Fast T1Rho measurements by spin-lock pre-encoded HASTE and bSSFP (SLIPS)

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Objective

To investigate optimal pulse sequences for fast $T_{1\rho}$ measurements and validate them against an established but slower sequence for measuring $T_{1\rho}$.

Background

Traditional $T_{1\rho}$ weighted imaging sequences developed for the structural and analytical studies of brain, cartilage, and spine are usually captured over a period of minutes. Adaptations of the standard sequence based on a $T_{1\rho}$ prepared Turbo Spin Echo (TSE-TSL) were later applied to the *in vivo* measurements of the freely diffusible flow tracer $H_2{}^{17}O$ water[1] as well as to the measurement of $^{17}O_2$ gas conversion to $H_2{}^{17}O$ as a marker of cellular metabolism[2]. However, these adaptations have only been able to achieve imaging times of 10-25 seconds/image. This is insufficient in the light of recent developments in $^{17}O_2$ gas delivery, where precise amounts of $^{17}O_2$ gas are inhaled by subjects over 20 seconds and the resultant regional metabolism is calculated over the next 30-60 seconds of signal change. This challenge prompted us to investigate sequences with high temporal resolution that retained both sensitivity to $H_2{}^{17}O$ as well as an acceptable SNR efficiency.

Methods

The same phase-alternating spin lock (SL) cluster[3] was pre-pended to standard Siemens 2D b-SSFP (SLIPS), HASTE, and TSE sequences. These were run on the same slice of six 15mL conical phantoms filled with PBS and serially diluted $H_2{}^{17}O$ to concentrations of 20mM (natural abundance) to 45mM, sealed and submerged in a 9cm diameter bottle of water. The bottle was placed in the center of a GE T/R birdcage head coil in a 1.5T Siemens Sonata clinical MR scanner. $T_{1\rho}$ constants for each $H_2{}^{17}O$ concentration were generated by using 6 spin lock times between 1-1000ms. The SLIPS and HASTE sequences were also compared on the same slice of the brain of pig *in vivo*.

Results

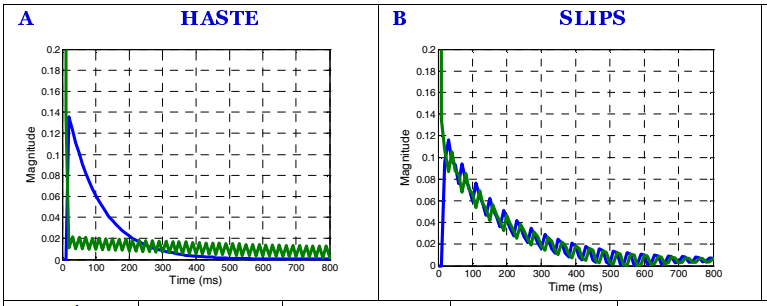

Figure 1. Bloch Equation simulation of longitudinal (green line) and transverse (blue line) magnetization in grey matter (T1=920ms, T2=100ms) during HASTE (echo spacing 10ms) and SLIPS (TR=10ms, 90° flip) readouts. Longitudinal magnetization begins as reduced to about 0.13 of equilibrium by 200ms of 100Hz spin lock. **(A)** In the HASTE sequence, decay is purely T2-weighted during readout, leading to a fast decay of signal, significant k-space blurring, and a need to reduce echo spacing by increasing bandwidth (and therefore losing SNR). **(B)** With SLIPS, however, decay occurs by a proportion of T2/T1 until a small steady-state is reached. In the centrically-sampled case, signal is assumed to be mostly weighted by the $T_{1\rho}$ pre-encode. However, T2/T1 decay suggests a potential reduction in sensitivity to $[H_2{}^{17}O]$.

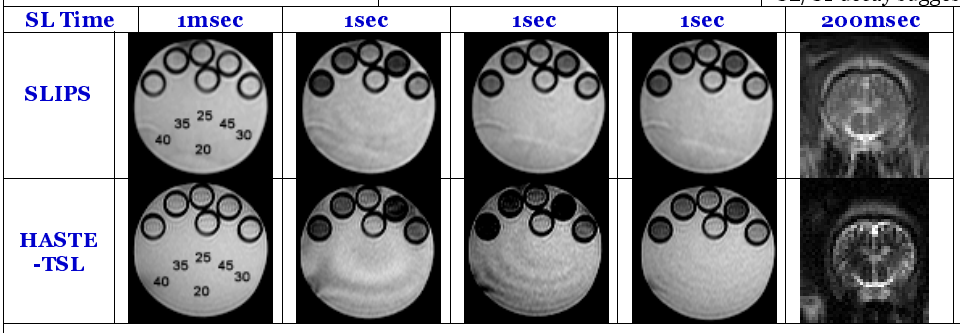

Figure 2. Shown are contrast due to $H_2{}^{17}O$ and images of pig brain without added tracer at 100Hz SL. The $[H_2{}^{17}O]$ in mM are written in the same order as the phantoms. In the phantoms, HASTE-TSL shows artifacts and these artifacts change with repeat imaging (10sec between images) despite the same positioning, parameters, and shim (FWHM 5Hz). Structural images have different contrasts, but worrisome is HASTE-TSL susceptibility (not shown) and lower SNR at every bandwidth. The SNR of the 1-2 sec acquisition time SLIPS images was better than HASTE-TSL and similar to the 210 second TSE-TSL images with the same voxel sizes.

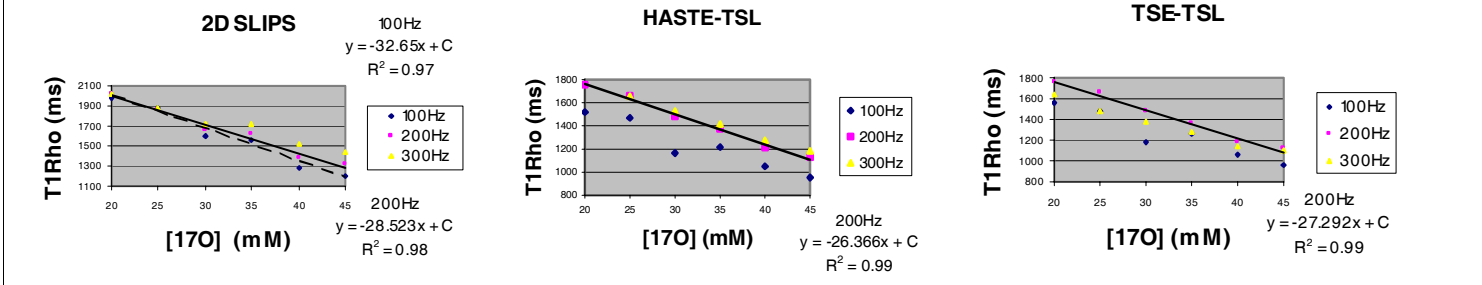

Figure 3. Decreases in measured $T_{1\rho}$ due to $H_2{}^{17}O$ in the phantoms for each sequence. At 200Hz of spin-lock, the SLIPS sequence is slightly more sensitive to ^{17}O concentration than HASTE-TSL and TSE-TSL (as indicated by the slope of the linear fit), however it was not possible to find sequence parameters for HASTE and TSE-TSL to eliminate moderate to severe artifacts at 100Hz to get reliable $T_{1\rho}$. As a result, the SLIPS sequence is shown to be more sensitive, especially at 100Hz, to ^{17}O concentration when compared to the new HASTE-TSL and standard TSE-TSL sequences.

Here we have shown for the first time that it is feasible to collect fast $T_{1\rho}$ weighted images, on the order of 1-2 seconds, for the quantification of contrast agents. We have compared two novel pulse sequences, SLIPS and HASTE-TSL, and found improved contrast sensitivity, reduced artifact, and improved SNR with the SLIPS sequence. Work is also underway to further compare these sequences to SLEPI[4] and $T_{1\rho}$-prepared spin locked SE-EPI. Another abstract was also submitted to show the utility of the SLIPS sequence to quantify metabolically-produced brain $H_2{}^{17}O$ in pigs given $^{17}O_2$ gas.

References 1. Tailor, et al. Magn Reson Med 2003;49:479-87 2. Tailor, et al. Neuroimage 2004;22:611-8
3. Charagundla, et al. J Magn Reson 2003;162:113-21 4. Borthakur, et al. J Magn Reson Imaging 2006;23:591-6

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