Optimisation of the MP2RAGE sequence to thalamic nuclei and brain stem imaging
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Introduction The MP2RAGE sequence has been recently introduced as a mean to obtain bias field free $T_1$-weighted images at ultrahigh field [1,2]. In the original work, the sequence parameter optimization was developed to obtain the conventional range of contrast (covering the $T_1$ range from WM to CSF). Although such a large range of $T_1$ range is desirable for normal segmentation applications, it is not ideal when looking at detailed visualization or segmentation of, for example, thalamic nuclei whose observation is essential in the neuro-surgical treatment of a wide range of neurological disorders (such as Parkinson’s and neuropsychiatric disorders) [3]. In this work we evaluate the possibility of optimizing the sequence parameters to deliver optimum contrast on a shorter range of $T_1$ values.

Theory and Methods
The predicted MP2RAGE signal amplitudes for several tissues were numerically calculated after solving the Bloch Equations as in reference [1], with the following parameters being varied: MP2RAGE $TR$, $TI_1$ and $TI_2$ (Fig. 1); Number of excitations per GRE module was set to 160 (full k-space coverage) or 120 (partial fourier k-space coverage); $\alpha_1$ and $\alpha_2$ (flip angles of the two GRE blocks); 5 $T_1$ values ranging from 1.1 (WM) to 1.9s (GM) (that should cover the different tissue $T_1$ values in the brain and thalamus area).

Contrast to noise by unit of time between two tissues was defined as: $(S_1-S_2)/\sqrt{\sigma_1^2+\sigma_2^2}/\sqrt{\text{MP2RAGE TR}}$ and the final contrast quality was evaluated as the sum of the 4 contrasts evaluated. The noise of the S, $\sigma_i$, was estimated by propagation and all sequence parameters were chosen from simulations in order to optimise the CNR for the desired $T_1$ range.

Experiments were performed on a 7T MR scanner (Siemens Medical Solutions, Germany). MP2RAGE data from 2 subjects (34/4) were acquired using an 8-channel head coil (Rapid Biomedical) using the following sequences: a) MP2RAGE$_{TR}/TI_1/TI_2=6/0.8/2.5$s and $\alpha_1/\alpha_2=4/5$ degrees (Protocol A); b) optimized for the white grey matter $T_1$ range MP2RAGE$_{TR}/TI_1/TI_2=6/0.7/1.6$s and $\alpha_1/\alpha_2=7/7$ degrees (Protocol B). Both acquisitions were performed using iPAT = 2 and 6/8 k-space coverage on the slice encoding direction, acquisition time of 10 mins. The matrix size and resolution were varied between the different subjects and was either: 256x192x160 and 1mm isotropic or 256x200x176 and 0.85mm isotropic.

Results
Figure 1 shows the lookup tables of the MP2RAGE signal intensity as a function of the $T_1$ values for the protocols with $TR=6$ secs optimized for full $T_1$ range contrast (Fig. 1a- Protocol A) or WM-GM contrast (Fig. 1b – Protocol B). The increased contrast between WM and GM is obtained by reducing the spacing between the two different inversion times. By using partial k-space sampling in the slice encoding direction it was possible to reduce the number of excitations per GRE block and the sensitivity of the resulting image to transmit B0 inhomogeneities. Optimization was performed increased $51\%$, which when taking into account the reduced number of excitations due to partial Fourier sampling is of $33\%$. The penalty paid is the ability to distinguish CSF which appears wrapped and overlaps the intensity of WM (see Fig.1b).

Figure 3 shows midbrain MP2RAGE and MP2RAGE$_{WMGM}$ images. It is possible to see an increased delineation of the thalamus and its medio dorsal, ventral lateral and pulvinar nuclei (red arrows) as well as increase contrast within the brain stem (yellow arrows). The two columns on the right side show the synthetic image created with the new sequence using the FLAWS concept [4], (note that in this acquisition both CSF and white matter were acquired close to their null point at the first and second inversion times respectively) or the unwrapped approach obtained by combining the knowledge between the ratio of both images [2] and the MP2RAGE intensity [1].

Future and conclusions