DREAM B_1^+ Mapping for Short-T_2 and -T_2* Components

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Introduction

Fast and robust in vivo B_1^+ mapping is an essential prerequisite for many applications in high field MRI. However, most B_1^+ mapping techniques are relatively slow, which makes integration into the clinical workflow difficult. Recently, the DREAM (Dual Refocusing Echo Acquisition Mode) approach has been introduced (1), allowing the acquisition of a 2D B_1^+ map in only a short fraction of a second. Moreover, the sequence is compensated for off-resonance, T_2* and chemical shift effects, making it robust for B_1^+ mapping in the presence of e.g. fat in the abdomen. In the present work, the DREAM approach is further refined for T_2 compensation by using also the *virtual* stimulated echo. Experiments on phantoms and in vivo at 7T were performed to study the impact of the new echo scheme on the accuracy of the method.

Theory

The DREAM approach employs a STEAM magnetization preparation sequence followed by a low-angle imaging train, where both the STE and the FID signals are measured as gradient-recalled echoes during a single readout (Fig.1). The unknown flip angle α of the STEAM pulses is derived from the ratio of the measured STE and FID signal magnitudes according to a simple analytic expression (Eq.1). The so-called "FID first" and "STE first" options (cf. Fig.1a,b) both employ a timing scheme according to Eq.[2], which equalizes the T_2* weighting of STE and FID signals, resulting in a T_2* compensated B_1^+ map. However, there is a T_2-evolution time difference $\Delta T_{T2} > 0$ between the signals (Eq.[3]), resulting in a slight T_2 weighting. In contrast, a novel, third sequence option (cf. Fig.1c), dubbed "STE* first", measures the so-called virtual stimulated echo (STE*), which represents the complex-conjugated counterpart of the STE. While the STE rephases after rotating the longitudinal magnetization into the transverse plane by the imaging RF pulse β, the STE* is further dephasing. Consequently, the STE* can simply be measured by employing the "STE first" option with inverted polarity of the STEAM dephaser gradient G_{m2} (see the extended-phase graph (2) in Fig.1). Moreover, for a timing scheme according to Eq.[4], both the spectral encoding time and the T_2 evolution time are identical for STE* and FID, namely TE_{FID}, (i.e. $\Delta T_{T2} = 0$). Accordingly, a T_2- and T_2*-compensated B_1^+ map may be derived from Eq.[1] using the "STE* first" option as shown in Fig.1c.

$$\alpha = \arctan\sqrt{2\, I_{STE}/I_{FID}} \quad [1]$$

$$T_S = TE_{STE} + TE_{FID} \quad [2]$$

$$\Delta T_{T2} = 2TE_{STE} \quad [3]$$

$$T_S = TE_{FID} - TE_{STE^*} \quad [4]$$

Methods

Phantom and in vivo brain experiments (nine normal volunteers) were performed on a 7T whole body research MRI scanner (Achieva, Philips Healthcare, Best, The Netherlands). Written consent was obtained according to the rules of the institution. The three different considered echo options were compared in experiments on a rubber phantom ($T_2 \approx 1$ ms) and in vivo, where a transversal slice through the ventricle of the brain was acquired (FOV = 320×190 mm^2, SENSE factor = 2, imaging flip angle β = 7°, STEAM flip angle α = 60°, pixel bandwidth = 1250 Hz, slice thickness = 5 mm, in-plane resolution = 3.3 mm, STEAM RF pulse shape = block shape, scan duration = 110 ms). For the rubber phantom, the three different echo schemes (FID first: TE = 0.88/1.72 ms, T_S= 2.6 ms; STE first: TE=1.11/1.95 ms, T_S= 3.06 ms; and STE* first: TE=1.11/1.95 ms, T_S= 0.84 ms) resulted in T_2 evolution time differences between STE$^{(*)}$ and FID of ΔT_{T2} = 3.44, 2.22 and 0 ms, respectively (cf. Eqs. [2,3]). For the in vivo experiments, slightly longer echo times were chosen (FID first: TE = 1.7/2.5 ms, T_S= 4.2 ms; STE first: TE=1.7/2.5 ms, T_S= 4.2 ms; and STE* first: TE=1.7/2.5 ms, T_S= 0.8 ms), resulting in an T_2 evolution time difference between the STE$^{(*)}$ and FID signals of ΔT_{T2} = 5 ms, 3.4 ms and 0 ms, respectively.

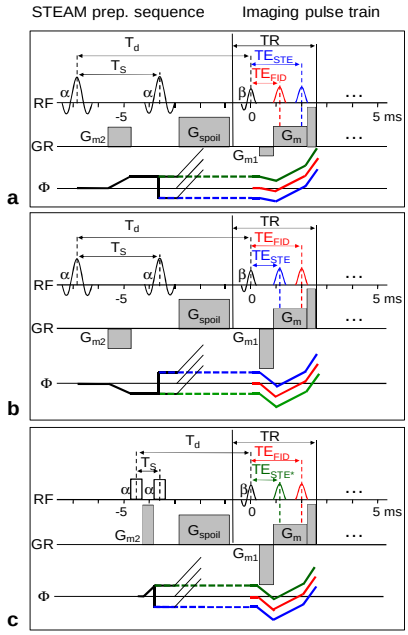

FIG. 1. **DREAM pulse sequence scheme,** shown for three echo options (a: FID first, b: STE first, c: STE* first). Φ denotes the extended phase graph of the switched gradients.

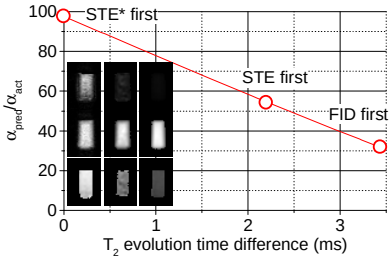

FIG. 2. **Impact of T_2 (rubber phantom):** The graph shows the normalized, predicted flip angle as a function of the STE/FID T_2-evolution time difference ΔT_{T2} characteristic for the different timing schemes. The underlying images are shown in the insert (top: STE, centre: FID, bottom B_1^+ map. From left to right: STE* first/ STE first/ FID first).

Results

Figure 2 shows the predicted flip angle for the rubber phantom as a function of the STE/FID T_2 evolution time difference ΔT_{T2} characteristic for the different echo timing schemes. While a negligible deviation from the actual flip angle is observed for the "STE* first" option, strong deviations are observed for the "STE first" and "FID first" option. The underlying images show that this is due to an enhanced signal decay of the stimulated echo. This result represents an experimental validation for the T_2-compensation of the "STE* first" option based on the virtual stimulated echo. Figure 3 shows in vivo B_1^+ maps of the central axial plane of the brain measured with the different echo timing schemes. The ventricular system shows a slight contrast, manifesting as a small, relative B_1^+ enhancement of the ventricle compared to the surrounding tissue (≤4%). The ventricular contrast reduces with increasing T_2-compensation, which indicates that this effect may partly be attributed to T_2 relaxation effects of the surrounding brain tissue.

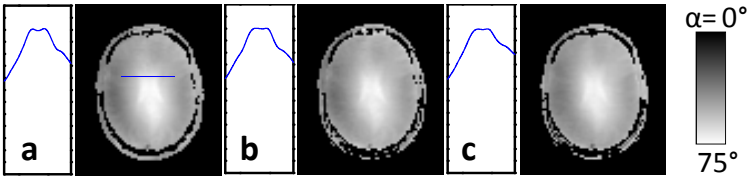

FIG. 3. **Impact of T_2 (brain):** B_1^+ maps of a transverse slice intersecting the ventricular system are shown for different timing schemes (a: FID first, b: STE first, c: STE* first) corresponding to an increasing T_2-compensation from left to right. In addition, 1D profiles of the B_1^+ maps selected along a line through the ventricle are shown.

Discussion

The novel DREAM echo scheme is particularly interesting for B_1^+ mapping of components with very short T_2 and T_2^*. This could be also an interesting option to map B_1^+ in multi-nuclei applications (e.g. ^{23}Na, ^{31}P). Furthermore, the use of the virtual stimulated echo represents an interesting option adding new degrees of freedom to the DREAM method.

References

1. Nehrke K. and Börnert P., MRM 2012;68:1517-26. **2**. Hennig J. Concepts Magn Reson 1991;3:125–143.