Three dimensional fast spin echo Bloch-Siegert B1 mapping with navigator based phase correction at 11.7T

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Purpose: A novel B1 mapping method based on the Bloch-Siegert (BS) phase shift has been introduced recently [1,2]. Compared to magnitude-based B1 mapping methods, this method measures B1 dependent phase shifts after off-resonant radio frequency (RF) pulses and has several advantages. It is ideal for fast B1 mapping, with important applications for multi-channel parallel transmission, and the off-resonant RF pulses can be easily added to gradient or spin echo types sequences. For applications at ultra-high field, fast spin echo (FSE) based BS sequences are better suited because they are less susceptible to B0 field inhomogeneity than gradient echo based sequences. However, phase errors due to subject motion and instrument instability are problematic for robust phase measurement. In this study, we adopted a twin-navigator motion correction scheme [3] to monitor and correct phase errors in the FSE BS sequence. The results demonstrated three-dimensional (3D) B1 mapping at 11.7 T using the sequence.

Methods: All experiments were performed on an 11.7T Bruker MR system using the pulse sequence shown in Fig. 1. A 25 mm inner diameter quadrature transmit/receive volume coil designed for rat brain was used. For in vivo rat brain experiments, 3D B1maps were acquired using this sequence with a TE/TR of 25/400 ms, a matrix size of 128 x 64 x 12, an echo train length of 4, and a resolution of 0.2 mm x 0.4 mm x 2 mm. We used 5 ms block pulses for the off-resonant RF pulses. The total imaging time was 6 minutes (one baseline image with no off-resonance pulse and two images with RF pulses at positive and negative off-resonance frequencies). The navigator echoes recorded in real-time the phase errors due to subject motion and phase differences between even and odd number of echoes and later corrected them during reconstruction. Results from positive and negative off-resonant frequencies were averaged before comparing with the baseline image. Experiments with different off-resonant frequency (4 kHz, 8 kHz, 12 kHz) and power levels (3, 6, 12 μT) were performed.

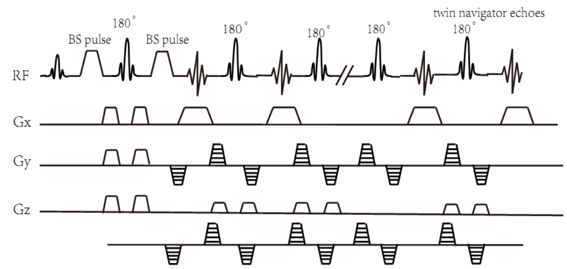

Fig. 1: A diagram of the FSE based Bloch-Siegert sequence with twin-navigator echoes. The first 180 degree pulse is flanked by two off-resonance RF pulses. Two navigator echoes are acquired after imaging echoes.

Results: Our results demonstrated that the twin-navigator echo based phase correction could correct phase errors frequently encountered when using FSE type sequences. After phase correction, both the individual phase images and the calculated B1 maps (Fig. 3) showed fewer artifacts due to phase errors and motions than images without correction. As previous described in [1], phase shift measured from the rat brain increases with the power of off-resonant RF pulses and decreases when the off-resonant frequency increases (Fig. 2). For in-vivo experiments using the block pulse, a power level of 6 μT and an off-resonant frequency of 4 k Hz were appropriate for B1 mapping at 11.7 T.

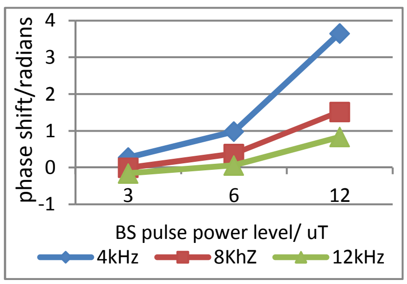

Fig. 2: Changes in Bloch-Siegert phase shift measured in the live mouse brain as results of changing power levels and off-resonant frequencies.

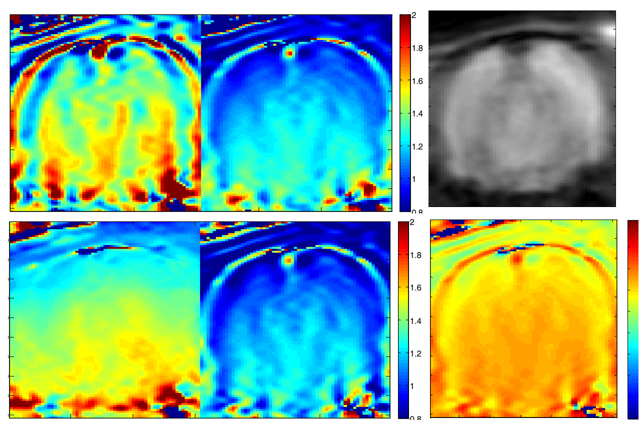

Fig 3: B1 mapping results of experiments on rat brain. Top, from left to right: phase shift map(radians) in ROI with off-resonance frequency of +4kHz, power level of 6uT, average phase shift map, magnitude image, reconstructed without motion correction; Bottom, phase shift map with off-resonance frequency of +4kHz, average phase shift map, and B1 map(gauss), reconstructed with motion correction.

Discussion and conclusion: In this study, we demonstrated that the twin-navigator based phase correction scheme could be used to reduce artifacts at ultra-high field. Previous studies have demonstrated the use of CPMG sequence [4]. Because of the shorten tissue T2 at ultra-high field strength, non-CPMG type of sequences allow shorter echo train and provides better signal-to-noise than CPMG type of sequences. The technique can be used to acquire 3D B1 map on high field scanners and can tolerate certain degree of subject motion and instrument instability.

Reference [1]. Sacolik LI, et al. MRM 2010;63:1315-22; [2] Sacolik LI, et al. MRM 2011;66:1333-38. [3] Mori S, et al. MRM 1998; 40(4): 511-16; [4] Basse-Lusebrink TC, et al. MRM 2012;67:405-18.