Use of a Composite Spin Lock Pulse for Background Suppression with Applications to Angiography and Perfusion Imaging

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Introduction: This abstract describes a new method of background suppression using spin locking that is based on the fact that no longitudinal relaxation occurs while spins are locked. This concept has been previously described using the term "adiabatic demagnetization in the rotating frame" [1]. The ability to efficiently demagnetize static tissue spins could improve contrast in angiographic sequences and obviate the need for subtraction in arterial spin label based perfusion measurements. Several previous reports [2-4] have described spin lock based angiographic methods which exploit the longer T1rho of blood to store the angiographic signal; this method differs in that the spin lock is used to eliminate static tissue signal.

Theory: For our method to generate angiographic or perfusion contrast, two simultaneous conditions need to be satisfied: the magnetization of static spins within a predefined volume must be minimized, and the spins outside this predefined volume should be minimally perturbed. This is accomplished as follows: (1) an initial slice-selective 90x prepulse is used to select a region for background suppression; (2) multiple non-selective (+360y/-360y) pulse pairs with a strength of $B1_{sl}$ lock these spins during TSL. The locked spins decay with a time constant T1rho; while the spins are locked, no regrowth of longitudinal magnetization occurs; spins outside the pre-defined volume undergo only on-resonance magnetization transfer (MT) effects; (3) after TSL, a z-crusher gradient dephases residual transverse magnetization; (4) a slice-selective 90x excites the longitudinal magnetization, which should be primarily due to inflowing, unlocked spins. For short TSL, this provides angiographic contrast, while for longer TSL, tissue perfusion would also be imaged. A graphical display of the behavior of the two different spin groups is shown as Fig 2.

Methods: This sequence was implemented at 1.5 T (GE Medical Systems), using EPI or SPIRAL readout with TR 3s/TE (16 ms EPI, 2.2 ms SPIRAL)/TSL 100-400 ms/$B1_{sl}$ 5-100 mG. TSL was limited to a maximum of 400 ms by amplifier duty cycle restrictions. A 3.2 ms slice-selective sinc pulse was used for the prepulse. The pulse widths of the ±360y locking pulses were adjusted based on $B1_{sl}$. For testing, the gradient for the initial 4 cm slice-selective 90x pulse was placed in the x-direction, permitting visualization of the locked and nonlocked regions on the same image.

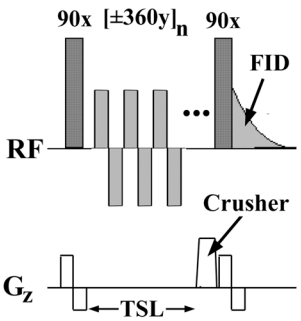

Fig 1: Pulse sequence

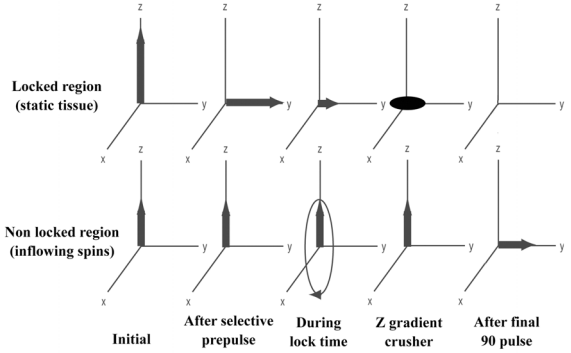

Fig 2: Behavior of locked and unlocked spins.

Results: Fig 3 shows the difference between images taken with and without the application of the spin lock pulse with increasing TSL for $B1_{sl}$=20 mG (85 Hz). The dark band is due to the slice-selective 90x prepulse, defining the locked region. Without the spin lock pulses, normal saturation recovery is present (upper row). When the spin lock pulses are on, background suppression to approximately the scanner noise level is seen for all TSL (lower images). No significant change in locking efficiency existed for $B1_{sl}$ between 20-100 mG; a slight increase in background signal was noted at 10 mG in the region overlying the frontal sinuses, where B0 is known to be inhomogeneous (not shown); this may reflect the lower limit of locking B1 power. Nonlocked spins showed decreased signal intensity with an appearance similar to MT (i.e., less effect on CSF than on the parenchyma). In the nonlocked region, for a TSL of 400 ms, CSF signal was reduced by about 50%, while the brain parenchymal signal was reduced by about 86%. Fig 4 shows the application of this technique to angiography.

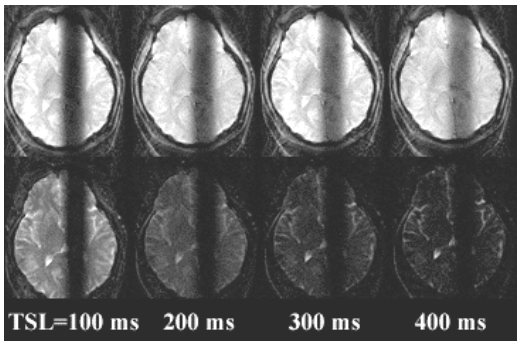

Fig 3: In-plane prepulse without (above) and with (below) inclusion of the spin lock pulses. $B1_{sl}$=20 mG.

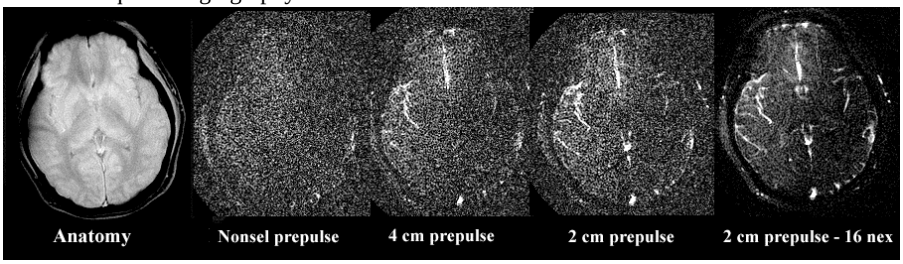

Fig 4: No inflow effects are seen using a nonselective, hard prepulse (200μs). As the width of the slice-selective prepulse is reduced, more vascular signal is seen (TSL=400 ms, $B1_{sl}$=30 mG, slice thickness=5 mm).

Discussion: Spin locking with low B1 fields has been demonstrated to demagnetize a pre-defined region of interest, suppressing background tissue to approximately the scanner's noise level for up to 400 ms. Three factors contribute to this suppression: (1) the relatively short T1rho of brain tissue (100-200 ms), (2) the z-crusher gradient which removes residual locked signal; and (3) the 2nd 90x pulse, which flips any residual signal out of the transverse plane. The locking field strengths are lower than those used in continuous arterial spin label perfusion imaging, and may offer an alternative for perfusion measurements at high fields with acceptable SAR. The use of composite ±360 locking pulses was effective in maintaining uniform magnetization outside the locked region. This composite spin lock pulse has the added advantage of B1 insensitivity, being an extreme example of the method described in [5] for T1rho imaging. Initial experiments suggest that on-resonance MT (which should be small in blood) plays the major role in decreasing the equilibrium magnetization of these spins. If TSL can be extended to 1-5 s, this method may permit imaging of cerebral perfusion without the need for subtraction of a control image.

References: 1. Anderson et al., Phys. Rev. 128:2023-2041 (1962); 2. Dixon et al., MRM 36:90-94 (1994); 3. Mescher et al., ISMRM abstract 1837 (1997); 4. Azhari et al., MRM 46:1041-1044 (2001); 5. Charagundla et al., J Magn Reson 162:113-21 (2003).