Retrospective Gating Strategies for Small Animal MR Imaging at 9.4 Tesla

S. D. Smith[1,2], S. Rashid[3], M. Wagshul[4], M. Yu[1], and H. Benveniste[1,5]

[1]Medical Department, Brookhaven National Laboratory, Upton, NY, United States, [2]SA Instruments, Inc, Stony Brook, NY, United States, [3]Biomedical Engineering, SUNY at Stony Brook, Stony Brook, NY, United States, [4]Radiology, SUNY at Stony Brook, Stony Brook, NY, United States, [5]Anesthesiology, SUNY at Stony Brook, Stony Brook, NY, United States

Introduction: The visualization of the functional characteristics of the Cardiovascular system in a living animal requires the development of techniques which are capable of obtaining high resolution images of moving tissue. In the special case of cyclical motion, such as that of a beating heart, imaging techniques that synchronize the operation of the MR Imaging apparatus to the basic cycle of motion can produce a series of "still" image frames for a succession of phase points in that cycle. Such images, while acquired over a period of many cycles can be viewed in a single "cine loop" to portray the motion of the "typical" cycle. The quality of the movies produced in this fashion is critically dependant on several different factors. These include the stability of al vital characteristics of the subject animal, the precision with which the phases of the cycle can be determined and the choice of MR pulse sequences parameters. Also, strategies to separate the effects of other unsynchronized cyclic motion, such as respiration, are essential. We have developed a technique for concurrent acquisition of ECG, Peripheral Pulse, Invasive Blood Pressure and Respiration synchronous to image data acquisition together with a method for retrospectively analyzing the wave forms such that a proper reordering of the MR dataset can be made prior to reconstruction. Such retrospective techniques offer several advantages when compared to "gated" imaging techniques for imaging the cardiac motion of mice and rats at 9.4 Tesla and compare results for several different strategies for determining the correct data ordering and for suppressing respiratory motion artifacts.

Apparatus: Imaging was performed using a 9.4 Tesla Bruker Biospec MRI system. Vital signs were measured with SA Instruments Small Animal monitoring system with the "Breakout Module" option. We used the breakout module to obtain analog outputs for up to four waveforms. This data was captured using a National Instrument DAQPad-6015 data acquisition device in combination with a National Instruments BNC 2090 adaptor. Timing pulses generated by the Bruker spectrometer at the time of each sequence repetition were also captured by the acquisition system. The digitized waveforms and timing markers were stored using MATLAB's Data Acquisition Toolbox. Post acquisition analysis of the wave forms allows determination of the cardiac phase corresponding to each timing marker, thus identifying the appropriate MR data strings for each phase in the cardiac cycle. The multiplicity of waveforms provides a redundancy of information that can be used to overcome timing assignment errors caused by interference or artifact in any individual waveform. It is also possible to ignore any data acquired during the time of respiratory motion.

Methods: Studies were acquired in both triggered and free running modes one right after the other for identical slice geometries, positions and sequence parameters. This allowed direct comparison of cine images obtained with a triggered acquisition to those created via retrospective reconstruction techniques from the free running acquisitions. A FLASH imaging sequence was used for these comparison with sequence parameters of TE= 2 ms and TR= 7.765 ms and a flip angle of 20 degrees. All images have slice thickness of 1 mm and in plane resolution of 0.1 mm per pixel in a 256x256 presentation format. Animals were anesthesized using an initial injection of Nembutol Sodium solution (50 mg/kg) and maintained using isoflurane in mixture with oxygen and air. Animal temperature was held steady at 37 degrees Centigrade using a warm air circulation system from SA Instruments. Careful control of animal body temperature is essential for maintaining a steady heart rate. Typical heart rates during these studies were 525 beats per minute for mice, allowing for as many as 12 image frames per heart cycle using the triggered technique. MR sequence parameters and geometries were identical for the two studies. The differing techniques were run consecutively on the same animal.

Results: Figure 1 shows the quality of the vital sign monitoring signals obtained during MR image acquisition. All triggered acquisition made use of ECG gate signal. The retrospective analysis of the data acquired in the free running acquisitions allowed for comparison of several different timing assignment techniques. Assignments based solely on time since last ECG R wave peak worked best providing images with the least motion type artifacts. Figure 2 compares a set of image frames acquired using triggered acquisition on a mouse to a set obtained from a retrospective reconstruction of data obtained with a free running acquisition as described above. The reconstruction used analysis of the captured ECG waveform for making timing assignments. The image set obtained from the retrospective analysis is of nearly identical quality to the one obtained from the triggered acquisition, but has the added benefit of providing two additional image frames thus demonstrating a more complete portrayal of the cardiac cycle.

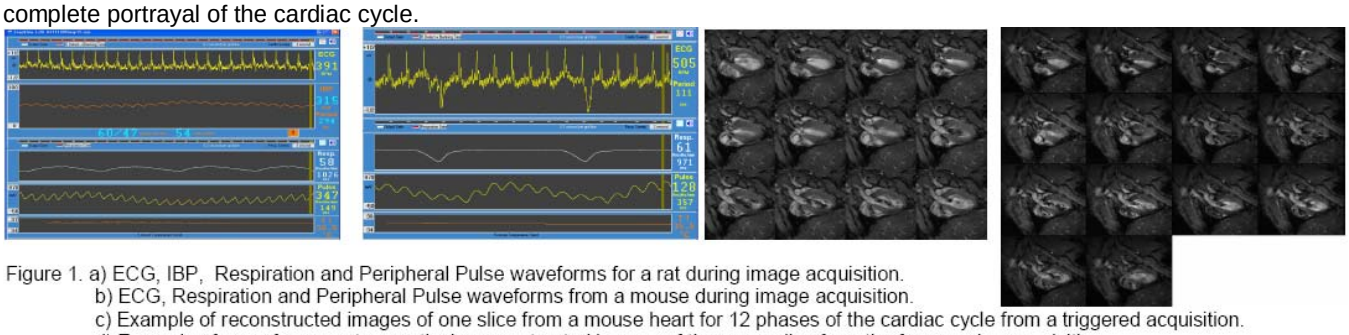

Figure 1. a) ECG, IBP, Respiration and Peripheral Pulse waveforms for a rat during image acquisition.
b) ECG, Respiration and Peripheral Pulse waveforms from a mouse during image acquisition.
c) Example of reconstructed images of one slice from a mouse heart for 12 phases of the cardiac cycle from a triggered acquisition.
d) Example of one of many retrospectively reconstructed images of the same slice from the free running acquisition.