k_T-PINS RF Pulses for Low-Power Field Inhomogeneity-Compensated Multislice Excitation

Anuj Sharma[1], Samantha Holdsworth[2], Rafael O'Halloran[2], Eric Aboussouan[2], Anh Tu Van[2], Julian Maclaren[2], Murat Aksoy[2], V Andrew Stenger[3], Roland Bammer[2], and William A Grissom[1]

[1]Biomedical Engineering, Vanderbilt University, Nashville, Tennessee, United States, [2]Radiology, Stanford University, Stanford, California, United States, [3]Medicine, University of Hawaii, Honolulu, Hawaii, United States

Introduction Simultaneous multislice (SMS) acquisitions are of significant interest for scan time reduction, especially in functional MRI and diffusion-weighted imaging[1,2]. However, SMS acquisitions at ultra-high field strength will suffer from spatially-varying contrast and SNR due to flip angle inhomogeneity resulting from B_1^+ inhomogeneity. Furthermore, at ultra-high field SAR will be a problem for multiband excitation pulses, since the SAR of a conventional SMS pulse increases at least linearly with the number of excited slices[3,4]. The problem of increased power deposition in multi-slice imaging has been recently addressed by the Power Independent of Number of Slices (PINS) technique[4]. In this work we propose a new class of patient-tailored multiband excitation pulses, called k_T-PINS, that combines PINS with k_T-points[5] tailored RF pulses to overcome B_1^+ inhomogeneity in SMS acquisitions at ultra-high field, without high SAR.

Theory k_T-PINS pulses are developed by capitalizing on the fact that both PINS and k_T-points pulses comprise trains of phase- and amplitude-modulated hard pulses that are separated by gradient blips. Thus, PINS pulses, which conventionally only deposit energy at discrete points along the k_z dimension in excitation k-space, can be augmented by introducing additional RF and gradient pulses that visit additional locations in the transverse (k_x-k_y) plane. This is illustrated in Fig. 2a. To design the k_T-PINS pulses we have extended a previously-described algorithm for parallel transmit spokes pulse design[6] to this problem. The inputs to the algorithm comprise the 3D B_1^+ and B_0 maps measured over the volume containing the slices, and a 3D target excitation pattern containing the target slice profiles. Note that even though the target pattern is specified over a limited FOV in the slice-dimension, the designed pulses will excite slices extending infinitely in z. The algorithm, illustrated in Fig. 1, starts with a hard pulse at DC, then adds new hard pulses and gradient blips on either side of that pulse using a greedy algorithm, until a desired total number of subpulses is reached. Between each subpulse addition, the RF weights, target excitation phase, and (k_x-k_y,k_z) locations of the subpulses are jointly optimized using a local descent-based algorithm.

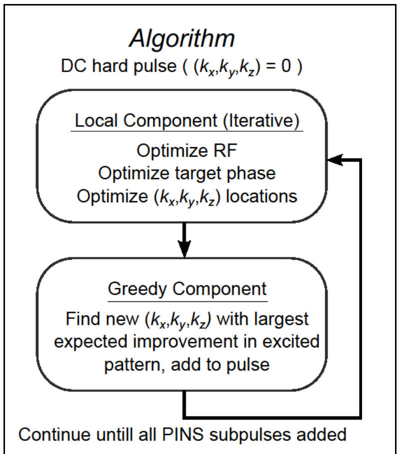

Figure 1: Illustration of the proposed k_T-PINS pulse design algorithm.

Methods Single-channel excitation experiments were performed in a $CuSO_4$ ball phantom to compare the proposed k_T-PINS pulses to conventional PINS pulses on a 7T Philips Achieva Scanner (Philips Healthcare, Cleveland, Ohio, USA). 3D $|B_1^+|$ and B_0 field maps were measured over a 23x23x12 cm FOV with a 64x64 matrix size. A conventional PINS pulse was then designed to excite slice profiles with time-bandwidth product of 3, thickness 5 mm, and slice separation 35 mm. The PINS pulse had 21 total subpulses of 50 µs duration each. A k_T-PINS pulse with 55 subpulses was then designed to produce the same excitation pattern, incorporating the measured B_1^+ and B_0 maps. The maximum gradient amplitude and slew rate were set to 40 mT/m and 150 mT/m/ms, respectively. Two identically parameterized scans were performed, one with each pulse, with FOV = 23 cm isotropic, 128x128 matrix size and TE/TR of 10/200 ms. The flip angle variance was computed in each excited slice by dividing out the receive sensitivity from the acquired images, where the receive sensitivity was measured by acquiring a 3D low angle gradient echo image of the phantom and dividing out the measured $|B_1^+|$ map. In addition, simulated excitation pattern predictions were used to compare the RF power deposited by k_T-PINS pulses to multiband (MB) spokes pulses[7]. Both pulses had time-bandwidth 2 and were designed to excite 3 slices of thickness 4 mm and 30 mm apart.

Results Figure 2 shows the designed pulses and the results of the phantom experiment. The three excited slices in the k_T-PINS experiment have a flip angle variance that is more than 30% lower than that for conventional PINS. Figure 3 illustrates k_T-PINS and multiband spokes pulses. k_T-PINS with 21 subpulses achieved 2.5 times less power deposition than the multiband spokes and a flip angle standard deviation of 3.7 degrees compared to 4.7 degrees for the spokes pulse.

Conclusion The proposed pulse is the first to enable multiband patient tailored imaging.

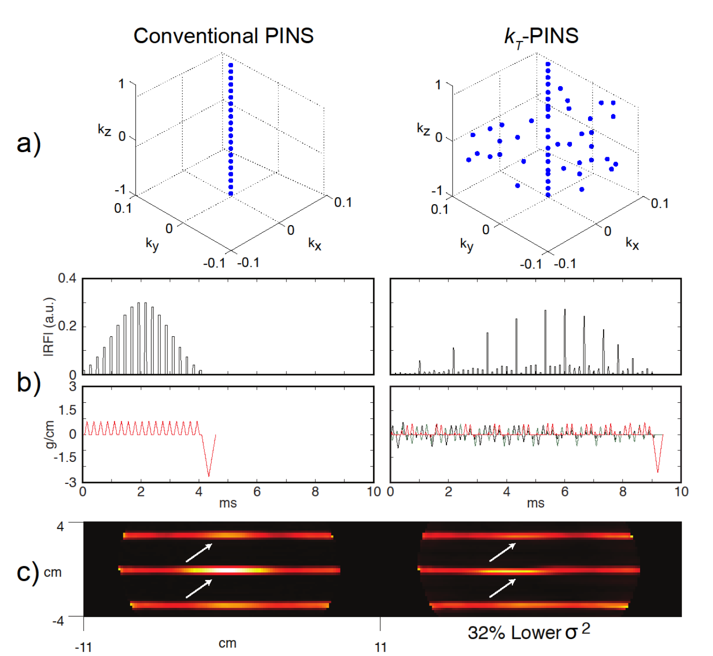

Figure 2: (a) k_T-PINS k-space trajectory and (b) pulse for multislice excitation with B_1^+ inhomogeneity compensation. (c) Additional RF and gradient sub-pulses in k_T-PINS improve flip angle uniformity at each slice. The 7T phantom images show significantly reduced flip angle variance using k_T-PINS excitation.

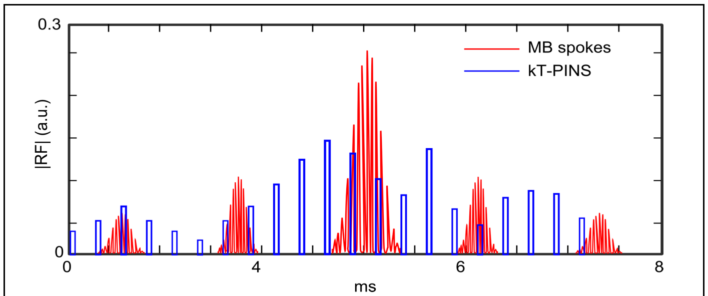

Figure 3: Comparison of multiband (MB) spokes and k_T-PINS pulses. The two pulses excite the same slice patterns, but the k_T-PINS pulse has 2.5x lower power.

References [1] D. A. Feinberg et al, PLoS ONE, Volume 5, Issue 12, 2010. [2] Larkman et al, MRM, 13:313-317, 2001. [3] E. Wong, ISMRM 2012, p. 2209. [4] D. G. Norris et al, MRM, 66:1234-1240, 2011. [5] M. A. Cloos et al, MRM, 67:72-80 (2012). [6] W. A. Grissom et al, MRM, 68:1553-1562, 2012. [7] A. Sharma et al, ISMRM 2013.