Rapid RF Field Mapping Using a Slice-Selective Pre-conditioning RF Pulse

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Introduction: In MRI, radiofrequency (RF) field (B_1) inhomogeneity can produce flip angle variations, which can ultimately lead to signal intensity variations and quantitative measurement errors. By independently calibrating the local spatial variation of B_1, the RF-related signal variations can be corrected. The most widely used B_1 mapping method is the double angle method (DAM) [1], which uses the ratio of two images acquired at two different nominal flip angles. However, it is inherently inefficient, due to a need for a long repetition time, TR ≥ $5T_1$. In this study, we describe a novel and efficient method for rapid B_1 mapping using a slice-selective pre-conditioning RF pulse (SS-Pre pulse) followed by an ultra-fast gradient echo (TurboFLASH) pulse sequence, and evaluate its accuracy and time efficiency against the DAM method at 3T.

Methods: The SS-Pre with TurboFLASH readout pulse sequence was implemented on a 3T whole-body MRI scanner (Tim Trio, Siemens). The SS-Pre pulse was designed as a slice-selective sinc pulse with nominal flip angle, α^{nom} = 60°, pulse duration = 2.8 ms, time-bandwidth product = 6, transmitter bandwidth = 2.1 kHz, and slice thickness = 6 times that of the imaging slice thickness [2]. Immediately after a SS-Pre pulse excitation, a TurboFLASH imaging sequence with centric k-space reordering was performed to image the residual longitudinal magnetization, with associated spoiler gradients to dephase the transversal magnetization (Figure 1). An effective saturation-recovery (SR) module [3] with recovery time ($t_{SR} \leq T_1$) can be optionally used to achieve a constant magnetization prior to the SS-Pre pulse excitation, in order to accelerate data acquisition, as has been done with DAM [4]. The pulse sequence parameters of SS-Pre with TurboFLASH readout sequence include: acquisition matrix =64x48 (64x32 for pelvis), TR/TE = 2.6/1.3ms, flip angle = 10º, bandwidth = 1500Hz/pixel, and slice thickness = 8mm. For signal normalization, a proton density (PD) image was acquired with identical imaging parameters, except without the SS-Pre pulse. The ratio of two images, a SS-Pre and a PD image, gave the measurement of the B_1 scale factor (κ) using the following equation: $\kappa(r) = \cos^{-1}(SSPre(r)/PD(r))/\alpha^{nom}$, at a position r. The pulse sequence was evaluated by imaging a T_1-doped water phantom (T_1=0.3s) and three healthy volunteers for brain and pelvic imaging (T_1=2s). To evaluate the sensitivity to off-resonance, phantom imaging was repeated with resonance offset ranging from 0-500 Hz (100 Hz steps). The total image acquisition times of the SS-Pre method were approximately 2s/0.6s (water) and 10s/2.3s (brain and pelvis) without/with using a SR module. For the reference measurements acquired by using DAM, the total image acquisition times were approximately 153.6s (water), 960s (brain), and 640s (pelvis).

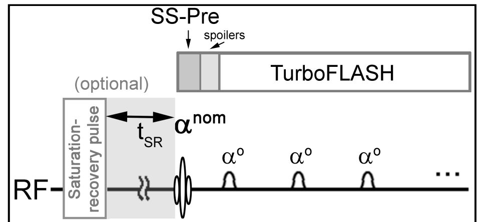

Figure 1. Sequence diagram of the SS-Pre with TurboFLASH readout method.

Results: Phantom experiments showed that the SS-Pre pulse sequence is insensitive to off-resonance, with less than 1.4% B_1 measurement error up to 500Hz off-resonance. Figure 2 shows the reference DAM κ maps and the corresponding κ maps measured by the SS-Pre method, as well as their corresponding profiles of κ. The region-of-interest (ROI) was chosen within the whole region for the phantom and the brain, and within a rectangular region (green, drawn in Fig.2) to avoid the motion artifact in the reference DAM measurements. The κ maps measured by the SS-Pre and reference methods showed excellent agreement within the ROI (water, brains, pelvises; mean difference =0.05%, 1.27%, 1.3%; 95% limits of agreement were -1.54% and 1.63%, -2.6% and 5.2%, -1.7% and 4.5%; respectively). The root-mean-squared error (RMSE) of the κ map compared to the reference map was less than 3% in both the phantom and in vivo volunteers, for both the SS-Pre method and SR SS-Pre method.

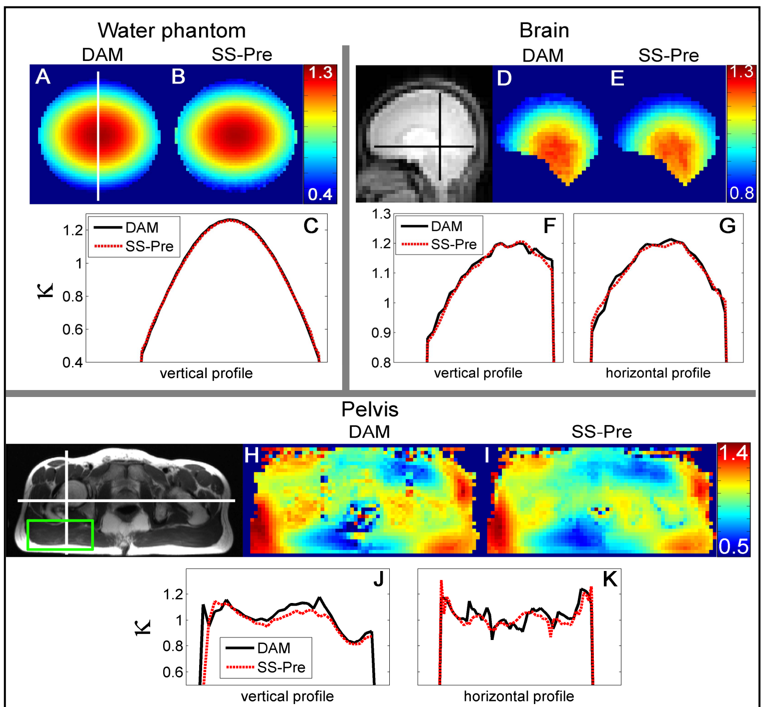

Figure 2. The B_1 scalemaps of water phantom, Brain, and Pelvis: (A, D, H) DAM, (B, E, I) SS-Pre, (C, F, J) vertical profiles, (G,K) horizontal profiles.

Discussion: This study demonstrates a new fast B_1 mapping method that can be used for a variety of applications, including body imaging applications. The SS-Pre method was faster compared to DAM, and produced B_1 measurements that were in excellent agreement with those measured by the DAM method. This method assumes ideal slice profile and B_0 insensitivity of the SS-Pre pulse, so that κ gives an indirect measurement of the actual B_1. This method can be used for quantitative MRI applications that require fast B_1 calibration.

References:

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