The Fiber Optic Stethoscope: An MR-Compatible Cardiac Monitoring and Gating System

Anja C.S. BRAU[1], Laurence W. HEDLUND[1], G. Allan JOHNSON[1]
[1]Duke University Medical Center, Center for In Vivo Microscopy, Box 3302, Durham, NC US;

Introduction

A fundamental problem associated with using the conventional ECG to monitor a patient´s cardiac activity during MR imaging is the corruption of the ECG signal due to adverse electromagnetic effects. The oscillating magnetic fields induce voltage artifacts in the ECG that do not reflect actual electrophysiologic events. This effect is particularly pronounced in MR microscopy of small animals, where strong, rapidly-switching magnetic field gradients are needed to obtain high spatial and temporal resolution, and the animal's ECG signal is just a few millivolts in amplitude. The spurious signals often resemble the QRS spike and can lead to erroneous cardiac gating. Furthermore, the artifacts often do not disappear until tens of milliseconds after the gradients turn off.

Several methods have been proposed to improve the quality of the ECG, and alternative measures of cardiac activity have been suggested [1-3]. However, none of these methods has been shown to provide reliable monitoring and gating ability in small rodents during cardiac MR microscopy. We present here a noninvasive, MR-compatible fiber optic "stethoscope" that detects mechanical cardiac activity rather than electrical activity, thus making it immune to electromagnetic interference. This photoplethysmograph system, based on optically detecting the compression of the esophagus in response to cardiac pulsation, provides a robust cardiac signal for monitoring and gating purposes during 2D and 3D *in vivo* MR microscopy of rats and mice.

Methods

A schematic of the fiber optic stethoscope setup is shown in Fig. 1.

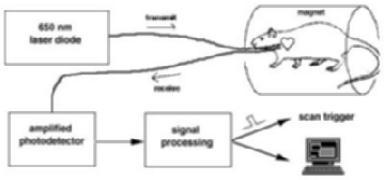

Figure 1. Schematic of fiber optic stethoscope setup.

Two 5-m step-index multimode optical fibers (Thorlabs, Newton, NJ) were used, one for transmission and one for detection of light. The last 10 cm of each fiber was stripped of buffer, and the bare fibers were bundled together for a total diameter of 250 microns. The fiber tips were cleaved at appropriate angles to maximize light detection. Light from a collimated 40 mW, 650 nm laser diode (Thorlabs), selected for its minimal tissue absorption, was focused into the transmit fiber using an optical lens. Twenty-eight rats (150-250 g) and one C57 mouse (40 g) were intubated and anesthetized with isoflurane delivered by a computer-controlled ventilator [4]. Pediatric electrodes were taped to the animal´s footpads to acquire a reference ECG signal. Average heart rates were 300 bpm for the rat and 400 bpm for the mouse. The bundled fiber optic probe was easily inserted down the animal´s esophagus to the mid-chest level with the aid of a tapered catheter oriented towards the heart.

As light from the transmit fiber impinged upon the esophageal wall, the amount of reflected and scattered light detected by the second fiber varied over the cardiac cycle as a result of systolic contraction. The optical signal was conveyed to an amplified photodetector (Thorlabs), and the electrical signal was passed to a signal processing box, which generated a 5 ms trigger pulse on the falling-edge of the detected signal for cardiac gating. The circuit also includes an adjustable lockout period to reject arrhythmias or other spurious pulses. The optical signals were displayed on a physiologic monitor along with ECG and airway pressure waveforms. All imaging was performed on a 2.0 T magnet (Oxford Instruments, Oxford, UK) with a 7-cm-diameter rf coil.

Results

Fig. 2 shows, from top to bottom, the waveforms for the detected optical signal, the corresponding gating pulses, the ECG and the airway pressure in a rat. The periodic variations in the detected optical signal arise from systolic compression of the esophagus. The variations are greatest during inspiration, when the lungs occupy the largest volume and further compress the esophagus. The cardiac gating pulses clearly match the frequency of the ECG, lining up perfectly with the QRS spike.

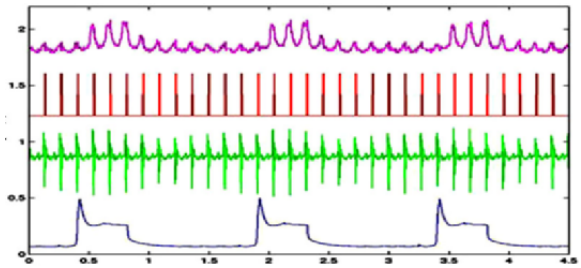

Figure 2. From top to bottom, the detected optical signal, corresponding gating pulses, ECG and ventilatory pressure. Signals are amplified and offset for better viewing.

Screen saves of the physiologic monitor taken during fiber optic-gated, CINE cardiac MR microscopy demonstrate the utility of the fiber optic stethoscope over the ECG. In Fig. 3(a), imaging gradients are off and the gating pulses are coincident with the QRS spike of the ECG. In Fig. 3(b), imaging gradients are turned on and the ECG is visibly corrupted by induced voltages, while the fiber optic system is unaffected and continues to provide a reliable cardiac signal.

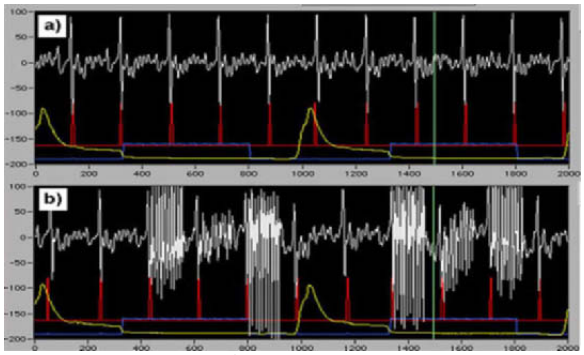

Figure 3. Screen saves of the physiologic monitor taken during MR microscopy of a rat. The ECG, gating pulses, airway pressure and exhalation window are visible. a) Imaging gradients off. b) Imaging gradients turned on.

Discussion

The fiber optic stethoscope overcomes the limitations of the ECG in an MR environment and is currently being used to support routine cardiac MR microscopy in rats and mice (see separate ISMRM abstract submission), effectively replacing the ECG. The influence of breathing on the detected signal suggests that ventilatory information can be extracted from this system as well.

The application of the fiber optic stethoscope is not limited to MR microscopy. It could also be extended to clinical FLASH imaging, in which rapidly-switching gradients interfere with ECG monitoring, or to X-ray CT imaging, during which cardiac monitoring is desired, but the placement of ECG electrodes may interfere with the image.

References

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