k_T-points RF Pulses for Pre-Compensation of B_1^+ Heterogeneity in DESPOT1

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Introduction: T_1 mapping has garnered increasing attention as a basic tool for MR imaging, in research and in the clinic. It holds the promise of a method for scanner-independent T_1 contrast, and provides useful quantitative tissue information. The method of driven-equilibrium single-pulse observation of T_1 relaxation (DESPOT1) [1], also known as the variable-flip-angle method, is one such T_1 mapping method, based on the acquisition of 3D spoiled gradient echo (SPGR) sequences over a range of flip angles, which provides fast volumetric T_1 mapping. However, DESPOT1 is notoriously dependent on flip angle calibration, an issue that is amplified at high field strength. We propose to use k_T-points pulses [2] to pre-compensate B_1^+ heterogeneity in the context of brain T_1 mapping with DESPOT1. B_1^+ pre-compensation is desirable to enable the use of optimal flip angles in protocols with reduced data acquisition.

Methods:

Pulse design: A conjugate gradient algorithm was implemented to derive the optimal sub-pulse amplitudes, phases and point locations [3] for non-selective 3D pulses. A new matrix formulation was used to optimize the speed of the algorithm to achieve practical convergence times of ~10s for a typical whole-brain prescription, using MATLAB (The Mathworks, Natick MA). A multi-resolution scheme with optimal choice of initial conditions minimized the likelihood of finding local minima, while ensuring fast convergence.

Experiments: We tested our implementation of k_T-points pulses on a 3T MR750 scanner (GE Healthcare, Waukesha, WI). The body coil was used for transmission, and a multi-channel head coil for reception. One agar ball phantom, and two healthy adult male participants (ages 26 and 34) were scanned with a DESPOT1 protocol. For each experiment, a B_1^+ map was collected using the Bloch-Siegert (B-S) method [4], with a 2-ms adiabatic off-resonant B-S pulse. The B_0 and B_1^+ maps were collected over the whole brain (28 6-mm slices) with TR/TE=450/5.7ms, matrix=64×64, and FOV=22cm. These maps were then fed to the 3D k_T-points pulse design script to design *x*, *y* and *z* gradient waveforms, and amplitude and phase waveforms for the RF pulse. A 0.2 ms rectangular hard pulse was chosen as the sub-pulse shape. The resulting 8-point k_T-points RF pulse width was 2.5 ms. For comparison purposes, a single hard pulse of 0.2 ms was used with an otherwise identical pulse sequence. SPGR data were acquired with TR/TE = 13/3 ms, matrix=128×128 (256×256 reconstructed), FOV=22cm, 28 6-mm, with 8 RF pulse flip angles (phantom and subject 1: 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°; subject 2: 3°, 6°, 10°, 15°, 20°, 25°, 30°, and 40°). Reference T_1 data were acquired in a single 6-mm sagittal slice using the inversion-recovery (IR) method with a fast-spin-echo readout (echo train length = 8), with 4 TIs (50, 400, 1100, and 2500 ms) [5]. In each, we evaluated the impact of B_1^+ pre-compensation on T_1 estimates, and compared the T_1 values obtained using DESPOT1 to the reference T_1 values in the common slice, in a large white matter region-of-interest, defined automatically using FSL on the IR data (TI = 400 ms), and corrected manually.

Results: T_1 values for the phantom are given in Table 1, and show a 2× reduction in variability and a 1.6× reduction in range of T_1 estimates from DESPOT1 with k_T-points vs. hard pulse. The use of a k_T-points pulse resulted in improved B_1+ homogeneity, which translated to improved homogeneity in the volumetric T_1 map (Fig. 1). The characteristic central "hot-spot" is attenuated by the k_T-points pulse, though some T_1 heterogeneity remains. Table 1 shows that in subject 1, T_1 variability was reduced in the by a factor of 1.2× and range by a factor of 1.4×. Fig. 2 shows the reference T_1 slice with the common slice from the DESPOT1 volume, highlighting the improved correspondence when the k_T-points pulse is used.

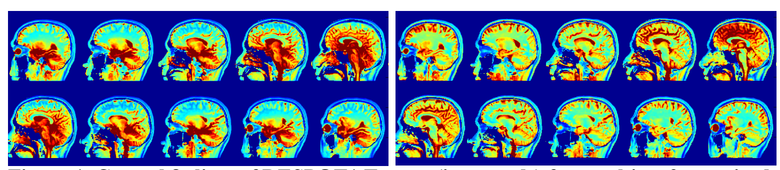

Figure 1. Central 8 slices of DESPOT1 T_1 map (in seconds) from subject 2, acquired with a hard pulse (left) and 8-point kT-points custom pulse (right).

Table 1. T_1 in the phantom and subject 1 from the reference method, and DESPOT1 with the hard and k_T-points pulses.

	RF pulse	mean ± std. dev. (ms)	range (ms)
Phantom	*reference*	*871 ± 6*	-
	hard	805 ± 128	536-1291
	k_T-points	768 ± 62	557-1017
Subj. 1 WM	*reference*	890 ± 62	778-1237
	hard	944 ± 221	532-2305
	k_T-points	1120 ± 186	758-2006

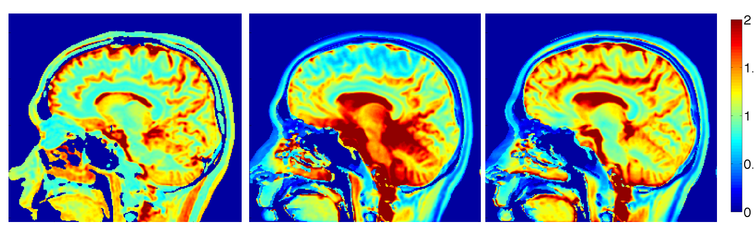

Figure 1. IR-FSE reference T1 map (left), and the same slice acquired with DESPOT1 using the hard (left) and 8-point kT-points (right) pulses, in subject 1.

Discussion: We have demonstrated pre-compensation of B_1^+ heterogeneity with the use of custom-designed k_T-points pulses for applications in fast volumetric T_1 mapping. Unlike post-hoc correction, B_1^+ pre-compensation truly enables the effective use of an optimal set of flip angles in the DESPOT1 protocol. Further work on the design of these tailored pulses will yield improved T_1 mapping results.

References: [1] Deoni et al MRM 49:515–526, 2003, [2] Cloos et al. MRM, *in press*, DOI 10.1002/mrm.22978 [3] Grissom et al., MRM 56:620-629, 2006, [4] Sacolick et al., MRM 63:1315-1322, 2010, [5] Barral et al. MRM 64:1057-1067 (2010)

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