Parallel transmission for 7T multi-shot diffusion-weighted imaging

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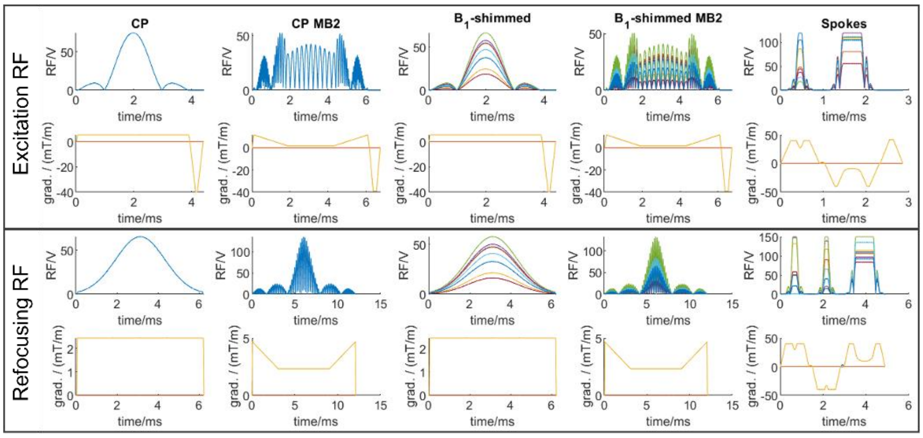
INTRODUCTION

Diffusion-weighted imaging (DWI) has an intrinsic low signal-to-noise ratio which can be improved by scanning at higher field strengths. However, the increased RF transmit inhomogeneity and shortened T_2 make DWI challenging at 7T. Parallel transmission (pTx) is a critical development to mitigate RF nonuniformity[1], while multi-shot sequences allow shorter echo times to accommodate the reduced T_2 values[2]. Here, we explore the application of pTx to a 7T readout-segmented 2D EPI (rsEPI) DWI sequence. We also discuss the origin of a fat artifact associated with VERSE'd[3] waveforms in multiband (MB) acquisitions[4].

METHODS

Two healthy volunteers were scanned on a MAGNETOM Terra 7T Scanner (Siemens Healthineers, Erlangen, Germany) using a rsEPI DWI sequence adapted from the vendor's RESOLVE[2] sequence to support pTx. Four runs were performed: single-band (SB) acquisition with circularly polarised (CP) pulses; SB acquisition with B_1^+-shimmed pulses; MB2 acquisition with CP pulses; and MB2 acquisition with B_1^+-shimmed pulses. An additional single-band acquisition with dynamic pTx (2-spokes excitation, 3-spokes refocussing) pulses was run on subject 2. DWI was performed using a tetrahedral encoding scheme[5] with two b-values (0, 1000s/mm^2). Six slices were acquired with the following parameters: TE = 58/99 ms; TR = 2500 ms; in-plane resolution = 0.8 × 0.8 mm^2; slice thickness = 3 mm (16.5 mm gap); 11 readout segments; echo spacing = 0.32 ms; GRAPPA factor = 3.

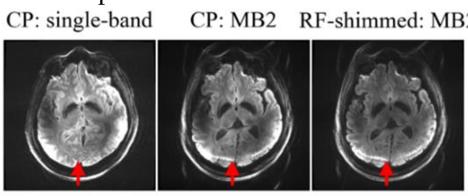
Bloch simulations were performed in MATLAB (R2021b, USA) to investigate the origin of a fat artifact associated with VERSE'd waveforms. Simulations were performed with four different sets of pulses (sinc, VERSE-sinc, spokes, VERSE-spokes) with over five different B_1 values.



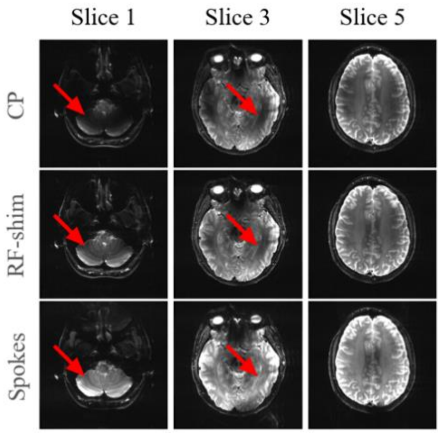
▲*Figure 1: Examples of RF waveforms and gradient shapes. PTx pulses were designed on a slice-specific basis. The vendor's VERSE'd waveforms were used for MB2 acquisitions.*

RESULTS AND DISCUSSIONS

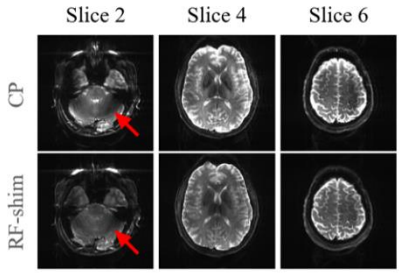
Figures 2 and 3 show the low b-value images in subject 2 for SB and MB2 acquisition, respectively. B_1^+-shimming improves RF inhomogeneity seen in the CP images in both acquisitions, and these are further improved with spokes pulses. Figure 4 shows fat artifacts present in the MB2 scans.



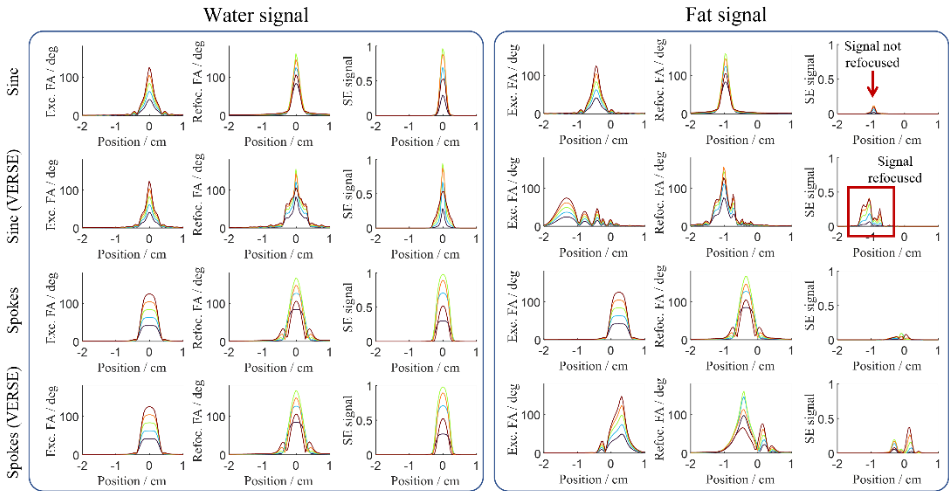
◄ *Figure 4: MB2 b=1000 s/mm^2 image showing fat artifacts in subject 1.*



◄ *Figure 2: SB b=0 images from subject 2 comparing CP, B_1^+-shimmed and spokes pulses.* ▼*Figure 3: MB2 b=0 images from subject 2 comparing CP and B_1^+-shimmed pulses.*



Bloch simulations (Figure 5) of the spin-echo signals from fat and water show that off-resonance fat frequencies are refocussed for the VERSE'd sinc waveforms but not the sinc waveforms. A similar trend is reflected in the spokes pulses, though the refocussed signal is not as extensive likely due to the bipolar gradients in the spokes pulses. Results from the simulations were further supported with additional phantom and in vivo scans.



▲*Figure 5: Bloch simulation of SE signal from both water and fat using sinc, sinc(VERSE), spokes and spokes(VERSE) pulses for different B_1^+ values (different line plot colours). Off-resonance effects of the VERSE'd pulses refocuses the fat signals while the sinc pulses do not.*

CONCLUSION

This work demonstrates the potential of multi-shot imaging and slice-specific pTx to provide uniform, high-resolution DW images of the whole brain at 7T. The study also shows that these methods can be combined with multiband RF pulses for improved scanning efficiency, but in this case, further work is required to improve fat suppression.

[1] Ibrahim et al. *Mag.Reson.Im* 2000; [2]Heidemann and Porter *MRM* 2010; [3]Conolly et al. *J.Magn.Reson.* 1988; [4]Setsompop et al. *MRM* 2012; [5] Conturo et al. *MRM* 1996