An experimental setup to simulate the magnetohydrodynamic (MHD)-effect with respect to intra cardiac ECG signals

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Target audience: Researchers who are interested in magnetohydrodynamics, electro-physiologic (EP) examinations and interventional MR Imaging.

Purpose: Electro-physiologic (EP) examinations represent an important tool for diagnosis and therapy in patients with electro-physiologic heart diseases. Multiple X-ray fluoroscopic images are used to guide the catheters to the locations of interest within the heart resulting in high radiation exposures for the patient as well as for the investigator. Therefore, it is of great interest to control the catheter guidance with different imaging modalities such as MRI.

However, in cardiac MRI, the surface electrocardiogram (ECG) signal used for cardiac gating is affected by the magnetohydrodynamic (MHD) effect [1-3]. If an electrical conductive fluid such as blood is flowing perpendicular to an external magnetic field B_0, the electrically charged particles are deflected by the Lorentz force F_L. This charge separation leads to a potential across the great vessels yielding altered surface ECG signals. Mainly the S-T segment and T wave of the ECG are affected due to the rapid systolic flow in the aortic arch causing a significant MHD potential (U_{MHD}). However, only limited knowledge is available regarding the impact of the MHD effect on intra-cardiac signals as needed for EP exams. Recently, an animal experiment was presented where altered EP signals in a magnetic field were measured in-vivo [4]. The aim in this work was to establish an experimental setup to simulate the MHD effect in a model system using common EP-measurement equipment with respect to a characterization of the pure MHD signal.

Methods: Measurements were performed on a 1.5 T system (Symphony, Siemens, Germany). To simulate the pulsatile flow of the beating heart, an MR-compatible Ventricular Assist Device (VAD) (MEDOS, Stolberg, Germany) was used. A u-shaped tube was connected to the VAD representing a closed circulation system filled with a distilled water-sodium chloride mixture (electrical conductivity at 21°C: 4.70+/-0.16 mS/cm) for simulating the electric conductivity of blood.

The EP-setup consists of a ten channel clinical EP-catheter connected to an EP-Tracer (CardioTek B.V., Maastricht-Airport) and a laptop for data registration (Fig. 1). Catheter signals were acquired with the lowest cut off frequency (0.05 Hz) of the high-pass hardware filters of the EP-Tracer. The phantom was designed with a diameter of 2.0+/-0.1 cm equivalent to the aortic arch. A catheter was placed into a slit of the phantom's wall to avoid motion of the electrodes (see Fig. 2a). More than half of the phantom's circumference is covered by electrodes. The potential between two electrodes 1/10 (channel1), 2/9 (channel2), 3/8 (channel3), 4/7 (channel4), 5/6 (channel5) was recorded (bipolar measurement). As shown in the upper schematics of Fig. 2a, the distance d between two electrodes increases from channel1 to channel2 and decreases for the other channels.

Additionally, 2D MR-flow measurements perpendicular to the flow at the catheter's position were performed with a through-plane velocity encoding of 60 cm/s, a spatial resolution of 0.9 x 0.9 x 8.0 mm, a temporal resolution of 64 ms and 10 averages to increase the SNR. Flow on and flow off measurements were subtracted to correct for Maxwell terms and Eddy currents. The non-MR compatible catheter was replaced by a rubber piece to avoid image artifacts and possible heating of the catheter. The through-plane velocities v_z averaged over the segmented tube were calculated for all time frames using Matlab (The Mathworks, USA).

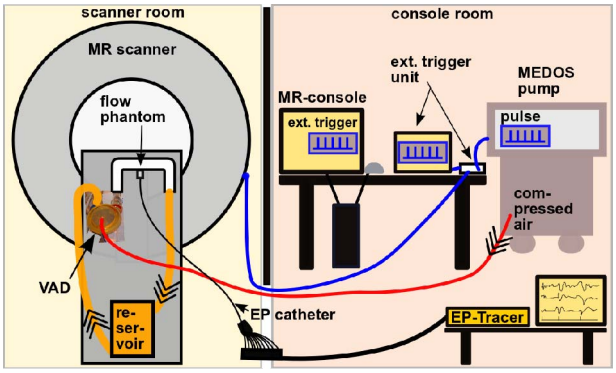

Fig.1: Measurement setup. (Blue cables: Connection to allow triggering for MR measurements)

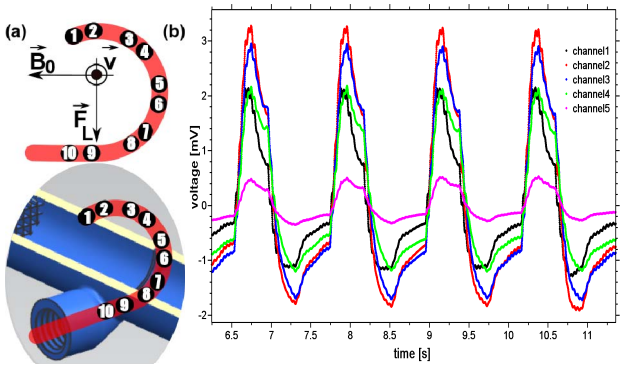

Fig.2: (a) Positioning of the catheter in the phantom and its orientation in the magnetic field B_0. The flow and the Lorentz force F_L are depicted. (b) Bipolar measurement of the MHD potential U_{MHD} versus time using different electrode distances.

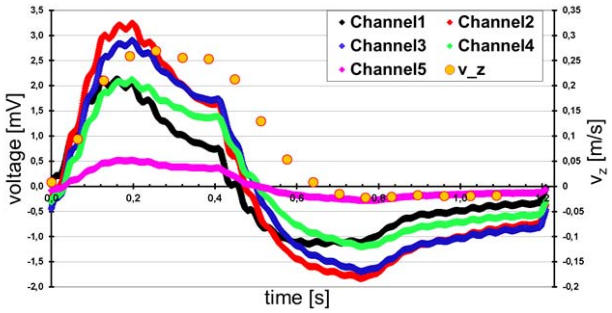

Fig.3: Comparision of v_z (yellow dots) measured by MR and the U_{MHD} occurring during one cardiac cycle (data taken from 2b).

Results: Representative curves of the MHD-effect during pulsatile flow (50 beats/min) are shown in Fig. 2b. A decrease of the potential with a decrease in d is observed. However, the signal of channel1 is clearly lower than expected due to shielding of the electrode 10 by the catheter inlet due to a construction issue. The data of v_z ($v_z \perp B_0$) measured by MR and the induced voltage are strongly correlated in early systole and mid/late diastole (Fig. 3). The rapid decrease of the potential starting at approximately 0.2 s (late systole) is caused by high-pass hardware filters of the EP-Tracer. With the MR table outside the scanner and the catheter at a position with a remaining B_0 field of approximately 110 mT, the total amplitude of the measured MHD potential depicts up to 11% of the one measured at the isocenter (not shown).

Discussion: A flow circuit for measuring the MHD-potential by using a common EP-setup was successfully established. The analyses of the MHD effect occurring in EP examinations carried out in a MR environment is of importance in order to establish tool boxes to remove MHD related effects from intra-cardiac ECG signals. This represents an essential step when aiming for EP examinations in a MR environment while providing diagnostic valuable data.

The material of the flow phantom is non-conductive; however, studies revealed that vessel wall's conductivity may be neglected [5]. As predicted by theory, the measured potential increased with increasing d, B_0 as well as v_z. The data of Channel 5 was acquired using a typical distance of neighboring electrodes as applied in clinical bipolar EP-measurements. The U_{MHD} was of the same order of magnitude as the action potential of the myocardium and cannot be neglected in EP-measurements. Further investigations must be carried out systematically analyzing the impact of different EP-Tracer settings (such as hardware filters) as used in EP examinations on the MHD signal. Moreover, measurements will be performed using an aorta shaped phantom to investigate the induced potential next to the VAD. In addition, for simulating the viscosity and the density of blood glycerol will be added to the water-sodium chloride mixture.

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References: [1] Tenforde *et al.* Bioelectromagnetics 1983 4:1-9. [2] Tenforde Biophysics&Molecular Biology 2005; 151:521-523. [3] Gupta *et al.* IEEE 2008;55(7):1890-96. [4] Tse *et al.* ISMRM2012 talk#206 [5] Abi Abdallah *et al.* ESB Congress2008 talk#266