Reduced scan time 3D FLAIR using modulated repetition and inversion time

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Introduction: Recently, traditional FLAIR imaging has undergone rapid progress so that 3D imaging of the entire brain using an extended modulated refocusing pulse train is possible within a clinically reasonable time [1]. However, a longer repetition time is still used to allow adequate signal recovery. Here we describe a technique which uses variable repetition and inversion time to reduce total scan time. The scan time is reduced considerably while maintaining near equal SNR and CNR when compared with the constant repetition time sequence.

Materials and Methods: The effective inversion time or the effective echo time of a sequence is defined as the time from excitation to $k_y = 0$. In a similar fashion, the effective repetition (TR) time of a 3D acquisition can be thought of as corresponding to the TR for $k_z = 0$ encoding line. By keeping the TR equal to the repetition time of a constant TR sequence for k_z near 0 but reducing the TR for $|k_z| > 0$ encoding lines, the sequence will exhibit similar signal and contrast as the constant TR sequence. *Sequence design:* The 3D FLAIR sequence was modified by varying the TR (realtime) in a predetermined smooth fashion from TR_{min} to TR_{max} (both user defined) over the k_z encoding space using a four term Blackman-Harris (B-H) window. In addition, the inversion time was calculated for each TR(n) using $TI(n) = T1_{CSF} \times (\log 2 - \log(1 + \exp(-T_{recov}(n)/T1_{CSF}))$ where $T_{recov}(n) = TR(n) - T_{acq} - T_{T2P}$, where T_{acq} is the acquisition time and T_{T2P} is the T2-Prep sequence time. Bloch simulations were performed to determine magnetization in gray matter, white matter and CSF. *MRI experiments:* Six volunteers were scanned on a Philips 3T scanner (Achieva TX, release 3.2.1) after IRB approval and informed consent. For the tested 3D mFLAIR sequence, TR was modulated between $TR_{min} = 2.9$ s and $TR_{max} = 8$ s for a scan time of 2:41 (300 slices). The constant TR comparison FLAIR sequence with matching contrast was specified with a TR of 8 s (identical to the TR_{max}) of the mFLAIR sequence resulting in a scan time of 4:00; the corresponding TI for CSF suppression was 2357 ms. The constant TR comparison sequence with matching scan time of 2:41 was specified using TR = 5.6 s and TI = 1844 ms. Other scan parameters were identical among the three sequences. Since parallel imaging was employed, SNR was measured using ROIs placed in corresponding magnitude and noise only images. SNR was measured in the grey matter (GM), white matter (WM) and CSF.

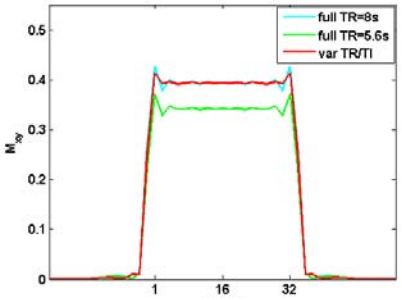

Figure 1: Simulated gray matter magnetization for (a) full TR=8s (b) full TR=5.6s and (c) variable TR, variable TI.

Results: As illustration, simulated transverse magnetization along z for one of the tissues (GM) is shown in Figure 1. Simulations show a near perfect match with signal from sequence with full TR=8s while comparable scan time constant TR=5.6s shows reduced signal for all tissues. Figure 2 shows sagittal slices and reformatted transverse slices obtained from the constant full TR=8s and the 3D mFLAIR sequence with varying TR. Visual inspection of all the images by a radiologist showed no perceptible differences between the constant TR=8s and the variable TR/TI sequence. Table below shows the measured mean SNR for WM, GM and CSF for the 6 volunteers with the three sequences. Measurements indicate excellent agreement of 3D mFLAIR with the longer scan time full (constant) TR sequence while comparable reduced scan time constant TR (=5.6s) FLAIR shows reduced SNR in GM and WM. CSF suppression is slightly better for the latter but the % change is from a much lower base value. Scan time reduction was about 30% in all cases.

SNR	Full TR = 8s	Full TR = 5.6s (% change)	Var TR/TI (% change)
GM	48.1	40.1 −16.6%	47.1 −2.1%
WM	32.2	30.4 −5.6%	32.2 0%
CSF	4.78	4.21 −11.9%	5.13 7.3%

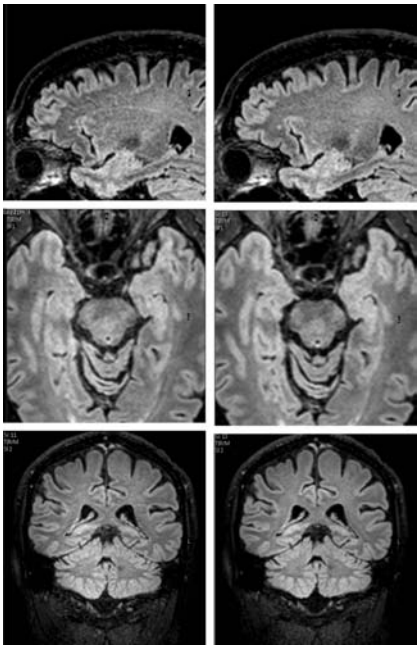

Figure 2: Native sagittal slice and reformatted transverse and coronal views obtained with 3D FLAIR with full TR=8s (left) and variable TR/TI (right).

Discussion: A new technique for reducing scan time while maintaining SNR, contrast and image quality with 3D FLAIR was described. Note that the scheme can only be employed with 3D imaging as it relies on the fact that the signal near the center of k-space determines SNR and contrast. Savings in scan time will be proportional to the TR used, so that a longer TR with greater dead time is even more conducive to the technique. For the scans performed, the specific absorption rate (SAR) and peripheral nerve stimulation (PNS) were always within FDA approved limits. A worst case estimate for all system limits and power deposition was derived by calculating the relevant values based on the prescribed minimum sequence time. SAR deposited increased from 9% for constant TR = 8s to about 13% for the varying TR sequence.

References: [1] B.A. Landman et al. Neuroimage, 2011:54:2854 -2866.