B1 mapping of coil arrays for parallel transmission

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INTRODUCTION

Accurate and fast B1 field mapping of transmit array coils is key in the field of parallel transmit imaging (1). Each individual coil element typically produces a strong flip-angle variation over the field-of-view (FOV). Such flip angle ranges are challenging for B1 mapping methods (2): The flip angle calculation in areas of low B1 amplitudes suffer from low SNR. The flip angle calculation in areas of high B1 amplitudes might not be unique. A common approach is therefore to measure a series of images at different power levels at the cost of total scan time (3). Resolving larger flip angles than 90° also requires taking the variation of the slice selection profile over the FOV into account (4). We propose a composite technique for B1 mapping that uses all coil elements for signal excitation whereas the flip angle produced by the individual coils is encoded using a magnetization preparation (5). Only one flip angle encoding scan is required per coil element plus one reference scan that is used for the calibration of all coils. The dynamic range of the excitation pulse of the imaging part is reduced over the FOV allowing a significant increase in precision with which low B1 field amplitudes from single coils can be determined.

METHOD

The sequence diagram of the flip angle encoding is shown in Fig. 1. The RF-pulse RF1 is played out on a single coil element preparing a longitudinal magnetization of $M_z(t=0)*\cos\alpha$ where α is the spatially varying flip angle. Transversal magnetization is spoiled with gradients along all 3 spatial dimensions. The longitudinal magnetization is excited by RF2 applying a spatially varying flip angle β. RF2 is a composite RF-field generated using all coils of the array. The reference image is acquired without magnetization preparation. The signal ratio of the images equals $S_p/S_r = (\cos\alpha-1) *\exp(-TD/T1)+1 \sim \cos\alpha$. If signal recovery between preparation and excitation is neglected, an α–map can be calculated by taking the inverse cosine of the signal ratio. The preparation pulse RF1 is applied with no or mild slice selection gradient to ensure a constant flip angle across the slice selected by the excitation pulse. With a maximum TD of 3.5ms the flip angle calculation stays within 2% accuracy up to α =155° given a minimum T1 of 270ms for fat tissue. The relative phases between the RF-field distributions of the different coils are calculated from additional scans using only one coil for excitation. These single coil images are acquired at short TR of 100ms. They are also used for optimizing the phases set to the different coils for the composite RF2, in order to avoid local low SNR that may be problematic for the signal ratio calculation. For imaging a multi shot interleaved EPI is used with 4 excitations acquiring a FOV of 40cm with a 36x64 k-space matrix. With a TR = 3s/100ms the total scan time was 108s/3.2s to determine the flip angle magnitude/ phase of the RF transmit fields from 8 coil elements.

For measurements a GE Signa HD 3T scanner was used with 23mT/m maximum gradient amplitude and 80T/(m*s) slew rate. The scanner is equipped with a body sized TEM transmit array coil. The 16 rungs of the coil were driven by 8 independent RF-amplifiers. Opposite rungs were combined with a 180° phase shift and controlled by the same amplifier.

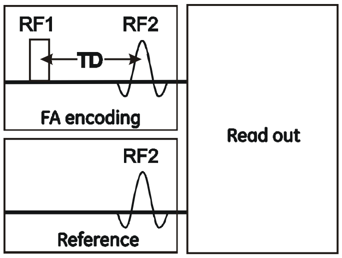

Fig. 1: schematic of B1 mapping

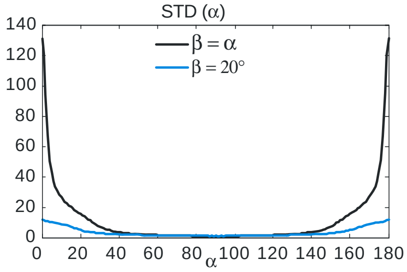

Fig. 2: precision of flip angle calculation

RESULTS

The Monte Carlo simulation in Fig. 2 calculates the standard deviation (STD) of flip angle α assuming a single coil excitation RF2 field (β=α) and a composite RF2 field with constant excitation flip angle β=20°. The STD for the composite RF2 field is a worst-case estimation for all 20°<β<160°. The simulation assumes a SNR=60, achieved with a 90° excitation flip angle. The STD of the estimated flip angle is below 5° (2°) and below 16° (3.5°) for all actual flip angles 20°(40°) < α < 160° (140°) using the composite and the single coil RF2 excitation respectively. For flip angles approaching zero, α becomes unpredictable using a single coil RF2 excitation, whereas the STD of α stays within 11.6° using the composite RF2 excitation. The image of a meat sample shown in Fig. 3A is acquired with a single coil. Such images from all coils were used to calculate relative phase maps of the individual coils as shown in Fig 3C. In Fig. 3B a reference image is shown applying a composite RF2 excitation with optimized phases set to the different transmit channels. The flip angle magnitude maps as shown in Fig. 3D were gained by analyzing the signal reduction when a 2ms hard-pulse is applied prior to the composite excitation pulse.

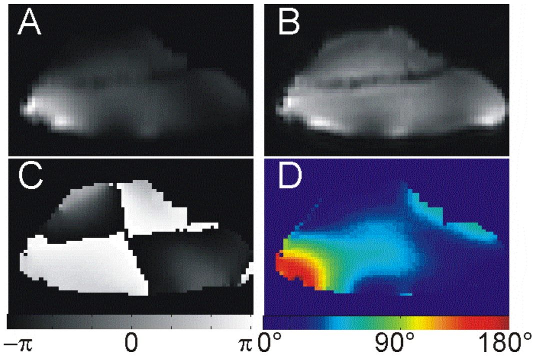

Fig. 3: single coil (A), composite coil (B) image, phase (C) and magnitude (D) B1 map

DISCUSSION

The proposed method makes use of the common FOV of multiple transmit coils to share a single reference image for the B1 field mapping of all coils. It reduces the required scan time by a factor of (n+1)/(2*n) compared to mapping the RF field distributions of n coils separately (6). Beside the scan time reduction the major advantage of the proposed technique is a significant increase in precision with which low B1 field amplitudes from single coils can be determined. This relaxes the requirements on the choice of the dynamic range of flip angles to be resolved. The basic concept of mapping single coils while using all coils for imaging is enabled by separating the flip angle encoding (via magnetization preparation) from the signal generation and read out. It's therefore not straightforward to extend the concept to other methods like e.g. multi spin echo acquisitions that apply different refocusing flip angles with a certain ratio.

A drawback of the technique is, that the phase map calculation requires an additional data set. The transversal magnetization generated by the RF field to be mapped is spoiled during magnetization preparation. It could be refocused after the first signal read out and still be recorded in a second read out of the same scan. However, an additional data set acquisition for phase calculation can typically be performed in less than a second applying short TR. This additional data set can then be used to find an optimized RF field composition for excitation. The excitation does not necessarily need to be homogeneous over the FOV. A finite excitation flip angle over the whole FOV already avoids local low SNR and allows to determine even zero flip angle from a single coil with finite uncertainty.

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