Influence of Strong Static Magnetic Fields on Myocardial Mechanics: Evaluation Applying Ultra-Wideband Radar

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Introduction and Motivation

ECG is excessively used for triggering MR data acquisition to image the heart in a certain stage of contraction or to prevent reduction of image quality by motion artifacts generated by the strong non-linear motion of the heart muscle. It is well established that the ECG is corrupted by the magneto-hydrodynamic effect (MHD). Hence, there is increasing difficulty to use the ECG for MR-triggering especially at B_0-fields beyond 1.5 T [1]. If the conducting particles of the blood are redirected by the magnetic field, it is only consequent to ask whether the electrical excitation spread over the myocardial muscle, which is based on ionic transportation, is redirected, too. Such an redirection should be visible in the ECG and in an deviant myocardial contraction which is directly dependent on the spatio-temporal devolution of the excitation spread. Unfortunately, investigating this effect using the ECG itself is not possible since it is dominated by the MHD effect. Thus, we propose a novel method, based on an ultra-wideband radar technique (UWB radar) to monitor the global myocardial dynamics inside an MR scanner. Electromagnetic waves can propagate through the body and are reflected at interfaces between materials with different dielectric properties. This feature of UWB-Radar (1-10GHz, P_{rms}~4mW) has proved its ability to monitor non-invasively the motion of organs within the human body [2] as well as obtaining images of internal structures .

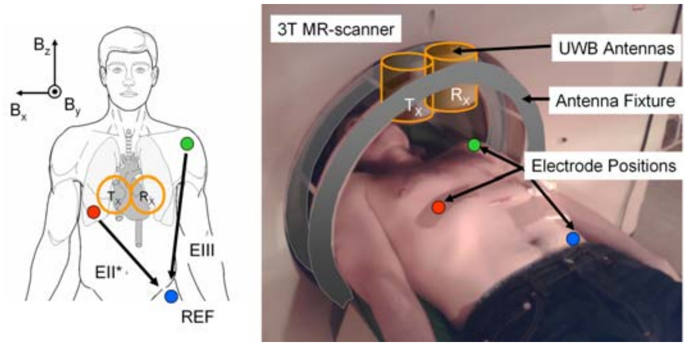

Fig. 1: *Left:* positioning of ECG electrodes and UWB antennas. *Right:* set-up of the combined ECG/UWB measurement at the 1-T position just outside the bore of the 3-T scanner (Bruker MEDSPEC 30/100).

Materials and Methods

We have already demonstrated the feasibility of a combined MR/UWB radar method [3]. Based on this experience we simultaneously acquired ECG and UWB radar data a) at $B_0 \approx 0$ (earth's magnetic field), b) at $B_0 = 1$ T at the edge of the bore of a 3-T MR scanner, and c) at $B_0 = 3$ T in the iso-centre of the scanner (s. Fig. 1). A volunteer was positioned in supine position and was asked to hold his breath to exclude breathing artifacts. The MR-compatible, tapered slot UWB-antennas (Tx/Rx) were positioned about 150 mm above the sternum in an appropriate plane through the heart (height of the 8th segment of the thoracic spine, Th8). The position of ECG electrodes and the position of the UWB antennas were not changed between the three different measurements. The resulting reflected UWB signal is a superposition of multiple reflections. In the simple case of well separated tissue interfaces, cross-correlation data $\mathbf{R}_{xy}(\tau)$ from the transmitted and received signals provide information of the propagation time τ necessary for the electromagnetic pulse to reach each interface. In our case $\mathbf{R}_{xy}(\tau)$ is provided by the UWB controller. We utilized an M-sequence UWB radar system [4] (up to 5 GHz) transmitting a periodic pseudorandom waveform (maximum length binary sequence, MLBS). Interfaces with high dielectric contrast, e.g. fat/muscle, as they occur at the body surface and the surface of the heart, dominate $\mathbf{R}_{xy}(\tau)$. Since we are interested in the movements of selected interfaces we observe the variation of $\mathbf{R}_{xy}(\tau)$ over time for each τ by a covariance analysis (s. Ref. [2], [5]).

Results

In Fig. 2 the median of n = 30 ECGs, the corresponding reconstructed UWB signals representing the global cardiac dynamics and the mean sinusoidal fit of the UWB data are depicted for $B_0 = 0$T, 1T, and 3T, respectively. To investigate, whether there is a significant change in the global myocardial mechanics between zero field and 1T or 3T we applied Student's *t*-test [$t(0.95,29)$, paired, two-sided] on the UWB data for each time step in the standardized ECG epoch $t=[0,\ldots,1.1\text{s}]$. We found no statistical significant change between all three UWB measurements. Additionally, the phase of the sinusoidal fit was compared applying a *t*-test [$t(0.95,29)$] to check for significant excitation delays. Again, there was no significant change in phase with increasing field. We find *p*-values well above the significance level (see Fig. 2, right panel), represented by $\alpha=1-\text{erf}(n/\sqrt{2})=5\%$ ($p(0T/1T)\approx0.29$, $p(0T/3T)\approx0.66$, $p(1T/3T)\approx0.62$). Thus, we cannot reject the null hypothesis, which states there is no significant change between measurements.

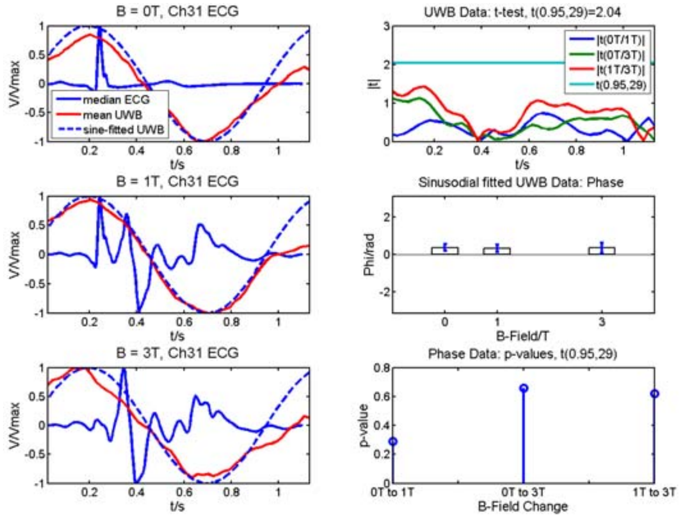

Fig. 2: *Left:* comparison of the median of 30 ECGs (EII*), the corresponding reconstructed mean UWB signals and the mean of the sinusoidal fitted UWB data for $B_0 = 0$T, 1T and 3T. *Upper right:* result of the *t*-test for each time step in $t = [0,\ldots,1.1\text{s}]$. *Middle and lower right*: comparison of phase of the fit and p-values of the *t*-test on the phase.

Acknowledgements

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