DREAM - A Novel Approach for Robust, Ultra-Fast, Multi-Slice $B_1$ Mapping
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Introduction
Fast and robust in vivo $B_1$ mapping is an essential prerequisite for quantitative MRI or multi-element transmit applications (1-3) like RF-shimming or accelerated multi-dimensional RF pulses. However, especially at higher field strength, the acquisition speed of current $B_1$-mapping approaches is typically limited by SAR constraints, $T_1$ relaxation times, or characteristic sequence properties, which makes a multi-transmit element $B_1$ calibration scan rather time consuming. Moreover, existing $B_1$ mapping approaches are typically prone to motion, since the flip angle is calculated from two or more acquisitions separated in time. In this work, a novel multi-slice $B_1$ mapping approach dubbed DREAM (Dual Refocusing Echo Acquisition Mode) is proposed, which derives a 2D $B_1$ map from a single, ultra-short acquisition of about 130 ms duration, which is more than an order of magnitude faster than most existing $B_1$ mapping techniques. Moreover, the transceive phase and $B_0$ are delivered in addition and for free. The performance of the approach is demonstrated in vivo by $B_1$ mapping experiments in the abdomen at 3T.

Theory
The DREAM method employs a STEAM (Stimulated Echo Acquisition Mode) preparation sequence (4) followed by a tailored single-shot low-angle gradient echo train (Fig.1). In contrast to existing rapid STEAM $B_1$ mapping techniques (5), both, the free induction decay (FID) and the stimulated echo (STE), are refocused quasi-simultaneously as gradient-recalled echoes $I_1$ and $I_2$, and their ratio is used to derive the actual flip angle of the STEAM preparation pulse sequence by a simple analytical expression (Eq.[1-3]). The small delay $\Delta t$ between the two echoes $I_1$ and $I_2$ is determined by the gradient-time area $A_{mc}$ of the STEAM dephaser gradient $G_{mc}$ and the readout gradient strength $G_{\alpha}$ (Eq.[4]). Moreover, the interval $T_2$ between the STEAM pulses can be chosen to have equal, but inverted static dephasing (i.e. $T_2^{*}$) times for $I_1$ and $I_2$ (Eq.[5]). Hence, apart from the actual STEAM flip angle $\alpha$, the off-resonance phase $\phi_0$ and the transceive phase $\phi_T$ can be determined from a single DREAM experiment (Eq.[6-7]).

Methods
Phantom and in vivo experiments were performed on a 3T MRI system (Philips Healthcare, Best, The Netherlands) equipped with an eight-channel parallel transmit extension (6). The accuracy of the DREAM approach was validated in simulations and phantom experiments, where the DREAM approach was compared with the AFI sequence (7) chosen as a reference. In vivo experiments were performed in the abdomen for five healthy volunteers. Written consent was obtained according to the rules of the institution. Transversal maps were acquired in Multi-2D acquisition (8 slices with FOV=450x270 mm², scan matrix= 64x38, imaging slice thickness = 15 mm, STEAM slice thickness = 45 mm, slice gap = 30 mm, nominal STEAM flip angle $\alpha=70^\circ$, nominal imaging flip angle $\beta=15^\circ$, $TE=2.3$ ms, $TR=0.6$ ms, $T_2=4$ ms, $T_2^*=9$ ms, $TR=3.2$ ms, profiles per shot = 38, total scan duration 1.1 s for 8 slices). The chosen echo timing scheme resulted in fat-water in-phase signals for both echoes, with the stimulated echo acquired first (cf. Eq.[5]). The STEAM slice thickness was chosen larger than the imaging slice thickness to avoid signal contaminations due to slice profile imperfections. Moreover, the slices were acquired in “first odd, then even” acquisition order to avoid slice cross-talk effects. To minimize $T_2$ effects, no startup echoes were acquired, and a low-high profile order was used. The eight-channel body coil (8) was used in quadrature mode for both, signal transmission and reception. The magnitude of $B_1$ was derived according to Eq.[3]. In addition, maps of the $B_0$ field and the $B_1$ phase were determined according to Eq.[6] and Eq.[7], respectively. The FID signal was also used for masking the $B_1$ maps by applying a simple signal threshold.

Results
Both, simulations and phantom experiments show a relatively good accuracy of the DREAM approach for STEAM flip angles from 10° to 70° with absolute deviations smaller than 2° for a broad range of $T_1$ and $T_2$ values (Fig.2). Figure 3 shows DREAM $B_1$ and $B_0$ maps of the abdomen along with the underlying FID and STE images. The dielectric shortening of the wavelength leads to typical standing wave patterns and inhomogeneous $B_1$, which are visible in the phase and magnitude maps of $B_1$, respectively. The slice through the pelvis partly extends the homogeneity sphere of the magnet, which is nicely depicted by the corresponding $B_0$ map (cf. Fig.3 right bottom).

Discussion
The DREAM approach offers some very favourable properties: The two signals, from which the flip angle is derived, are generated by a single RF pulse. Moreover, the $B_1$ mapping sequence is divided into a preparation sequence for $B_0$ encoding and an imaging sequence for spatial encoding. This results in an extremely short acquisition time and a rather low SAR burden. Furthermore, motion is efficiently frozen due to the short acquisition duration per slice. Finally, the transceive phase is delivered, facilitating advanced applications like local SAR determination via $B_1$ mapping (9).

References