The Impact Of Magnetisation Transfer Effects On Inversion-Recovery Sequences Using A Fast Spin-Echo Readout

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Introduction

The fast spin-echo (FSE) and rapid acquisition with relaxation enhancement (RARE) sequences were originally introduced as methods for acquiring magnetic resonance (MR) images in short acquisition times[(1)]. Since then, however, RARE or FSE readouts have been incorporated into other pulse sequences, such as in fluid-attenuated inversion-recovery (FLAIR)[(2)] and double inversion-recovery (DIR)[(3)] sequences. It has previously been reported that the contrast in MR images obtained using FSE sequences is strongly affected by magnetisation transfer (MT) effects[(4, 5, 6)], due to the fact that any given imaging slice will experience substantial off-resonance irradiation from the radiofrequency (RF) pulses (particularly the large number of 180° refocusing pulses) that are applied to the other slices. Furthermore, the effect will be greater as the number of slices that are acquired within the repetition period is increased, because the number of RF pulses per unit time will be consequently higher. The MT effects will lead to the image signal intensity values being reduced in tissue types with a large bound water component, due to a lowering of the equilibrium magnetisation, and the observed relaxation times of such tissues will also be decreased[(7)]. The latter is especially pertinent in the case of FLAIR-FSE and DIR-FSE sequences, as the reduction in the values for the longitudinal relaxation times (T_1) would be expected to cause a change in the inversion times that are required to null the tissues in question. This phenomenon has not been reported in the literature, however, and so an investigation was performed into the impact of MT effects on FSE-based inversion-recovery sequences.

Methods

Images were acquired with 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. A FLAIR-FSE sequence was generated by adding a 180° inversion pulse to a standard three-dimensional FSE sequence, which excites several thick "slabs" in a manner analogous to standard two-dimensional (2D) spin-warp imaging, and then uses a second set of phase-encoding gradients to subdivide those slabs into "slices". An optimised interleaved inversion scheme[(8)] was utilised, which minimises the dead time between pulses and data readout and thereby improves the imaging efficiency. This sequence was used to obtain images of a MT phantom (25% thermally cross-linked bovine serum albumin dissolved in saline, with 0.01% sodium azide fungicide) and a bottle of water (Evian, France), which were scanned simultaneously in the same field of view. A 2-slab acquisition was used first, and then separate experiments were carried out with 4, 6, 8, 10 and 12 slabs; in all cases, the slabs were acquired in 2 acquisitions and there were 6 slices per slab, of which 1 slice from each end of every slab was discarded to reduce wraparound artefacts. For each of the multi-slab acquisitions, the inversion time was adjusted in steps of 10 ms to determine the point at which the signal from the MT phantom was maximally suppressed. The inversion time was then adjusted in steps of 20 ms to find the point at which the signal from the water was maximally suppressed. Other imaging parameters were a repetition time of 6000 ms, an echo time of 45 ms, a slice thickness of 1.5 mm, an echo train length of 32, an echo spacing of 11.320 ms, a field of view of 24 cm × 12 cm and a matrix size of 256 × 128. The width of the inversion pulse was set to be 1.3 times the width of the imaging slab, and the scanning time was 5 min 13 s per data set.

Results

Table 1 shows the respective inversion times that were found to give maximal suppression of the signals from the MT phantom and from the bottle of water, for each of the experiments using a different number of slabs. The results presented are mean values for all of the slices in the central slabs (only the central slabs were considered, for the reasons that are discussed below). It can be seen that the inversion time required to null the MT phantom steadily decreased as the number of slabs was increased. In contrast, the inversion time required to null the water (which would not be expected to be influenced by MT effects) remained approximately constant; there is a suggestion that the inversion time may even have increased with the number of slabs, although that is perhaps more likely to have been due to the limits on the accuracy of the experiment.

Table 1

Number Of Slabs	Inversion Time To Null/ms	
	MT Phantom	Water
2	375.0 ± 3.5	1420.0 ± 7.1
4	370.0 ± 3.5	1440.0 ± 7.1
6	358.8 ± 3.5	1440.0 ± 7.1
8	341.3 ± 3.5	—
10	330.0 ± 5.0	1450.0 ± 10.0
12	310.0 ± 5.0	1450.0 ± 10.0

Note. It was not possible to investigate the bottle of water with an 8-slab acquisition, as the repetition time would have had to have been increased so as to allow all of the sequence elements to fit within the TR period.

Conclusions

The results show that if the number of slabs (or, by inference, slices in the 2D case) per unit time is increased, this will lead to a decrease in the inversion time that maximally suppresses the signal from any substance that is known to be subject to MT effects. This is as a result of a reduction in the observed T_1 value with increasing number of off-resonance RF pulses: using the theoretical equation for the FLAIR-FSE pulse sequence[(9)], the T_1 values that would be expected to be nulled by the inversion times given above range from 541 ms for the 2-slab acquisition to 447 ms for the 12-slab acquisition. The important consequence for FLAIR-FSE and DIR-FSE imaging sequences is that this sequence-dependent reduction of the T_1 values of the tissue types in question means that the optimal inversion times to null those tissues may need to be determined empirically according to the acquisition parameters used. For example, it has previously been demonstrated[(10)] that the optimal parameters for a DIR-FSE sequence to null white matter and cerebrospinal fluid (at a magnetic field strength of 3 T) varied from TI_1 = 2750 ms and TI_2 = 480 ms for a single-slab acquisition, to TI_1 = 2684 ms and TI_2 = 420 ms for a 12-slab acquisition, to TI_1 = 2586 ms and TI_2 = 390 ms for a 14-slab acquisition. Two further conclusions can be drawn from the present work. The first is that these MT effects are likely to be more apparent at higher magnetic field strengths, due to an increase in the power of the RF pulses that are used. Second, and potentially more problematic, is the fact that the MT effects will not be the same for all of the slabs in the acquisition. Considering the outer slabs, the frequency offsets of the pulses applied to the other slabs will be greater than they would be for the central slabs, and so it is to be expected that the outer slabs will experience less of an MT effect; this is backed up by observations made in the images acquired here (data not shown). A situation is likely to arise, therefore, where the observed T_1 values for a given tissue type will vary over the slabs in a multi-slab acquisition, which could make it difficult to obtain a satisfactory null for that tissue over the entire image.

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