Realistic MHD modeling based on MRI blood flow measurements.

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INTRODUCTION: The electrocardiogram (ECG) is acquired during MRI for two main purposes. First, the ECG is used to synchronize image acquisitions with heart activity during cardiovascular applications in order to suppress cardiac motion artifacts, or display images at pre-determined cardiac phases. The second purpose is monitoring, to determine the vitality of the patient. The MR environment distorts the ECG signal. The major distortion, called the MagnetoHydroDynamic (MHD) effect, is induced by the charged particles in the blood flowing through the high static magnetic field and thus occurs even in the absence of the MRI pulsing. This effect is exacerbated in High (3T) or Ultra-High (7T, etc…) field Cardiac MRI, interventional MRI, or MRI stress-tests. The principal contribution to the MHD effect is the flow through the aortic arch, explained by its overwhelming strong velocity and geometrical orientation perpendicular to B_0 and vessel radius [1]. The MHD contribution was previously computed under some simplified assumptions by solving the Navier-Stokes equation under a pulsatile gradient pressure profile modeled by a lumped Windkessel model [2]. This solution allowed for the creation of artificial MHD and ECG signals [3], but struggles in modeling the high frequencies present in real observed MHD effects. We propose a new model for the MHD effect on ECG signals, based on actual measured blood flow data. Such artificial data will be helpful for building and assessing the quality of methods aiming at denoising ECG signals acquired during MRI or for separating ECG from the MHD contribution.

METHODS: A previously described 3D model of the human torso [4] was combined with a model of the aortic arch. The latter was modeled by 15 consecutive L=1cm long cylindrical sections. Given the notation introduced in figure 1 and assuming that the aorta has rigid non conductive walls together with laminar, unidirectional flow, it can be shown [2] that the surface body potential (Φ) at a point $M=(x_M,y_M,z_M)$ is :

$$\Phi(M,t) = \frac{B_0 \sin\varphi_V L}{4\pi} \frac{\sin(\theta_V)x_M - \cos(\theta_V)y_M}{((x_M - x_A)^2 + (y_M - y_A)^2 + (z_M - z_A)^2)^{3/2}} q(t), \quad (1)$$

with $q(t)$ being the blood flow in the section of the aorta located at the position (x_A, y_A, z_A). One subject underwent a cardiac examination on a 1.5T GE (Waukesha,WI) MR scanner. Blood flow measurements were performed on two cross-sections of the aortic arch (ascending and descending) with a Phase Contrast CINE sequence (TR=10.48ms, TE=5.04ms, flip angle=20, F0V = 350X350mm, 30 cardiac phases, 8 views per segment, Velocity Encoding=150cm/s). ECG signals were also acquired for this subject outside the MR bore and with the aorta located in the isocenter, both in the head-first and the feet-first orientations, so that the MHD voltages could be estimated [5]. The orientation of the arch in the MRI's coordinate frame was also determined from the MRI images.

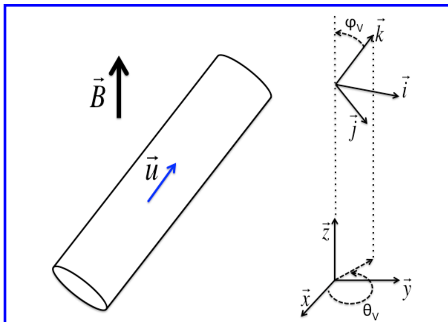

Figure 1: Flowchart of the MHD problem. The static magnetic field (**B**=B0**z)** is along the z direction and the blood velocity (**u**=u(r,t)**k)** is along k direction.

RESULTS: The blood flow was measured in the ascending and descending aorta and was also extrapolated for the aortic arch (Figure 2). The 15 sections were divided into three categories (based on their positions), the potential resulting from the blood flow was computed using equation 1 and summed to model the MHD effect induced by the flow through the aortic arch. This MHD effect was compared with the previous modeling [3] and with MHD effect estimated on measurements at several surface electrodes (Figure 3).

DISCUSSION: The proposed method overcomes the limitations of the previous models [1,2,3], as it reproduces the observed high frequencies and is shown to be in good agreement with the measured MHD. The differences between the modeled and measured MHD effect can be explained by oversimplified assumptions: rigid non-conductive aortic wall, linear conduction through the thorax, laminar and unidirectional flow. Evidences recently presented by Markl *et al.* [6] have shown that the flow in the aorta is twisted and contains vortices. In this abstract, we have introduced a more realistic MHD model based on MRI blood flow measurements, which will be useful for designing and evaluating new ECG and MHD separation and denoising techniques.

REFERENCES:

1. Gupta A, *2008*, **IEEE Trans. Biomed. Eng.**, 1890-1896.
2. Abi-Abdallah D, *2007*, **PhD thesis, Univ. Techno. Compiegne**.
3. Oster J, *2011*, **Proc. Europ. Soc. Mag. Reson. Med. Biol.**, 546.
4. VanOosterom A, *2004*, **Heart**, 165-168.
5. Tse, Z, *2011*, **Proc. Intl. Soc. Mag. Reson. Med. 19**, 3742.
6. Markl M., *2005*, **Journ. Of Thorac. Cardiov. Surg.,** 456-463.

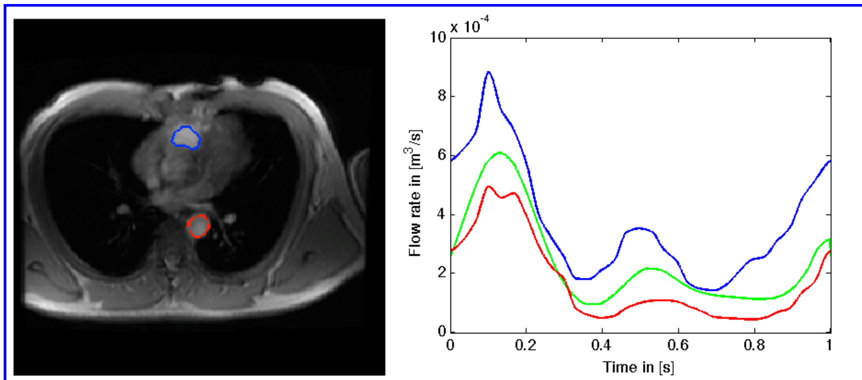

Figure 2: Left: Region of interest delineations for blood flow measurement in the aortic arch ascending (blue) and descending (red). Right: Blood Flow measured in the ascending rate (blue) and descending (red) and extrapolated in the aortic arch (green).

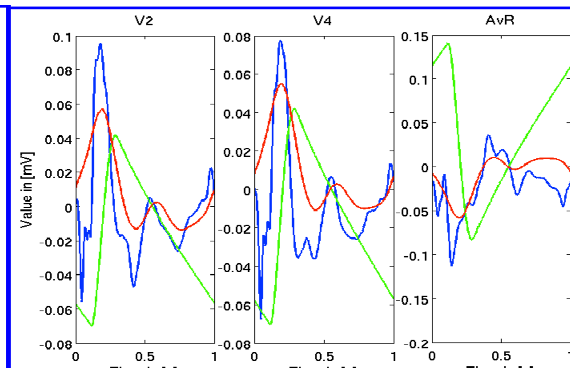

Figure 3: Comparison of the proposed MHD modeling (red), the previous modeling [3] (green) and the estimation of the real MHD effect (blue) on three different ECG leads.