Simultaneous B_1+ and B_0 mapping using Dual-Echo Bloch-Siegert (DEBS) sequence.

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Introduction: There is increasing interest in using quantitative magnetization transfer imaging (qMTI) protocols for investigation of the myelin integrity in the central nervous system. Although alternative methods have been recently proposed [1,2], qMTI is usually performed using a long-duration off-resonance RF saturation pulse followed by a spin-echo or gradient-echo imaging sequence [3]. Because qMTI results obtained from pulsed saturation experiments rely on an accurate knowledge of the power and offset frequency of RF saturation, inhomogeneities of the transmit RF field (B_{1+}) and/or the main static field (B_0), such as those observed in high field NMR imaging (≥ 3T), will lead to systematic errors in qMTI indices. It has been verified that qMTI results improve when corrections for B_{1+} and B_0 deviations are applied [3,4]. However, to accomplish this, it is necessary to carry out independent field mapping acquisitions, leading to a consequent increase in the acquisition time.
In this work we investigate the feasibility of fast and simultaneous assessment of ΔB_0 and B_1+ for qMTI studies.

Theory: In a typical pulsed saturation qMTI experiment a shaped off-resonance MT pulse if followed by a low angle excitation pulse, phase encoding and readout at every repetition. By shifting the MT pulse position and removing the gradient crusher, the MTI sequence can be converted in a Bloch-Siegert B_1+ mapping sequence [5] (Fig. 1). In a Bloch-Siegert (BS) B_{1+} mapping method, two images are acquired with an off-resonance pulse applied symmetrically around the water resonance. The phase difference between these two images ($\Delta\varphi_{BS}$) is proportional to the square of the B_1+ magnitude: $\Delta\varphi_{BS} = (B_{1+})^2 \cdot 2K_{BS}$, where K_{BS} depends on the pulse shape and the off-resonance frequency ($\Delta\omega$). Finally, by adding a second gradient echo to this sequence a ΔB_0 mapping can be performed, based on the phase difference $\Delta\phi$ of the two acquired echoes at the times TE1 and TE2: $\Delta\phi = \gamma\, \Delta B_0 \cdot$ (TE2-TE1), where γ is the proton gyromagnetic ratio.

Methods: The dual-echo Bloch-Siegert (DEBS) sequence was implemented on a 3T Siemens Verio (Siemens Healthcare, Erlangen, Germany). Data analysis and visualization were done in Matlab 2006b (The MathWorks, Inc., Natick, MA, USA). Experiments were performed on the brain of one healthy volunteer using a 12-channel phased-array head-coil. Acquisition parameters were: FOV = (256 mm)^2, in-plane resolution = (1 mm)^2, slice thickness = 5 mm, TR/TE1/TE2 = 70/10/15 ms, FA =20°. The off-resonant RF pulse used in this sequence was a 4 msec Hanning-filtered Gaussian pulse, ±8 kHz off-resonance (ω_{BS}), nominal flip angle = 400°. This pulse produces Bloch-Siegert phase shifts of ~11 rad/gauss^2. Acquisition time was ~36 s. For comparison, B_{1+} maps were also carried out using single-echo Bloch-Siegert sequence (identical parameters as used for DEBS, TE = 10 ms) and Dual Angle Method – DAM (TR/TE = 7000/2.45 ms, FA1 = 35°, FA2 = 70°). Standard GRE field map (TR/TE1/TE2 = 400/4.92/7.38 ms, FA = 60°) sequence was also used to map ΔB_0.

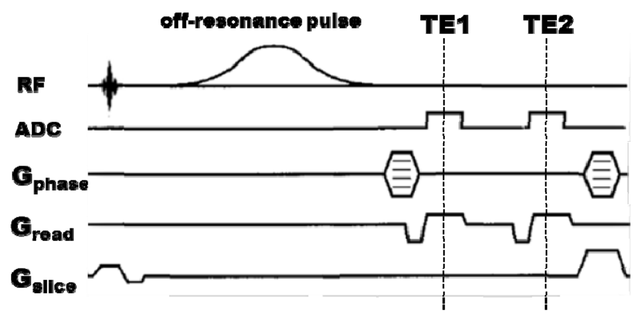

Figure 1: *A dual-echo Bloch-Siegert sequence.*

Results and Discussion: Representative ΔB_0 and B_1+ maps obtained from DEBS sequence are shown below. Field maps derived from DEBS (Figs. 2a and 2c) agree with those derived from standard GRE field map (Fig. 2d) and DAM sequences (Fig. 2b). No significant difference was observed between B_1+ maps acquired with DEBS and standard single-echo Bloch-Siegert sequence (image not shown). In contrast to other methods used for B_1+ correction in qMTI, such as the double-angle method (DAM) and Actual Flip Angle (AFI), which use short on-resonance RF pulses to estimate B_1+ variation, our method allows direct evaluation of the MT-pulse power. Moreover, since identical imaging parameters (FOV, resolution, slice thickness, etc) can be used for B_1+ mapping and MTI, it assures efficient image registration. Compared to other simultaneous ΔB_0 and B_1+ mapping methods, based on AFI sequence [6,7], DEBS is less demanding in terms of gradient and RF spoiling. Future work will aim at the optimization of DEBS sequence parameters for 3D ΔB_0 and B_1+ mapping.

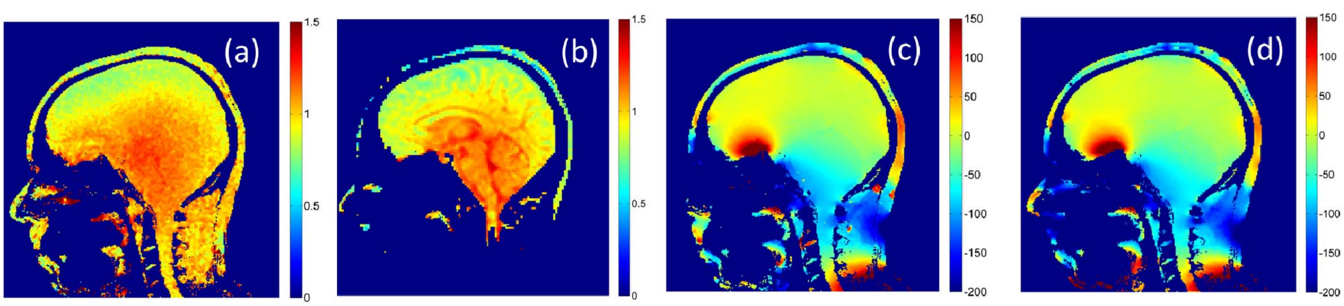

Figure 2. *In vivo results showing field maps acquired with DEBS and standard sequences: B_1+ maps derived from* **(a)** *DEBS and* **(b)** *DAM. ΔB_0 maps acquired with* **(c)** *DEBS and* **(d)** *GRE field map sequences; B_1+is expressed in normalized units (true flip angle/nominal flip angle). ΔB_0 is expressed in Hertz.*

References: [1] Gloor et al, MRM 2008, [2] Dortch et al, MRM 2011, [3] Sled and Pike, MRM 2001, [4] Underhill et al, Neuroimage2009, [5] Sacolick et al, MRM 2010, [6] Amadon and Boulant, ISMRM 2008, [7] Lenz et al, ISMRM 2011.