Rapid Dark Blood Imaging with High SNR from Random Velocity-Encoding Variation Method in Radial SSFP Acquisition

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Introduction:

Attaining a high contrast to noise ratio (CNR) between the vessel wall and lumen is essential for many cardiovascular imaging applications like atherosclerotic plaque characterization. Current dark blood imaging techniques have a variety of limitations in clinical application. Slab-selective saturation pulses are ineffective in suppressing in-plane flow (1). Double inversion recovery Turbo Spin Echo sequences (DIRTSE) substantially increase the overall acquisition time (2), and T2-preparation pulses result in decreased signal to noise ratio (SNR) (3). In this study, a radial steady-state free precession (SSFP) sequence is developed with random amplitude velocity-encoding gradients applied prior to data acquisition. The effect of the random velocity-encoding gradients is to selectively dephase flowing spins at the center of K-space and lead to non-refocused velocity encoding over each TR so that flow signal is suppressed while preserving the high SSFP signal for stationary tissue. This acquisition technique can achieve high SNR and CNR in dark blood imaging with an extremely short acquisition time.

Materials and Methods:

The true-FISP SSFP (Coherent Steady-State Free Precession) sequence acquires relatively high signal amplitude with gradient refocusing along all three imaging axes over each short repetition time (TR). However, spins moving into the slice present with high signal amplitude since they have experienced no prior nutation, dephasing or relaxation effects (4). To achieve the goal of high contrast between static and moving spins, this study proposed including a random bipolar gradient prior to radial SSFP data acquisition in each TR (Figure 1). The magnitude of the velocity-encoding gradient is randomly varied to cause the phase of all flowing spins to vary randomly for each projection. This view-dependent phase variation results in the cancellation of signal from flowing spins in the center of k-space without disturbing the signal from stationary spins. Further, the stationary spins would fully refocus over each TR, while moving spins would experience a form of velocity spoiling and generate an incoherent SSFP signal. The flow suppression was optimized on a Siemens Sonata 1.5T scanner by maximizing the gradient variation (0 ~ 40 mT/m) of the velocity encoding lobes. Additional chemical shift selective (CHESS) pulses were applied prior to each acquisition in order to suppress the undesirable fat signal.

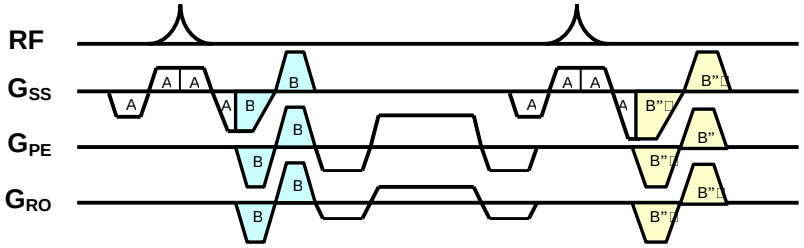

Figure 1. Pulse sequence diagram for radial SSFP with bipolar randomly velocity-encoding gradient. During each sequence cycle we apply bipolar random gradient (shaded regions) to achieve balance for zero gradient moment and completely diverse for first gradient moment within each repetition time in order to suppress flow spins and maintain high signal intensity In stationary spins.

Results:

Figure 2a shows static and flow phantom images acquired with a traditional radial SSFP sequence. Figure 2b confirms the feasibility of SSFP dark blood imaging via random bipolar gradient velocity encoding in a radial acquisition sequence, (Fig. 2b). Note the strong suppression of flowing spins while maintaining the high signal for the stationary object. Figure 3a shows an *in vivo* image with a standard radial SSFP sequence in comparison with the additional velocity-encoding random gradient implementation (Fig. 3b). The total acquisition time for the true-FISP with bipolar random gradients is less than 24 seconds per slice, which is 52% shorter than the standard DIRTSE, shown in Fig. 3c.

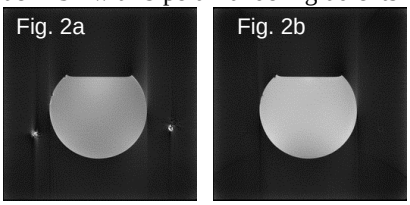

Figure2. Stationary and flow phantom images. (a) Conventional radial SSFP (b) Radial SSFP with bipolar random gradient (Center object is stationary water phantom which is surrounded by two flowing water

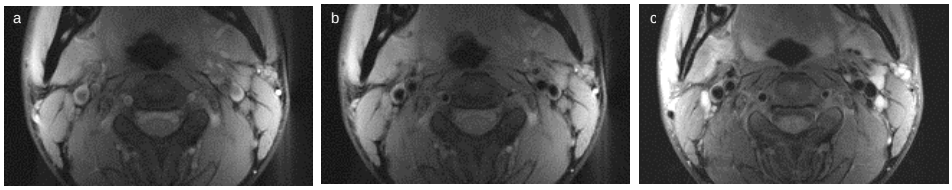

Figure3. Volunteer in vivo images. (a) Conventional radial SSFP (b) Radial SSFP with bipolar random gradient (c) Standard sequence (DIRTSE) in carotid vessel wall image

Conclusions:

This study suggests that random bipolar-velocity encoding gradients with radial SSFP sequences can provide successful flow suppression and achieve high CNR between stationary tissues and flowing blood. This study utilizes the oversampling properties of radial trajectories to effectively eliminate the normally bright blood signal in SSFP acquisitions. At the same time, the bipolar gradients maintain the phase properties of static spins resulting in the desired high SNR images. Appling the random velocity encoding gradients in all directions (Slice-Select, Phase-Encoding and Read-Out) can achieve better flow suppression, especially near the carotid bifurcation where in-plane eddy-flow exists as well. Adjusting the bipolar gradient's first moment can achieve a higher level of phase dispersion for flowing spins at the expense of increased TR. This simple flow cancellation technique can be applied to any other k-space trajectory that oversamples the low spatial frequencies of k-space (i.e., rosette, multi-interleaf spiral). Radial True-FISP with randomly velocity-encoding gradients offers great promise in rapid dark blood imaging of the carotid artery wall and achieves the goal of high vessel wall/lumen CNR for clinical evaluation of atherosclerosis and vessel stenosis in a rapid acquisition.

References:

[1] Nayak et. al., JMRI, 13, 807-812, 2001. [2] Parker et. al., MRM, 47, 1017-1021, 2002. [3] Brittain et.al., MRM, 33, 689-696, 1995. [4] Markl et. al., Proc. ISMRM 11, p293, 2003