Four-Dimensional Spectral-Spatial Fat Saturation Pulse Design at 3T

Feng Zhao[1], Jeffrey A Fessler[2], and Douglas C Noll[1]

[1]*Biomedical Engineering, The University of Michigan, Ann Arbor, MI, United States,* [2]*EECS, The University of Michigan, Ann Arbor, MI, United States*

Introduction: The conventional spectrally selective fat saturation pulse [1] may perform poorly with inhomogeneous B_0 and/or B_1 fields at high fields. To mitigate this problem, Zhao et al. proposed a tailored 4D spectral-spatial (SPSP) fat saturation pulse that is robust to B_0/B_1 inhomogeneity [2]. In this work, we extend the value of this method by investigating the fact that the 4D SPSP fat sat pulse tackles the field inhomogeneity problem in fat sat in a much more efficient way (in terms of pulse length) than the conventional spectral fat sat pulse. Using the proposed design, we shorten the standard fat sat pulse length by a factor of two with single coil transmission at 3T. Furthermore, we propose to use a different excitation k-space trajectory, i.e., "spiral nonselective" (SPINS) trajectory [3], for the 4D SPSP fat sat design, and it is investigated for B_0 inhomogeneity compensation by phantom experiments and *in-vivo* human knee imaging experiments at 3T.

Theory: The 4D SPSP pulse [2] is tailored to match local spectral profiles of the 3D space. Beyond its robustness to field inhomogeneities [2], this seemingly harder pulse design is effective for shorter pulses than the conventional spectral pulse. The conventional fat sat pulse has a relatively rapid transition between the water and fat spectra to accommodate the B_0 inhomogeneity of the whole 3D volume; in contrast, the 4D SPSP fat sat pulse only needs to handle much narrower spectra of each local voxel, which can be achieved with smoother transition bands in the frequency domain. In other words, the proposed method makes the task in frequency domain easier than the conventional method, and therefore shortens the pulse length.

Furthermore, we propose to use SPINS trajectory for each 3D spatial k-space (k_x-k_y-k_z) that is repeated in the 4D excitation k-space (k_x-k_y-k_z-k_f) [2], and it is compared with the "spoke" trajectory [4] proposed in [2]. Spoke trajectory is generally efficient when k_z needs to be sampled more densely than k_x-k_y, such as 2D B_1 inhomogeneity compensation with slice selection [4]. As the target pattern of the 4D fat sat problem typically has nearly isotropic variations in the 3D space, SPINS trajectory, which is targeted for non-selective excitation, can potentially design the pulse more efficiently than spoke trajectory. Moreover, as SPINS trajectory traverses k-space center more densely and more slowly, specific absorption rate (SAR) and/or peak RF power could be smaller than those of spoke trajectory. Fig. 1 shows examples of these two trajectories.

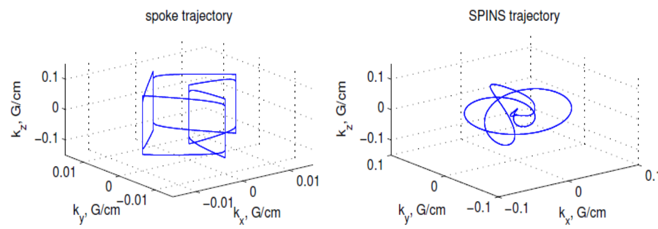

Fig.1: Examples of spoke trajectory (left) and SPINS trajectory (right)

Methods and Results: We compared the 4D fat sat pulses with spoke trajectory and SPINS trajectory. For a reference, a standard 5 ms Shinnar-Le Roux (SLR) [5] fat saturation pulse with 400 Hz minimal phase passband (for 3T) was also implemented. All the experiments were carried out on a 3T GE scanner with single channel head transmit/receive coil.

In the phantom experiment, we designed 3 different 4D fat sat pulses, i.e., 4.8 ms spoke trajectory, 2.5 ms spoke trajectory and 2.5 ms SPINS trajectory, for a 7 cm axial slab of a cylinder filled with distilled water ($CuSO_4$ doped) and mineral oil based on a 3D B_0 map acquired online. The images were acquired with 3D spoiled GRE sequences that have a 7 cm slab-select excitation and spin-warp readout, and the imaging parameters were: T_R = 213 ms, FOV = 14 cm × 14 cm × 7 cm, data size = 64 × 64 × 15. For each pulse, a pair of 3D images were acquired with fat sat on or off. Fig. 2 shows the B_0 maps and the results of different pulses for every third axial slice, where the results are the magnitude of the ratio images taken between the images with fat sat and the ones without fat sat. As can be seen, all the pulses kept the water signals very well, but the 4D fat sat pulses suppressed the oil signals more completely than the SLR fat sat pulse in the presence of B_0 inhomogeneity. The 4.8 ms spoke pulse and the 2.5 ms SPINS pulse worked similarly well, but the 2.5 ms spoke pulse did not suppress oil completely. Furthermore, the 2.5 ms SPINS pulse produced about 40% less global SAR than the 2.5 ms spoke pulse according to the report on the scanner. Although 4D fat sat has higher SAR than the SLR fat sat in general, all those 4D fat sat pulses used in our experiments produced much lower SAR than the relevant limit.

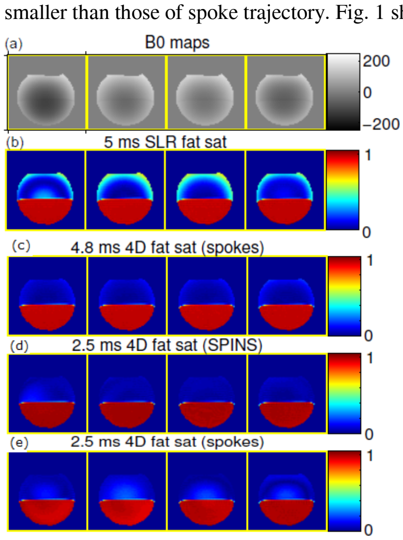

Fig. 2: The B_0 map and the ratio images by different pulses (every third slice) in the phantom experiment. Oil is on top of water, and the B_0 map is in Hz.

We also applied the 2.5 ms SPINS 4D fat sat pulse to *in-vivo* knee imaging. The FOV of the design was 28 cm × 28 cm × 6.5 cm, and the 5 ms SLR fat sat pulse was also applied for comparison. The images were acquired with 3D spoiled GRE sequences with spin-warp readout, and the imaging parameters were: T_R = 91 ms, FOV = 28 cm × 14 cm × 6.5 cm, data size = 256 × 128 × 13. Fig. 3 shows the B_0 maps and the results for two representative slices. The 2.5 ms 4D fat sat generally suppressed fat much better than the 5 ms SLR fat sat, especially in the regions with high field inhomogeneity.

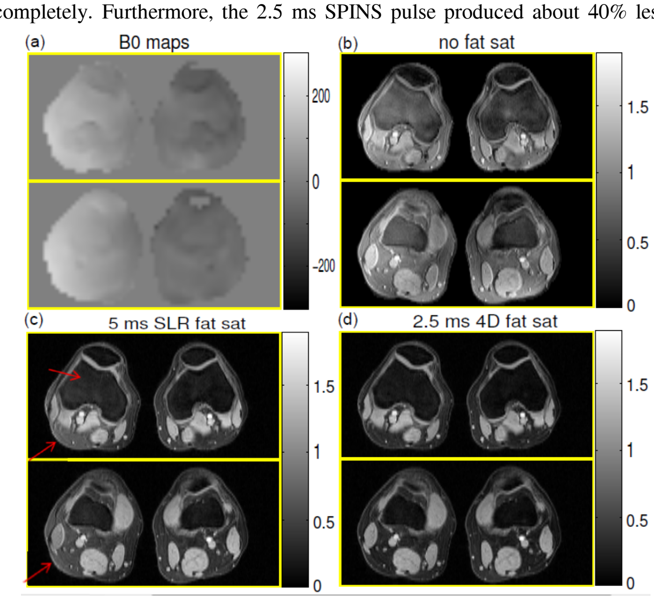

Fig. 3: Knee imaging experiment results (two slices). The B_0 map is in Hz.

Conclusions: We demonstrated that the 4D fat sat can simultaneously mitigate the field inhomogeneity problem and reduce the pulse length by a factor of 2 at 3T. We also demonstrated that the proposed 4D fat sat pulse with SPINS trajectory can potentially perform better than the previously proposed spoke trajectory in terms of fat sat quality, pulse length and SAR.

References: [1] Frahm et al., Radiology 1985: 156. [2] Zhao et al., Proc. ISMRM 2012: 636. [3] Malik et al., MRM 2012: 67. [4] Saekho et al., MRM 2006:55. [5] Pauly et al., IEEE TMI, 1991: 10. **Acknowledgements**: This work is supported by NIH Grant R01NS58576.