Dark-blood True-FISP Imaging Using Dual Steady States

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Introduction: Dark-blood imaging is important for a variety of clinical applications, especially vessel-wall imaging where nearby bright blood can easily obscure the signal from atherosclerotic plaques. The most common dark-blood technique is based on double-inversion magnetization preparation; however, this technique requires a prohibitive amount of time for many applications such as screening for atherosclerotic plaques. True-FISP acquisitions are rapid, but typically have bright-blood due to the inflow effect. This abstract describes a new dark-blood true-FISP imaging technique based on establishing separate steady states in and out of the plane.

Methods: True-FISP is a rapid coherent steady-state technique with good SNR. Recent work [1] and practical experience have shown that inflowing spins are fully relaxed and consequently have high signal. To reduce this effect it is possible to establish an incoherent steady-state for a neighboring slab containing the inflowing spins.

RF spoiling, achieved by varying the phase of the slab select RF pulse, can be used to reduce the signal from spins in a slab adjacent to the imaging volume. Gradient spoiling, however, cannot be directly used without destroying the coherency within the imaging slice; however it is possible to encode the slab spins at a different *k*-space location when compared to those within the slice. Such a sequence is shown in Figure 1. Note that the spins experience a balanced gradient overall, but the slice-select gradient is not refocused during the readout for slab spins. This effectively encodes the slab spins at a different k_{slice} location than those within the imaging slice.

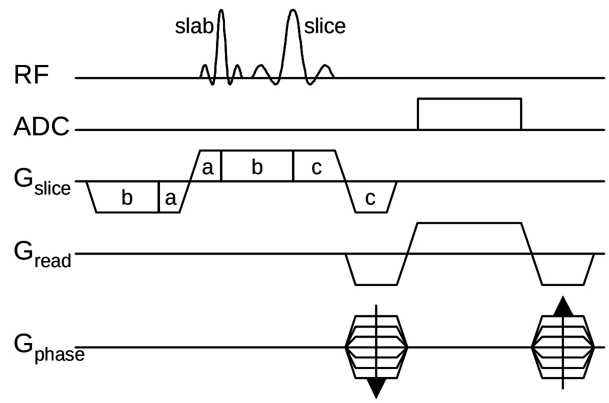

Figure 1. Pulse-sequence diagram for the dual *k*-space dark-blood true-FISP technique. During the readout the slab spins are dephased by the gradient area labeled "b". The slab excitation uses RF spoiling for an incoherent steady-state while the slice excitation uses phase alternation for coherent steady-state. All gradients are refocused leading to the true-FISP condition for the in-slice spins.

Results: Figure 2 shows four true-FISP images of the carotid arteries. All were acquired with a 256^2 matrix and a 200mm FOV. The slab selection pulses used RF spoiling and a 90º tip angle while the slice selection pulses used phase alternation and a 70º tip angle. Image a) is a standard true-FISP acquisition with no slab selection. Image b) is the true-FISP sequence of Figure 1 with the slab placed superior to the slice while the slab is placed inferior to the slice in image c). Image d) has both superior and inferior slabs. Note the excellent suppression of inflowing spins and consistent True-FISP contrast within the slice. Total acquisition time for the sequence was 2.25 seconds. The minimum TR of the sequence was extended by 1.5 ms over the standard True-FISP to permit inclusion of the slab-selection RF pulse and extra gradient area **b** (Figure 1).

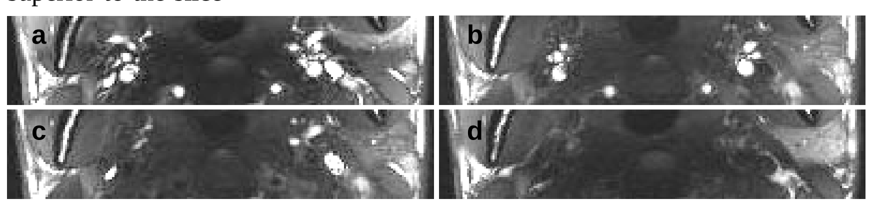

Figure 2. Dual k_{slice} encoded true-FISP carotid images. No slab (a), inferior or arterial slab (b), superior or venous slab (c), both slabs (d).

Discussion: The initial results in Figure 2 demonstrate the excellent dark-blood contrast achievable with this technique; typically suppression of greater than 90% is obtained. It is important to use a large slab, both in order to reduce the signal content of the slab at moderate k_{slice} offsets and to ensure that fully relaxed spins cannot flow into the slice. By using a large tip angle for the slab selection it is possible to ensure that rapidly flowing spins are in steady-state even though they may only experience a single excitation. In addition, the large tip angle results in a small signal from the FLASH-like steady-state in the slab, which is important for avoiding unwanted signal contamination. Essentially, this sequence utilizes the FLASH-like steady-state in the slab to reduce the inflow effect in the slice and the *k*-space separation to reduce the signal from slab spins. Other beneficial combinations of steady-states may prove complementary for various applications.

The RF pulses can be implemented either as separate slice and slab excitations or as a family of combined excitations with varying phase in the slab region and constant phase in the slice region. In addition, maximum-phase pulses designed with the Shinar-LeRoux [2] technique may be desirable for the slab because of their non-refocusing properties. Such RF design techniques may also lead to shorter pulses, thereby reducing the impact on the minimum TR.

Conclusion: We have demonstrated a steady-state dark-blood imaging technique. This technique should allow for rapid imaging of vessel walls and may have significant impact on the utility of MRI in routine screening for atherosclerotic plaques.

References: [1] Markl, et al. Proc. ISMRM. 293. 2003. [2] Pauly, et al. IEEE TMI. 10: 53-65. 1991.