ECG Electrode Placements for Magnetohydrodynamic Voltage Suppression and improving Cardiac Gating in high-field MRI

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Background: The accuracy of Electrocardiogram (ECG) gating for synchronization of MR scanner image acquisition and cardiac electrical activity is of great importance for acquiring high-quality Cardiac Magnetic Resonance (CMR) images free of motion artefacts. The distortion of ECG traces by Magnetohydrodynamic Voltages (VMHD) induced by interaction between the MRI static magnetic field (B_0) and rapid left-ventricular blood ejection during systole can lead to false and/or intermittent QRS complex detection and images with severe motion artefacts [1]. We hypothesized that an optimized electrode placement for the reduction of induced VMHD could be derived based on a thoracic model to increase the accuracy of QRS complex detection.

Objectives: To increase the accuracy of QRS complex detection by reducing the measured VMHD using optimized ECG electrode placements.

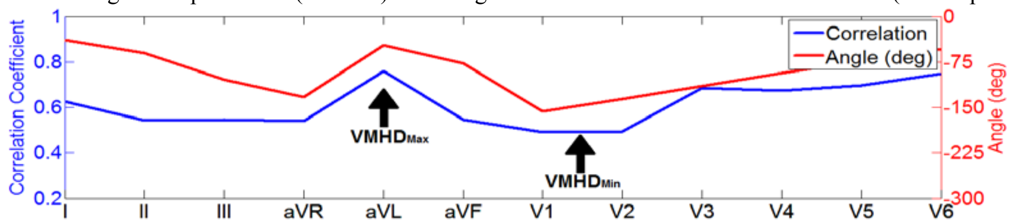
Methods: A vector model based on thoracic geometry [2] was calibrated using 12-lead ECGs recorded in four subjects in a GE 3T scanner to estimate VMHD distributions on the thorax. 4-lead ECG electrode placement was then optimized to: (1) minimize VMHD magnitude and (2) reduce displacement from the SA node for maximizing QRS complex amplitude (Fig. 1a,b). A gradient-descent optimization routine was utilized to predict the optimal 4-lead ECG placement based on angular displacement and heart/aorta geometry (Fig. 1c,d). Model results were then validated using five healthy subjects. Sensitivity (Se) and Positive Predictability (+P) rates for detection of R-waves were compared between conventional and MHD-suppressed lead placements for single-lead QRS complex detection [3].

Results: A 43.41% reduction in VMHD during the S-T segment (Fig. 1f) was observed in ECGs using the MHD-suppressed placement relative to the conventional placement, while preserving the QRS complex (Fig.1e), resulting in an average increase in the Se and +P rate of 14.22% and 15.48%, respectively (Fig. 1e-g). R_{peak} amplitude inside the MRI in the MHD-suppressed placement had <5% deviation from the standard placement outside of the MRI (Fig.1e). As compared to the conventional electrode placement (Fig. 1c-d), MHD suppression may result from decreased visibility of the aorta through the lungs at the MHD-suppressed placement.

Conclusions: Electrode placement recommendations were computed and validated in a 3T MRI, illustrating an increased accuracy in QRS complex detection using the MHD-suppressed placement.

Ref: [1] Gregory, MRM, 2014. [2] Oostendorp, IEEE., 2004. [3] Pan, IEEETransBiomed., 1985.

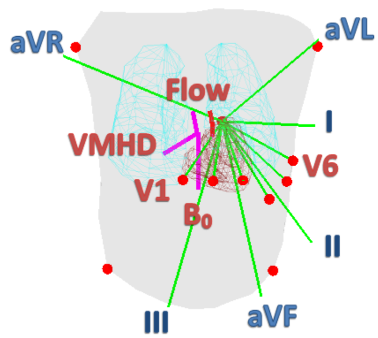
a) Thoracic model to predict minimum and maximum VMHD in electrodes based on angular displacement between the electrode vector and the VMHD vector. Electrode angular displacement (**red line**) and Electrode VMHD distribution (**blue line**) are shown. Electrode VMHD distribution (**blue line**) was calculated using Inverse Correlation Coefficients between 12-lead ECGs obtained inside and outside of the bore, whereas a 0 represents no MHD voltage while a 1 represents full MHD voltage. Electrode angular displacement (**red line**) is the angle between the electrode vector and lead I (frontal plane).

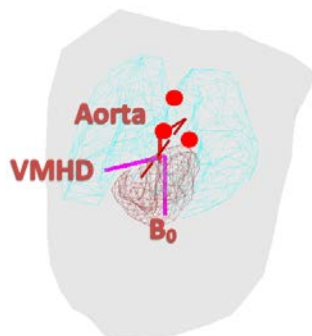


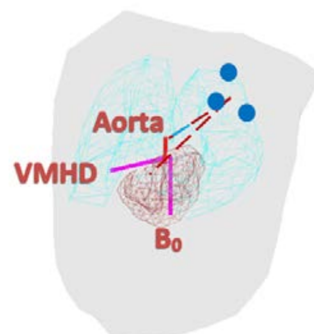
b) Mapped electrical vectors (green) from 12-lead ECG in the thoracic model [1], used to determine angular displacement between leads and VMHD during model validation.

c) Standard electrode placement for ECG gating (red). Electrical vector from electrodes is nearly unobscured from heart and aorta by the lungs.

d) MHD-suppressed electrode placement (blue). Electrical vector is in view of heart, but remains obscured from aorta by superior lobe of the lung.





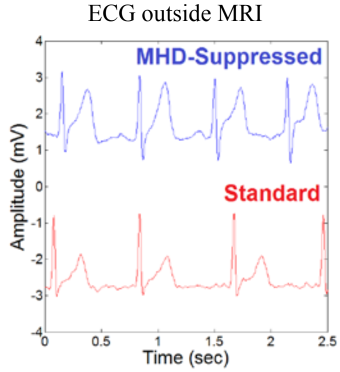


e) 4-lead ECG recordings obtained outside the MRI in the standard and MHD-suppressed locations. R_{peak} in the MHD-suppressed case was found to have a <5% deviation from the standard placement.

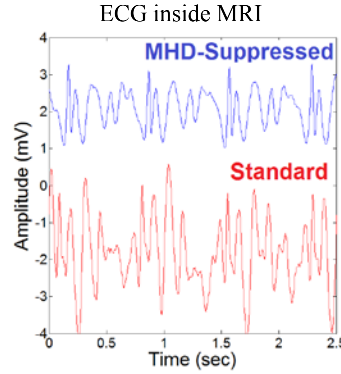
f) ECG recordings obtained inside the MRI in the standard and MHD-suppressed locations. VMHD was reduced by 59% in the MHD-suppressed case relative to the standard placement.

g) Subject transverse slice of ascending and descending aorta acquired using ECG-gating.

ECG outside MRI



ECG inside MRI



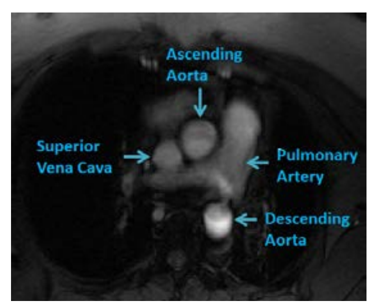


Table 1: Evaluation of MHD suppression in Each Subject for QRS complex Detection

	Improvement in QRS Complex Detection		**Level of MHD Suppression in ECG Segments (Peak-to-Peak)**		
	Se	*+P*	*P-wave*	*QRS Complex*	*S-T segment*
Subject 1 *M/20yrs/108kg*	3.10%	14.59%	0.44mV (25.41%)	0.27mV (11.32%)	2.55mV (64.38%)
Subject 2 *M/20yrs/72kg*	8.33%	26.67%	0.06mV (23.19%)	0.14mV (17.25%)	0.87mV (55.39%)
Subject 3 *M/21yrs/68kg*	25.00%	33.33%	0.13mV (18.50%)	0.36mV (38.91%)	0.52mV (28.21%)
Subject 4 *M/27yrs/82kg*	11.11%	11.11%	0.09mV (33.72%)	0.18mV (44.61%)	0.10mV (19.27%)
Subject 5 *M/26yrs/77kg*	23.53%	13.93%	0.33mV (52.64%)	0.07mV (10.36%)	0.89mV (49.89%)
Mean	14.22%	15.48%	0.21mV (30.69%)	0.20mV (24.49%)	0.99mV (43.41%)
Std. Dev.	9.63%	16.99%	0.16mV (13.45%)	0.12mV (16.11%)	0.93mV (18.96%)

Figure 1: Development of electrode placement recommendations for increased accuracy in QRS complex detection and MRI gating.