Elimination of T_1 Weighting in FLAIR by Optimized Double IR – Could this be the Only T_2-Weighted Sequence Needed?

A. J. Madhuranthakam[1], S. N. Sarkar[2,3], R. F. Busse[4], and D. C. Alsop[2,3]

[1]MR Applied Science Lab, GE Healthcare, Boston, MA, United States, [2]Radiology, Beth Israel Deaconess Medical Center, Boston, MA, United States, [3]Harvard Medical School, Boston, MA, United States, [4]MR Applied Science Lab, GE Healthcare, Madison, WI, United States

Introduction: Fluid-attenuated inversion recovery (FLAIR) is widely used for its improved conspicuity of long T_2 lesions by suppressing cerebrospinal fluid (CSF). Concerns remain, however, that the IR imparts T_1 weighting that can decrease detectability and lead to mischaracterization of some lesions. Frequently both T_2 and FLAIR images are acquired in clinical protocols to guard against these concerns (1,2). Optimization of FLAIR to detect MS lesions, for example, has stressed the importance of very long repetition times (TR) to minimize T_1 weighting (3).

Recently, interest in double IR (DIR) preparations (4) to highlight certain types of brain lesions has intensified (5). Typically, DIR is optimized to null white matter (WM) and CSF, producing even stronger T_1 contrast than FLAIR. We demonstrate that the two inversion times in a DIR can be optimized to simultaneously null CSF and eliminate T_1 weighting, rather than null WM and CSF. Such optimization produces an image with pure T_2 weighting over the range of T_1's typical of brain tissue.

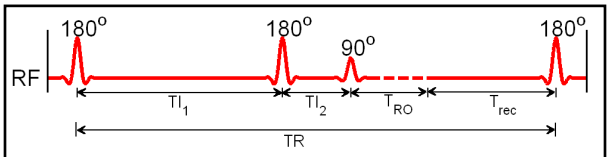

Fig. 1. Pulse sequence describing the timings between RF pulses

$$S = M_0\left[1 - 2e^{-TI_2/T_1} + 2e^{-(TI_1+TI_2)/T_1} - e^{-(TR-T_{RO})/T_1}\right].e^{-TE_{eff}/T_2}$$

$$TI_2^{max} = T_1 \ln\left(\frac{2}{1+e^{-(TR-T_{RO})/T_1}}\right)$$

$$TI_1 = T_1 \ln\left(\frac{2}{2e^{-TI_2/T_1} + e^{-(TR-T_{RO})/T_1} - 1}\right) - TI_2$$

Methods: Our optimization at 1.5T follows that of Rydberg et al. (3) in which T_1 and T_2 values of normal tissue and MS lesions were used to optimize FLAIR. (T_1, T_2) of (1300, 110) ms for MS lesion; (700, 80) ms for WM and a T_1 of 4200 ms for CSF were assumed. Three primary goals were targeted: 1) suppress CSF; 2) eliminate T_1 contrast between lesion and WM at excitation; and 3) increase T_2 contrast between lesion and WM.

For each TR, TI_2 values were calculated ranging from 0 to TI_2^{max} (where the two inversion pulses coincide), (eqn. [2]). For each TI_2, the corresponding TI_1 that nulls CSF was calculated (eqn. [3]). Using each pair of (TI_1, TI_2), the signals for both lesion and WM (eqn. [1]) were calculated at the time of excitation (TE=0) (fig. 2). The TI pair at which both signal curves cross provides identical signal for lesion and WM, thus eliminating the T_1 contrast. An excitation at this TI pair provides characteristic T_2 decay (fig. 3a, solid lines).

Optimized DIR was implemented with a 3D-FSE sequence using variable refocusing flip angles (6) and extended echo train lengths (7). The sequence was evaluated on a normal volunteer using the optimized TI values along with an optimized FLAIR sequence at the same TR.

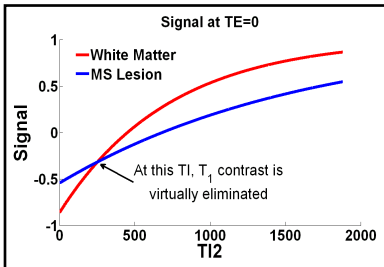

Fig. 2. Signal plots at TE=0 for WM and MS lesion at 1.5T, while CSF is completely suppressed.

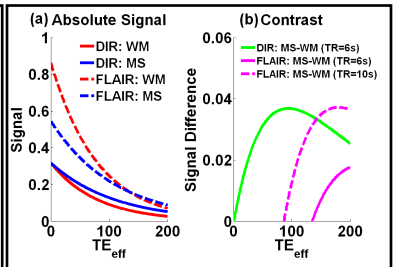

Fig. 3. Absolute signal and contrast for DIR and FLAIR at 1.5T. Peak contrast with DIR is achieved at a shorter TE_{eff} (with same TR).

Results: Simulations: Simulated curves showed superior or equivalent contrast between lesion and WM for optimized DIR relative to FLAIR. Optimized DIR was most noticeably superior at shorter TR's. For a 6s TR, the optimal TI_1 and TI_2 were 2032 ms and 252 ms respectively. The signal decay for both lesion and WM using these optimized TI values show a characteristic T_2 decay (fig. 3a, solid lines). For comparison, the signal decay for FLAIR is also shown (fig. 3a, dashed lines). Because WM starts with a higher FLAIR signal than the lesion due to its shorter T_1, a longer TE_{eff} is used to enhance T_2 difference, which is further exemplified by the contrast curves (fig. 3b). Using our optimized DIR approach, the maximum contrast vs. TE is achieved at a TE_{eff} of 90 ms, while the peak contrast with FLAIR is beyond 160 ms (magenta in fig. 3b). The TR with FLAIR needs to be increased to 10s (dashed magenta line, fig. 3b) to achieve similar contrast for these assumed lesion relaxation rates as DIR at 6s.

Volunteer images acquired using optimized DIR and FLAIR, each in 6:00 minutes, are shown in fig. 4. Acquisition was performed in the sagittal plane and the reformats are shown in axial and coronal planes. Optimized DIR images show enhanced gray/white matter contrast and signs of greater detectability of small hyperintensities in WM (arrow).

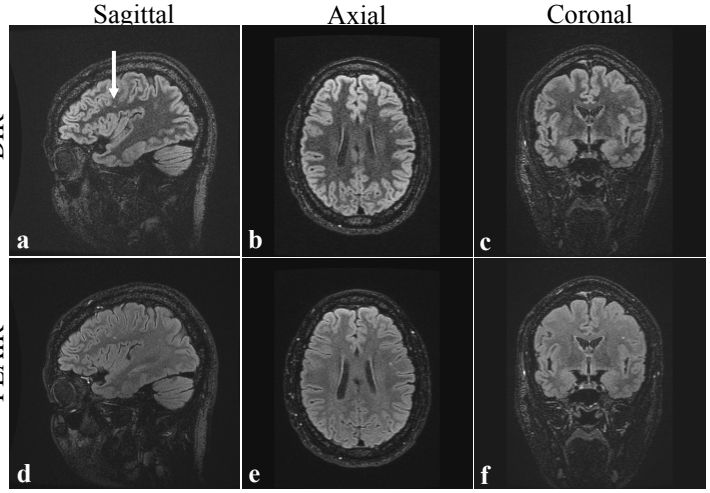

Fig. 4. DIR (a-c) and FLAIR (d-f) images acquired using TR=6 sec in a normal volunteer. Note the higher GM/WM contrast and increased conspicuity of a small WM hyperintensity using DIR (arrow).

Discussion: DIR preparation inversion times can be optimized to minimize unwanted T_1 weighting, enabling the acquisition of CSF-suppressed images with pure T_2 weighting. Shorter TRs may then be used without compromising contrast to reduce scan time for 3D whole-brain imaging. Our results suggest that this approach may be particularly useful for improved lesion detection and T_2 characterization accuracy relative to FLAIR when shorter TRs are used. Clinical evaluation is required, but this optimized DIR shows potential for replacing the combination of T_2 and FLAIR in many clinical protocols.

Reference: 1) Filipi et. al. JMRI 21: 669-75 (2005); 2) Yousry et. al. AJNR 18: 959-63 (1997); 3) Rydberg et. al. MRM 34: 868-77 (1995); 4) Redpath et. al. Br. J. Radiology 67: 1258-63 (1994); 5) Wattjes et. al. AJNR 28: 54-59 (2007); 6) Mugler, ISMRM; p.687 (2000); 7) Busse et. al., MRM 60: 640-49. (2008).