Observation of cardiovascular dynamics by field recording with an NMR probe

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Introduction:

NMR-based magnetic field probes have recently been used for monitoring fields and potential field perturbations generated by components of MR systems, including main magnets, gradients, and shim coils. At the temporal resolutions required for this purpose, current probes offer field resolution in the order of microteslas [1]. According to Ref. [1], the field resolution of such probes scales strongly with the temporal resolution of the measurement. Therefore, at lower bandwidth yet significantly higher field resolution can be achieved.

At such level of sensitivity, NMR probes should enable observations also of fields and field fluctuations that originate from magnetized tissue. Containing diamagnetic materials with volume susceptibilities up to about χ = -9 ppm [2], the magnetized body and its parts cause field changes up to the order of χB_0. At the body's surface and in the surrounding volume these effects typically drop to a small fraction of this value. However, field fluctuations on the order of several Hz due, e.g., to breathing are frequently observed at 3T and correspondingly stronger effects occur at 7T and beyond.

Due to such susceptibility effects, heart motion and pulsatile blood flow equally cause magnetic field perturbations outside the chest, which indirectly reflect cardiac function and would hence be interesting to observe. The aim of the present work was to explore this possibility using NMR probes designed to yield high sensitivity for fields fluctuating at up to 100 Hz.

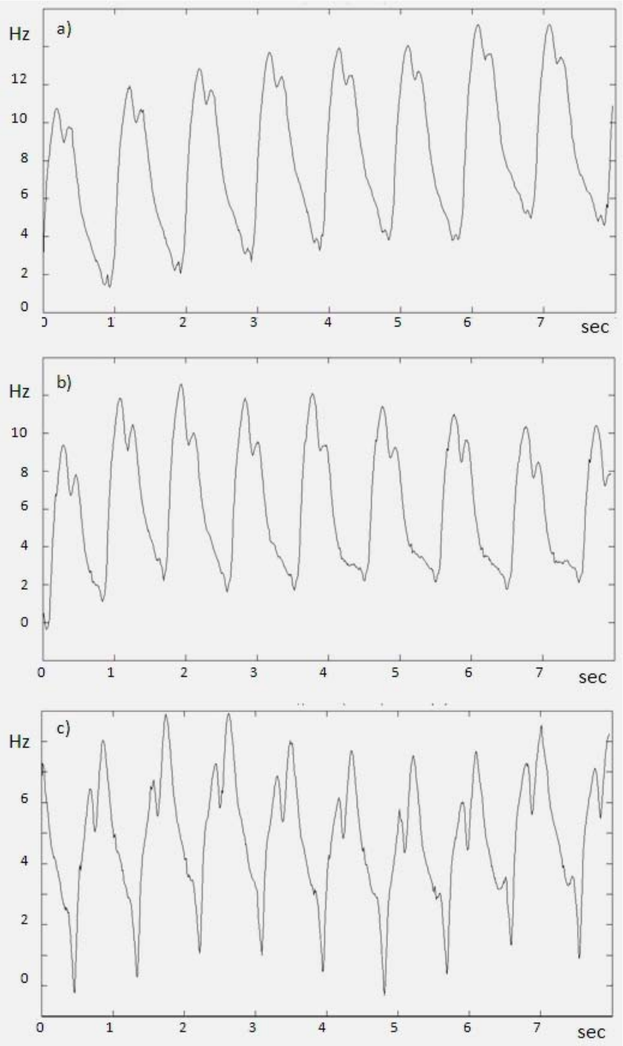

Fig. 1 Magnetic field time courses at three positions on the chest along the sternum, measured with an NMR field probe.

Methods:

Targeting a temporal resolution of 10 ms, an NMR probe was built from a 2.2 mm borosilicate capillary filled with water and doped with $GdCl_3$ such as to obtain fast transverse relaxation with T_2 = 3 ms. For RF transmission and reception, the capillary was placed in a tightly wound solenoid coil made from PTFE-coated silver wire. The coil was tuned to 297.8 MHz, matched, and connected to custom-built transmit/receive circuitry including pre-amplification. Via coaxial cable, the pre-amplified signal was fed into a laboratory spectrometer (National Instruments) for demodulation and recording at a bandwidth of 1 MHz. The spectrometer was configured for continuous signal reception. The probe was excited via a custom-built transmit chain, consisting of a pulse generator, a modulation stage and a power amplifier.

For field measurements, the probe was excited every 10 ms with 90° block pulses of 10 us each and its signal was received continuously, resulting in interruptions only by the excitation pulses and a few additional us of T/R switching and filter delay. The signal time course was then segmented into individual FIDs of just under 10 ms duration. The phase time courses of the FIDs were calculated, unwrapped, and subject to linear regression to give one frequency measurement per 10 ms interval.

Measurements were performed on a healthy volunteer in the bore of a Philips 7T Achieva whole-body MR system (Philips Healthcare, Cleveland, USA). The field probe was placed on the volunteer's chest, starting from the center of the sternum and gradually shifting it towards the head in steps of 2 cm. At each position, a field measurement was performed during a breathhold of 8 seconds.

Results and Discussion:

Figure 1 shows resulting time courses of frequency variation for the first three probe positions. They reveal substantial, highly periodic field variations at the cardiac frequency, which are attributed to motion of the heart and blood flow in the heart and the neighboring vasculature. As should be expected, the shape of these curves depends on the position of observation, indicating that the field fluctuations vary significantly across space and thus contain information about the position and geometry of the underlying anatomy. The exact interpretation of these curves is intriguing and remains to be pursued. The most immediate question is arguably which type of motion causes the two distinct field peaks that are observed in each cycle at all three positions. They may reflect myocardial motion but may also be due to particular phases of blood flow in the heart and/or ascending aorta. Further studies will need to establish which aspects of cardiovascular dynamics are actually observed and how much more evidence can be gained by increasing the temporal and spatial resolution of the measurement. Increasing the latter is expected to be fairly straightforward by using an array of field probes. Increasing the temporal resolution will, among others, clarify the effective bandwidth of the field dynamics. The sharp negative peaks in Fig. 1 c) consist of single field samples, indicating that the underlying fluctuations last for less than 10 ms, thus suggesting a bandwidth of more than 100 Hz. If this observation can be confirmed and perhaps even higher-bandwidth dynamics can be observed, NMR-probe measurements may offer an alternative to EKG recording in the magnet.

References: [1] De Zanche et al. MRM 60:176–186 (2008), [2] Schenck, Med. Phys. 23(6):815-850 (1996)