COMPARISON OF FOUR PHASE BASED METHODS FOR THE B_1^+ MAPPING AT 7T

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INTRODUCTION: In ultra-high field MRI the increase of signal to noise ratio (SNR) comes together with longer T_1 and shorter T_2* relaxation times, higher specific absorption rates (SAR) and higher B_1 field inhomogeneities. The use of parallel transmit technology has increased the need for fast B_1^+ mapping routines to calibrate transmit coil arrays and to correct for B_1 inhomogeneities. Phase-based methods for B_1 mapping have been shown to be more accurate than magnitude-based methods [1] as the phase of the signal is insensitive to T_1 relaxation effects and coil sensitivity profiles (B_1^-). In this work we compare four phase-based methods taken from literature and adapted to 7T: A) the optimized Mugler method of Storey [2,3,4], B) the Morrell method [5], C) the Santoro method [6,7,8] and D) the Bloch-Siegert method of Sacolick [9]. The methods are compared in terms of the sensitivity to the B_1 and B_0 inhomogeneities, SAR levels and repetition times (TRs), using simulations together with phantom and *in vivo* experiments.

METHODS: All four methods make use of the difference of two phase images obtained for two different rotation senses of the magnetization **M** during the respective composite pulses (Figs. 1, 2). **Simulations:** MATLAB (The MathWorks, Inc, Natick, USA) is used to simulate the dynamics of **M** during the composite pulses (Fig.2). Sensitivity is represented by the phase angle accrual as a function of the B_0 offset [Hz] and B_1 inhomogeneities (Fig. 3). B_1 is expressed in terms of the total flip angle (total FA), which accounts for the total duration and amplitude of the applied RF pulse regardless of its phases (A, B, C) or off resonance frequencies (D). These curves are used for interpolating the measured accrual phases to generate B_1 maps. **Experiments:** All sequences have been implemented on a Siemens 7.0T Scanner (Magnetom, Siemens, Erlangen), using the IDEA software version VB15a. All four methods were implemented as 3D methods, using rectangular non selective composite pulses and the same imaging module (3D GRE) in which the excitation pulse is replaced by each of the four composite pulses A, B, C, D. The standard basic birdcage coil (Siemens) was used, with an 18cm diameter spherical phantom filled with water (50mM Na). The four MR protocols are identical (FOV=200cm, Matrix 128x88x44, TE=2.4ms) apart from the FAs and the repetition times TRs. FAs have been chosen, when possible, according to previous reports. TRs have been adjusted to accomplish identical SAR levels for all approaches (30% of the standard mode). Values are: Total FA_A/TR_A =120°/105ms, Total FA_B/TR_B=270°/240ms, Total FA_C/TR_C=96°/63ms, Total FA_D/TR_D=765°/360ms. For comparison, a B_1 map of the same phantom is obtained with the double angle method [10,11] using two 2D GRE images with nominal α=60°, 2α=120°, TR/TE=2s/2.5ms. *In vivo* experiments in the brain of a healthy volunteer have been performed with methods A and C. Protocol as in phantom experiments but with nominal FA_A/Total FA_A/TR_A =18°/108°/182ms and nominal FA_C/Total FA_C/TR_C =8°/76.8°/85ms (SAR=90% in standard mode).

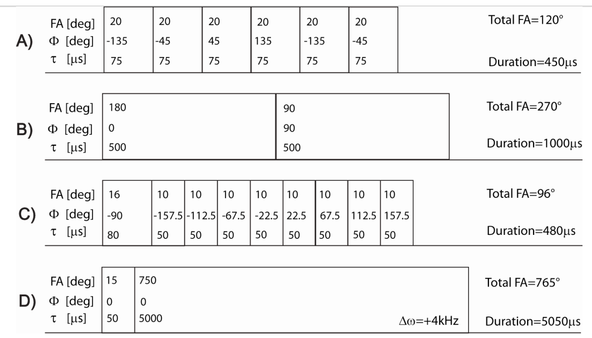

Fig.1. Diagrams of the composite pulses for the four methods. FA, ϕ and τ are the flip angle, RF-phase and duration of single sub-pulse. The corresponding total FA and total duration of each pulse are also given.

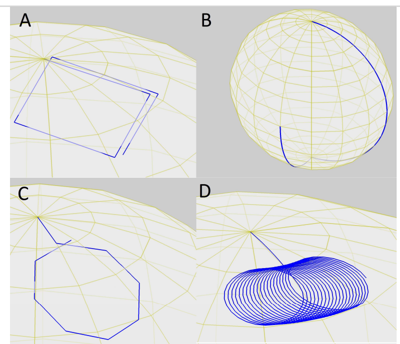

Fig.2. Evolution of **M** in the unitary sphere for the four methods, under ideal conditions. Parameters as in Fig.1.

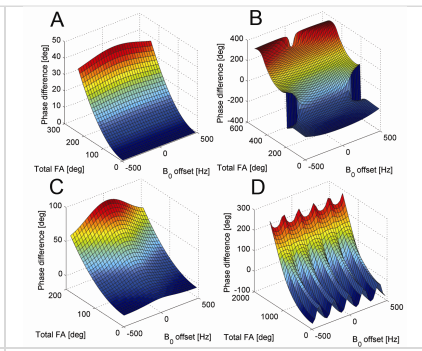

Fig.3. Sensitivity curves. The accrual phase of the four methods are plotted vs the total FA of the composite pulses and a B_0 offset distribution of 500Hz. The total FA distribution differs for A, B, C, D.

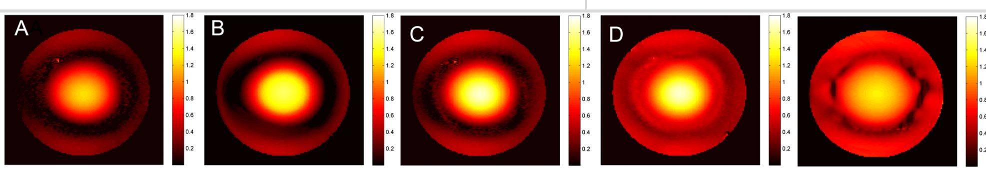

Fig.4. Central axial partition of the B_1 maps obtained with the four methods A, B, C, D. All the maps are normalized to their nominal FAs (see text). The last B_1 map was derived from the double angle method. Acquisition times: 13min 42s (A), 31min 20s (B), 8min 16s (C), 47min 6s (D).

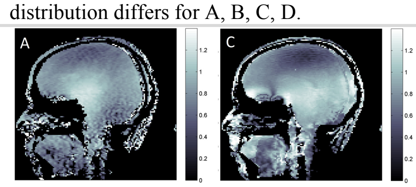

Fig.5 Central sagittal partition of the 3D B_1 maps in the brain for method A and C, normalized to their nominal FA. Acquisition times 23min 45s (A), 11min 06s (C).

RESULTS: The maps are normalized to the nominal respective flip angles. The results match the predictions obtained with the sensitivity curves: method A) shows a flat dependency on B_0 and a sensitivity of about 10° for total FA=120°, this may be increased by increasing the nominal FA at expenses of TR. For total FA <100° method C) has the highest sensitivity of about 40°; C) also shows higher dependency on the B_0 offset which may cause susceptibility artifacts. However given the small total FA and the small usage of transverse magnetization, this method allows for faster TR. Method B) has a very high sensitivity and low dependency on B_0 offsets within a range of ±333Hz. However this method employs the highest transverse magnetization and it may therefore require long TR in vivo (T1~1s). Method D) is less affected by the low signal areas, but requires a total FA of 765°, which results in the highest SAR levels and longest TR. As currently implemented only methods A) and C) could be tested *in vivo* at 7T. Method B) required a longer acquisition time (51min) whereas method D) resulted in very high SARs, inapplicable *in vivo* at 7T.

CONCLUSIONS: All four methods provide similar B_1 maps, confirming the reliability of phase based methods. Sensitivity may be adjusted based on expected SNR. *In vivo*, when SAR is not a problem, method A) provides the best tolerance to B_0 offset. When speed and SAR are crucial, method C) seems to be most suitable because of its high sensitivity. Consequently, method C) appears to be an ideal candidate for cardiac gated B_1-mapping which is essential for cardiovascular MR at 7.0 T.

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