T1 Weighted Whole Brain Imaging with Uniform Contrast at 3T using Parallel Transmission

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Introduction T1 weighted magnetic resonance images of the brain are a central tool for neuroscience, providing anatomical substrates for functional studies and the source data for morphometric analyses. Many studies employ the MPRAGE sequence [1] to achieve T1 weighting combined with true 3D coverage and efficient data acquisition. Although higher field strength scanners benefit from improved SNR, increased RF field (B_1) inhomogeneity in both the transmit and receive fields is a problem. At 3T brain images typically have elevated signal in the centre of the head. The effect of the receiver is multiplicative and can therefore be removed by a bias field correction. The transmit effect however results in spatially variable flip angle and hence variable contrast. This can lead to reduced conspicuity of key anatomical structures; particularly the deep grey matter nuclei, and can impair automated tissue classification by standard programs such as FSL-FAST (http://www.fmrib.ox.ac.uk/fsl/) or SPM (http://www.fil.ion.ucl.ac.uk/spm/).

The MPRAGE sequence consists of an inversion pulse followed by a rapidly acquired series of gradient echoes each following a small flip angle RF pulse. Sensitivity to B_1 inhomogeneity can be reduced by using adiabatic inversion pulses and linear rather than centric phase encode ordering [2], however contrast variation resulting from the nonuniform excitation by the small flip angle pulses is still seen. We have explored the use of tailored small flip angle RF pulses delivered using a parallel transmission system, to improve MPRAGE performance.

Methods T1 weighted volume brain scans for the entire head can be acquired with frequency encoding in the foot-head direction so slab selection is unnecessary. Thus the pulse design optimized homogeneity without spatial selectivity using a uniform target limited to the brain region only. Pulses were designed in the small tip angle approximation (STA) using the image domain formalism proposed in [3] with magnitude least squares optimization [4]. A 3D spiral k-space trajectory with maximum extent 6 cycles/m (Fig 1) was used; selected to match the inherent geometry of the B_1 inhomogeneity problem with a maximum modulation of one cycle over the head. The radial k-space velocity was defined as a Fermi function in order to limit the peak pulse amplitude at the centre of k-space to control SAR. The total RF pulse duration was 2ms, allowing easy integration into a rapid pulse sequence. The frequency response of the pulse was controlled by explicitly optimising for a uniform response in water betweem -50 and +50 Hz and for fat at -435 Hz. Use of a wide water band provides robustness against off resonance effects, while inclusion of the fat resonance offset avoids highly spatially variable fat excitation which can produce distracting image contrast. Pulse optimization requires B_0 and B_1 field maps which were acquired only acquired for three orthogonal planes to limit the time needed for calibration.

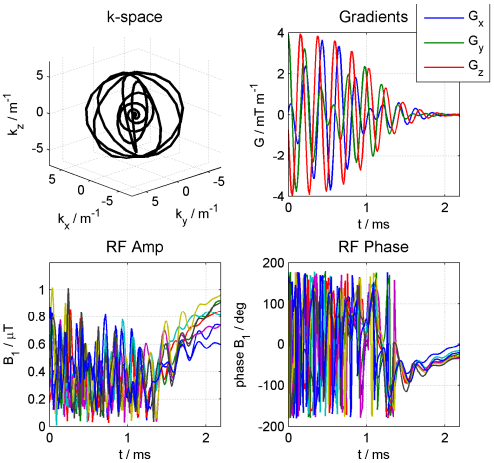

Fig 1 K-space trajectory, gradients and optimised RF pulse (colours represent different RF channels)

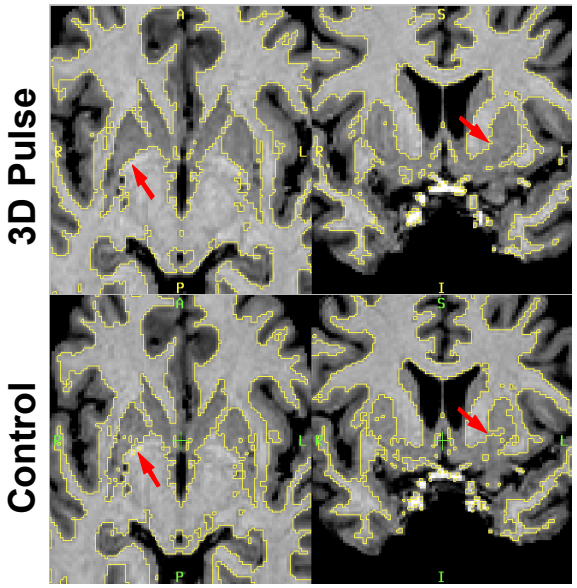

Fig 2 Bias-field corrected images for two different planes. Yellow lines indicate grey/white matter segmentation produced by FAST.

All scanning has been performed using a whole-body 3T Achieva MRI system (Philips healthcare, the Netherlands) fitted with an 8 element parallel transmission body coil [5]. A standard 8 channel SENSE head coil was used for signal reception. Slice selective B_1 maps were acquired using Actual Flip angle Imaging [6,7] with the array mapping method described in [8]. B_0 field maps were acquired using a dual echo sequence; total field mapping time was ~5m40s. A standard 3D MPRAGE protocol with isotropic resolution 1.2 mm^3 was used: T_I=1250ms, with 199 pulse acquire echoes per inversion, TR=12ms TE=4.6ms, flip angle 8°, interval between inversion pulses 4000ms, SENSE factor 2, scan time 5 min. The 3D pulse presented here was compared with the standard pulse for the base sequence operating at the same flip angle. Images were analyzed using FSL, by first applying BET for brain extraction and using FAST for bias field correction and tissue classification. To facilitate direct comparison the optimized and control images were co-aligned by rigid registration.

Results Figure 2 shows comparisons between the bias-field corrected images with the grey/white matter segmentation marked on as an overlay. Contrast and segmentation accuracy are both improved for deep grey matter nuclei and more uniform performance was seen in cortical regions (whole brain grey/white matter contrast improved P<0.001). The optimized RF pulse is plotted in Fig 1. The total RF power for this pulse (integrated $|B_1|^2$) was only 22% of that of the sequence standard pulse . Increased SAR is always a concern when using parallel transmission however we note that the scanner SAR estimate (not accounting for constructive interference between electric fields) was 2% of the maximum allowable, giving a very large margin for error. Indeed this SAR estimate is itself dominated by the power required for the adiabatic inversion pulse which is transmitted with the coil's quadrature setting.

Discussion & Conclusions: After bias field correction a contrast difference on Figure 2 is still apparent; it is subtle but the segmentation is clearly improved when using the 3D pulse, with consistent performance over the whole brain. Thus a 3D k-space trajectory with parallel transmission can be used to improve this widely used sequence. The main drawback is the need to acquire subject specific field maps. In this work we have used three orthogonal planes for calculation - further investigation into optimal placement/orientation of acquired field data is planned.

References: [1] Mugler et al, MRM 1990:15 [2] Deichmann et al, MRM 2002:47; [3] Grissom et al, MRM 2006:56; [4] Kassakian, UCB PhD Thesis 2006; [5] Vernickel et al, MRM 2007:58; [6] Yarnykh, MRM 2007:57; [7] Nehrke, MRM 2009:61; [8] Nehrke et al, ISMRM'08 #353