An optical fiber-based gating device for cardiac and abdominal MRI of small animals

A. Rengle[1], L. Baboi[1], H. Saint-Jalmes[2,3], R. Sablong[1], and O. Beuf[1]

[1]Creatis-LRMN, CNRS UMR 5220, Inserm U630, INSA-Lyon, Université Lyon 1, Villeurbanne, France, [2]PRISM Villejean, Faculté de Médecine, Université Rennes 1, Rennes, France, [3]Département d'imagerie, Centre Eugène Marquis, Rennes, France

Introduction

MRI on living organism involves the monitoring of both respiratory and heart motions in the thorax and abdominal region in order to synchronize acquisitions to reduce the motion artifacts. Today, the signal conventionally used to measure cardiac cycle is the electrocardiograph (ECG) signal. However, this electric signal is affected by radiofrequency (RF) fields used for MR imaging as well as by the magnetic field gradients applied for image encoding. Because of the weak amplitude of the ECG signal recorded on small animals, to obtain an uncorrupted ECG is challenging [1–5]. For respiratory motion, an air cushion associated to a pressure sensor is commonly used. However, due to its relatively large dimension, its use within narrow diameter coils or with dedicated phased array surface coils that are in close contact with animal skin is limited. By contrast, the light propagation inside the optical fibers is not influenced by any electromagnetic perturbations. The goal of this work was to build a simple optical-based gating device able to monitor the respiration and heart beats using optical fibers and to be used for small animal cardiac and abdominal MRI.

Material and Methods

A pair of optical fibers, one for light transmission and one for light detection, was used. Each 200 µm diameter fibers was optically insulated to decrease the ambient light noise. The tip of each fiber was stripped on a 2 cm length and then cleaved and polished to maximize light detection. The fiber's tips were bundled together with epoxy glue. Using a HFBR-1405 optical fiber transmitter (Agilent Technologies Inc., Santa Clara, CA, USA), a continuous 820 nm wavelength light was focused into the transmit fiber. The detected light was carried out of the magnetic field by the receive fiber to a HFBR-2405 optical fiber light-voltage amplified receiver. The output voltage, which is proportional to the received light, was passed through a custom-built signal-processing circuit for further amplification and filtering. The signal processing circuit consists in two active wide band pass filter and an amplifier with adjustable gain placed between these two filters. Each active wide band pass filter is composed of a 0.2 Hz active Sallen-Key high pass filter and a 30 Hz active Sallen-Key low pass filter. The amplifier with adjustable gain is an operational amplifier in inverting configuration with an adjustable gain in scale of 100/1,000/10,000. The processed output signal was interconnected with a commercial Trigger Unit HR V2.0 (Rapid Biomedical, Würzburg, Germany) for gating purpose. Ethical guidelines for experimental investigations with animals were followed, and the experimental protocol was approved by the Animal Ethics Committee of our institution. The fiber optical pair was fixed using soft medical adhesive tape on thorax skin and the animals were inserted inside the volume coil. The experiments were performed on a Bruker 4.7T Biospec system (Bruker, Ettlingen, Germany). A quadrature 32 mm inner diameter birdcage coil (Rapid Biomedical, Würzburg, Germany) was used. The efficiency of the optical device was assessed on heart mice and liver mice. Images synchronized with the optical device were then compared with images acquired with an air cushions sensor and without synchronization. For short axis heart imaging, a CINE FLASH and a Black Blood (BB) CINE FLASH were used with the following parameters: 30 x 30 mm^2 FOV, 256 x 192 matrix, 4 averages; TR/TE = 10/2.9 ms; 25° flip angle; 1 mm slice thickness and TI = 120 ms for BB only. With a heart rate of 350 bpm, a total of 12 frames per heart cycle were obtained with the FLASH and only 6 frames with the BB FLASH. For axial liver imaging, a fat suppressed (FS) multiple Spin-Echo (SE) was used with the following parameters: 30 x 30 mm^2 FOV; 0.7 mm slice thickness; TR = 6000 ms; TE = 20, 40 and 60 ms; 256x192 matrix, 24 slices.

Results

The optical-based signals were well correlated with both respiratory and heart motions (Fig. 1). The physiological signals were totally unaffected by the electromagnetic perturbations induced by RF pulses and gradients switching. Signal was independent of RF flip angle pulse and sequence used even with fast gradient switching sequences such as Echo Planar Imaging (EPI). Signal amplitude was large enough to perform a straightforward adjustment of the gating levels with good differentiation between cardiac and respiratory signal amplitudes. The adjustable amplifier gain offers compatibility with different experimental conditions such as the fiber tip location on the thorax and the animal size (mice or rats). Interfaced with the commercial trigger unit used, the gating levels, delays and acquisition windows were easily adjusted for respiratory gating only or for dual respiratory and cardiac gating (cardiac gating with blanking during inspiration), depending on application and sequence used. MR images of mice heart depict no visible motion artifacts (Fig. 2). No differences were seen compared to MR images acquired using a sensitive air cushion sensor. The mean Signal-to-Noise Ratio (SNR) measured in the myocardium wall with FLASH sequence was 51 ± 2 on image synchronized with optical fiber device and was 50 ± 2 on image performed using air cushion. By contrast, the mean SNR measured on images without synchronization was 21 ± 3. The MRI images acquired with a synchronized FS SE sequence performed on mice liver depict no motion artifacts, even close to the heart in the upper region of the liver.

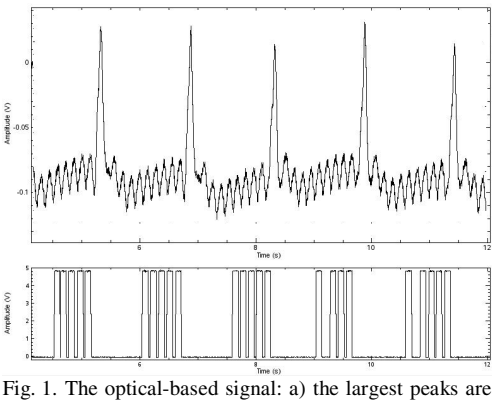
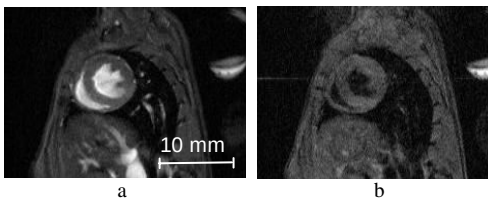


Fig. 1. The optical-based signal: a) the largest peaks are attributed to respiratory cycle and the small oscillations are attributed to heart motion; b) the output trigger signal from Trigger Unit.



a b

Fig. 2. MRI images acquired on a mouse heart using: a) a CINE FLASH sequence; b) a Black Blood CINE FLASH sequence.

Conclusions

Full fiber optics-based signal from heart and respiratory motion were recorded on small animals. Such signal was suitable for MRI acquisition triggering on thorax and abdomen. The adjustments of gating levels can be easily performed using a commercial trigger unit. The thin diameter of the optical fiber pair allows the installation within narrow volumes such as small birdcage coils or surface coils. The optical fiber-based device could be an attractive alternative compared to commercial triggering devices for small animal MRI using high field strength narrow bore systems.

References

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