DEBLURRING IN 3D GRASE ASL BY USING VARIABLE FLIP ANGLES AND K-SPACE DEMODULATION

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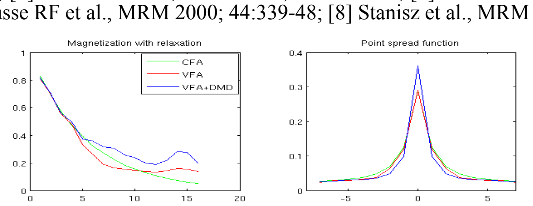
Introduction: Arterial spin labeling (ASL) is an MRI technique to measure cerebral blood flow (CBF) directly and noninvasively. However, ASL suffers from low signal-to-noise ratio (SNR). Three-dimensional imaging techniques, such as 3D gradient- and spin-echo (GRASE), can increase the SNR and measure the perfusion signal in the whole brain at a single inflow time, which greatly benefits CBF quantification [1]. However, a major limitation of this technique is the introduction of significant blurring in the images along the inferior-superior direction due to T2 decay during the relatively long readout time required for whole-brain coverage. A multi-shot 3D GRASE PROPELLER method has thus been recently proposed to reduce the through-plane blurring [2]. However, this approach is not suitable for functional studies due to its long acquisition time. To achieve rapid whole-brain coverage with reduced blurring, a k-space view-sharing method was recently introduced [3]. However, since the readout duration is still long, there is still considerable residual blurring, especially at the gray/white matter (GM/WM) interface, due to the relatively short T2 time in WM. For fast spin-echo sequences, modulation of the refocusing flip-angles has been shown to maintain higher echo signal for later echoes and thus reduce image blurring [4, 5]. In this study, a method based on variable flip-angle (VFA) and k-space demodulation (DMD) is proposed for 3D GRASE to manipulate the echo signal and collect images with reduced blurring along the inferior-superior (partition) direction.

Methods: This sequence was based on the k-space view sharing 3D GRASE sequence [3], with all parameters as in [3] unless specified explicitly below. To maintain image contrast, higher flip-angles were employed for central k-space than for outer k-space. A Kaiser-window approach was used to achieve a fast pseudo steady-state [5, 6], with largest/smallest flip-angle=162º/45º. A full-window ramp was applied to modulate the first 9 flip-angles, and a half-window ramp to modulate the last 7 flip-angles. The method proposed by Busse et al. [5] was employed for the first 7 echoes to correct the variations in echo amplitude introduced by the variable flip-angles. To enhance the later echo signal (and thus reduce blurring), a method based on k-space demodulation was used, similar to the method proposed by Busse et al. [7]. The demodulating factors k were estimated from: $k(i)=MTF(i)/(MTF(i)^2+1/(SNR*MTF(i))), i=1,2,...,n$, where MTF is the modulated transfer function [5], and SNR is the signal-to-noise ratio of the control image. To maintain the same contrast as in the original sequence, the demodulation method was applied to echoes from 8th to 16th only (note that, for our sequence, the centre of k-space occurs in echo number 3). To investigate the robustness of the proposed method to varying T1 and T2 values (given that these values are not known, and can vary throughout the brain), the dependency of the full width at half maximum (FWHM) of the point spread function (PSF) as a function of T1 and T2 was simulated. In vivo whole-brain datasets were acquired on a 3T scanner (2 healthy subjects) with the 3D GRASE sequence using both VFA and constant flip-angle (CFA), with identical parameters apart from flip-angles (162º for CFA, flip-angles for VFA as described above; TR/TE=3750/56ms, $4\times4\times6mm^3$, 20 partitions with 30% oversampling, matrix size=$64\times51\times20$, postlabeling delay=1540 ms, 120 measurements) [3]. Since the demodulation approach affects the overall SNR by manipulating the signal of later echoes, the spatial SNR of the perfusion images from the 2 subjects was assessed for the three methods.

Results: Assuming T1/T2 = 1600/100ms [8] for the correction, our numerical simulations show that the signal of later echoes is better maintained using the proposed method than with either CFA or VFA approaches alone, leading to a PSF with higher peak amplitude and narrower FWHM (Fig. 1). Figure 2 shows that the proposed method is superior to the CFA and VFA methods over the whole range of T2 values. Fig. 3 shows that the ASL perfusion images obtained with the proposed method (VFA+DMD) from 2 subjects have reduced blurring compared to the other two methods without DMD. Although the VFA method shows less blurring than CFA at the GM/WM interface (red arrows in Fig. 3), it does introduce more blurring in other areas, possibly due to echo signal loss caused by flip-angle modulation without correction [5]. The SNR values for subject 1 were: 23.3, 32.1 and 34.5, for VFA+DMD, CFA and VFA respectively; the corresponding values for subject 2 were: 16.8, 23.2 and 24.9.

Discussion: An image deblurring method based on variable flip-angle and k-space demodulation for 3D GRASE ASL perfusion has been proposed. The simulations demonstrate that our method is robust to varying T1 and T2. Furthermore, since blurring is more severe in WM due to its lower T2, it is especially problematic for accurate CBF quantification with constant flip-angle, due to the relative large voxel size and partial volume effects expected in ASL; this has been shown in the simulations (see Fig. 2). The in vivo results are consistent with the simulations and show that our method has the capability of reducing the blurring in both GM and WM. Although the SNR of the proposed method is lower compared to the other two methods (~75%), SNR can be recovered by increasing the number of measurements. Therefore, the proposed method, combining variable flip-angles with k-space demodulation, should provide more accurate estimates of CBF in both GM and WM by reducing image blurring.

References: [1]Fernandez-Seara MA et al., MRM 2008;59:1467-71; [2] Tan H et al., MRM 2011;66:168-73; [3] Liang X et al., 19th ISMRM: 2106, 2011; [4] Hennig J et al., MRM 2004; 51: 68-80; [5] Busse RF et al., MRM 2004; 51: 1031-37; [6] LeRoux P et al, JMR 2003; 163: 23-37; [7] Busse RF et al., MRM 2000; 44:339-48; [8] Stanisz et al., MRM 2005;54: 507-12.



(a) (b)

Figure 1: Simulation results including relaxation effects: (a) echo amplitude, and (b) point spread function. VFA: variable flip angle; CFA: constant flip angle; DMD: demodulation.

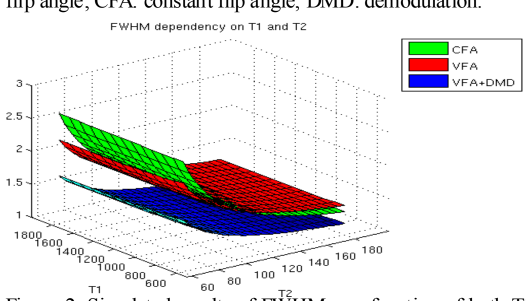


Figure 2: Simulated results of FWHM as a function of both T1 and T2 for all 3 methods

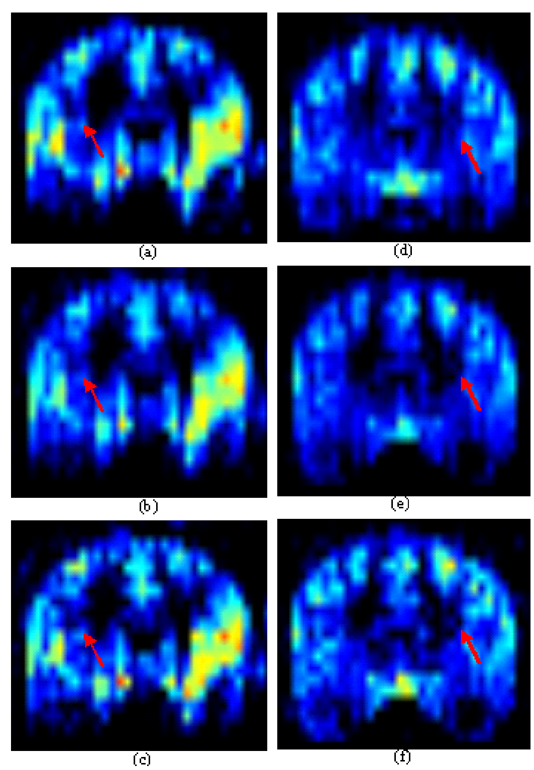


Figure 3: Mean perfusion images from 2 subjects (one per column) for all three methods: CFA (top), VFA (middle) and VFA+DMD (bottom). Red arrows show areas where more blurring occurs at the GM/WM interface with the CFA method. Reduced blurring can readily be observed along the inferior-superior direction for VFA+DMD (bottom row).