Spatially resolved observation of cardiovascular magneto-dynamics with NMR field probes

Simon Gross[1], Benjamin Emmanuel Dietrich[1], Christoph Barmet[1,2], and Klaas Paul Prüssmann[1]
[1]*Institute for Biomedical Engineering, University and ETH Zurich, Zurich, Switzerland,* [2]*Skope Magnetic Resonance Technologies, Zurich, Switzerland*

Introduction: It has been shown that NMR field probes [1,2] can be used for the observation of cardiovascular dynamics in a strong magnetic background field [3]. These field fluctuations are produced most notably by changes in the local susceptibility distribution due the displacement of blood and different tissues during the heartbeat, thus reflecting the mechanical activity of the heart. On this basis, it is hypothesized that the underlying spatio-temporal field patterns may contain useful information relating to cardiovascular physiology. However, so far their measurement has been limited to single positions using a single NMR probe at a temporal resolution of 10 ms. The goal of the present work was to extend these studies by adding detailed spatial resolution and enhancing the temporal resolution. Aided by concurrent ECG recordings, the resulting spatio-temporal field maps are explored with a view to potential physiological correlates.

Setup and Method: 15 NMR field probes ($GdCl_3$-doped H_2O, T_1=T_2=1.5 ms, Ø 2.2 mm, [4]) were mounted on two rows (7+8) spaced by 29 mm, where one row was offset by 15 mm. The two rows were mounted on a displaceable lever at a distance of 25 mm (cf. Fig. 1). Using this geometry the probes formed an equilateral triangular grid. They were connected to a dedicated home-built MR spectrometer made from packaged ADC and FPGA components (National Instruments Corp., Austin, TX, USA) [4]. Field measurements were performed by recording FIDs following a 90° pulse. The phase courses thereof were unwrapped and fitted with a linear model, yielding one field value per FID. The repetition time was set to 5 ms. With this method, a field measurement precision of below 1 nT was reached. All the experiments were performed in a 7 T Achieva human MR scanner (Philips Healthcare, Cleveland, USA). The integrated ECG of the scanner was used to record an ECG simultaneously with the field measurements.

Figure 1

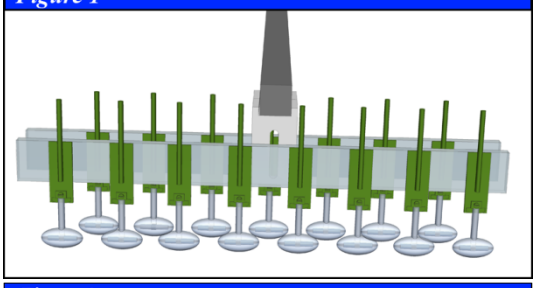
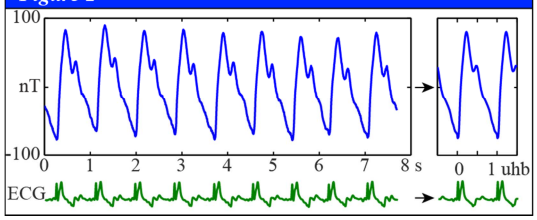


Figure 2

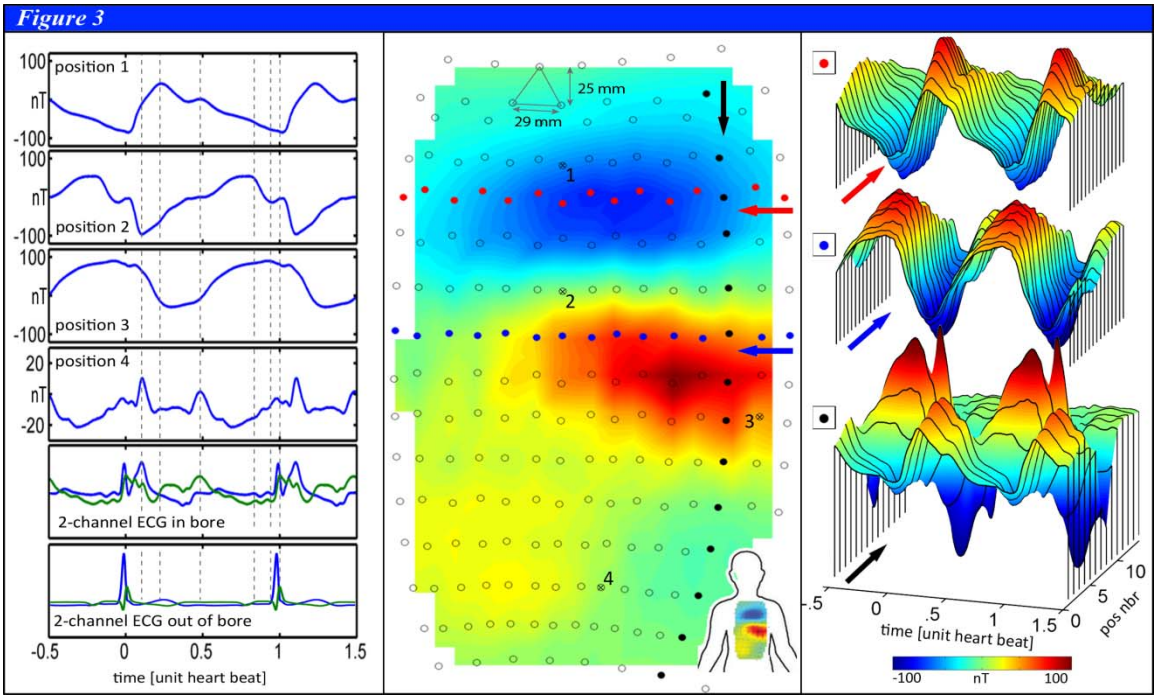


Experiment and Analysis: The field probe array was placed above a healthy volunteer's chest at a distance of approximately 1 cm. Starting just underneath the chin, the array was successively displaced in steps of 25 mm towards the feet. The field fluctuations were measured during an 8-seconds breathhold at each of 14 steps (210 probe positions in total). An example of one such field measurement as well as the corresponding ECG is given in Fig. 2. Note that the ECG suffers from severe magnetohydrodynamic (MHD) artifacts. In order to compare the field curves acquired in different array positions, the signals were aligned with the ECG signal and, using the R-wave (in the ECG) as a reference point, cut into parts corresponding to full cardiac cycles. Since the pulse rate varies slightly, the individual chunks were stretched to a unit time scale (unit heart beat, uhb) and then averaged. The average curve for the given data are shown in Fig. 2 on the right. The variance over different cardiac cycles was very small, reflecting the highly reproducible nature of the acquired signals.

Results and Discussion: Fig. 3 shows different representations of the averaged data set. The left column shows the field-time evolution at four different positions (as indicated in the central plot), together with an averaged ECG acquired inside the scanner bore and a reference ECG taken outside the magnetic field. Several characteristic time points are marked in order to study their spatial context. The central column shows the interpolated field intensity map at time t = 0 (R-wave) for all 210 probe positions. The area measures 20x35 cm and covers the chest as indicated at the bottom. The circular markers indicate the individual probe positions as measured by using static gradients [5]. The distortions of the probe positions are due to static magnetic field inhomogeneities of the background field. In the right column, the spatio-temporal variability of selected lines in the field intensity map is shown. The exact interpretation of the acquired data is unclear. Nevertheless, a few characteristics are remarkable: i) the field variation at position 3 strongly resembles the dynamics of the ventricular volume. This speculation is reinforced by the matching probe position and the correct timing within the cardiac cycle. ii) the double-peak pattern observed at position 1 and at some positions on the red line might originate in valve closing events. Here as well, position and timing fit. iii) The sharp peaks in the readout at position 4 occur simultaneously with the MHD artifacts in the ECG signals and might thus have a common source.

Conclusion: Cardiovascular magneto-dynamics were observed with enhanced temporal resolution (200 Hz) and with multiple NMR field probes simultaneously. The possibility to acquire an ECG simultaneously with the magnetic field measurement and the protocol to synchronize the field time evolutions of different subsequent experiment now allows comparing and correlating this novel method with other, well established cardio-vascular diagnostic techniques (blood pressure, flow, ventricular volume measurements, etc.) that are not MR-compatible. Also the temporal synchronization with conventional cardiac MR imaging is now straightforward and will help to identify the underlying physiological processes.

Figure 3



References: **[1]** R.V. Pound, W.D. Knight, Rev. Sci. Inst. 21:219 (1950). **[2]** De Zanche et al., MRM 60:176 (2008). **[3]** Prüssmann et al., Proc ISMRM 19 (2011). **[4]** Dietrich et al., Proc. ISMRM 19 (2011). **[5]** Barmet et al., MRM 62:269 (2009).