Introduction

Simultaneous multislice (SMS) acquisitions are of significant interest for scan time reduction, especially in functional MRI and diffusion-weighted imaging. 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. The problem of increased power deposition in multi-slice imaging has been recently addressed by the Power Independent of Number of Slices (PINS) technique. 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 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$_x$ dimension in excitation k-space, can be augmented by introducing additional RF and gradient pulses that visit additional locations in the transverse ($k_y$-$k_z$) 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 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 ($k_y$,$k_z$) locations of the subpulses are jointly optimized using a local descent-based 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 excise 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 image, where the receive sensitivity was measured by acquiring a 3D $B_1^*$-weighted image. The flip angle variance was computed in 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 slice. The 7T phantom images show significantly reduced flip angle variance using $k_T$-PINS excitation.

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.

References