Fast B_1 Mapping using a STEAM-based Bloch-Siegert Preparation Pulse

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Introduction

Fast and accurate B_1-mapping is an essential prerequisite for multi-element transmit applications like e.g. RF-shimming [1] or multi-dimensional RF pulse design [2,3]. However, at higher field strength, the acquisition speed of B_1-mapping sequences is typically limited by SAR constraints, relaxation times, or characteristic sequence properties. Furthermore, the measuring time of a multi-transmit B_1 calibration scan scales with the number of transmit channels, increasing the need for efficient sampling schemes. In this work, a novel STEAM-based [4] preparation sequence is presented, which employs the recently introduced Bloch-Siegert B_1-mapping approach [5]. This preparation sequence stores the B_1-inhomogeneity related Bloch-Siegert phase shift along the longitudinal axis, which allows the fast readout of multiple stimulated echoes by a subsequent train of small angle pulses. Thus, the SAR burden and T_2* relaxation are significantly reduced, allowing for fast and efficient B_1-mapping. The flexibility and versatility of this concept is demonstrated in experiments on phantoms and in vivo.

Methods

B_1-mapping experiments were performed on phantoms and in vivo (five healthy volunteers) on a 3T MRI system (Philips Medical Systems, Best, The Netherlands) equipped with eight transmit channels [6] and an 8-element TX/RX body coil [7]. A Bloch-Siegert-STEAM pulse sequence was implemented and used in a slice-selective or non-selective manner as B_1-mapping magnetization preparation for a modified transient gradient echo sequence (Fig. 1). For non-selective excitation, $(\beta)_{0°}(2\beta)_{90°}$ composite 90° block pulses [8] were employed to increase the operational B_1 range of the STEAM sequence. A Fermi-pulse was used to induce the Bloch-Siegert shift as proposed in [5]. Transversal B_1-maps of a water-filled body phantom (400 mm ∅) were acquired in a multi-slice acquisition (slice-selective magnetization preparation, slices: 10, FOV: 450×450 mm², scan matrix: 128×64, s1ice thickness: 15 mm, gap: 10 mm, flip angle: 15°, TE: 1 ms, TR: 2.25 ms, Fermi pulse duration: 1ms, profiles per shot: 32, shot interval: 1.5 s, total scan duration: 6 s) . In vivo B_1-maps of legs and abdomen were acquired using a 3D EPI sequence (non-selective magnetization preparation, FOV: 450×270×75 mm³, scan matrix: 128×32×5, EPI factor: 5, flip angle: 15°, TE: 6 ms, TR: 10 ms, Fermi pulse duration: 5 ms, profiles per shot: 16, shot interval: 1.5 s, total scan duration: 6 s). The actual peak B_1 of the Fermi pulse, and thus the B_1-map, was derived from the phase difference of two images acquired with +/-4 kHz frequency offset according to Eq. 6 in ref. [5].

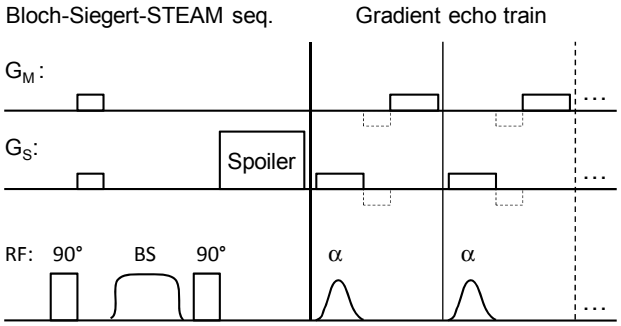

FIG. 1. **Pulse Sequence Scheme**, consisting of Bloch-Siegert-STEAM magnetization preparation (left) that is read out by a train of small angle pulses (right). Note that the rephaser gradients of the gradient echo sequence (dashed frames) have been inverted and shifted to the preparation pulses to spoil spurious signal from non-prepared longitudinal magnetization. For clarity, the non-selective mode of the preparation pulse is shown, and furthermore, the phase encoding gradients have been omitted in this diagram.

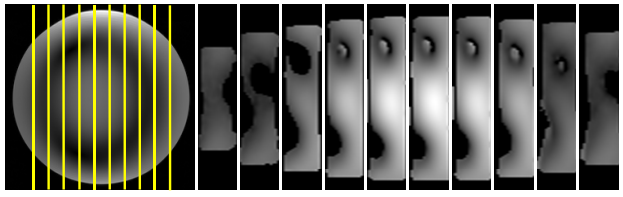

FIG. 2. **Phantom Experiments:** B_1-maps measured with a Bloch-Siegert-STEAM magnetization prepared multi-slice acquisition (right). The interleaving of the individual acquisitions resulted in a scan time of about 6 seconds for ten slices. The survey image (left) indicates the positions of the slices (yellow lines).

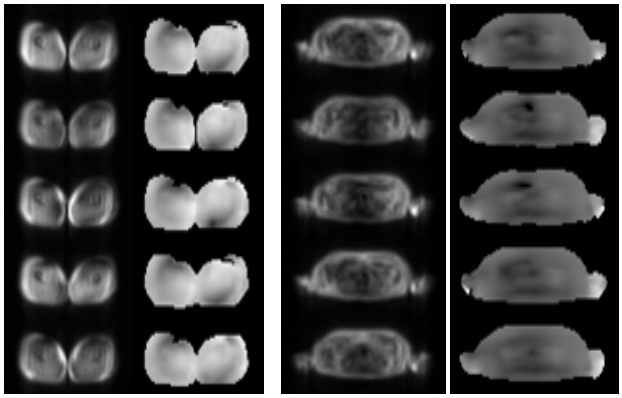

FIG. 3. **In vivo Experiments:** B_1-maps and underlying images of legs (left) and abdomen (right) measured with a Bloch-Siegert-STEAM prepared 3D-EPI sequence are shown, revealing the typical B_1 shading artifacts.

Results

Fig. 2 shows the B_1-maps of the body phantom. The multi-slice acquisition allows a complete coverage of the imaging volume of the scanner in 6 seconds scan time. The maps show strong B_1 inhomogeneities as expected for this phantom at 3T. Fig. 3 shows in vivo B_1-maps of legs and abdomen along with the underlying MR images. The maps reveal transmit shading artifacts typical for these anatomies at 3T. Due to the stimulated echo signal, T_2* relaxation is minimized for the chosen echo time, thus facilitating EPI readout. The whole-body-SAR of the sequence was reduced by more than a factor of 10 compared to the conventional sequence with one Fermi pulse per excitation.

Discussion

The presented approach separates the B_1-mapping sequence in a preparation sequence and an imaging sequence. This results in a drastic SAR reduction, which may be traded to improve the scan efficiency by a multi-slice acquisition, or to improve the B_1-mapping sensitivity by means of stronger Fermi pulses. Another benefit of the STEAM sequence is the inherent robustness against chemical shift and susceptibility artefacts, facilitating EPI sampling despite the long Fermi pulse. The stimulated echo results in a 50% signal loss, which is, however, generally acceptable for B_1-mapping due to the large voxel size. The STEAM sequence can be further extended by flow-suppression gradients or chemical-shift selective RF pulses. Finally, the B_1-mapping preparation sequence can be easily combined with other pre-pulses (outer volume suppression, navigators, etc.).

References

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