Quantitative evaluation of magnetohydrodynamic effects on the electrocardiogram

M. Jekic[1], R. Dzwonczyk[2], Y. Ding[3], S. V. Raman[2], and O. P. Simonetti[4]

[1]Biomedical Engineering, The Ohio State University, Columbus, Ohio, United States, [2]The Ohio State University Medical Center, Columbus, Ohio, United States, [3]Davis Heart and Lung Research Institute, Columbus, Ohio, United States, [4]Internal Medicine and Radiology, The Ohio State University, Columbus, Ohio, United States

Introduction: Diagnostic electrocardiogram (ECG) monitoring inside the MRI magnet room may be necessary during and after exercise and pharmacologic stress testing [1]. However, ECG signals may be distorted by magnetohydrodynamic (MHD) effects resulting from blood flow within the static magnetic field. These effects are most pronounced when flow is rapid and oriented perpendicular to the magnetic field, as in the aortic arch [2]. Peak aortic arch flow approximately coincides with the T-wave and may mask changes the S-T segment of the ECG. It is well known that the ECG is non-diagnostic within the bore of any high field MRI magnet. However, diagnostic ECG monitoring of a patient lying on the MRI table but outside of the bore may be important during and after exercise or dobutamine stress in the magnet room. It is important to understand the extent of the MHD effect that may be encountered in these conditions.

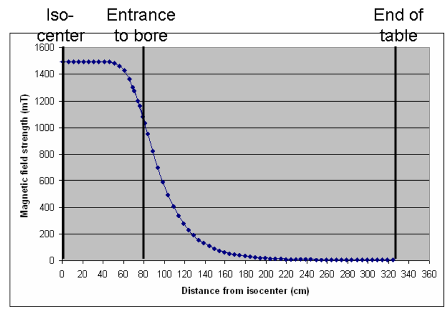

Figure 1: Magnetic field as a function of distance from isocenter measured down the length of the extended patient table.

Purpose: To determine a magnetic field threshold at which MHD effects become significant.

Methods: We measured the magnetic field of a 1.5T Siemens Avanto magnet with a gaussmeter axial probe (LakeShore Model 420) in 5 cm increments from the edge of the fully extended magnet table to isocenter. We acquired MRI scout images in 3 subjects to find the distance from the aortic arch to the isocenter, which was used to determine the magnetic field (B) at the aortic arch at various table positions. The induced MHD voltage across the aorta may be expressed as [2]:

$$\mathbf{V} = \int \mathbf{u} \times \mathbf{B} \cdot d\mathbf{L},$$

where u is the blood velocity (m/s), B the magnetic flux density (T), and L is the distance vector between electrodes. This can be simplified to V = uBL when each vector is uniform and orthogonal. Therefore, as a worst-case scenario, we positioned the electrodes horizontally across the heart, approximately perpendicular to both the magnetic field vector and the velocity in the aortic arch. This relationship also indicates that the MHD signal should be linearly proportional to B for any subject.

We acquired 2 minutes (at least 100 heartbeats) of supine ECG data using the MEDRAD Veris system at 5 table positions, starting with the table fully extended and the subject feet-first towards the magnet and moving in 40-50 cm increments toward the isocenter. We repeated the measurement outside of the MRI room to serve as a "baseline" ECG signal with no magnetic interference. Using MATLAB, we identified the peak of each R-wave, and segregated the data into individual heartbeats (RR-intervals). We subsequently averaged all heartbeats to obtain the "mean beat" at each table position. We subtracted the baseline mean beat from the mean beat at each table position to determine the ECG signal deviation due to MHD as a function of field strength.

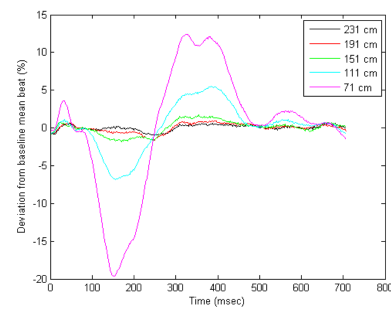

Figure 2: Example deviations from baseline in one subject with aortic arch at five distances from isocenter.

Results: The magnetic field plot relative to isocenter is displayed in Figure 1 with vertical lines indicating the magnet bore opening and the end of the patient table when fully extended. Deviation from the baseline mean beat in one subject is shown in Figure 2 at various distances between the aortic arch and magnet isocenter. Peak deviation as a function of magnetic field strength is shown in Figure 3 for all 3 subjects, exhibiting strong linearity (r = 0.9259). This figure indicates that at a magnetic field up to 100 mT, the maximum deviation from baseline is contained within approximately 5%.

Conclusions: The MHD effect for a given subject is linearly proportional to the magnetic field. While the field plot in Figure 1 is specific to our magnet and shielding, the MHD effect as a function of B extrapolates to other systems. For the 1.5T Siemens magnet used in this study, the results indicate that diagnostic ECG monitoring is feasible with the magnet table fully extended and the patient positioned feet-first. Positioned head-first, the aortic arch lies at approximately 300 mT, and MHD effects exceed 10% of baseline. This data is an important first step in developing approaches to remove the MHD effect, enabling continuous diagnostic ECG monitoring during pharmacologic or physical exercise stress within the magnet bore.

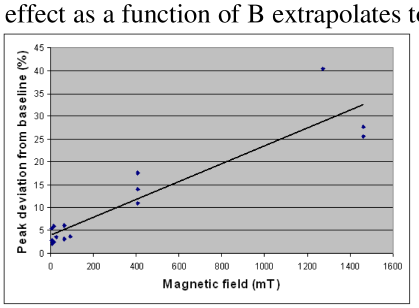

Figure 3: Regression between peak deviation from baseline and magnetic field strength.

References:

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