Cardiac Gating Free of Interference with Electro-Magnetic Fields at 1.5T, 3.0T and 7.0T

T. Frauenrath[1,2], S. Kozerke[3], P. Boesiger[3], and T. Niendorf[1]

[1]Division of Exp. MRI, Dep. of Radiology, RWTH Aachen University, Aachen, NRW, Germany, [2]Dept. of Phoniatrics, RWTH Aachen University, Aachen, Germany, [3]Institute for Biomedical Engineering, University and ETH Zurich, Switzerland

Introduction

In clinical MRI cardiac motion is commonly dealt with using ECG based synchronization. ECG recordings are prone to interference from electromagnetic fields and to magneto-hydrodynamic effects, in particular at (ultra)high magnetic field strengths [1]. For all these reasons, a non-invasive, cardiac monitoring and gating approach, which offers immunity to electro-magnetic field interferences is conceptually appealing. For this purpose a cardiac monitoring and gating device that employs acoustic signals was proposed [2]. The objective of the current study was to explore the suitability of acoustic cardiac gating (ACG) at (ultra)high magnetic fields strengths. The efficacy and robustness of acoustic triggering was examined at 1.5T, 3.0T and 7.0T for cardiac gated 3D phase contrast MRA (3D PC MRA) of the human brain.

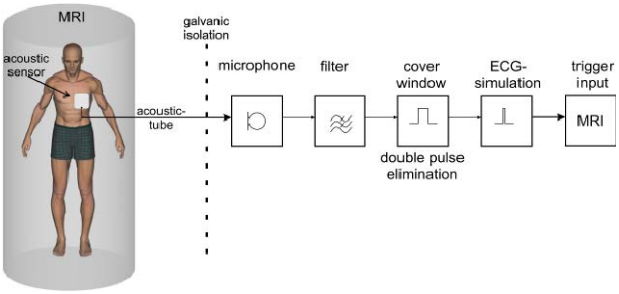

Fig.1: Basic principle of the acoustic cardiac gating (ACG). Full galvanic decoupling between the patient and the signal conditioning/conversion electronics is accomplished to achieve insensitivity to interference with electro-magnetic fields including ultra-high strength magnetic fields.

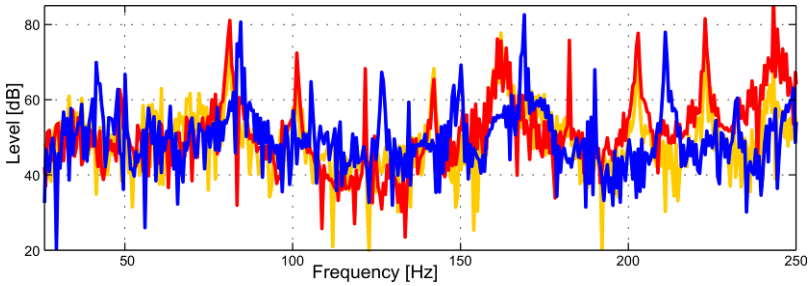

Fig.2: Acoustic noise spectrum obtained from the MRI examination room during 3D PC MRA imaging (TE=6.4ms, TR=12.0ms). Blue: 7.0T, Red: 3.0T and Orange: 1.5T. Comparable power intensities, at very high amplitudes are present at all measured field strength. Peaks related to TE and TR are present.

Materials and Methods

An acoustic sensor and a wave guide were employed for signal acquisition and transmission of the phonocardiogam. Signal processing was conducted using dedicated electronic circuits (Fig. 1). The resulting waveform was delivered to the internal physiological signal controller circuitry of a clinical scanner. Volunteer studies were performed on 1.5T, 3.0T and 7.0T whole-body MR systems (Achieva, Philips, Best, The Netherlands). 3D PC MRA (TE=6.4ms, TR=12.0ms, matrix=384x384, FOV=(240x168)mm^2, trigger delay=shortest) was performed to evaluate acoustic triggering in a prospective gating regime. For comparison the same imaging protocol was conducted using conventional ECG-triggering. The traces of the physiological waveforms were recorded for all ACG and ECG gated measurements. The ACG and ECG waveforms derived from 3D PC MRA at 1.5T, 3.0T and 7.0T where analyzed with a LabVIEW (National Instruments) program to assess trigger reliability and to detect false triggers and mis-synchronization.

Results

Recordings of acoustic heart tone inside the magnet bore are affected by noise due to gradient switching consisting of several very sharp harmonic components (see Fig. 2 for a frequency range of 0-250Hz). For this reason, filtering was applied to eliminate high-frequency noise by means of a 2nd order low-pass Bessel filter ACG provided cardiograms free of interference with electro magnetic fields or magneto-hydrodynamic effects at 1.5T, 3.0T and 7.0T (Fig. 3) and proved to be suitable for robust synchronization. For comparison, ECG waveforms showed T-wave elevation and other waveform distortions, which were pronounced at 3.0T and 7.0T as demonstrated in Fig. 3. At 7.0T, the physiological logging of acoustically triggered 3D PC MRA data revealed a mis-triggering rate of <1% at 7.0T. Consequently, acoustically triggered 3D PC MRA acquisitions resulted in MR angiography of superb quality free of motion artifacts even at (ultra)high magnetic field strengths, as shown in Fig. 4. Conversely, frequent R-wave misregistration occurred in ECG-triggered acquisitions at 3.0T and 7.0T potentially resulting in motion artifacts.

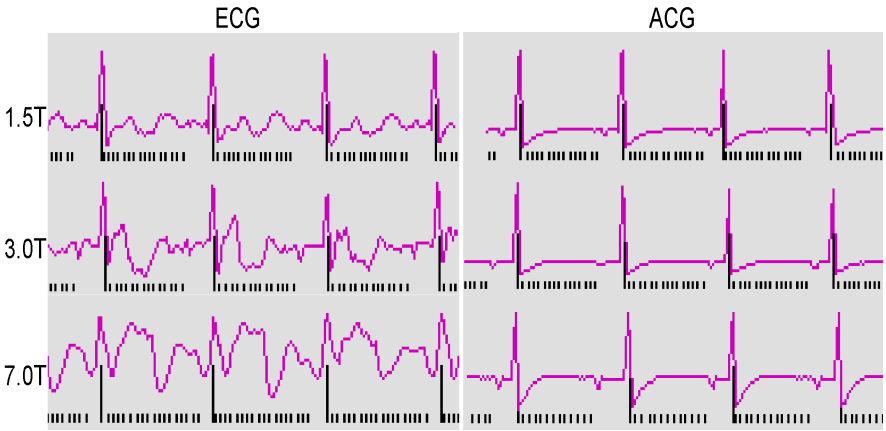

Fig.3: Traces of the cardiac activity obtained from electrocardiographic **(left)** and acoustic **(right)** measurements at different field strengths. Note the T-wave elevation in the electrocardiograms obtained at 3.0T and 7.0T.

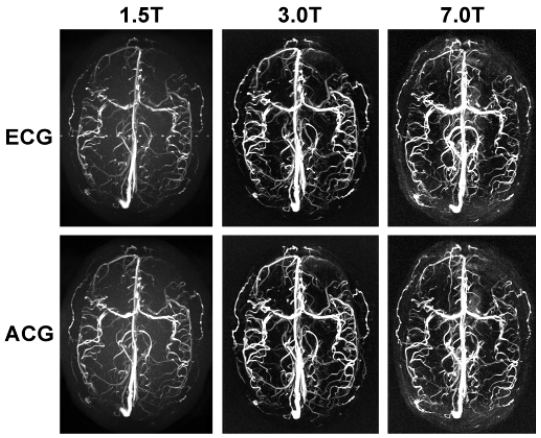

Fig.4: 3D PC MRA in healthy subjects at 1.5T **(left)**, 3T **(mid.)** and 7T **(right)** using ECG **(upper row)** and ACG triggering **(lower row)**.

Discussion and Conclusions

The proposed acoustic cardiac monitoring and gating approach was found to be independent of magnetic field strength, insensitive to interference with electromagnetic fields, which renders ACG to be suitable for cardiac gated (ultra)high-field imaging. The efficacy of the acoustic gating approach has been shown for 3D PC MRA at 1.5T, 3.0T and 7.0T. It should be noted that ACG's insensitivity to electromagnetic interference caused by gradient switching offers a means to accommodate cardiac gated peripheral (vascular) imaging which has been elusive hitherto due to fairly severe distortions in the ECG signal caused by off-center positioning of the heart. In summary, we anticipate an extension of the proposed acoustic gating approach to synchronization of MRI and MR spectroscopic acquisitions with other structure or motion borne sounds including ultra-high-field imaging in the presence of brain pulsation; tissue elasticity related sound response functions; voice production and speech imaging.

References: [1] Stuber M. et. al.; Magn. Reson. Med. 48:425 (2002) [2] Niendorf T. et. Al; 15th Annual Meeting of the ISMRM, Berlin, Germany 765 (2007)