Characterization of Vortex Flow in the Left Ventricle by Phase Contrast Magnetic Resonance Imaging

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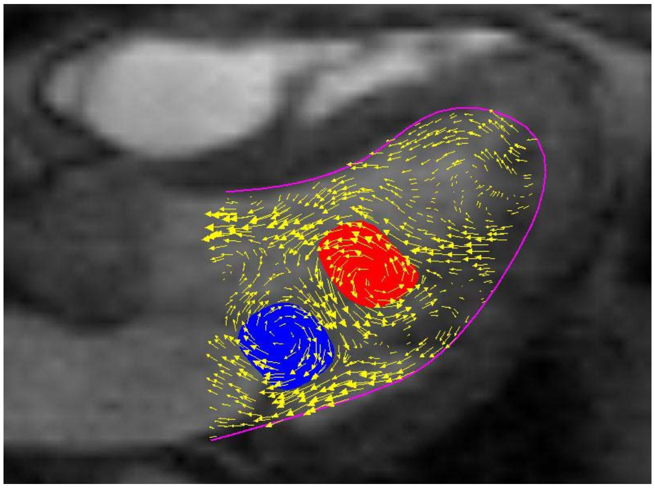

Figure 1: Counterclockwise (red) and clockwise (blue) vortex regions in the left ventricle.

Introduction: Characterization of turbulence phenomena in fluid transport systems is useful in understanding energy conservation, dissipation, and exchange. Vortices, structures exhibiting circular or swirling motion, are central in defining flow fields and flow structure. Formation of vortices and changes in their structure are determined by structural geometry of the system as well as other global system properties. Previous work [1] suggests that the geometric structure of chambers in the heart optimizes vortex formation and vortex flow. Asymmetry in both chamber inlets and outlets and chamber geometry assist in optimizing energy conservation and dissipation during specific portions of the heart cycle. Studies using magnetic resonance imaging [2] and direct numerical calculation [1] show that vortex formation helps redirect blood flow between chambers in the heart and prevent blood flow collisions, thereby minimizing excessive energy dissipation in the heart. Abnormal asymmetry in chamber geometry due to cardiac disease or other pathophysiological conditions may adversely affect the efficiency of the heart; such asymmetry may exhibit itself as a change in vortex formation and flow that are noticed *in vivo* [3,4]. Therefore, the study of vortex formation and flow in the heart may be a useful tool for evaluating and diagnosing cardiac conditions.

Low temporal and spatial resolutions limit the effectiveness of imaging techniques to evaluate blood flow fields in the heart. Previous studies [3, 4] have demonstrated the use of contrast echocardiography and echo particle image velocimetry to evaluate vortex formation; however, these methods require echo contrast injection and the particle tracking process reduces spatial resolution. Phase contrast magnetic resonance imaging (PC-MRI) directly measures the velocity field, eliminating the step of particle tracking and preserving spatial resolution. The goal of our study was to demonstrate feasibility of using PC-MRI to quantitatively evaluate vortex formation and flow using the visualization methods developed for contrast echocardiography.

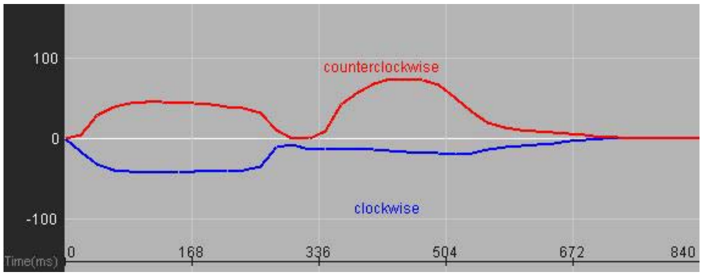

Figure 2: LV Vortex Formation.

Methods: Eight subjects underwent MRI on a 1.5T system (Avanto, Siemens, Malvern, PA). Of these eight subjects, five had normal LV function and three had either severe LV dysfunction or cardiomyopathy. A two-dimensional in-plane (x-velocity and y-velocity) velocity field was acquired in a three-chamber horizontal long-axis view of the left ventricle of each subject using a breath-hold segmented k-space gradient echo acquisition with parallel acceleration rate 2 (TR/TE 5.7/3.1 ms, temporal resolution 68 ms, voxel size 2.5mm x 2.5mm x 6mm). Omega Flow (Siemens Ultrasound, Mountain View, CA) was used to process velocity field data to obtain graphical visualization of LV vortex formation and flow as well as obtain parameters characterizing vortex formation (vortex depth (VD), vortex length (VL), vortex width (VW), sphericity index (SI), relative strength (RS), vortex relative strength (VRS), vortex pulsation correlation (VPC)).

Table 1: Vortex parameters (Mean ± Standard Deviation) for normal and abnormal groups.

	VD	VL	VW	SI	RS	VRS	VPC
Normal	0.290±0.043	0.594±0.171	0.222±0.042	2.718±0.870	1.407±0.311	0.355±0.097	-0.112±0.695
Abnormal	0.300±0.174	0.617±0.232	0.239±0.060	2.769±1.518	0.722±0.375	0.201±0.081	0.046±0.523

Results: Mean and standard deviation of parameters for subjects with normal and abnormal LV function are presented in Table 1. Low standard deviations for a number of the parameters (VD, VW, and VRS for normal group; VW and VRS for abnormal group) suggest that vortex flow patterns may be consistent across individuals. VW was greater (0.239±0.060 vs. 0.222±0.042) and RS and VRS were lower (0.722±0.375 vs. 1.407±0.311; 0.201±0.081 vs. 0.355±0.097) in the abnormal group compared to the normal group, corresponding with results from vortex studies using echocardiography [3]. Figure 1 shows LV clockwise vortex regions (blue regions) and counterclockwise vortex regions (red regions) as well as flow patterns (yellow arrows) resulting from vortex formation. Figure 2 shows strength of clockwise and counterclockwise LV vortices over one cardiac cycle.

Conclusions: We demonstrate in this preliminary study that PC-MRI techniques may be used to quantitatively evaluate LV vortex flow characteristics. Further studies involving a larger sample size and robust comparison with echocardiography results will be necessary to gain additional insight into the use of these techniques for understanding intra-cardiac blood flow.

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