Sa2RAGE sequence improvements and in-vivo brain RF-shimming at 7 Tesla

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Introduction: At ultra high magnetic field (≥7T), it is important to correct the transmit magnetic field (B_1^+) inhomogeneity resulting from the interference phenomenon observable when the RF wavelength becomes comparable to or smaller than the sample size. To correct for B_1^+ inhomogeneity it is worthwhile to be able to measure it precisely. This work presents improvements to a recently proposed B_1^+-mapping technique: Saturation prepared with 2 RApid Gradient Echoes (Sa2RAGE) [1]. Furthermore in-vivo RF-shimming [2] results are shown demonstrating the validity of this method.

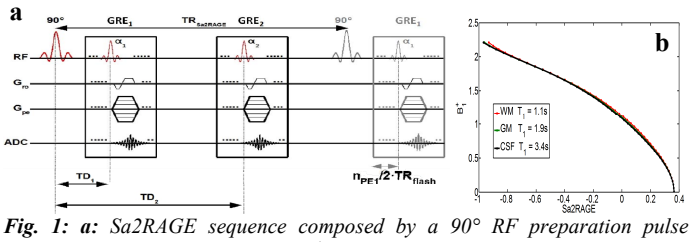

Fig. 1: a: *Sa2RAGE sequence composed by a 90° RF preparation pulse followed by two GRE blocks. The B_1^+ field can be interpolated from the ratio of the signals acquired during each GRE block. It is considered that these signals arise from the point where the center of k-space is acquired [3].* ***b:*** *Dependence of B_1^+ on Sa2RAGE for different brain tissues (the B_1^+ values are presented as relative multiplicative factor of a desired flip angle), Protocol A is used.*

Methods: The value of each parameter of the Sa2RAGE sequence (Fig. 1**a**) was optimized in [1] according to Contrast to Noise Ratio by unit of time (CNR) and T_1-sensitivity considerations. The following set of parameters was determined: $TR_{Sa2RAGE}/TR_{flash}/TD_1/TD_2/\alpha_1/\alpha_2/n_{PE1}/T_1$=2.4s/2.9ms/104ms/1.8s/4°/11°/64/1.5s. This protocol will be referred as protocol A. A lookup table (Fig. 1**b**) built from these parameters is used to associate the Sa2RAGE ratio between the two images (GRE1/GRE2) provided by the sequence to a B_1^+ value. The sequence was improved by using partial Fourier and parallel imaging acceleration (GRAPPA) in the 1st phase encoding direction (cf. Fig.1). By doing this, the center of k-space can be acquired earlier allowing TD_1 to be reduced hence leading to an improved T_1-insensitivity. A Siemens 7T parallel transmit (pTX) system equipped with an eight channel transmit-receive array (Rapid Biomedical, Germany) was used to perform B_1^+-shimming in-vivo. For subject safety, simulations of the RF coil were performed and the worst case scenario (sum of in phase electric fields over the whole brain) implied that the maximum power delivered by each coil element was limited to 0.919W/10s and 0.306W/6min. The experimental protocol was approved by local ethics committee and one healthy subject providing informed consent was scanned. The B_1^+ field produced by each channel of the array was computed using a matrix inversion of the complex B_1^+ maps produced when all but one channels are activated [4]. According to [5], B_1^+-shimming was performed by optimizing the Magnitude Least Squares problem: $\mathbf{x}=\min\{||\,|\mathbf{M}\cdot\mathbf{x}|-\mathbf{b}||^2\}$, where M is the matrix linked to the individual B_1^+ profiles, **b** a vector representing the targeted B_1^+ distribution (typically a unitary vector) and **x** a vector of which complex component x_n gives the magnitude and phase to apply to coil n of the array ($n\in[1,8]$).

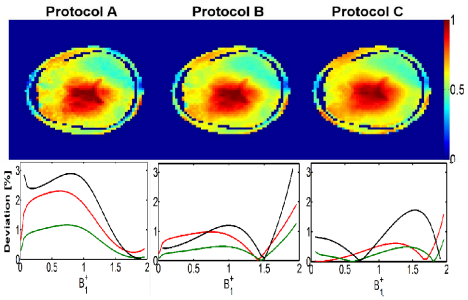

Fig. 2: Top: *Axial views of 64x64x20 3D pictures acquired with a 4x4x5mm resolution in 48s.* ***Bottom:*** *Error introduced on the estimated B_1^+ maps for the tissues in Fig. 1**b** by considering a fictitious T_1=1.5s.* ***Protocol A:*** *Full k-space acquisition (TD_1=104ms).* ***B:*** *6/8 partial Fourier (TD_1=56ms).* ***C:*** *6/8 partial Fourier + GRAPPA (TD_1=39ms).*

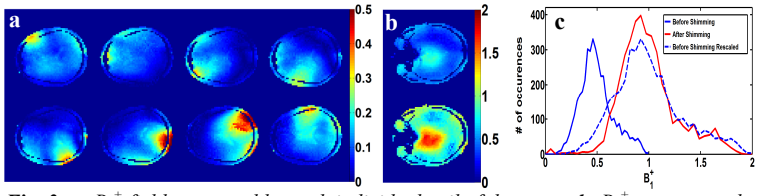

Fig. 3: a: *B_1^+ field generated by each individual coil of the array.* ***b:*** *B_1^+ maps over the brain before (top) and after (bottom) shimming.* ***c:*** *Histograms showing the distribution of B_1^+ within the shimming ROI. For comparison purposes, the mean of the B_1^+ distribution before shimming was adapted to the one obtained after (dashed line).*

Results and discussion: The use of 6/8 partial Fourier encoding in the phase direction implies that the center of k-space was acquired after 16 steps instead of 32 (n_{PE1}=64) allowing a decrease of TD_1 to 56ms (protocol B). Moreover, the additional use of GRAPPA (acceleration factor = 2) in the same encoding direction makes the minimum available TD_1=39ms (Protocol C). Fig. 2 presents brain B_1^+ maps acquired with the different protocols. When using protocol C the errors introduced in WM/GM/CSF B_1^+ estimations were always smaller than 1.7% (plot in Fig. 2**C**) when compared to the 3% in the case of protocol A (Fig. 2**A**). The T_1-insensitivity improvement is also illustrated on the B_1^+ maps by the reduction of CSF/WM and GM/WM contrasts in the maps from Fig. 2**A** to 2**C**.
Fig. 3**a** shows the individual coil B_1^+ maps after matrix inversion. The comparison between B_1^+ maps before and after RF-shimming is displayed on Fig. 3**b** where the scaled overall B_1^+ distribution over the head can be observed after RF shimming (note that bottom image of Fig. 3**b** has a mean value of relative B_1^+ close to one). Although the central area of high B_1^+ was not completely eliminated after RF shimming (Fig. 3**b**), the histograms representing the distribution of B_1^+ values on the region where shimming was performed (Fig. 3**c**) illustrate the fact that after shimming the B_1^+ distribution is narrower than before. Quantitatively, this corresponds to a 16% reduction of the observed inhomogeneity.

Conclusion: The accuracy of the Sa2RAGE sequence was improved successfully by using partial k-space sampling schemes as well as parallel imaging. In-vivo B_1^+-mapping and shimming were performed in spite of the tight SAR constraints imposed by RF coil simulations. The low SAR intensity and fastness (3D volume acquired in 48s and potentially 24s if 8 slices suffice) of Sa2RAGE demonstrates that this sequence is adequate for in-vivo B_1^+-mapping at high fields. The B_1^+ distribution obtained after using the presented shimming technique is in agreement with literature [6]. Further homogeneity improvements lie in the use of additional methods such as Transmit SENSE and multispectral RF pulses.

References: [1] F. Eggenschwiler et al, ISMRM Annual Meeting, 2010, [2] D. I. Hoult, JMRI 12, 2000, [3] J.P. Marques et al, Neuroimage, 2009, [4] D. Brunner et al, MRM 61, 2009, [5] K. Setsompop et al, MRM 59, 2008, [6] K. Setsompop et al, MRM 60, 2008.

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