Rapid Flow Monitoring based Magnetohydrodynamic Voltages: Case Studies in Carotidal and Aortic Flow

Kevin James Wu[1], T. Stan Gregory[1], Ehud J. Schmidt[2], John Oshinski[3], Zion Tsz Ho Tse[1]

[1]Engineering, the University of Georgia, Athens, GA, USA
[2]Radiology, Brigham and Women's Hospital, Boston, MA, USA
[3]Radiology, Emory University Hospital, Atlanta, GA, USA

Background: Advanced physiological monitoring within the bore of the MRI scanner is a technical challenge addressed through varying approaches, attempting to provide accurate patient monitoring during conventional MRI procedures and clinical interventions [1]. The Electrocardiogram (ECG) is a clinical diagnostic tool in MRI, commonly utilized to monitor high-risk patients, and in cardiac MRI synchronization to obtain images free of motion-based artifacts, despite complications that arise in acquiring high-fidelity intra-MRI ECG recordings [2]. Limitations in acquiring diagnostic quality ECGs inside the MRI are often attributed to Magnetohydrodynamic (MHD) voltages (V_{MHD}), induced due to systolic blood flow interactions with an external magnetic field [3]. We hypothesized that V_{MHD} extracted from varying flow source, can be used as a rapid tool for regional flow volume monitoring [1,4]. This methodology could be utilized in a stand-alone device with a portable magnetic field source, capable of real-time beat-to-beat flow estimation [5].

Methods: Conventional Velocity-Encoded Phase Contrast MRI (PCMR) was acquired in one healthy subject along the aortic arch and in the left common carotid artery. 12-lead ECGs were acquired during a 20-second breath-hold outside (Fig. 1a) and inside the MRI bore (Fig. 1b) while a secondary recorder was used to acquire a single bipolar anterior-posterior lead at the carotid artery. The common carotid artery was selected for its physical isolation from the sinus node, close proximity to the body surface, and high flow rate. Blood flow was quantified in the carotid artery and aortic arch using PCMR (Fig. 1cd), and used to correlate time-integrated carotidal lead signals with extracted time-integrated aortic V_{MHD} from the 12-lead ECG (Fig. 1e).

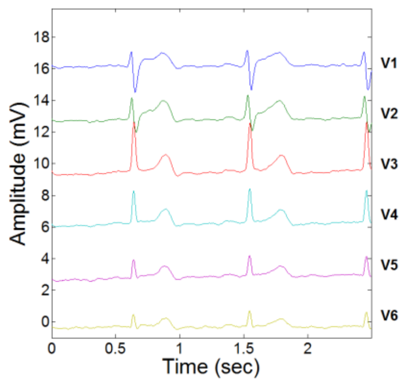
Results: During exercise stress testing, MRI-derived peak flow was shown to increase with an elevated heart proportionally in the ascending aorta and the common carotid artery, with an 8.49% difference in elevation and a 7.32% difference in return between the two vasculature sources. MHD-derived flow volumes were shown to increase by 76.5% in the carotid artery and 88.1% in the aorta, illustrating a close correlation between carotidal and aortic derived MHD and flow (Fig. 1d). MHD-derived flow was found to predict flow volumes as estimated from the MRI with an error of <10%.

Conclusions: V_{MHD} has been shown to be a promising technique for deriving real-time beat-to-beat flow and its functionality has been validated in carotidal and aortic flow in a human subject during exercise stress testing. This will potentially allow for the development of improved methods of intra-MRI SV estimation, which is of particular importance in the monitoring of high risk patients, such as those with histories of ischemia or stroke, as well as the development of a portable device for assessing blood flow through more accurate V_{MHD}.

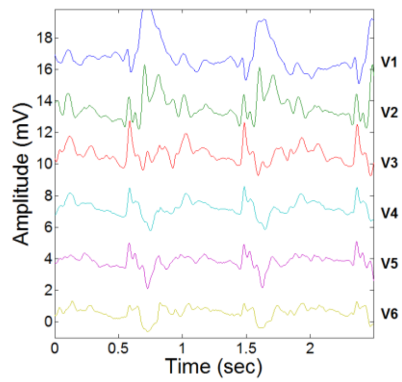
References: [1] Tse, MRM, 2013. [2] Gregory, MRM, 2014. [3] Gupta, IEEETransBioMedEng., 2008. [4] Gregory, JCMR, 2015. [5] Wu, Circ, 2015.

Funding: AHA 10SDG261039, NIH R03 EB013873-01A1

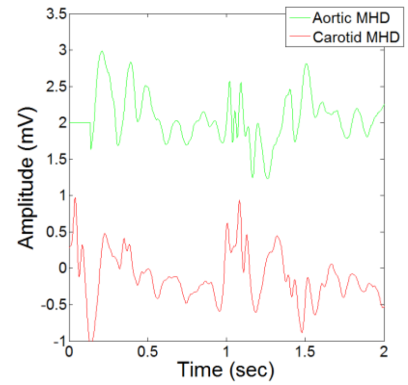
a) 12-lead ECG acquired outside the MRI



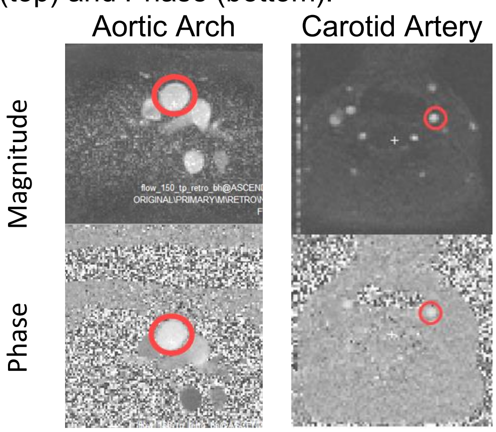
b) 12-lead ECG acquired inside the MRI (3T)



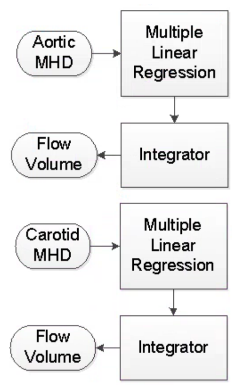
c) Single Lead Carotid and Aortic MHD acquired at 3T



d) Phase Contrast MR (PCMR) transverse plane images of the aortic arch and left common carotid artery used to estimate systolic: Magnitude (top) and Phase (bottom).



e) Estimation of MHD-derived Stroke Volume (SV) using Carotid and Aortic MHD Voltages in 3T



f) Increase in MHD-derived Flow Volume during exercise stress testing in aortic and carotidal flow.

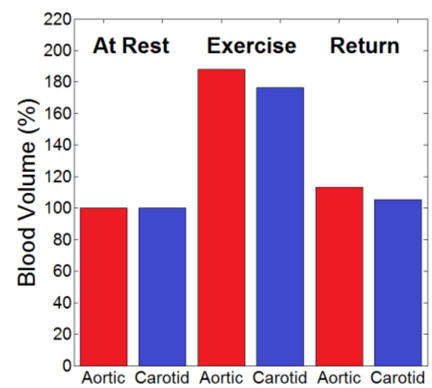


Figure 1: Correlation between induced Carotidal and Aortic Magnetohydrodynamic Voltages (VMHD).