Balanced 2D Radial Acquisition SSFP of the Mouse Heart at 7 Tesla

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Introduction:

Steady State Free Precession(SSFP) has become a popular tool for human cardiac imaging due to its high signal to noise ratio(SNR) and excellent contrast between myocardium and blood. Application thus far has been limited to the clinical arena as steady state is prone to artifacts, which become pronounced at higher field strengths where most small animal imaging is performed. Furthermore the short repetition time and gradient demands have made the application to small animal systems extremely challenging. Here we describe solutions to these problems with the development of a balanced SSFP 2D radial acquisition(RA) sequence for cardiac studies in the mouse at 7T. RA was chosen to minimize the demands on the gradients, to enable short repetition times and provide a sequence that has a high immunity to motion-induced phase artifacts(1). SSFP was shown to be a viable imaging technique for the mouse heart with minimal artifacts and high signal to noise ratio. The sequence has been implemented with data acquisition during the rewinders to provide an additional increase in SNR, provide increased temporal resolution and permit the creation of B0 maps.

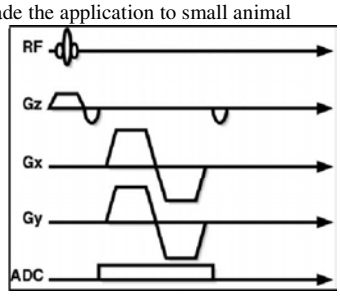

Figure 1: Pulse Sequence Diagram for Dual Encoded b-SSFP 2D RA Sequence

Methods:

Imaging was performed on a 7T 210 mm horizontal bore magnet interfaced to a GE EXCITE platform (EPIC 12.0). A 30 mm diameter surface coil was constructed to cover the mouse heart. The diagram of the 2D b-SSFP RA sequence is shown in Figure 1. Phantom studies were performed to tune the sequence, explore the SSFP artifacts and validate the development of the steady state at 2T and 7T. Animal studies were performed in accordance with Duke IACUC protocols. C57/BL6 mice were injected with a combination of diluted Nembutal and Butorphanol. An IP catheter was inserted to maintain anesthesia with additional injections of Nembutal. ECG pads were placed on front right and left forepaws and were connected to a commercially available SA instrument system, which reduced gradient noise on ECG signal. A temperature probe monitored and stabilized core body temperature in the animal with an external warm air heater.

The typical field of view was 5 cm with a 1.5 mm slice, a bandwidth of 125 kHz and TR of 4.5 ms. With 8000 views per phase and 8 cardiac phases of the heart cycle, the acquisition time is ~7 minutes. The sequence employs full rewinders to restore the phase at the end of each full trajectory, in accordance with the requirements for steady state(2). The sequence yields 2 radial samples during each repetition; radial out- at TE 1.2 ms with a trajectory moving from the center of K space; radial in- at TE 3 ms when the rewinders have returned the trajectory from the periphery of K space. Thus with this sequence one gets two images during each TR, with the possibility of improving SNR(3). Data was reconstructed for each set of views (radial out and radial in) as magnitude images using a novel non-uniform fast Fourier transform algorithm implemented in Matlab [*].

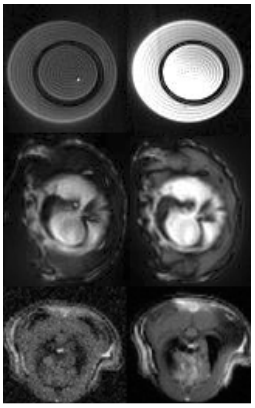

Figure 2: a) Images of Copper Sulfate phantom at 7T without (left) and with (right) rewinders; b) images of perfused mouse at 7T without (left) and with (right) rewinders c) images of live rat study done at 2T without (left) and with (right) rewinders

Results and Discussion:

SSFP at 7T was maintained in a copper sulfate phantom as seen in Figure 2, improving signal to noise ratio up to 4 times relative to a standard 2D RA sequence without the rewinders. Maintaining the steady state at 7T posed several challenges. To reduce artifacts the sequence had to be symmetric with trapezoidal rewinder gradients and alternating sign RF pulses. A phase offset of pi/2 was implemented to limit the strong artifacts present when spins are on resonance. To further reduce banding artifacts, the sequence employed phase addition to every RF pulse which in turn resulted in the ability to alter the location of banding artifacts with possible extension to multiple acquisition steady state free precession(4). The immunity to fluctuation in signal intensity of the RA sequence makes it a robust sequence to use during the development of SSFP and thus was not prone to artifacts normally associated with steady state formation. The SNR in the myocardium with the b-SSFP technique was increased by a factor of 2, while in the blood the increase in SNR was 1.5. Design of the sequence to encode during rewinders allows one to create B0 inhomogeneity maps as well as change contrast, increase temporal resolution and combine the images to enhance SNR.

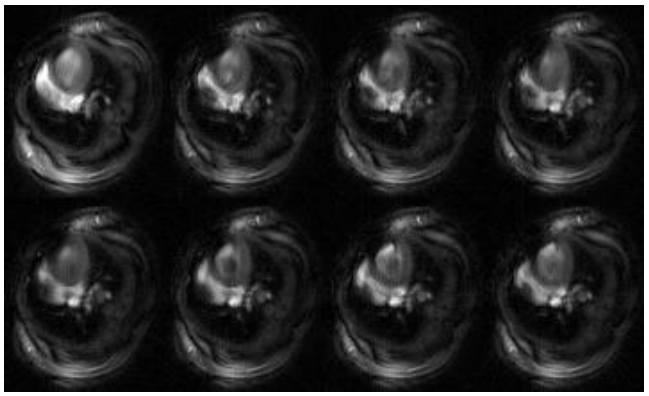

Figure 3: 2D RA b-SSFP images @ TE (effective) of 1.2 ms and 8 phases of the cardiac cycle in a live 25 gm C57/BL6 mouse

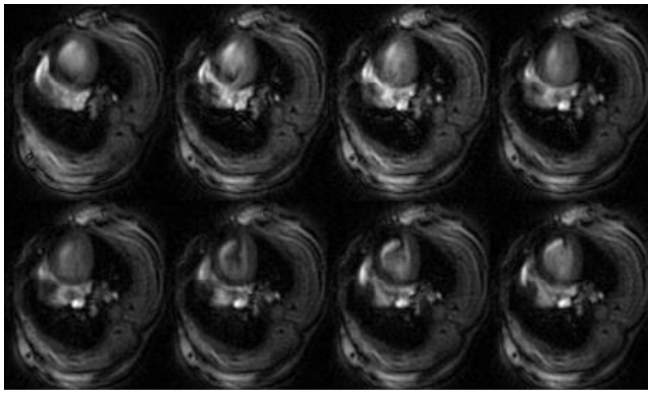

Figure 4: 2D RA b-SSFP sequence images at TE (effective) of 3ms, 8 phases of the cardiac cycle in a live 25 gm C57/BL6 mouse

Conclusion:

Balanced SSFP has been shown to be a useful technique to improve SNR of blood and myocardium and to generate cine cardiac images in the mouse with limited banding artifacts. 3D projection encoding is particularly appealing for small animal imaging because of the immunity to variations in the magnetization. Unfortunately this reduces the flow dependent contrast between blood and myocardium. Extension of the SSFP to 3D RA will address this problem. Work to do so is under way.

References:

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