Very fast volumetric B1+ mapping at 7 Tesla using DREAM

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Introduction

The B_1^+ transmit field determines the spatial distribution of RF excitation, refocusing and/or magnetization preparation. With the move towards higher fields, RF homogeneity problems caused by wave propagations effects have become obvious, which can compromise clinical diagnosis. All approaches to counteract these effects, such as special RF pulses (1) and parallel transmit techniques (RF-shimming (2,3) and transmit SENSE (4,5)), require knowledge about the actual B_1^+ fields involved. Furthermore, measured B_1^+ maps can be used to estimate electric tissue parameters and E-field components (6), giving potential new diagnostic information and allowing prediction of the specific absorption rate (SAR) increasing patient safety for ultra high field imaging. However, currently available B_1^+ mapping techniques, either encoding the B_1^+ into signal phase or amplitude (7-12) are inefficient, because of the frequent repetition of the B_1 encoding process and the need for at least two separate measurements for B_1^+ fitting. This is a serious issue especially in parallel transmit applications, where mapping time scales linearly with the number of transmit channels.

To overcome these limitations, in this work, a new, very fast, simple and safe B_1^+ mapping approach for ultra-high field imaging is introduced allowing volumetric B_1^+ brain mapping in less than 10s.

Methods

One ingredient of the new approach is to separate the B_1^+ sensitivity encoding process from its spatially resolved detection (9,10). Here a stimulated echo (STE), dual (α) RF pulse preparation scheme is chosen, storing the prepared magnetization in M_z, exposed only to slow T_1 relaxation (see Fig.1). After this preparation, two longitudinal states are available, the STE state: $M_{z2} = M_o/2 \sin^2(\alpha)$ and the untouched remaining one: $M_{z1} = M_o \cos^2(\alpha)$. Using a repeated, efficient gradient echo block, the STE magnetization is imaged. The new idea is to sample not only the STE signal ($\sim M_{z2}$) via the STEAM (stimulated acquisition mode) (13), but also the FID ($\sim M_{z1}$) generated by the (β) RF pulse simultaneously (see Fig.1). Therefore, this dual echo sampling sequence is named DREAM (dual refocusing echo acquisition mode). Since, the tip angle of the gradient echo (β) influences both signals (I_1, I_2) in the same way: B_1^+ can be calculated from the $\arctan(2|I_2|/|I_1|)$. Furthermore, the transmit phase can be estimated via $\arg(I_1 * I_2)/2$ if appropriate sequence timing (for T_d T_s, T_{E1}, and ΔT) is chosen. This simple and very robust sequence allows for efficient, multi-slice (single-shot) B_1^+ mapping and is used here as a volumetric approach.

For confirmation, phantom and in-vivo experiments were performed using a 7T scanner (Achieva, Philips HealthCare, Cleveland) equipped with an integrated quadrature transmit and, 32-channel receive array head coil (Nova Medical). Mapping performance was tested using a FOV: 300×192×320mm³ using isotropic voxel resolutions of 5×5×5mm³ (Td/Ts/TE1/ΔT: 9/5/1.97/1ms) resulting in a total scan time of 9.7s and 2.5×2.5×2.5mm³ ($T_d/T_s/TE_1/\Delta T$: 9/5/2.1/1ms), total scan time of 39s. 38 echo pairs were read-out using a TR between 4.3/5ms after each preparation. For the two slice selective RF pulses (α, β) tip angles of roughly 60° and 10° and different thicknesses ($slice_\alpha = 2\ slice_\beta$) were chosen, to improve mapping accuracy. The timing was optimized to ensure that both gradient echoes are sampled in a water/fat in-phase condition. In volunteer scans the influence of external dielectric material ($BaTiO_3$ + deuteriated water) for tailoring the spatial distribution of the electromagnetic field (14,15) was briefly investigated using the low resolution protocol.

Results

Figure 2 shows selected low resolution B_1^+ maps measured in a spherical phantom filled with water. Characteristic wave propagation effects are visible. Figure 3 shows selected high resolution in-vivo B_1^+ maps, illustrating the almost two-fold higher B_1^+ in the middle of the brain. Figure 4 shows selected low resolution B_1^+ maps measured without and with field shaping dielectric pads placed under the neck of the volunteer. Slight improvements of the RF field homogeneity and its extent are visible in areas such as the temporal lobe and base of the brain.

Conclusion

DREAM, as a very fast, robust and save B_1^+ mapping approach, can become a very valuable tool for ultra-high field MR supporting conventional high-field applications, electrical property imaging and parallel transmit MRI. Such a short volumetric 10s scan can support corresponding optimization with the patient in place. The sequence is safe in terms of SAR (only 17% of the legal limit), is not limited by gradient performance or available maximum B_1^+ and can easily be expanded to map more than one transmit channel or appropriate superposition. It is rather robust due to the simultaneous acquisition of the two echoes, which are not separated in time (reduced motion problem) and can easily be implemented.

References

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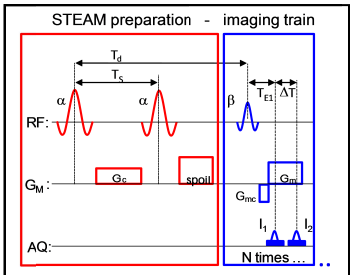

Fig.1. DREAM sequence scheme. In the STEAM-type magnetization prep. B_1^+ is encoded (red). In the repeated imaging train (blue) the STE and the FID is sampled to calculate B_1^+.

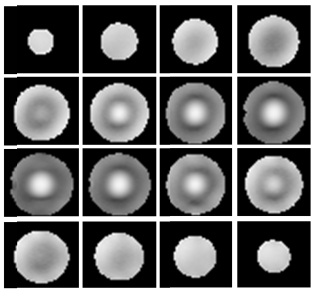

Fig.2. Volumetric DREAM B_1^+ mapping. Selected slices of the isotropic 3D map of a water shere (voxel: 5x5x5mm³, measured in 10s). Wave propagation effects are visible.

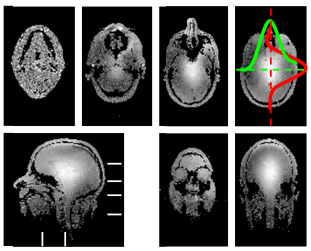

Fig.3. Volumetric DREAM B_1^+ in-vivo. Selected reformats (voxel: 2.5x2.5x2.5mm³, measured in 40s). The tics in the saggital map indicate the reformat's positions. A 2-fold B_1^+ increase in the centre is visible.

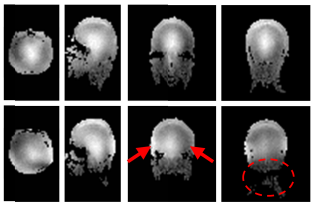

Fig.4. Volumetric DREAM B_1^+ in-vivo. Selected reformats transversal, sagittal, coronal (voxel: 5x5x5mm³, measured in 10s), top row: without, bottom row: with dielectric pads in the neck - changes of RF field homogeneity visible (arrows).