ACT-MR: ACoustically Triggered Cardiovascular Magnetic Resonance Imaging

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Purpose

In current clinical MR practice, cardiac motion is dealt with using electrocardiographic (ECG) gating to synchronize data acquisition with the cardiac cycle. ECG, being an inherently electrical measurement, is corrupted by interferences with electromagnetic fields and by magneto-hydrodynamic effects, in particular at high magnetic field strengths (1). Consequently, artifacts in the ECG trace and T-wave elevation might be mis-interpreted as R waves resulting in erroneous triggering together with motion corrupted image quality. In addition, first- to third degree burns resulting from induction of high-voltages in ECG hardware have been reported (2, 3). For all of these reasons, a non-invasive, fully MR compatible cardiac monitoring and gating approach, which presents (i) no risk of high voltage induction and patient burns, (ii) immunity to electromagnetic interferences, (iii) suitability for all magnetic field strengthss, (iv) patient comfort and (v) ease of use is conceptually appealing for the pursuit of robust and safe clinical cardiovascular MR (CVMR). To meet all these challenges, the first aim of this study is to develop a cardiac monitoring and gating device that employs acoustic signals (acoustic cardiogram:ACG). Next, we examine and demonstrate the clinical efficacy and robustness of acoustic triggering in CVMR applications at 1.5 T and 3.0 T including prospective gating and retrospective triggering regimes.

Methods

An acoustic sensor and an acoustic wave guide were employed for signal acquisition and transmission to an electric unit (Fig. 1) while accomplishing galvanic decoupling. Signal conditioning and conversion were conducted outside of the scanner room using dedicated electronic circuits, with the ultimate goal of providing a robust waveform immune to interference from electromagnetic fields. The waveform was delivered to the internal physiological signal controller circuitry of a clinical scanner without modifying the scanner's hardware. Volunteer studies (n=10) were performed on 1.5 T MR and 3.0 T MR systems (Achieva, Philips, Best, The Netherlands) using a 5-element cardiac coil at 1.5 T and a 6-element cardiac coil at 3.0 T (both coils are products of Philips, Best, The Netherlands). For both clinical setups, the acoustic sensor was integrated into the coil, placed on top of the subject's shirt and positioned at the anterior left side of the torso (Fig 2) to obtain acoustic cardiograms. For comparison, ECG was recorded for all subjects. Note, that neither the ACG- nor the ECG-waveforms are patient emergency condition indicators. A retrospectively triggered 2D CINE SSFP technique (TE=1.6 ms, TR=3.1 ms, matrix=192x192, FOV=35 cm, 30 cardiac phases) was used to examine the applicability of acoustic gating for reliable tracking of myocardial contractions over entire R-R intervals. A black blood prepared gradient echo technique (TE=3.0 ms, TR=6.0 ms, matrix=256x256, FOV=35 cm, views per segment = 19) was employed to evaluate acoustic triggering in a prospective gating regime. For this purpose, the trigger delay was adjusted to restrict the data acquisition period to the mid-diastolic phase.

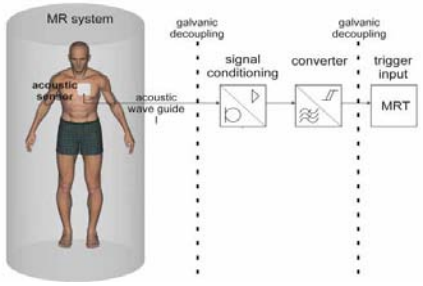

Fig.1: Basic principle of the acoustic MR stethoscope. Full galvanic decoupling between the patient and the signal conditioning/conversion electronic is accomplished.

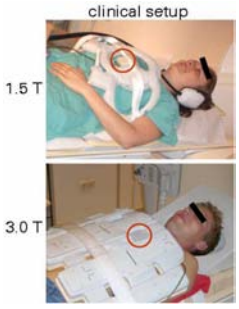

Fig.2 Clinical setup at **top)** 1.5 T and **bottom)** 3.0 T including the integration of the acoustic sensor into the cardiac coil arrays.

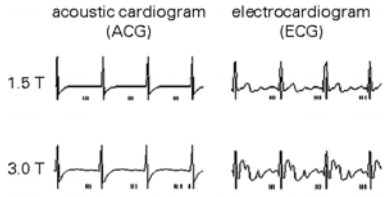

Fig. 3: Traces of the cardiac activity obtained from acoustic **(left)** and electrocardiographic **(right)** measurements at 1.5 T **(top)** and 3.0 T **(bottom)**. Note , the T-wave elevation in the electrocardiograms obtained at 3.0 T. Warning: Neither, the ECG- nor the acoustic waveforms are patient emergency condition indicators.

Results

The acoustic MR-stethoscope provided cardiograms at 1.5 T and 3.0 T free of interferences from electromagnetic fields or magneto-hydraulic effects and hence is suitable for synchronization (Fig 3). In comparison, ECG waveforms were susceptible to T-wave elevation which was pronounced at 3.0 T (Fig 3, bottom right). Full R-R interval coverage, acoustically triggered CINE imaging at 1.5 T and 3.0 T produced images free of motion artifacts (Fig. 4). Conversely, R-wave mis-registration occurred in ECG-triggered CINE 3.0 T due to T-wave elevation, which made high-field CINE imaging prone to motion artefacts (Fig. 4). RF-zipper-artifacts, often induced by the analog-digital converter of the fibre-optic ECG-device were not present when using the MR-stethoscope since it is galvanically decoupled from the scanner room. The merits of acoustic triggering were further explored in prospectively gated, blood suppressed anatomic imaging, which provided image quality competitive or even superior to that obtained from the ECG-gated approach as indicated by Fig. 5.

Conclusions

The proposed acoustic cardiac monitoring and gating approach was found to fully meet the demands of cardiac triggered MRI, including insensitivity to electromagnetic fields, trigger reliability - even at high magnetic field strengths - and MR compatibility which all have practical, patient comfort, economic and safety implications. The clinical efficacy of the acoustic gating approach has been shown for CVMR. Its superior robustness has been demonstrated by eliminating the frequently-encountered difficulty of mis-triggering due to ECG-waveform distortions. ACT-MR substantially reduces the complexity of patient preparation by obviating the need to set up ECG-electrodes and position ECG-leads, and hence ACT-MR serves to streamline clinical MR. In conclusion, we anticipate an extension of this work (i) to evolve towards cardiac triggered imaging at very high magnetic field strengths of B_0=7.0 T and beyond and (ii) to advance towards synchronization of MRI and MR spectroscopy acquisitions with other physiological motion, such as respiratory and speech organ motion.

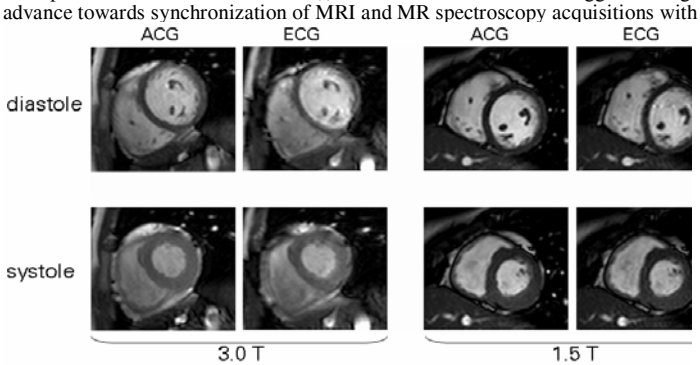

Fig. 4: Two chamber SAX obtained at diastole **(top)** and systole **(bottom)**. Images were derived from 2D CINE acquisitions at 1.5 T **(left)** and 3.0 T **(right)** using retrospective acoustic (ACG) and electrographic (ECG) cardiac triggering.

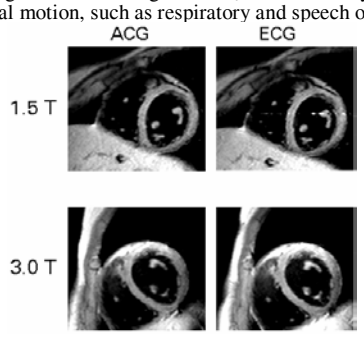

Fig. 5: Two chamber SAX obtained at diastole. Images were derived from blood suppressed 2D gradient-echo imaging at 1.5 T **(top)** and 3.0 T **(bottom)** using prospective acoustic **(left)** and electrographic **(right)** cardiac gating.

References: (1) Stuber M. et. al.,Magn. Reson. Med. 48:425 (2002), (2) Kugel H. et. al., Eur Radiology 13:690 (2003), (3) Shallock FG et. al., Radiology 232:635 (2004)