Vorticity Imaging of Diastolic Dysfunction by Phase Contrast MRI

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Introduction

Heart failure is a worldwide problem of epidemic proportion. Diastolic dysfunction is increasingly recognized as an important cause of heart failure. In fact, diastolic dysfunction accounts for as much as 50% of heart failure cases. Measuring the type and degree of diastolic dysfunction, is however difficult without extensive invasive testing using catheterization techniques. Doppler echocardiography is the most frequently used method for diagnosing and quantifying diastolic heart failure. However, the evaluation of diastolic dysfunction by echocardiography is controversial and limited by a lack of a consensus regarding what is normal for the parameters measured, and by the perceived lack of reproducibility of the technique. Therefore, we sought to develop a better technique for evaluation of diastolic function. It is known from the fundamentals of fluid mechanics that the filling of a chamber is aided by the formation of vortical fluid structures, or "vortices". The formation of vortical structures within the heart has been proposed and identified by others (1). However, the technique of Doppler echocardiography lacks sufficient temporal resolution in order to resolve vortical structures. Therefore, we sought to identify such vortices using phase contrast MRI. We further hypothesized that heart failure patients either would not develop vortices with filling or that the characteristics of their vortex formation would be different than normal subjects.

Methods

A total of 10 subjects were recruited to undergo the phase contrast MRI protocol, four with abnormal diastolic function (all male) and six with normal cardiac function (3 female, 3 male). Subjects with abnormal relaxation defined by Doppler echocardiography were identified using an echocardiography database. Abnormal relaxation was defined as the combination of reduced mitral inflow E/A ratio (<0.75), elevated pulmonary vein S/D ratio (>1.0) and Doppler Tissue Imaging showing reduction in the septal myocardial velocity (E') less than 8cm/sec, and ratio of E/E' <10, consistent with normal filling pressures. The normal subjects had no clinical heart disease and normal diastolic filling, confirmed by Doppler echocardiography. Phase contrast MRI was then performed to map out the three dimensional flow field throughout the cardiac cycle using a CINE acquisition. The imaging parameters were TR=14 ms, TE=min, FOV=32x16 cm, matrix=128x64, and thickness=4 mm. Time resolution equal to TR was obtained with a 4X acceleration by using a custom-designed UNFOLD (2) reconstruction technique, unique to phase contrast MRI (additional abstract submitted).This permitted acquisition of one cross section within a single breath-hold of 16 heartbeats. The field at 5 axial location separated by 1cm was mapped out over multiple breath-holds. After acquisition, the vorticity field ($\nabla \times V$) was computed and streamlines of flow were mapped. The presence of a vortex was then defined as an area of high vortcity magnitude coupled withlooping flow.

Results

All 6 normal subjects exhibited two prominent vortices, one associated with the anterior mitral leaflet and the other associated with the posterior mitral leaflet. The anterior vortex was particularly prominent, typically of diameter of 1.5cm. One of the abnormal subject's data was inadequate for interpretation while two of the remaining three did not have the formation of a vortex. An example of three normals and one abnormal are shown in Figure 1. A clear difference is apparent with the normal subjects exhibiting a prominent and well-visualized anterior vortex, high regions of vorticty along the posterior wall, and a vortex at the head of the inflow jet was variable. Diastolic dysfunction in the abnormal subject (Figure 1d) was not conducive to production of an anterior vortex. Although high levels of vorticity were seen in the area we would expect to see circular fluid streamlines indicative of a vortex. Without the streamlines, the high vorticity can be attributed to flow adjacent to the wall. Details regarding characterization by echocardiography of the abnormal subject included normal systolic function and isolated diastolic dysfunction characterized by abnormal relaxation. The abnormal subject did have the clinical syndrome of heart failure

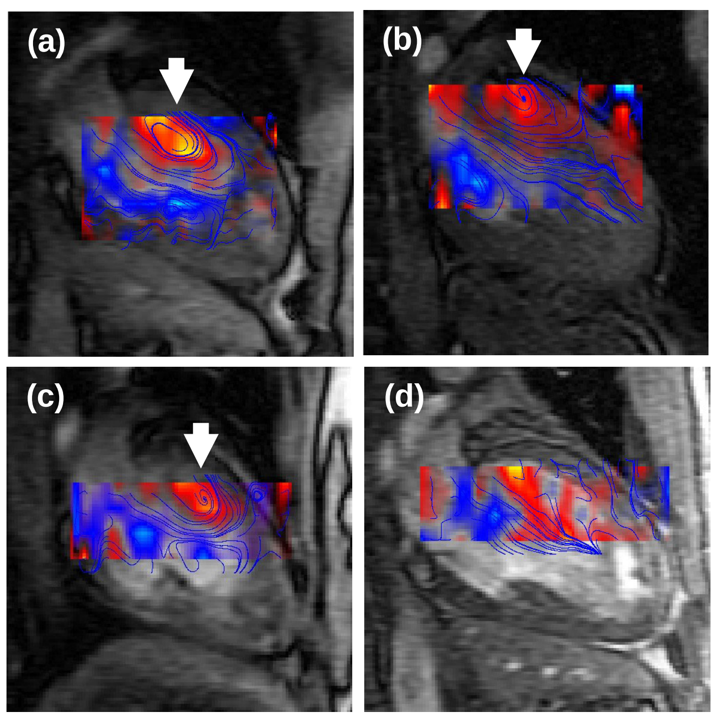

Figure 1. MRI reconstruction of flow in the left ventricle for (a-c) normal subjects, note anterior vortex structure (arrows) and (d) abnormal subject with impaired relaxation and no distinguishable vortex pattern. Figure shows cross section of 3D vorticity field color coded for clockwise flow (blue-white) and counter-clockwise flow (red-yellow). Blue lines indicate flow streamlines. Background images are reference long axis views.

Conclusions

The technique of phase contrast MRI has promise for evaluation of diastolic filling, specifically the formation of vortices during early rapid diastolic filling. Normal subjects exhibit strong vortex formation during early diastolic filling with a particularly prominent vortex with unique rotation and vorticity characteristics present adjacent to the anterior mitral leaflet. Subjects with abnormal relaxation do not exhibit this prominent anterior vortex early in diastolic filling.

References

1. Kim et al. JACC 26.224-238, 1995
2. Madore et al. MRM 42:813-828, 1999.