Mechanical gating system for MR Cardiac Imaging

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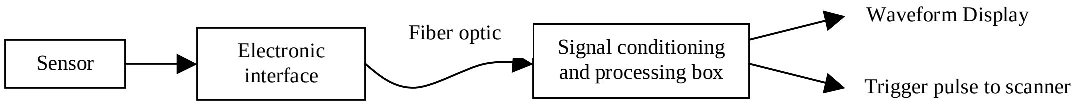
Introduction:

Reliable triggering of the cardiac signal is essential for cardiac gated MR imaging. The traditional method involves using the electrocardiogram (EKG) R-peak for triggering purposes (1). At field strengths 1.0T or higher, artifacts induced in the electrocardiogram due to the magneto-hydrodynamic effect, gradient and RF switching result in unreliable triggering and hence, poorly gated cardiac studies. In another method, the vectorcardiogram (VCG) is used and requires the EKG R-peak waveform acquired outside the scan room for reference purposes (2). We propose a novel method using a mechanical sensor for cardiac gating. The mechanical sensor is a highly motion sensitive device and is used to detect surface vibrations specific to the area of interest. In our study, we placed the mechanical sensor near the cardiac region to detect the motion of the heart. The detected motion information was then used for cardiac gating.

Method:

A mechanical sensor is placed on to the person's chest close to the heart and held in place with a strap. Details on the sensor technology can be found at http://www.nexense.com/technology.html. These sensors have been adapted for MR compatibility. The block diagram for the mechanical gating system is as shown in Figure 1. The sensor can operate in different modes including displacement and acceleration. Based on the mode of operation, blood pressure or valve motion of the heart can be detected in displacement and acceleration modes, respectively. For the purpose of this study, we chose to operate in the acceleration mode and the mechanical cardiac signal, mechano-cardiogram (MKG), detected is as shown in Figure 2 with reference to the EKG waveform. The detected MKG signal represents the true motion of the heart enabling accurate cardiac phase identification that isn't readily available from an EKG waveform as it represents the electrical impulses that initiate cardiac motion. The sensor is then connected via an electronic interface to a signal conditioning and processing box placed outside the scan room. A trigger point is detected for each cardiac cycle from the 1KHz sampled MKG signal at this stage. The onset of systole and diastole phases as indicated in Figure 2 are chosen as the trigger points in this study. The trigger pulse is then used for acquisition synchronization. The MKG waveform along with the trigger pulses is also available for display on a monitor from the signal conditioning and processing box. Although this method can be used at any field strength, the volunteer results demonstrated here were acquired on GE 1.5T LX EXCITE Echo Speed and Twin Speed systems.

Figure 1



Results:

In this investigational study, we have successfully scanned all six volunteers to date. By design, the mechanical sensor is immune to electromagnetic (EM) interference, including RF and gradient noise as well as other extraneous noise sources. The sensor also detected the motion of the heart consistently and reliably during normal breathing and suspended respiration. The cardiac gated images and MKG signals during a scan are shown in Figures 3 and 4. The FIESTA long axis (LAX) and short axis (SAX) cardiac images from a 23 yr old normal female volunteer on a Twin Speed system are shown in Figures 3b and 3c, respectively. The MKG signal during a breath hold, from the same volunteer, is shown in Figure 3a with the trigger point selected at onset of systole. The FIESTA SAX and LAX cardiac images from a 28 yr old normal male volunteer on an Excite Echo Speed system are shown in Figures 4b and 4c, respectively. The MKG signal during a breath hold is shown in Figure 4a with the triggers selected at the onset of diastole in this case.

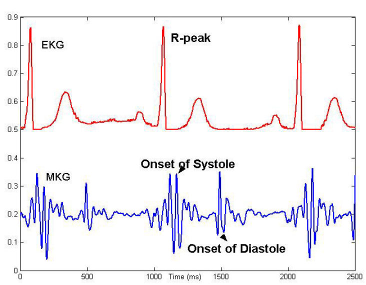


Figure 2. MKG waveform (acceleration mode) with systole and diastole along with the EKG waveform for reference

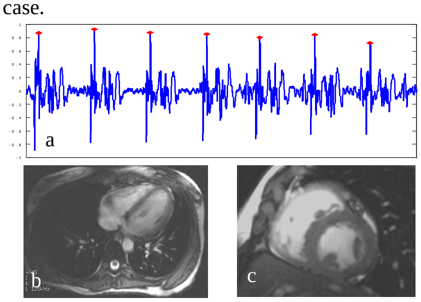


Figure 3. a) Mechanical cardiac signal (acceleration mode) from a 23 yr old normal female volunteer during a scan on 1.5T GE Twin Speed system. The red dots represent the systole triggers used for cardiac gating b) FIESTA LAX view c) FIESTA SAX view

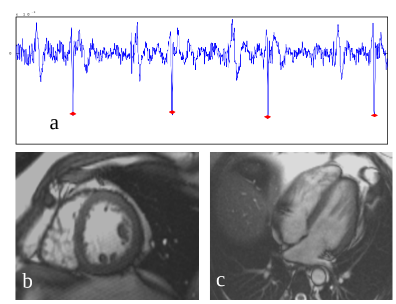


Figure 4. a) Mechanical cardiac signal (acceleration mode) from a 28 yr old normal male volunteer during a scan on 1.5T GE Excite Echo Speed system. The red dots represent the diastole triggers used for cardiac gating b) FIESTA SAX view c) FIESTA LAX view

Discussion/Conclusions:

The motion information derived from the mechanical sensor can be reliably used for cardiac gating as:

a) The detected MKG signal is not affected by the magneto-hydrodynamic effect from the static magnetic field or EM interference from the gradient field or RF switching.
b) Triggers at different phases of the cardiac cycle including ventricular relaxation and atrial relaxation phases among other phases can be used as trigger points for scan synchronization to help study cardiac anatomy and function.
c) The MKG from a single sensor can represent true motion of the heart and hence give accurate cardiac phase information, that isn't readily available from an electrocardiogram signal
d) The MKG represents the true mechanical activity during premature ventricular contractions (PVC) and atrial fibrillation among other abnormal rhythmic activity of the heart.

Hence, this method of cardiac imaging using a mechanical gating system can open up many more applications in the near future.

References:

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2. Novel real-time R-wave detection algorithm based on the vectorcardiogram for accurate gated magnetic resonance acquisitions, Fischer SE, Wickline SA, Lorenz CH, Magn Reson Med. 1999 Aug 42 (2):361-70