3D MRI with self-gated detection of physiological motion in the mouse

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Introduction

In order to capture physiological motion dynamics and eliminate motion-related artifacts, data acquired from peripheral devices such as ECG and respiratory billows have become an integral part of many MR imaging protocols. Alternative imaging methods for motion detection have been proposed that derive motion data directly from the MR signal. In "self-gated" methods[1], motion sensitive data is acquired without the addition of extra radiofrequency or gradient pulses, thus minimizing or eliminating any time cost. These sequences have the potential advantage of being directly sensitive to motions that affect MR image data and also eliminate the need for additional measurement hardware and software. Currently self-gated methods have been presented for two-dimensional imaging[1-3], where the center of k-space at each slice provides spatial sensitivity. However, there is a preference for three-dimensional image data in many applications, particularly for mouse MRI. Here, we demonstrate a self-gated imaging method compatible with most 3D, Cartesian acquisition sequences.

Methods

We modified a standard 3D Cartesian gradient echo sequence by displacing the two phase-encode gradient pulses on both axes. This permits acquisition of a consistent MR signal—independent of phase-encoding—during the ramp of the initial readout pulse. A pulse sequence diagram is provided in Figure 1. The data collected during this readout ramp were processed to generate physiological signals. Data points were selected based on their relative sensitivity to respiratory or cardiac motion and then processed to generate a gating signal. The amplitude of deviations were used for respiratory gating, while peaks in the cardiac signal were used to assign cardiac phases.

All MRI data were collected on a 7.0T magnet using a SMIS console and 250 mT/m gradients (200 us rise time). Images were acquired using a 25 mm inner diameter Litzcage volume coil (Doty Scientific, Inc., Columbia, SC). MR images were acquired with the following parameters: TE = 2 ms, matrix 200×128×128, FOV = 35×25×25 mm, flip angle 15°, and 32× over-sampling. In order to achieve sufficient temporal resolution within the duty cycle limits of the gradients, acquisitions were run in groups of 128 (with 10 ms spacing) followed by a delay of 920 ms (for a total TR = 2.2 s and 2.5 hr imaging time). Traditional physiological measurements were acquired by placing mice on a molded "sled" (Dazai Research Instruments, Toronto, Canada) equipped with a pneumatic pillow and ECG electrodes with data collection using a BIOPAC system (BIOPAC Systems, Inc., Goleta, CA).

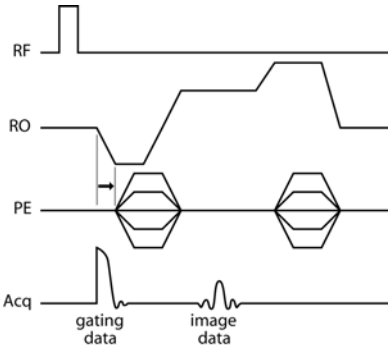

Figure 1: Modified 3D gradient-echo sequence. Hard, non-selective radiofrequency (RF) pulses are applied with phase modulation for RF spoiling. The two phase-encode (PE) gradients are shifted to allow acquisition of data during the readout (RO) ramp, which provides spatial encoding independent of phase-encode values. The ramp data is used for gating. Imaging data is collected in the standard fashion.

Results

Figure 2 provides a sample of the MR generated physiological data with comparison to traditional measures. Different time periods of the ramp showed more or less sensitivity to respiratory or cardiac motion. Data collected during the first ~30 us of the ramp were heavily modulated by respiratory events but were relatively insensitive to cardiac phase. On the other hand, both cardiac and respiratory motions were apparent from data collected between 50 and 70 us. Using the MR-generated physiological data, cardiac images were reconstructed. Axial slices from 3D volumes at systole and diastole are provided in Figure 3.

Discussion and Conclusions

We have demonstrated the feasibility of self-gated methods for 3D Cartesian MRI sequences. Additional spatial information provided by collecting signal during the initial readout ramp appears beneficial—at least in acquisition using volume coils—and can be achieved without time cost. In the future, a real time implementation that selects only the required phase encodes for reacquisition will greatly reduce the overall imaging time.

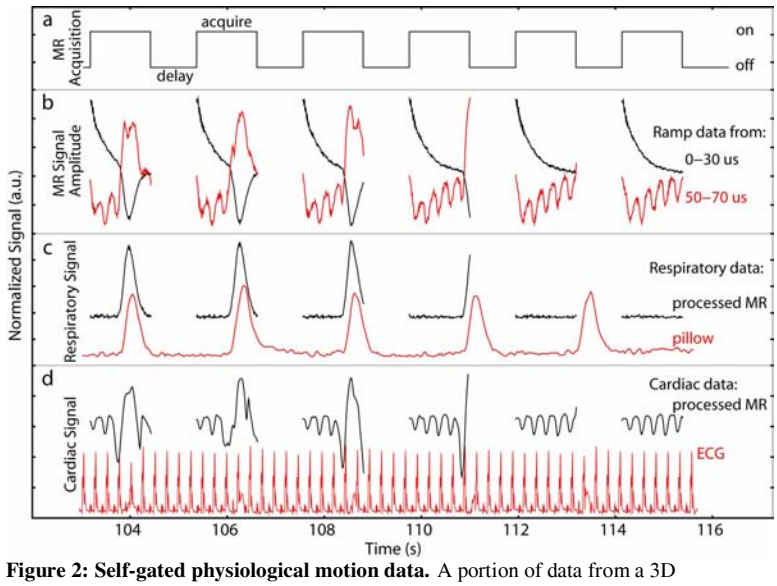

Figure 2: Self-gated physiological motion data. A portion of data from a 3D acquisition are plotted against time. In (a), the time periods of MR acquisitions and delays are shown. The corresponding amplitudes of the MR signal are shown (b) for the indicated times on the ramp, which was 200 us in total duration. Processing of the MR signal from these time points were used to produce respectively a respiratory (c) and cardiac (d) signal for gating. Data collected simultaneously from a pneumatic pillow (c) and ECG electrodes (d) are provided for comparison.

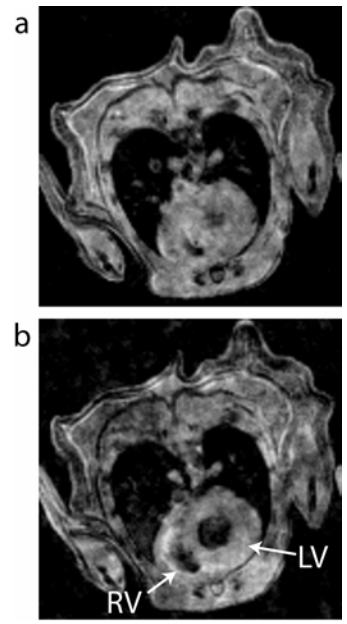

Figure 3: Thoracic mouse image. Slices from three-dimensional images of the mouse thorax, showing the heart in systole (a) and diastole (b). The right (RV) and left (LV) ventricle are labeled.

Acknowledgements

The authors gratefully acknowledge financial support from the New York State Department of Health, NYS Spinal Cord Injury Research Board, (SC1R04-9) and the National Institutes of Health (HL78665).

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