Improvement in T_2-weighted imaging at 7T by using k_T-points

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Introduction:

T_2-weighted images are widely used for the diagnosis of brain diseases involving gray and white matter lesions such as multiple sclerosis. The increased signal-to-noise ratio (SNR) available at high field strengths (≥3T) should provide higher spatial resolution; however, the inhomogeneous distribution of the RF field (B_1^+) causes undesirable signal and contrast variations of GM/WM across the brain. These artifacts impair the quality of T_2-weighted images at high field and could mislead any medical diagnosis. The aim of this work is to improve the uniformity of whole brain T_2-weighted anatomical images at 7T by combining short 3D tailored RF pulses (k_T-points) [1] with a variable flip angle turbo spin echo (SPACE [2]) sequence using both the single-channel and parallel-transmit (PTx) systems.

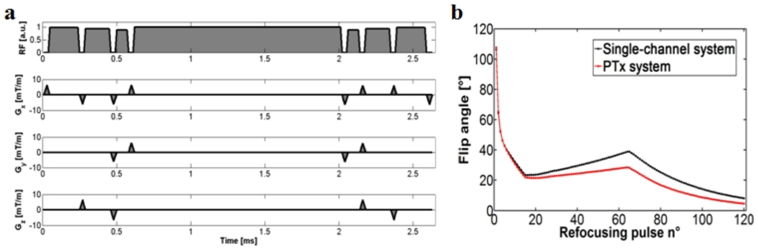

*Fig. 1: **a:** Set of symmetric sub-pulses and gradients (4 k_T-points) used to replace the original hard pulses of the TSE sequence on the single-channel system. For sake of SAR reduction, sub-pulse amplitudes were set to be identical by distributing their durations over the total pulse duration (RF_{Dur}). **b:** Flip angle train for the SPACE sequence when using protocols presented for the single-channel (black) and PTx (red) systems.*

Methods:

Two healthy subjects, who provided informed consent, were scanned on a Magnetom 7T scanner (Siemens Healthcare Sector, Germany). A 32 channel coil (Nova Medical, USA) and a customized eight channel transmit-receive array coil (RAPID Biomedical,Germany) were used on the single-channel and PTx systems. The k_T-points were found using the SOLO algorithm [3] and subject-specific B_1^+ profiles acquired using the SA2RAGE sequence [4]. On the PTx system, the B_1^+ field produced by each channel of the array was computed using a combination of relative and quantitative B_1^+-maps [5]. It was decided to excite the k-space trajectory defined by the optimized k_T-points in a symmetric way: the **k=0** position at the center of the trajectory and the remaining sub-pulses symmetrically split around it with their amplitude halved (Fig. 1a). This ensures that the CPMG conditions remain fulfilled when the k_T-points are used to replace the non-selective excitation and refocusing hard pulses in SPACE's echo train (Fig. 1b).

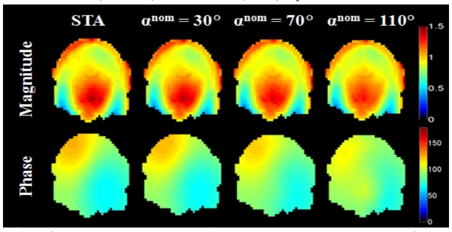

Fig. 2: Excitation profiles $e(\mathbf{r})$ of a symmetric 3 k_T-points for the single-channel system calculated via STA approximation (1st column) and full Bloch simulation of several FA values (columns 2-4). Magnitude: $|e(\mathbf{r})| = tan^{-1}(M_{xy}/M_z)/\alpha^{nom}$; Phase: $\varphi(e(\mathbf{r}))=\varphi(M_{xy})$.

On the single-channel transmit system, standard SPACE with non-selective hard pulses and a SPACE with 4 k_T-points were acquired (TR/TE = 1s/313ms, echo train length (ETL)/echo spacing (ES) = 120/5.68ms, RF_{Dur} = 2.11ms, **res. = 0.8x0.8x0.8mm³**, matrix = 320x320x208, **T_{acq} = 4min15s**). On the PTx system a standard SPACE with whole brain B_1^+ shimming and one with 3 k_T-points were acquired (TR/TE = 6s/460ms, ETL/ES = 120/7.66ms, RF_{Dur} = 3.08ms, res. = 0.75x0.75x0.85mm³, matrix = 256x256x176, T_{acq} = 13min08s) were acquired.

To focus on contrast and signal homogeneity improvements, bias field correction [6] was applied as a post-processing step to remove any bias from the receive coils.

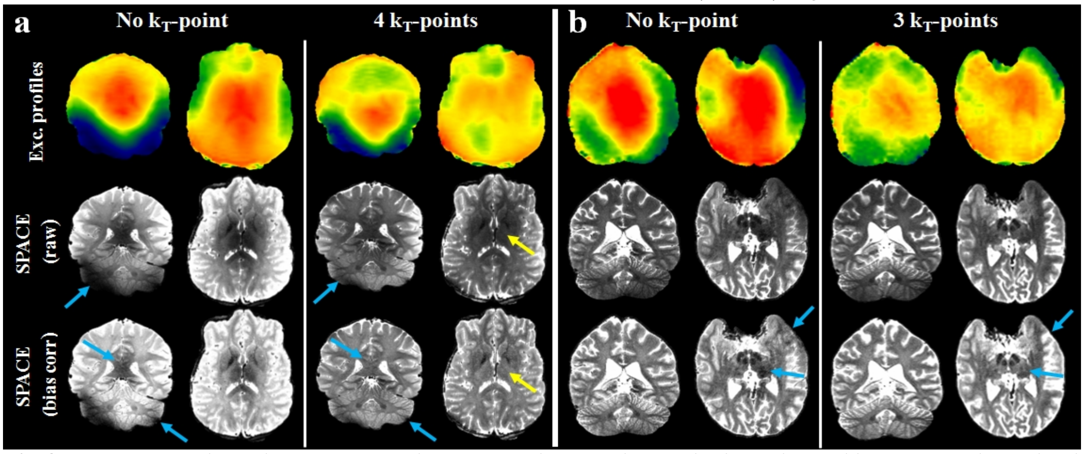

*Fig. 3: Excitation profiles and SPACE images, before (second row) and after (third row) bias field correction, obtained with and without the use of k_T-points on the single-channel (**a**) and PTx (**b**) systems. Identical RF_{Dur} were used for the images acquired with and without k_T-points. Bias field correction significantly reduced signal variations due to the non-uniform receive field distribution (yellow arrows). Using k_T-points highly improves signal and contrast homogeneity on regions of low and high intensity in the original excitation profile (blue arrows).*

Results and discussion:

Fig. 2 displays the full Bloch simulations of the excitation profile of a symmetric 3 k_T-point trajectory at different flip angles. Such simulations demonstrate that the excitation profiles remain remarkably similar to the STA approximation solution even when simulating large flip angles, as 110°. Fig. 3a shows that using k_T-points on the single-channel system improves the excitation profile homogeneity which leads to considerable improvement in the cerebellum and in the central brain region (blue arrows). The darker region still observable in the brain centre when k_T-points are used (yellow arrows) is significantly reduced on the bias field corrected images, demonstrating that it is due to the receive coil profile (B_1^-). The excitation profiles obtained with the PTx system (Fig. 3b), outperform those of the single-channel system despite a smaller number of k_T-points, further improving the quality of SPACE images. The improvements from the use of k_T-points came at the cost of increased SAR that will be alleviated in future work by carefully using a variable number of k_T-points across the readout train, similarly to the dynamic shimming procedure suggested in [7]. For example the initial refocusing pulses, crucial for driving the magnetization to equilibrium, would benefit from a higher number of k_T-points whilst the later pulses in the train could use less.

Conclusion:

This work demonstrates that replacing the original hard pulses of the SPACE sequence by symmetric sets of sub-pulses that excite an optimized k-space trajectory provides high quality T_2-weighted images with good signal and contrast homogeneity even on standard single-channel transmit systems. Combining this methodology with parallel transmission gives access to a brain anatomy free from artifacts resulting from the common B_1^+ inhomogeneity observed at 7T. The presented technique thus enables high resolution T2w, T2w FLAIR and T2w DIR imaging at 7T.

References: [1] Cloos et al, MRM 67, 2012, [2] Mugler et al, ISMRM, 2001, p.438, [3] Ma et al, MRM 65, 2011, [4] Eggenschwiler et al, MRM 67, 2012, [5] Setsompop et al, MRM 60, 2008, [6] Zhang et al, IEEE Trans Med Imag 20, 2001, [7] Malik et al, MRM 68, 2012.

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