Uniform whole human brain T_1-weighted imaging at high field using 3D MDEFT with optimised preparation pulses

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Introduction

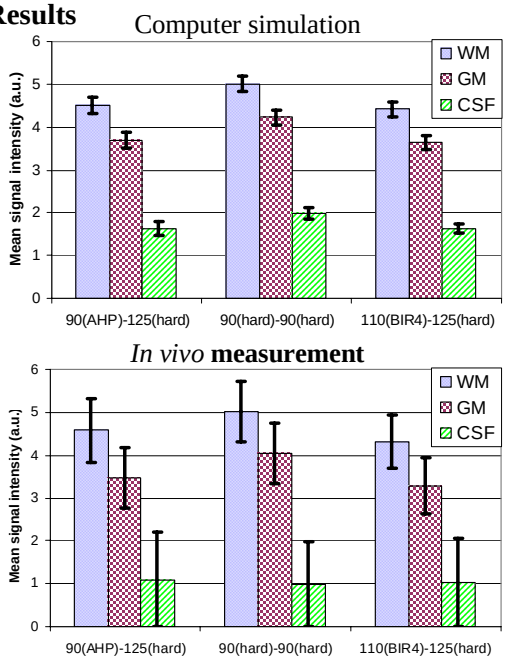
T_1-weighted MRI of the whole brain is problematic at high field strength due to the increased T_1 values of brain tissue and greater B_1 inhomogeneity (due to RF field/sample/coil interactions[1]) relative to low field. Previously, we have shown that uniform whole brain images can be acquired with good T_1-weighting at 4.7T using the MDEFT sequence with a reduced flip angle hard inversion pulse[2]. With this modification, the B_1 sensitivities of the inversion pulse and the excitation pulses cancel each other out. Here, we investigate the effect of modifying the saturation pulse of the MDEFT preparation scheme in order to achieve optimal T_1-weighting and B_1 insensitivity for whole brain structural imaging at 4.7T.

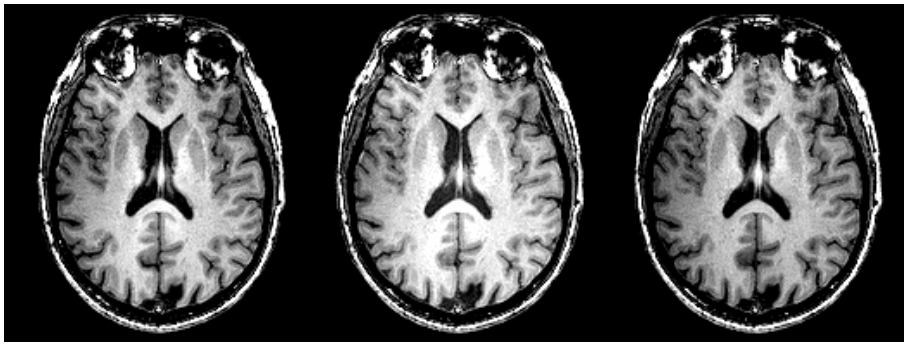
Methods

The standard MDEFT scheme is: $90°_{saturation}$ - τ_1 - $180°_{inversion}$ - τ_2 – [image], where τ_1 and τ_2 are delay times which allow a controlled amount of T_1 relaxation. Computer simulations of the Bloch equations[3] were performed in which the following versions of the sequence were investigated: (*i*) using a hard saturation pulse in combination with both hard and adiabatic inversion pulses; (*ii*) using an adiabatic saturation pulse with flip angles different from 90°, in combination with a hard inversion pulse. Simulations were performed for a range of nominal flip angles for both the saturation and inversion pulses and over a range of B_1 field strengths (nominal value ± 50%). T_1 was assumed to be 1.5s for grey matter (GM), 1.05s for white matter (WM) and 4.6s for cerebrospinal fluid (CSF). The optimum combination of nominal flip angles and relaxation delays for each version of the MDEFT preparation was chosen as that which gave the best compromise between average GM-WM CNR and insensitivity to B_1 variation.

Based on the results of the simulations, three versions of the MDEFT sequence were implemented on a SMIS/Philips 4.7T whole body MR scanner: (*i*) adiabatic half passage (AHP) FOCI[4] saturation pulse (90°) with hard 125° inversion pulse (τ_1=223ms and τ_2=349ms); (*ii*) hard 90° saturation pulse and hard 90° inversion pulse (τ_1=286ms and τ_2=286ms); and (*iii*) BIR-4[5] 110° saturation pulse with hard 125° inversion pulse (τ_1=258ms and τ_2=315ms). For the calculation of the sequence timings, the total scan time was fixed as 12 minutes. The nominal flip angle of the excitation pulse was calculated by the simulation to give maximum SNR without compromising the point spread function of the image[3]. 2-shot centre-out phase encoded spoiled 3D FLASH imaging was used for image acquisition (TE=5.1ms; TR=13.1ms). The image acquisition matrix size was 256 (read; 2x oversampled) x 176 (2D phase encode) x 224 (3D phase encode) and the image resolution was 1x1x1mm^3.

Results





(a) 90° (AHP) - 125° (hard) (b) 90° (hard) - 90° (hard) (c) 110° (BIR-4) - 125° (hard)

Comparison of the results of the computer simulations with *in vivo* measurements for the different brain tissue types (GM, WM and CSF) are shown in the graphs (left) and example images using each of the three sequences are shown above. In order to select voxels from the *in vivo* data, the images were segmented (using SPM2[6]) into GM, WM and CSF and masks were created using a 60% probability threshold. It can be seen from the images that each of the parameter sets chosen displays a good degree of B_1 insensitivity. Also, the values of tissue signal intensity from the simulations and *in vivo* measurements match well (see graphs). The standard deviations of the *in vivo* data (error bars on graphs) are greater than predicted by the simulations. This is likely to be due to noise in the MR data, the presence of a range of T_1 values for each tissue type, and possibly a larger range of B_1 inhomogeneity than accounted for in the simulations. In order to evaluate the relative performance of each of the sequences, the ratio of the GM and WM signal difference to their average standard deviation was calculated. The values of this ratio were 1.51, 1.40 and 1.60 for the 90° (AHP) - 125° (hard), 90° (hard) - 90° (hard) and 110° (BIR-4) - 125° (hard) sequences respectively. Also, the total number of pixels that were classified as GM, WM or CSF was highest for the 110° (BIR-4) - 125° (hard) approach. This shows that this sequence is the most effective at differentiating between GM and WM at 4.7T.

Conclusions

We have shown that it is possible to acquire uniform T_1-weighted images of the whole brain at 4.7T using the MDEFT sequence with several combinations of RF preparation pulse types and flip angles. The simplest modification is to use a hard 125° inversion pulse with a standard adiabatic saturation pulse. However, it is also possible to achieve similar, uniform T_1 contrast using hard 90° pulses for both saturation and 'inversion', *i.e.* using no adiabatic pulses at all. The optimum sequence uses a 110° adiabatic saturation pulse with a hard 125° inversion.

References **1** Hoult, D.I. JMRI 12:46-67 (2000) **2** Thomas, D.L. *et al.* ISMRM 12th Meeting p84 (2004), **3** Deichmann, R. *et al.* NeuroImage 12:112-127 (2000) **4** Ordidge R.J. *et al.* MRM 36:562:566 (1996) **5** Staewen,R.S. *et al.* Invest. Radiol. 25:559-567 (1990) **6** www.fil.ion.ucl.ac.uk/spm

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