Bi-plane Imaging with SSFP

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Introduction: Fully refocused steady-state free precession (SSFP [1,2]) or fast imaging with steady precession (BFFE, TrueFISP, FIESTA) has proven useful within cardiac imaging due to its high SNR and excellent blood-myocardium contrast. This is particularly true in real-time applications where the high efficiency of SSFP combined with increased signal-to-noise ratio has led to previously unattainable fast imaging. Since SSFP is a steady-state imaging sequence, the acquisition of multiple 2-dimensional slices is typically sequential. That is, one slice must be completely acquired before the second is imaged, requiring the establishment of the steady-state before data acquisitions, reducing data acquisition efficiency. This work demonstrates a new fully-refocused SSFP sequence that time-multiplexes the acquisition of two orthogonal slices, resulting in simultaneously acquired, temporally matched images without interruptions to the imaging steady-state (Fig 1).

Methods: The pulse sequence utilized is demonstrated in Fig 2. During each TR, the slice encoding and phase encoding gradients are switched in logical coordinates, leading to the acquisition of perpendicular slices. Since both slices are acquired in steady-state there is no need for interruptions and scanning can continue unimpeded. Effectively, the TR for each slice is doubled. Since SSFP is coherent imaging, magnetization is maintained from TR to TR implying that magnetization for one slice (S_1) remains during the excitation of the alternate slice (S_2). However, because the slices are perpendicular, the S_1 magnetization is phase encoded to a limited region and the signal is projected onto S_2, resulting in a darkened band that localizes the slices with respect to each other. The dual slice pulse sequence was implemented on a 3.0T Philips Intera scanner equipped with moderate strength gradient hardware yielding 21 mT/m/s maximum amplitude and 100 mT/m/s maximum slew rate. The acquisition parameters were: TR 7.5ms with TE=TR/4; 128^2 matrix; 8mm slices; 45º flip. Images were acquired continuously without the need to interrupt steady state.

Results: Perpendicular bi-plane images acquired from a stationary spherical phantom are displayed in Fig 3. The intersection of the two slices is readily apparent in both images as a dark band. Furthermore, the dually-excited intersection region reaches a bi-stable steady-state as it receives excitations that follow a α/α /-α/-α excitation pattern as opposed to the α/-α typical for SSFP. This excitation pattern results in a transfer function akin to that of the FEMR technique and varies based on slice [3].

Discussion: The ability to images two slices continuously without having to interrupt the imaging steady state can be very valuable for applications such as catheter tracking or measurement of cardiac function [4]. In real-time imaging, this method allows for the acquisition of two temporally registered images of interest for cardiac imaging. Two complementary long axis views can be acquired, yielding an effective method for simple measurements of cardiac function (EF and ventricular volume) similar to those used in X-ray and echocardiographic assessments [5]. The method does double TR for each slice, limiting the applications of the technique to situations with either lower resolutions or fast gradients. During cine acquisitions, two slices acquired within a breath-hold can be imaged without interruptions to the steady-state, yielding two complete, temporally and spatially registered movie loops.

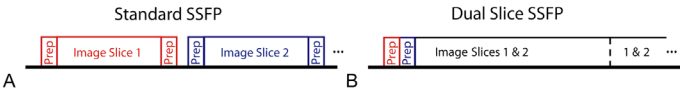

Figure 1: During the acquisition of two slices with standard SSFP (A), data for the acquisition of one slice must be completed before the acquisition of the second slice begins. Each interruption requires the use of a preparatory phase that reduces imaging efficiency and causes artifacts. When using the proposed pulse sequence (B), two slices can be acquired simultaneously and continuously without disturbing the steady state and without repeating preparatory phases.

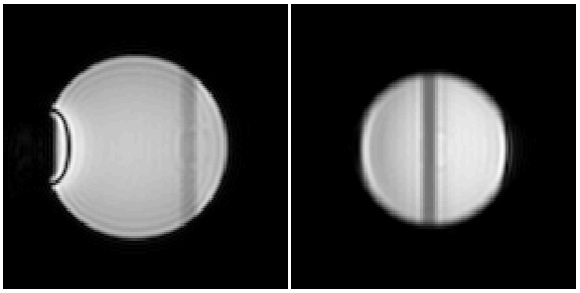

Figure 3: Perpendicular images of a spherical stationary phantom acquired with the dual-slice SSFP sequence. Both images were acquired simultaneously without interruptions to the steady-state. Both images display a dark band corresponding to the projection of the magnetization of the alternate slice. Note that this band exhibits a different behavior for each slice.

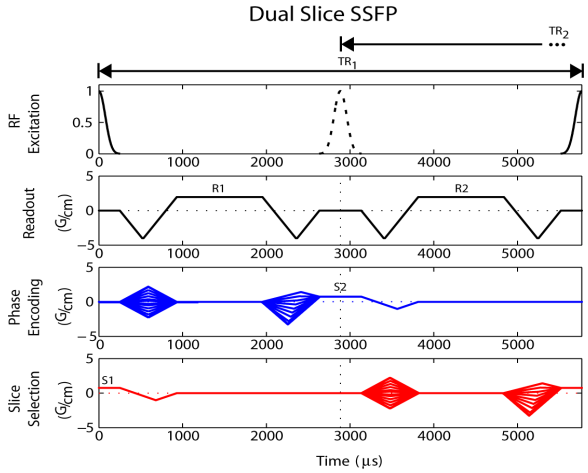

Figure 2: Pulse sequence diagrams for standard bi-plane SSFP. The pulse sequence closely resembles the standard SSFP sequence up to the transition between the readout and the slice selection for the perpendicular slice (S_2). In standard SSFP all TRs in the sequence excite the same slice (S_1) and the acquisition of a second slice would follow after completion of S_1. However, in the dual-slice imaging sequence, the slice selection gradient is transferred to the phase encoding direction and combined with the phase encoding rewinder. The next RF pulse (~ 2900us in this example) effectively selects a slice perpendicular to the original (S_2).

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