A Composite Spin-Lock Pulse For $\Delta B_0 + B_1$ Insensitive $T_{1\rho}$ Measurement

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Introduction: Significant artifacts arise in $T_1\rho$weighted imaging from B_1 and B_0 inhomogeneities. While composite spin-locking preparatory pulses[1-3] that can correct the artifacts from B_1 inhomogeneities have been described, they do not correct artifacts arising from B_0 inhomogeneities. These B_0 artifacts severely limit the accuracy of $T_1\rho$relaxation time measurements, especially at lower spin-locking field in high B_0 field systems. This report describes a composite spin-locking pulse, which is self-compensating for both B_1 and B_0 inhomogeneities. Experimentally obtained $T_1\rho$ weighted images and numerical simulations are used to examine the performance of the new composite pulse. These results confirm that the new pulse greatly reduces the artifacts from B_0 inhomogeneities when compared with the B_1-compensating spin lock pulse currently used.

Theory: Fig. 1 shows the diagram of the self-compensating hard pulse (top) and our new pulse (bottom). The difference is that an 180^0 hard pulse is added just before the 180^0 phase shift in the spin lock pulse.

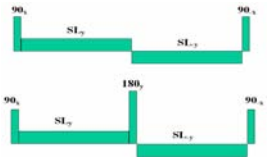

Fig. 1 Self compensating hard spin lock pulse (top). The new hard spin lock pulse (bottom)

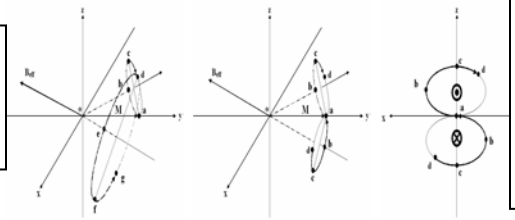

Fig. 2 The precession of magnetization during the 2nd half of the spin lock pulse in old (a) and new pulses (b). The projection in the x-z plane of the precession of M from y-axis (c).

Figure 2 illustrates the precession of magnetization during the 2nd half of the spin lock pulse in the general case with the old pulse (left) and new pulse (middle) and the trajectory in the x-z plane of the magnetization M. If $\Delta B_0 = 0$, the effective field $B_{eff} = B_1 \hat{y} + \Delta B_0 \hat{z}$ is aligned along the y-axis, and there are no artifacts in the images from either pulse sequence. However, when $\Delta B_0 \neq 0$, the effective field is not aligned along the y-axis, and makes an angle with the y-axis. After inverting B_1, the effective field changes direction while M does not alter correspondingly. With the new pulse, during the 2^{nd} half hard pulse, M also changes its position, corresponding to the effective field. Thus, the trajectory of M is from a→b→c→d→c→b→a, and dephasing due to ΔB_0 is fully refocused, and there are no artifacts in the resulting images.

Methods: To verify our method, the old and new spin lock preparation pulses were implemented with a fast (or turbo) spin echo $T_{1\rho}$ pulse on a Philips Achieva 3T system. An oil phantom was measured with both old and new pulses. The parameters are as following: spin lock field at 27 Hz, and spin locking time 4, 8, 16, 32, 40, 60, 80, 100 msec. Matrix size 256x256, oversampling factor in readout direction is 2, echo train length ETL = 16, Field of view FOV = 20 cm, slice thickness is 4 mm, TE = 15 msec, and TR = 2 sec. We believe the ring artifacts in the $T_{1\rho}$ weighted image with the old pulse are caused by ΔB_0, and to verify this, we did simulations using the measured B_1 and B_0 map. The old and new pulse sequence was tested by imaging a human head.

Results: Fig. 3 shows $T_{1\rho}$ weighted images of the oil phantom. The odd rows are the images with the old hard pulse. From left to right, time of spin lock TSL = 0, 4, 6, 8, 16, 32, 40, 60, 80, 100 msec. The even rows show the corresponding images with the new hard spin lock pulse. Fig.4 show the simulation with old and new pulse sequences. Fig. 5 shows the images of a human head with old (top) and new (bottom) pulse sequence.

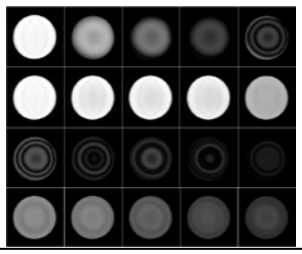

Fig. 3 $T_1\rho$ weighted images with old (even row) and new (odd row) pulse sequence.

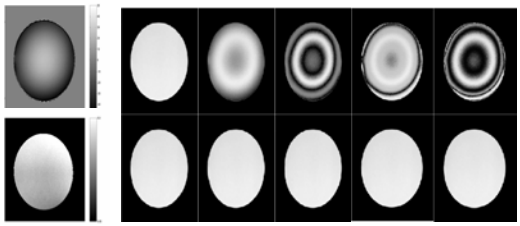

Fig. 4 Left are the measured field map and B_1 map and right are simulated $T_1\rho$weighted images from old pulse (top) and from new pulse (bottom), from left to right, TSL = 0, 8, 40, 60, 100msec

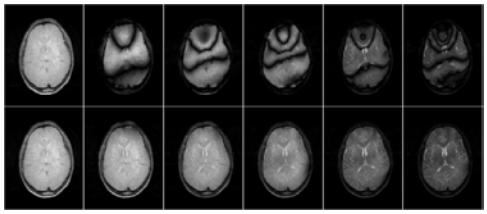

Fig. 5 $T_1\rho$ images of a human brain at TSL = 0, 8, 20, 40, 60, 80 ms Top: images from old pulse; Bottom: images from new composite pulse.

Discussion: We have introduced a new pulse to compensate both B_1 and B_0 field inhomogeneites. The improved composite pulse performs well in applications at 3T and permits more uniform $T_1\rho$images and more accurate measurements of $T_1\rho$

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