Self-Navigated 2D SSFP Sequence for Simultaneous Respiratory and Cardiac Motion Detection

A. Shankaranarayanan[1], A. Brau[1], M. McConnell[2], J. Brittain[3]

[1]Global Applied Science Lab, GE Healthcare, Menlo Park, CA, United States, [2]Cardiology, Stanford University, Palo Alto, CA, United States, [3]Global Applied Science Lab, GE Healthcare, Madison, WI, United States

Introduction:

Motion, including respiratory and cardiac motion, during an MRI scan can introduce artifacts in the reconstructed image thus degrading the image quality and rendering the image non-diagnostic. A variety of methods have been proposed to overcome these motion artifacts, either by gating to external signals (respiratory bellows, electrocardiogram, peripheral pulse) or by using extra RF and gradients to generate "navigator" signals. External gating is heavily dependent on the transducer to generate the signal and signal interference due to MR imaging can cause the cardiac gating to fail. On the other hand, acquisition of navigator signals reduces scan efficiency and can potentially interfere with the imaging process. Recently "self-gated" and "self-navigated" methods have been proposed that derive physiologic motion waveforms directly from MR data acquired during normal imaging [1,2,3,4]. In one such approach, motion is detected by acquiring samples of the DC (center of k-space) signal every TR during the time window following any slice-select rewinder and prior to any subsequent gradients [3,4]. The method was demonstrated for traditional gradient echo imaging in the abdomen.

In this work, we investigate the feasibility of the method in context of SSFP imaging and demonstrate its application in 2D cardiac imaging.

Methods:

The following method was implemented on a 1.5T Signa TwinSpeed system (GE Healthcare, Milwaukee, Wisconsin) with a maximum gradient strength of 40 mT/m and maximum slew rate of 150 mT/m/msec. A 2D SSFP (a.k.a FIESTA, True FISP, fully balanced FFE) sequence was utilized with the following imaging parameters: TR/TE = 4.2ms/2.4ms, flip=50°, receiver BW = ± 125kHz, FOV=34 cm, 256x256 acquisition matrix, NEX = 1 and slice thickness of 7mm. For comparison, a 2D self-navigated gradient echo sequence was also utilized with the imaging parameters: TR/TE = 8ms/3.5ms, flip=30°, receiver BW = ± 125kHz, FOV=34 cm, 256x256 acquisition matrix, NEX = 1 and slice thickness of 7mm.

Self-Navigation Process: Self-navigation was performed by acquiring 4 points (16us) immediately following the slice-rephasing gradient and before any subsequent gradients. For the multi-coil acquisition, a peak detection algorithm was used to detect the coil with maximum signal. A low pass (LP) FIR (Finite Impulse Response) filter was used to isolate frequencies in the expected range of respiratory motion and a bandpass (BP) FIR filter was used to isolate frequencies in the expected range of cardiac motion. All filtered data were corrected for group delay when comparing to the physiologic signals.

Volunteer Experiments: Following informed consent, healthy volunteers were imaged while detecting the DC (self-navigated) signal each TR as desribed above. For comparison, a respiratory bellows signal and a peripheral pulse signal from the index finger were recorded simultaneously. The first set of experiments were performed during free breathing while for the second set of experiments, each volunteer was asked to hold their breath. These experiments were carried out for both SSFP and gradient echo sequence. The filtered magnitude DC data was then compared to the physiological signals and qualitative correlations were observed to determine the effectiveness of the self-navigation data in detecting respiratory and cardiac motion.

Results:

Figure 1a compares the LP filtered version of self-navigated SSFP data (dashed line) and the respiratory bellows signal (solid line) during a free breathing scan. Figure 1b shows the comparison of LP filtered version of self-navigated data and the respiratory bellows signal for a gradient echo sequence. Note that the correlation of the self-navigated data to the respiratory bellow, in both cases, is excellent. The mean signal level for SSFP self-navigated data was found to be higher than that of gradient echo (~33%), as one would expect in SSFP imaging. Figure 1c shows the plot comparing the BP filtered version of SSFP self-navigated data with the peripheral pulse signal and Figure 1d shows a similar comparison for a gradient echo sequence. The similarity of the waveforms can be observed. The timing of the peak waveform in the self-navigated data was noted to be earlier (~200ms) when compared to the start of the R wave in the peripheral pulse signal, potentially due to the transit time for blood to travel from heart to the periphery. The delay was observed in both the SSFP and gradient echo case.

Figure 2a shows the plot of comparison of the LP filtered version of SSFP self-navigated and the respiratory bellows signal during a breath held scan. Figure 2b shows similar comparison for a gradient echo sequence. Note that both the waveforms showed very little variations during the breath hold. Some oscillations can be seen in the respiratory bellows signal. Presumably, the small amplitude high frequency oscillations are due to the cardiac motion. This is not reflected in the self-navigated data because of the low-pass filtering. Figure 2c shows the comparison between the BP filtered version of SSFP self-navigated data (dashed line) and the peripheral pulse signal (solid line). Again, the timing of the peak in self-navigated data was observed to be earlier. A similar trend is seen in the signal from the gradient echo sequence (Figure 2d).

Discussion and Conclusion:

The feasibility of the DC motion detection technique described before for a gradient echo sequence [3] is shown in the context of SSFP cardiac imaging. The initial results indicate that both respiratory and cardiac motion can be efficiently derived from the filtered magnitude SSFP self-navigated data, potentially eliminating the need for external physiologic monitoring without increasing pulse sequence complexity. The motion information extracted from the self-navigated signal could be used in a variety of cardiac imaging applications, including gating image acquisition to detected respiratory and cardiac motion or retrospective correction of motion corrupted data. Future work will also investigate the feasibility of the self-navigated technique in 3D cardiac applications such as whole heart coronary imaging.

References: [1] Larson et al, MRM 51:93-102, 2004. [2] Crowe et al, MRM 52:782-788, 2004 [3] Brau A et al, ISMRM 2005, 508. [4] Brau A et al, MRM in press.

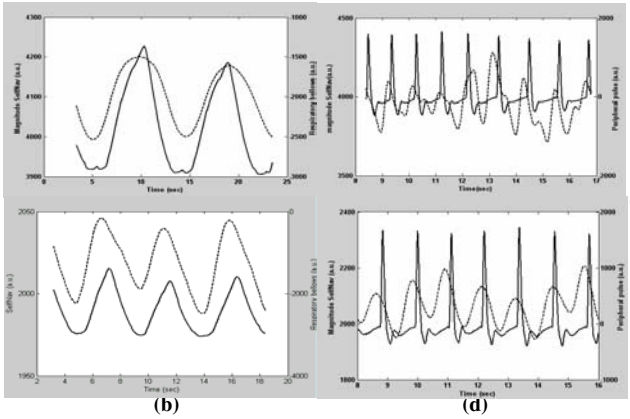

Figure 1: Free breathing experiment. (a) Comparison of low pass filtered SSFP self-navigated data and respiratory pulse. (b) Similar comparison with the gradient echo sequence. Note that the mean signal level is higher for SSFP signal. (c) Comparison of bandpass filtered SSFP self-navigated data and the peripheral pulse. Similarity of the waveforms can be seen. (d) Shows the same comparison for gradient echo sequence.

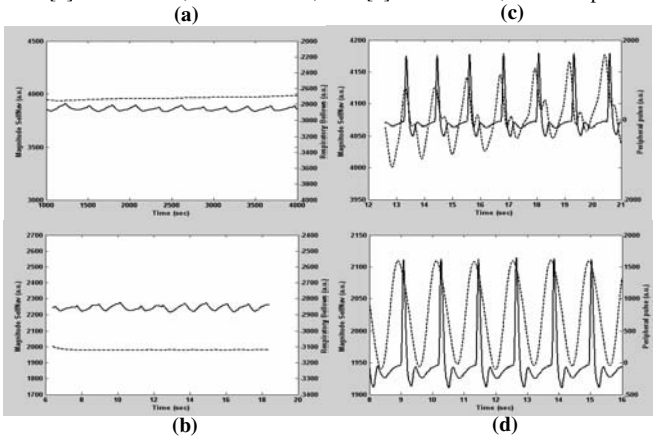

Figure 2: Breath held experiment. (a) Comparison of lowpass filtered SSFP self-navigated data and respiratory bellows. (b) Similar comparison with the gradient echo sequence. The small oscillations in the respiratory bellows signal are presumably due to the cardiac motion. (c) Comparison of bandpass filtered SSFP self-navigated data and the peripheral pulse. (d) Comparison for gradient echo sequence.