Experimental Study of the Magnetohydrodynamic (MHD) Effect with Respect to Intracardiac ECG Signals

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1 OBJECTIVES

To assess the status of the cardiac electrical system for diagnosis and therapy, electro-physiologic (EP) studies are an important tool for diagnosis and therapy in patients with electrophysiological disorders (Josephson, 2008); (Schneider, 2005). Electrode catheters are inserted into the heart and guided to the location of interest using X-ray fluoroscopic images. Hence, the patient and the investigator are exposed to X-rays and might accumulate a high radiation dose. Therefore, it is of great interest to use different imaging modalities such as Magnetic Resonance Imaging (MRI) for catheter guidance. However, the surface electrocardiogram (ECG) signal is strongly affected by the magnetohydrodynamic (MHD) effect (Tenforde et al., 1983), (Tenforde, 2005); (Gupta et al., 2008). Charged particles of an electrical conductive fluid such as blood with a velocity component v_z perpendicular to the external magnetic field B_0 are deflected by the Lorentz force $\boldsymbol{F}_L$. This charge separation gives rise to a potential across the great vessels. At the level of intracardiac catheter use, the potential can be defined as $U_{MHD} = v_z \cdot d\ B_0$, where d denotes the electrode distance. However, only limited knowledge is available for intracardiac ECG signals with respect to the MHD effect. A recent animal experiment reported altered EP signals inside the MR scanner (Tse et al., 2012). Therefore, intracardiac signals acquired in a MR environment have to be investigated in detail to characterize the alteration caused by the MHD effect in order to provide diagnostically valuable data.

The aim of this work is to establish an experimental setup with common EP equipment to simulate the MHD effect in a model system and to analyse the pure MHD signal.

2 METHODS

All measurements were performed on a 1.5 T MR scanner (Symphony, Siemens/Erlangen, Germany). A closed flow circuit was established at the MR scanner table (Figure 1b) and filled with a distilled water-sodium-chloride mixture (electrical conductivity at 23±1°C: 5.33±0.18 mS/cm) to simulate the electrical conductivity of blood. A MR-compatible Ventricular Assist Device (VAD) (MEDOS, Stolberg, Germany) connected to a u-shaped tube phantom (inner diameter: 22.1 mm) was used for mimicking the pulsatile flow of the beating heart (50 bpm). The tube was constructed using a rapid prototyping method. A standard sized 6F EP catheter (St. Jude Medical, Minnesota, USA) was placed into a slit in the phantom wall (Figure 1a). The slit allows for reproducible positioning of the catheter as well as assuring the electrodes are stationary. As shown in the upper schematics of Figure 1a, d between the first two electrode pairs (1/10, 2/9) are about equal, whereas d decreases continuously from pairing 3/8 to 5/6. The EP catheter is connected to a pre-amplifier (EP-Tracer, CardioTek B. V., Netherlands) for measuring potentials in the mV-range. A laptop was connected for data registration. The electrodes of the surface ECG were connected to the liquid as well as to the ground to provide a reference for the pre-amplifier. Bipolar measurements were carried out using the lowest cut-off frequency (0.05 Hz) of the high-pass hardware filters of the EP-Tracer.

3 RESULTS

Figure 2 shows representative curves of the MHD-effect during pulsatile flow in a 1.5 T MR scanner. The signal of electrodes 1/10 is smaller than the one between the electrodes 2/9. However, this deviation is within the limits of the experimental accuracy. A linear decrease of the potential with a decrease in *d* is observed (not shown). Additionally, it is important to note the underlying unknown shift and scaling of the voltage signal in the vertical direction. This is due to the impact of the high pass filter of the pre-amplifier on the MHD signal.

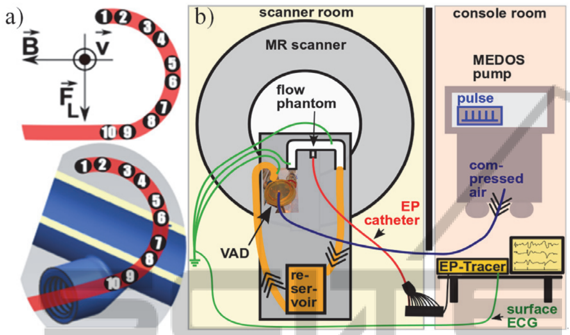

Figure 1: EP catheter positioning in the phantom and its orientation with respect to the flow velocity $\boldsymbol{v}$, the external magnetic field $\boldsymbol{B}$, and the Lorentz force $\boldsymbol{F}_L$ (a), and experimental setup (b).

4 DISCUSSION

The investigation of MHD potentials detected with common EP equipment is important for developing EP exam procedures in a MR environment. Therefore, a MRI compatible flow circuit was successfully established. The linear dependency between the measured potential and *d* (as well as B_0, both not shown) predicted by theory was clearly observed and validates the model system. Typical electrode distances as between the electrodes 5/6 revealed a significant MHD potential which cannot be neglected. The non-conductive walls of the flow phantom are not expected to bias the outcome of the measurement significantly since studies revealed that vessel wall conductivity may be neglected (Abdallah et al., 2008). Further investigations will analyse the impact of different recording modalities such as hardware filters on the detection of the MHD signal. Furthermore, glycerol will be added to the saltwater for simulating the viscosity and the density of blood.

The time course of MR velocity data at the catheter position (not shown) agrees very well with the EP-Tracer data (apart from filter effects). Hence, additional simple and quick MR flow measurements at the location of interest during an EP exam may be used to remove the MHD related potential from intracardiac ECG signals representing an essential step towards diagnostically valuable data. Additionally, in vivo data, e.g. from animal models, is required for the validation of these methods.

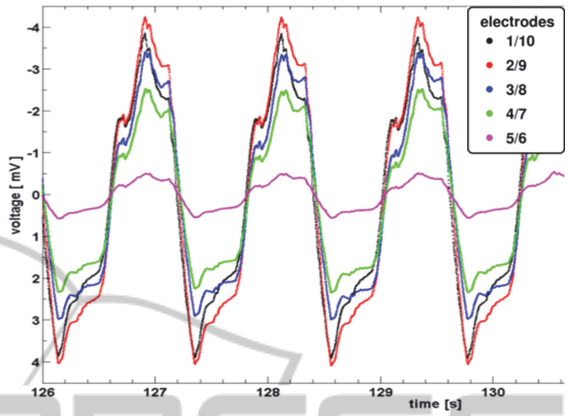

Figure 2: MHD potential time course.

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