Optimisation of double-inversion recovery sequences at 7T

J. E. Dixon[1], P. S. Morgan[2], M. J. Brookes[1], E. C. Tallantyre[3], N. Evangelou[3], and P. G. Morris[1]

[1]Sir Peter Mansfield Magnetic Resonance Centre, School of Physics and Astronomy, The University of Nottingham, Nottingham, Nottinghamshire, United Kingdom, [2]Academic Radiology, The University of Nottingham, Nottingham, Nottinghamshire, United Kingdom, [3]Clinical Neurology, The University of Nottingham, Nottingham, Nottinghamshire, United Kingdom

Introduction: Multiple sclerosis (MS) is traditionally thought of as a disease of the white matter (WM). However, there is poor correlation between the extent of WM disease seen on MRI and patient symptoms, and histopathological studies have shown significant demyelination in the grey matter. For this reason, there has been a great deal of recent interest in the detection of GM lesions *in vivo*. However, MRI is relatively insensitive to these lesions, particularly at low field. Double-inversion recovery (DIR) sequences at 3T have been used to be minimise the signal from WM and CSF, thus providing increased WM-GM contrast and improving the detection and classification of lesions within the cortex and deep GM[1,2]. The intrinsically low SNR in DIR images suggests the importance of developing the sequence for use at higher field strengths. This requires the determination of inversion times to provide optimal contrast between GM and WM. The sequence must also address the effects of the variation in flip angle due to the inherent B_1 inhomogeneity at high field, as SAR limitations do not always permit the use of adiabatic pulses at 7T. In addition, the sequence must operate with a sufficiently short TR to maintain a reasonable scan time. In previous work[2,3], inversion times have been found empirically, but this has not yet been successfully transferred to 7T, suggesting the need for a more adaptable method for the determination of optimal timing parameters. To this end, an equation has been derived which can be used to calculate the required inversion times for a variable TR at any field strength. Similar theory has also been used to develop a fluid-attenuated inversion-recovery (FLAIR) sequence that can be used at 7T with a range of TRs.

Theory: In DIR sequences, the longitudinal magnetisation at the point of image acquisition can be found using the following equation:

$$M_z = M_0\left[1-\exp\left(-\frac{(TI_2)}{T_1}\right)\right]+M_{eq}\cos\alpha\exp\left(-\frac{(TI_2)}{T_1}\right)\left[1-\exp\left(-\frac{TI_1}{T_1}\right)\right]+M_{eq}\cos^2\alpha\exp\left(-\frac{TI_1}{T_1}\right)\exp\left(-\frac{(TI_{21})}{T_1}\right)$$

TI_1 is the time delay between the inversion pulses (flip angle α), and TI_2 is the time between the second α-pulse and the acquisition. For a GM-only image, the longitudinal magnetisation at this point must be zero for both WM and CSF. This can be calculated assuming a knowledge of the flip angle and the relaxation times of WM and CSF at the relevant field strength. The equilibrium magnetisation, M_{eq}, can be calculated as a proportion of M_o assuming that the longitudinal magnetisation at the end of the acquisition period is zero:

$$\frac{M_{eq}}{M_0}=\left[1-\exp\left(-\frac{\tau}{T_1}\right)\right]$$

τ represents the time between the end of the acquisition and the start of the next sequence, which can be reduced in order to lower scan time. The TR is then found by summing TI_1, TI_2, τ and the length of the acquisition period.

Methods: 7T images were acquired using a Philips Achieva system with 16-channel SENSE receive coil and head only transmit coil. Single-slice DIR images were acquired using turbo-spin-echo readout with 192 mm x 168 mm FOV; TSE factor = 13. FLAIR images were acquired using TSE factor 13; FOV was 192 mm x 180 mm. Single-slice DIR images were also acquired at 3T using a Philips Achieva system with 8-channel SENSE coil and a whole-body transmit coil. FOV was 256 mm x 192 mm, with TSE factor 14. All images had 1 x 1 x 2 mm^3 voxels. Inversion times were found using the theory above and assuming full inversion at 3T. An inversion-recovery experiment was performed to measure the flip angle at 7T, which was found to be 140° in the frontal and occipital lobes, 160° in the centre of the head, and 108° in the temporal lobes.

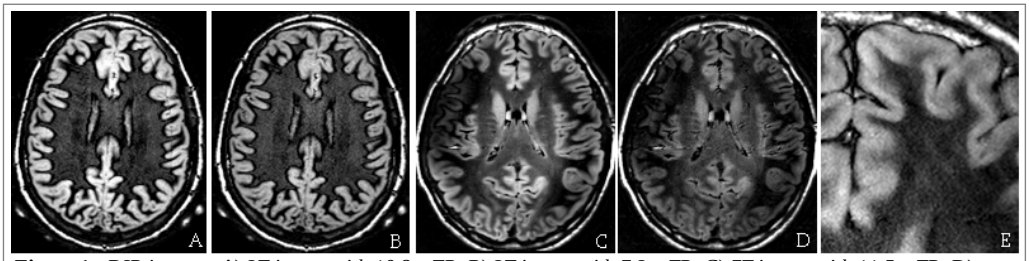

Figure 1 *- DIR images: A) 3T image with 10.8-s TR, B) 3T image with 7.3-s TR, C) 7T image with 11.5-s TR, D) 7T image with 5.6-s TR, E) High-resolution 7T image with 11.5-s TR.*

Results: Figure 1A shows DIR images acquired at 3T and 7T, using the above scanning parameters. Fig 1E shows a close-up of a 7T DIR image acquired with the same time delays as (C) but higher resolution (0.4x0.4x2.0 mm^3). Scan times were 3m16s, 1m36s and 10m11s for 7T images, respectively, and 3m16s and 2m12s for 3T images. Figure 2 shows 7T FLAIR images acquired using 11.1-second (fig 2A) and 5.6-second (fig 2B) TRs. Fig 2C shows a close-up of a high-resolution (0.4x0.4x2.0 mm^3) scan obtained using the same timing parameters as for fig 2A. Scan times were 3m09s, 1m35s and 9m33s, respectively. Figure 3 shows the signal levels of GM, WM and CSF on 7T DIR and FLAIR images as a function of TR.

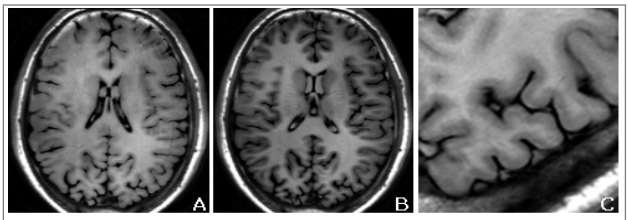

Figure 2 *– 7T FLAIR images: A) 11.1-s TR, B)5.6-s TR, C) High-resolution image with 11.1-s TR*

Discussion: As is evident from the images in figure 1, due to the inherent B_1 inhomogeneity, the desired contrast is not available throughout the whole of the 7T images. However, with the aid of flip angle maps, inversion times can be calculated which successfully null the WM and CSF in most of the image. Figure 3 confirms that, for both the FLAIR and DIR sequences, reducing the TR results in a loss in overall signal in the image but does not affect the nulling of WM and/or CSF.

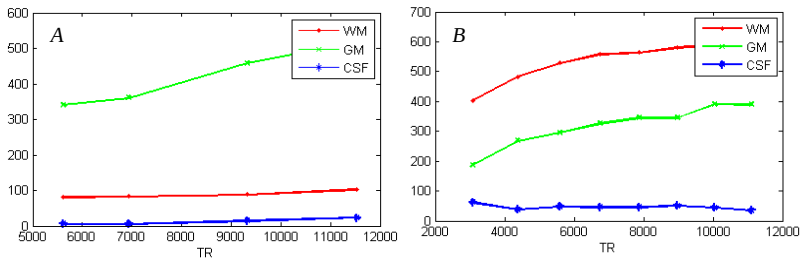

Figure 3*: Mean signal in GM, WM and CSF at 7T as a function of TR, for A) DIR image, and B) FLAIR image.*

Conclusion: Double-inversion recovery images have been successfully acquired using a 7T MR scanner, with a range of repetition times. Use of the above theory to calculate inversion times for a given inversion flip angle permits the nulling of CSF and WM in any area of the brain, despite the problems associated with B_1 inhomogeneity at this high field strength. The increased SNR at 7T allows us to acquire high-resolution images which promises to be a useful tool in the study of cortical demyelination in MS.

References: [1] Geurts JJ, et al. Radiology 2005; 236:254 [2] Turetschek et al. Magn Reson Imaging 1998;127-135 [3] Redpath & Smith. Brit J Radiol 1994;1258-1263.