varian Inova 4.7T whole body scanner with a single tuned 53 MHz homemade knee coil.

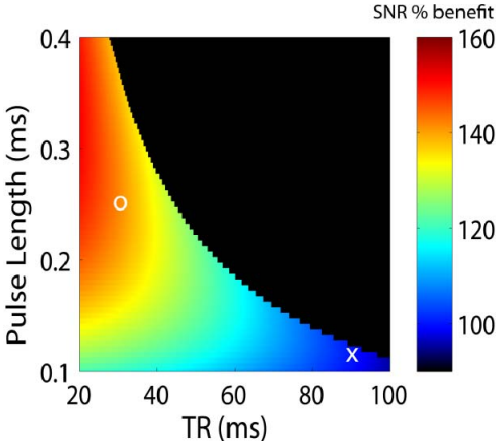

Figure 1: Simulation benefit of PASS (relative value 142%, marked by O) vs TSC (relative value 100%, marked by X) for the knee at constant SAR and scan time assuming relaxation parameters from reference [4]

RESULTS/DISCUSSION: To first validate the method using the agar phantom, a comparison was made between the SNR gain predicted by the simulations and that observed in the sodium images. The relaxation properties of 10% agar gel are fairly close to that of cartilage, especially in the dominant T2f domain. The simulations predicted a 42% increase for the PASS parameters over the TSC parameters that was verified experimentally with a 41% increase. For human cartilage, the simulation results (Figure 1 above) indicate that there should be a 42% increase in SNR when using PASS instead of TSC. Sodium knee image quality was better for PASS than TSC in nine volunteers (Figure 2), and resulted in a mean SNR gain of 26+/-5% in the cartilage, which is still a significant gain but much less than the predictions. The disagreement between simulation and experiment in vivo may be due to partial volume effects with sodium in synovial fluid, or that the relaxation parameters used for our simulations are not accurate for sodium in human articular cartilage in vivo at 4.7T. While there was a significant SNR benefit with the use of PASS instead of TSC, it comes at a cost of increasing both T1 weighting (from 0.5% to 17%) and T2 weighting (from 5% to 8%). Nonetheless, the quality of sodium images of the human knee can be improved markedly using a steady state approach to the projection image acquisition.

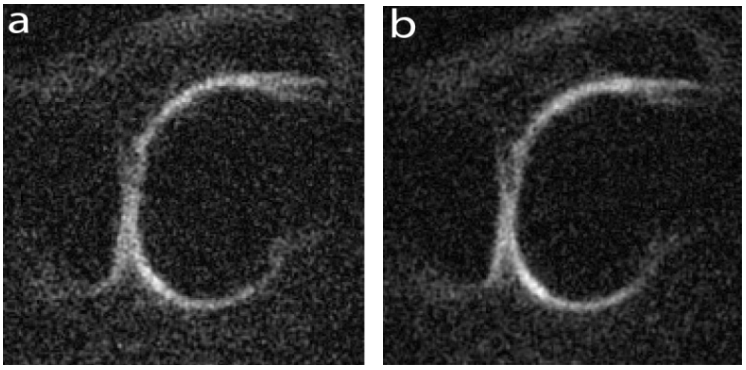

Figure 2: Sodium MRI of the knee using (a) TSC parameters (flip angle= 89°, TE/TR = 0.120/90 ms, 1 average) (b) PASS parameters (flip angle= 74°, TE/TR = 0.185/30 ms, 3 averages). Scan times are equivalent at 9 minutes each

References: [1] Wheaton, Radiology **231**(3): 900 (2004) [2] Wang, J Magn Reson, **30**(3): 606 (2009) [3] Shapiro, MRM, **47**(2): 284 (2002) [4] Reddy, MRM **39**(5): 697 (1998) [5] Stobbe, MRM **59**(2): 345 (2008)