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

F. Eggenschwiler, A. W. Magill, T. Kober, R. Gruetter, and J. P. Marques

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.

Methods: The value of each parameter of the Sa2RAGE sequence (Fig. 1a) 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: $TR_{Sa2RAGE}/TR_{field}/TD_1/TD_2/a_1/a_2/\alpha_{pTX}/\alpha_{pRX}/T_1=2.4s/2.9ms/104ms/1.8s/4°/11°/64/1.5s$. This protocol will be referred as protocol A. A lookup table (Fig. 1b) 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 1$st$ 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: $x=\min_{\|x\|_2} \{ \| M\cdot x- b\|_2^2 \}$, 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 ($n \in \{1,8\}$).

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 ($\alpha_{pTX}/64$) 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. 2C) when compared to the 3% in the case of protocol A (Fig. 2A). The $T_1$-insensitivity improvement is also illustrated on the $B_1^+$ maps within the brain and shimming ROI for comparison purposes, the mean of the $B_1^+$ distribution before shimming was adapted to the one obtained after (dashed line).

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.


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