MP2RAGE contrast optimization at 7T and applications

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Introduction MPRAGE provides good contrast between different brain tissues (1) and is often used for anatomical reference, brain segmentation and classification. The inhomogeneity of the transmit, B_1^+, and receive B_1^- fields, already visible at 3T are more pronounced at 7T, creates a bias field. Two main approaches are used to combat such effects: (a) estimation of the bias field by post-processing techniques; (b) acquisition of a GRE image with identical scan parameters as in the MPRAGE (2). To create a Bias Field independent image we recently proposed the MP2RAGE (see Fig. 1) sequence (3,4) with the following combination (4) of the two contrasts:

$$S=GRE_{TI1}\,GRE_{TI2}\,/\,(\,GRE_{TI1}{}^2+GRE_{TI2}{}^2) \qquad \text{Eq.1.}$$

The contrast optimization between brain tissues in the final combined image was done via numerical simulations. Because of the increased B_1^+ inhomogeneity at 7T, the flip angles had to be optimized to yield a final image insensitive B_1^+ inhomogeneities (3). The resulting image can be made virtually B_1 field, M_0 and T_2^* independent and hence, purely T_1-weighted and can be used for segmentation or T_1 estimation.

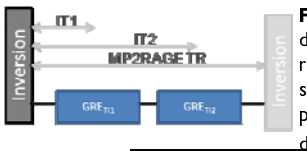

Figure 1 MP2RAGE sequence diagram. The MP2RAGE block is repeated for each phase-encode step. Within each GRE block the phase-encode steps in the third dimension (slab) are acquired.

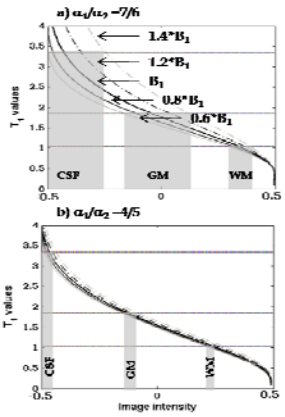

Figure 2 Image intensity of S as a function of T_1 for (a) the parameters that optimize contrast and (b) the parameters that compromise contrast and B_1 insensitivity. The black, dark grey and light grey lines represent an error on the effective B_1^+ of 0, ±20% and ±40%.

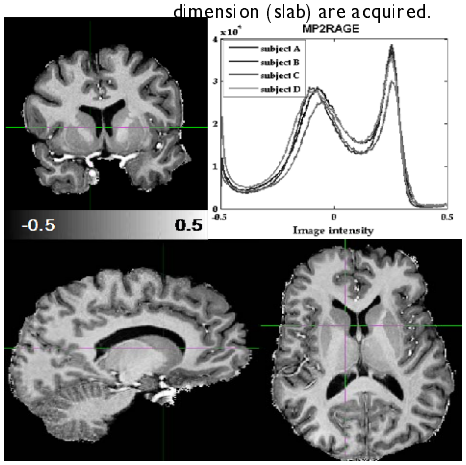

Figure 3 Image obtained for subject A using Eq.1 covering the entire brain showing the effective bias field free nature of the selected parameter combination. The histogram of the intensities of the four subjects shows both the reproducibility and emphasizes the ability to distinguish CSF, GM and WM without the need of any further Bias Field Correction.

Methods The predicted MP2RAGE signal amplitudes for several tissues were numerically calculated after solving the Bloch Equations with the following variables and assumptions:

- The repetition time MP2RAGE TR (Fig. 1) was varied from 4 to 12 secs in steps of 0.5 secs; *(i)* Number of excitations per GRE module was set to 160; *(ii)* TI_1 and TI_2 (were varied from 0 to MP2RAGE TR in steps of 100ms); *(iii)* α_1 and α_2 (were varied from 1-15 degrees); *(iv)* T_1 values of WM/GM/CSF=1.05/1.85/3.35 s at 7T. *(v)* Signal was considered to come from the center k-space point;

Contrast to noise by unit of time between two tissues was defined as: $(S1-S2)/\mathrm{sqrt}(\sigma_{S1}{}^2+\sigma_{S2}{}^2)/\mathrm{sqrt}(\text{MP2RAGE TR})$. The noise of the S, σ_S, was estimated by error propagation of Eq.1. The parameters TR, TI1, TI2, for all possible combinations of α_1 and α_2 were chosen from simulations in order to optimise the CNR per unit time between GM-WM and CSF-GM in S.

MP2RAGE was implemented on a 7T MR scanner (Siemens Medical Solutions, Erlangen, Germany). Data from 4 subjects (25±4) were acquired using a 8-channel head coil (Rapid) using the following sequences: MP2RAGE TR=8500ms, TI1=1000, TI2=3500 ms; α1=4, α2=5, iPAT=3 and 6/8 k-space coverage, acquisition time of 11.20 mins. For all experiments, matrix size and voxel size were kept at 256x256x160 and 0.82x0.82x0.82, respectively. Before combining the images as in Eq. 1, the magnitude image GRE_{TI1} was corrected using the phase of GRE_{TI1} and GRE_{TI2}. This correction was necessary because at time TI_1 not all signals had passed the zero-crossing point.

Results The optimum contrast between CSF, GM and WM was found to be obtained with the following parameters a) TR=8.5 sec TI_1/TI_2=1.0/3.5 α_1/α_2 =7/6. The optimum parameters when considering a transmission field that at 7T can vary by ±40% (estimated from B1 field maps obtained at 7T), while accepting a reduction of the contrast to noise ratio between tissues of 13% was found to be at α_1/α_2 =4/5 keeping the other sequence parameters constant. The improved insensitivity of S to B_1^+ is clear when comparing Fig. 2a and Fig. 2b, where the dispersion of the signal intensity of any of the tissues to a variation of ±40% on the transmission field was significantly reduced as can be observed by the width of the grey boxes.

Figure 3 shows both coronal, saggital and transverse images of a representative subject where the insensitivity to B_1^+ and B_1^- is clear. The histogram of the intensity distributions of S of the 4 subjects emphasizes the reproducibility of this measurements as well as its potential for segmentation given the clear peak distinction between CSF, GM and WM. Using the simulation data shown in Fig. 2B it was possible to estimate the T_1 values at 7T of different brain regions: thalamus=1.21±0.09; palidum = 1.00±0.04; caudate=1.43±0.09; putamen=1.35±0.06; WM= 1.00±0.03; stem WM=1.08±0.07; CSF=3.45±0.13; GM= 1.75±0.05 which are in good agreement with literature (5).

Conclusions In this work we optimized the contrast of the MP2RAGE for brain tissues at 7T. This contrast is fully independent of B_1^-, T_2^* and proton density. It can be used as a two point estimate of T_1, when care is taken to make sure the final image is B_1^+ independent.

The proposed contrast is suitable for applications such as image segmentation given its ability to separate CSF, GM and WM even in whole brain histograms and, given the long TR and low flip angles used is very low SAR intensive.

References (1) Mugler, J. P. et al, Magn. Res. Med. 15: 152-157. ;(2) Van de Moortele PF et al. ISMRM workshop on advances in high field MR, 2007; (3) Van de Moortele PF et al., Annual Meeting HBM Organization, Sidnei 2008; (4) Marques et al, Proc. ISMRM 2008, 1393; (5) Wright et al, MAGMA, 21 (1-2):121-130;