Implementation Of A Three-Dimensional Double Inversion-Recovery Sequence At 3 Tesla

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Introduction

The double inversion-recovery (DIR) sequence, which was first introduced by Redpath and Smith (1994)[(1)], involves the application of two 180° inversion pulses before a standard magnetic resonance (MR) readout. By judicious choice of the two inversion times, the sequence can be designed to null simultaneously the signals from two different tissue types, thereby allowing better visualisation of the remaining tissues. Boulby *et al.* (2004)[(2)] developed a three-dimensional (3D) version of the DIR sequence, and used this to null white matter (WM) and cerebrospinal fluid (CSF) so as to acquire images of the grey matter (GM) of the neocortex. That study used a 1.5-T MR scanner, however, and the DIR imaging sequence has not previously been implemented at higher magnetic field strengths. A change in the magnetic field strength will result in a change in the longitudinal relaxation times of the various tissue types, which will in turn cause a change in the inversion times that are required to null the tissues in question. The optimisation of a 3D DIR sequence at 3 tesla is described here, and an image acquired using this sequence is presented.

Methods

The 3D DIR sequence was generated by adding two 180° inversion pulses to a standard 3D fast spin-echo (FSE) sequence. An optimised interleaved inversion scheme[(2, 3)] was used, which minimises the dead time between pulses and data readout and thereby improves the efficiency of the sequence. Images were acquired using a GE Signa Excite HD 3-T MR system (GE Healthcare, Milwaukee, WI, USA), using the body coil to transmit and an 8-channel phased-array head coil to receive the signal. The imaging parameters required to null the tissue types in question depend not only on the inversion pulses applied but also on the type of readout that is used, as this will have an effect on the evolution of the longitudinal magnetisation; the theoretical equation for the magnetisation available immediately prior to the 90° imaging pulse for the DIR-FSE pulse sequence was presented in Meara and Barker (2005)[(4)]. Using this equation, and values for the longitudinal relaxation times (T_1), it is possible to predict combinations of values for the two inversion times TI_1 and TI_2 that will null the signals from WM and CSF for a given repetition time (TR), echo train length (ETL) and echo spacing (ESP). Given these values for TI_1 and TI_2, it is then possible to calculate the available magnetisation for GM at various TR values, which will be directly proportional to the signal-to-noise ratio (SNR) in the resulting DIR image; dividing this by the square root of the repetition time gives a measure of the total imaging efficiency irrespective of the degree of averaging[(2)]. This approach was used to determine an appropriate value for TR, and a protocol was then derived to obtain 3D DIR images of the whole brain in an acceptable scanning time.

Optimisation

Figure 1 shows a graph of the (normalised) available magnetisation M_A for GM divided by the square root of the repetition time as a function of TR, assuming T_1 values of 830 ms for WM, 1250 ms for GM and 4300 ms for CSF[(2)], and using an ETL of 32 and an ESP of 10 ms. The peak of this graph is relatively broad, with a value for $M_A/\sqrt{TR}$ of at least 98% of the maximum value for TR values in the range 8000 ms to 11 000 ms. On the basis of this, a repetition time of 8000 ms was chosen. Using the theoretical values at this TR as a starting point, values for TI_1 and TI_2 to null WM and CSF were then empirically determined, first using a single-slab acquisition (for speed) and then for a multi-slab acquisition. 12 slabs were acquired in 2 acquisitions of 6 slabs each, with 2 dummy acquisitions; there were 10 slices per slab with 2 slices from each end of every slab being discarded to reduce wraparound artefacts, leaving 72 usable slices. Other imaging parameters were an echo time of 21.2 ms, values for Nskip_1 and Nskip_2[(2)] of 2 and 0 respectively, values for tj_1 and tj_2 of 17 ms and 420 ms respectively, corresponding to inversion times of TI_1 = 2684 ms and TI_2 = 420 ms, a slice thickness of 2 mm, an ETL of 32, an ESP of 10.592 ms, a field of view of 24 cm and a matrix size of 256 × 192. Whole-brain coverage was achieved in a total scanning time of 16 min 33 s.

Figure 1

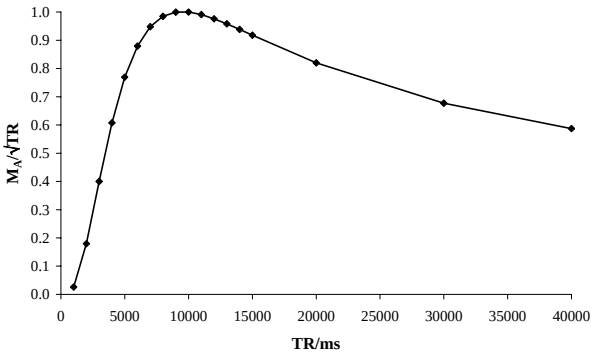
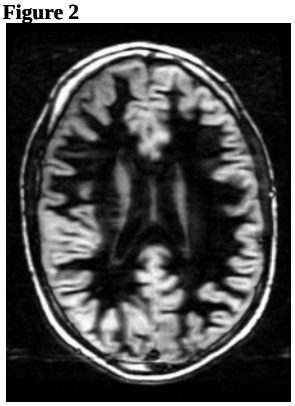


Figure 2



Results And Discussion

Figure 2 shows an example image slice that was extracted from a whole-brain data set. Using the theoretical equation for the DIR-FSE pulse sequence[(4)], the inversion times used would be expected to null T_1 values of 618 ms and 4512 ms. The value of 618 ms is considerably shorter than typical values for the T_1 of WM reported in the literature, and it is also shorter than the value derived from the single-slab acquisition (for which TI_1 = 2750 ms and TI_2 = 480 ms correspond to T_1 values of 715 ms and 4608 ms). This difference is likely to be due (at least in part) to the fact that the DIR sequence, like all FSE sequences, will show considerable magnetisation transfer effects[(5)]: each slab in the 3D acquisition will experience a large number of off-resonance pulses, in addition to the pulses that are applied directly to that slab. This will result in a (sequence-dependent) reduction of the T_1 values of various tissue types, which underlines the need for empirical optimisation of the inversion times.

Conclusions

To the best of our knowledge, this is the first report of the implementation of a DIR imaging sequence at a magnetic field strength of 3 tesla. An optimum repetition time of 8000 ms was derived theoretically from SNR considerations, but it was found that other imaging parameters must be determined by experiment. The optimised 3D DIR sequence gave good-quality images of the cortical and subcortical GM, while achieving excellent suppression of the signals from WM and CSF. Further improvements could be made by the application of fat saturation, which was not used in this case. There are many disease states that affect the GM of the brain, including epilepsy, tuberous sclerosis and multiple sclerosis. The 3D DIR sequence enables high-resolution images of the cerebral GM to be acquired, in the absence of the partial-volume effect, allowing abnormalities caused by these diseases to be identified easily. The application of the DIR sequence at 3 T gives an improvement in the SNR compared to lower magnetic field strengths, which should further increase the utility of the resulting images.

References

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