Optimized vascular signal reduction in contrast enhanced 3D T1 Turbo Spin Echo Imaging

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Introduction: Contrast enhanced MRI is the method of choice for visualization of most abnormalities of the brain. Pre- and post-contrast 3D T1, T2 and FLAIR imaging is routinely used in assessing primary central nervous system tumors. A study of contrasting lesions can provide information on the type and grade of tumor as well as help in staging treatment therapy (1,2). 3D T1 TSE with tailored refocusing pulses can provide high resolution images which can be used for early detection of lesions in diseases like multiple sclerosis. However, accompanying vascular enhancement can interfere with small metastasis in white matter and gray matter and complicate diagnosis. Techniques for vascular suppression include motion-sensitized driven equilibrium (MSDE) which has been used as a preparation sequence prior to acquisition with b-SSFP (1) or TSE (2) sequences in carotid vessel wall imaging. Typically, each MDSE preparation module is played out once per acquisition sequence. Here we show that employing controlled vascular crushing gradients (along all three axes) integrated into the 3D T1 TSE sequence can provide images which are mostly free of vascular signal [1,2] without appreciable loss in SNR/CNR.

Materials and Methods: A schematic of the pulse sequence is shown in Figure 1. A standard 3D TSE sequence with a modulated refocusing angle train was altered to include motion sensitizing gradients (MSG) along all three axes. PE refers to phase encoding gradient, SE corresponds to slice encoding and SR to slab refocusing. The red and blue dotted vertical lines indicate the center of the first and second data acquisition windows which corresponds to m_0 (0^{th} gradient moment) = 0 while m_1 is non-zero. As a result flowing spins will not be refocused at the center of the data acquisition window. The gradient strengths and therefore the first moment could be adjusted on the fly from the user interface to increase or decrease motion sensitivity. *MRI experiments:* Five healthy volunteers were scanned on a Philips 3T scanner (Achieva TX, release 3.2.3) after IRB approval and informed consent. The volunteers were administered a dose of 0.03 mmol/kg of Gadofosveset which has a prolonged vascular half life and therefore suitable for running several scans in tandem without a noticeable drop in the intrinsic vascular signal. To further ascertain a fair comparison, the scans were done in a reverse order for every other volunteer. Scan parameters (Seq 1): TR/TE = 500/33 ms, etl = 30 (centric encoding), 4 dummy echoes, SENSE (y) = 2.2, SENSE (z) = 1.7, 160-180 slices, VENC (x) = 2.7 cm/s, VENC (y, z) = 5.3 cm/s, res = 1mm^3, scan time < 2 mins 30 s. Comparison sequences included the above 3D T1 TSE sequence without the extra VC gradients (Seq 2) and a standard 3D T1 FFE scan to show vasculature (Seq 3). Two quantitative measures were assessed from the images: (a) vessel suppression and (b) SNR. To assess vessel suppression, MIPed (18 mm thick) images covering the entire brain were processed using ROIs drawn in the brain while excluding the nasal mucosa and eye balls. Thresholding was performed to get voxels corresponding to vascular signal. Noise only images were also obtained as a second scan for SNR measurements.

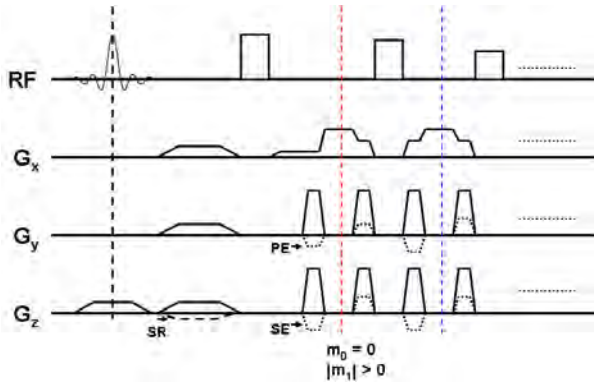
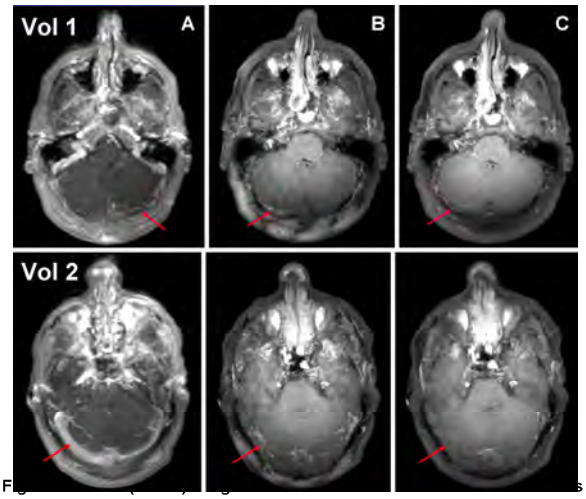


Figure 1: Sequence diagram of a 3D T1-w TSE sequence with vascular crushing gradients along three axes.



obtained with (A) 3D FFE (B) 3D T1 TSE (no VC) and (C) 3D T1 TSE with VC.

Results: Figure 2 shows representative MIPed images obtained using the three sequences. Enhancing tissues which have stationary or slow moving spins such as in the nasal mucosa, choroid plexus and pituitary gland enhanced on all three sequences. Table below provides the percentage change for the two measures across the three sequences. Introduction of the vascular crushing gradients resulted in a 10% decrease in SNR (23.7 vs 26.2) when compared with the base sequence with TE=22ms. However, the vascular signal for Seq 1 was approximately a third of the signal for Seq 3.

	Seq 1	Seq 2	Seq 3
Voxels (% change)	0	+195	+1198
SNR (% change)	0	+10	N.A.

Discussion: The vascular crushing capability offered by such a design is a result of the attenuation of moving spins due to the first moment of the sensitizing gradients (2). The reduction in SNR observed in stationary tissue is caused by additional signal decay due to T2, diffusion and eddy current effects. In addition, since the sequence has MSG, any gross motion of the head will also result in SNR reduction. Previous methods such in references (3) and (4) which use MDSE preparation for 3D T1 imaging do not account for any inflow after the preparation sequence which may not be adequately suppressed. By integrating motion sensitizing gradients along 3 axes in the TSE sequence ensures vascular suppression through the acquisition. The VENC along the phase and slice encoding axes was lower than along x, since no gradients along y, z can be played during readout. The minimum velocity sensitivity needs to be balanced against the need to keep TE short.

References: [1] I. Koktzoglou et al. *J Cardiovasc Magn Reson* 2007; 9:33-42. [2] J. Wang et al. MRM 2007; 58:973-981. [3] E. Nagao et al. *AJNR* 2011; 32:664-670. [4] M. Yoneyama et al. *Magn Reson Med Sci*, 08/2014 [Epub].