In Flow Effects in Alternating Differenced Balanced Steady State Free Precession Imaging: A Brain Study

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Introduction: The central signal singularity phenomenon in balanced steady state free precession (b-SSFP) results in highly localized variations in magnetization with perturbation of scan parameters. Recently, a version of this phenomenon using alternate perturbation of excitation angle and/or phase has been studied [1]. Phase perturbed steady-state free precession has been used for positive contrast imaging of SPIO labeled nanoparticles in a phantom as a means for tracking labeled cells [2]. While the technique can provide excellent background suppression by selectively exciting a narrow band of frequencies, translation to in-vivo imaging may pose some challenges. For example, the effect of flowing spins has not been studied for the sequence. Based on the application, this can be an important contributing factor to the final result. Here we apply excitation and phase perturbed differenced b-SSFP imaging in the brain to illustrate the point.

Theory and Methods: The gradient waveforms in a b-SSFP sequence have zero net area in each TR and are first order moment nulled along the read and slice directions at each RF excitation. However, the MR signal from b-SSFP exhibits flow sensitivity depending on the first moments of gradient activity between RF excitation and data readout [3]. For example, if the net first moment is M_1, the phase introduced would be $\varphi = \gamma . M_1 . v$ where v is the flow velocity. If interleaved b-SSFP acquisitions (NSA = 2) with a constant α ($\Delta\alpha$ = 0°) and phase ($\Delta\phi$ = 0; φ and ϕ in radians througout) are subtracted, the net effect is zero. However, when parameters like α and/or ϕ are alternately perturbed, the sequence becomes sensitive to flow related off-resonant spins. This sensitivity of b-SSFP to steady and pulsatile inflow has also been shown earlier in the context of the standard sequence [4]. In flow effects result in a substantial increase in signal after subtraction when compared with no inflow. At phase perturbations corresponding to sequence selectivity around $\phi = \pi$, the sequence is typically sensitive to fast flowing blood. At lower ϕ values, the sequence becomes sensitive to slower velocities. Figure 1 shows the simulation using a numerical solution to Bloch equation for b-SSFP [5]. The steady-state signal is obtained by subtracting even and odd echoes for b-SSFP with the following parameters: TR/TE = 4.8/2.4ms, NSA=2 (interleaved), $\Delta\phi$ = 0, blood T1/T2 at 3T. When $\Delta\theta$ = 0, the subtracted signal is negligible while with Δs (ratio of inflowing spins) = 0.2 and $\Delta\theta$ = 4°, a strong signal is obtained at off-resonance $\phi = \pi$.

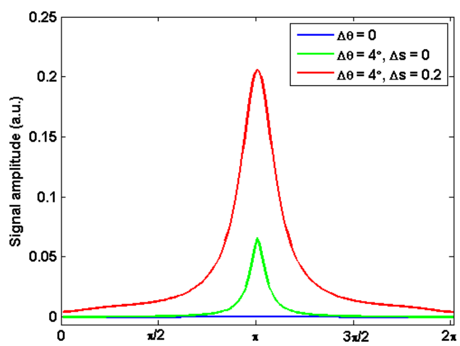

Figure 1: Difference steady-state signal from interleaved b-SSFP acquisition with alternating (θ, ϕ) perturbation. (Δθ, Δϕ) = 0 gives no signal while Δθ = 4°, Δϕ = 0 gives off-resonance sensitivity. In flowing spins provide a much larger signal response.

MR Experiments: Six healthy volunteers were scanned under an IRB approved protocol on a Philips 3T Achieva scanner (Release 3.2.1) using an eight channel head coil. Images using 3D non-segmented b-SSFP with alternating scan parameters were obtained in 24 (scan time: 12.5s) or 48 (scan time: 23s) overcontiguous slices from a transverse slab of the brain centered on the pons using a sagittal slice. The following imaging parameters were used: FOV=23cm, res.=0.9×0.9×2mm, TR/TE=4.8/2.4ms, $\Delta\theta$=4°–8°, $\Delta\phi$ = 0.

Results: Figure 2 shows maximum intensity projection images obtained by taking the difference of the interleaved NSA=2 b-SSFP acquisitions with alternate perturbations of ($\Delta\theta$, $\Delta\phi$). The MIPed images are from slabs with 48 slices. When the sequence is sensitive to phase shift $\varphi = \pi$ ($\Delta\phi$ = 0), in flow effects from fast flowing blood dominate while at other lower phase shifts, signal from CSF pulsatility dominates the positive contrast. Repeatability of the results for any given ($\Delta\theta$, $\Delta\phi$) was excellent.

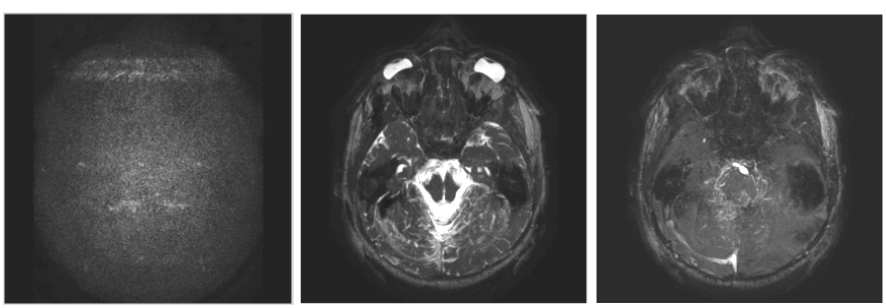

Figure 2: MIPed images obtained from difference of the two interleaved b-SSFP sequence with perturbation Δθ = 0°, Δϕ = 0 (left), Δθ = 4°, Δϕ = 0.6 (middle), Δθ = 4°, Δϕ = 0 (left),

Discussion: Positive contrast imaging using the central singularity phenomenon has the potential to provide excellent off-resonance contrast. In-vivo studies could suffer from inflow effects of blood and other moving fluids. In the brain, signal from CSF is relatively higher than from other brain tissue (T2/T1≅0.6; blood T2/T1≅0.03 at 3T). In addition, CSF exhibits a large range of velocities. As a result, the sequence becomes sensitive to CSF pulsatility over a considerably large off-resonance range. Spins that have left the imaging slice/slab can still contribute to the s-s signal since gradient activity is not confined to the region of excitation and the gradients are completely balanced [4]. Slice profile can affect moving spins differently but were not considered here as 3D imaging circumvents the issue to some extent. Means to reduce this sensitivity to inflow need further exploration.

References: [1] Ingle RR et al. *ISMRM* 2011:378. [2]] Ingle RR et al. *ISMRM* 2011:4520. [3] Markl M. et al *MRM* 2003;49:945-952. [4] Markl M. *MRM* 2003;50:892-903. [5] Hargreaves B. et al. *MRM* 2001;46:149-158.