Phase Contrast Imaging of Vortex Rings During Diastolic Filling of the Left Ventricle

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Introduction

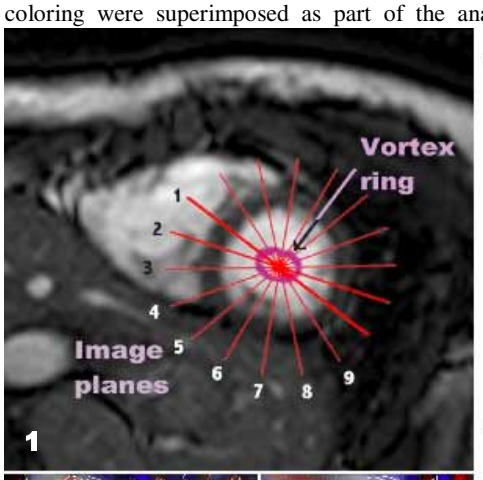
Diastolic filling of the left ventricle is characterized by the formation of a fluid vortex distal to the mitral valve leaflets. Recent studies [1,2] have indicated the presence and timing of vortex formation may be clinically valuable for assessment of diastolic dysfunction. Studies of vortex formation have traditionally been derived from single plane measurements obtained from Doppler echocardiography or phase contrast MRI. However, limiting the measurement to individual planes neglects the fact that vortices generally form in the shape of a ring surrounding the orifice. Thus, more rigorous methods of measuring vortex behavior should be enabled by sampling the behavior of the entire vortex ring. One possibility is to use phase contrast MRI with a 3D volume acquisition, but this requires a lengthy, navigator-gated acquisition. In this study, we sought an alternative optimal sampling strategy for characterizing the entire vortex ring with a minimal number of imaging planes.

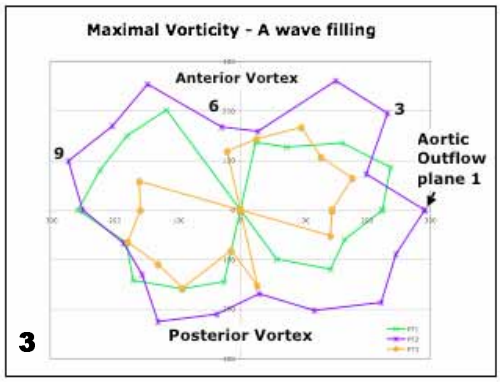
Methods

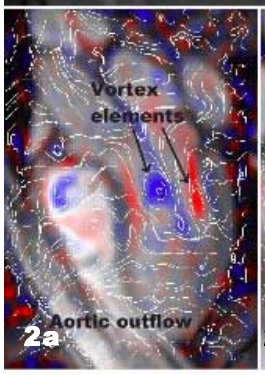
We utilized a 3T MRI scanner (Philips Achieva) to obtain phase contrast velocity measurements from 3 normal volunteers. Nine image planes were oriented in a radial stack with an axis of rotation aligned between the center of the mitral valve and ventricular apex. This maintained a perpendicular orientation of each image plane to the vortex ring. For each image plane, the two in-plane components of velocity were measured in separate breath-hold periods. Within each image plane, the early and atrial filling vortices were identified and the peak vorticities (planar vorticity defined as $xi_z = dv_y/dx - dv_x/dy$) were measured. The average value of peak vorticity from all image planes was computed as a representation of overall vortex ring strength. This value was based on 18 individual measurements per subject since each of the 9 image planes should intersect the vortex ring twice (Fig. 1). We then assessed alternative geometries in which fewer than 9 planes were acquired by measuring average vorticity based on various subsets of the full 18 measurements. For each subset, the average percentage error relative to using all 18 measurements was reported. This analysis was performed for both the E and A wave rings in each subject and the errors pooled to determine a mean error given a subset of axial planes.

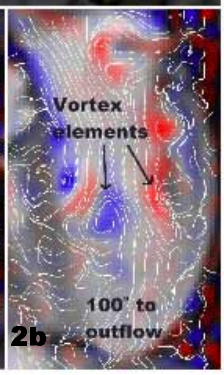
Results

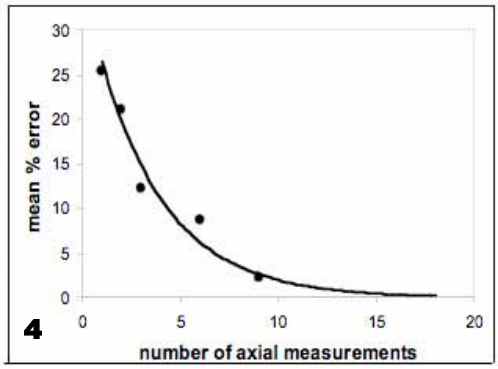
Figure 1 shows the imaging scheme, with a vortex ring superimposed upon an axial view of the left ventricle. Analysis began at the best representative aortic outflow plane, designated as plane 1. Figure 2 shows representative slices illustrating the formation of the initial filling vortex ring. Figure 2a is an image along the aortic outflow tract, while 2b represents an image oriented 100˚ from it, about the long axis. Streamlines and coloring were superimposed as part of the analysis to visualize bloodflow direction and circulation. A composite of the maximal vorticity calculations seen during the A wave injection phase along each imaging plane is presented in Figure 3. For each of the three participants, a consistent decline or absence of a vorticity measurement was noted between 80˚ and 120˚ from the outflow plane. The sequential error analysis examined the changes in the average ring vorticity values for each ring and subject. The errors were pooled, averaged and plotted against the number of axial measurements, yielding an inverse exponential relationship (Fig 4) and mean errors up to 25%.











Conclusions

The apparent vorticity is strongly influenced by the plane of acquisition. Thus, the use of a single imaging plane (2 axial measurements) for characterizing the diastolic filling vortices in the left ventricle may prevent the investigator from obtaining reliable, and repeatable, measurements of the vortex ring. Our preliminary analysis indicates 4 axial planes, at minimum, are required to ensure average vorticity measurement errors of less than 5%. The use of multiple axial planes also ensures detection of the vortex ring as anatomy or pathology alters the local fluid dynamics.

References [1] Gharib etal. 2006 PNAS **103**(16);p 6305-8; [2] Gill etal 2004 ISMRM, #1823