Imaging Vignette

Multiplanar Visualization of Blood Flow Using Echocardiographic Particle Imaging Velocimetry

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Echocardiographic Particle Imaging Velocimetry (ECHO-PIV) is a noninvasive technique where acoustic reflections from ultrasound contrast agents are tracked frame by frame for characterizing 2-dimensional cardiac and vascular flow fields. Three-dimensional asymmetries in flow sequence can be interpreted by using multiplanar reconstructions of echo-PIV images obtained by biplane echocardiography (Fig. 1, Online Videos 1, 2, and 3). For example, the sequence of flow in a normal left ventricle (LV) (Fig. 2, Online Video 4) is consistent with the formation of asymmetric toroidal vortex ring in early diastole (Online Video 5). The asymmetric vortex is cleared in systole as blood is ejected through a narrow jet in the LV outflow with surrounding shear layers (Fig. 3, Online Video 4). Asymmetry of filling vortex and shear layers during ejection explain previously reported Doppler recordings of skewed velocity distributions in the LV cavity (1). The left atrial (LA) flow (Fig. 4, Online Video 6) illustrates the presence of multiple small circulating vortices. The jet from the right upper pulmonary vein passes peripherally along the wall with minimal entrainment. The vortices in the cavity vanish with the onset of mitral valve opening. The presence of multiple transient vortices in the normal subject may have beneficial effects in avoiding LA stasis in sinus rhythm. Flow in the descending thoracic aorta (Fig. 5, Online Video 7) shows skewed axial velocity profiles. Although high velocity forward motion is underestimated, retrograde streaming in systole is visualized. In addition, strong secondary recirculating flows are seen in diastole. Presence of flow asymmetry and retrograde flow from descending thoracic aorta has been recently identified as a potential pathway for retrograde cerebral embolism of plaques formed in descending thoracic aorta (2).

Figure 1. Biplane Recordings of Echo Contrast Particle Imaging Velocimetry

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Figure 1. Continued

High-temporal resolution contrast echocardiography is recorded from transthoracic apical long-axis view (A) and 2-chamber view of the left ventricle (B). Note the intracavitary vortex (blue arrow). Left atrial flow in transesophageal 4-chamber view of the left atrium (C) and 2 chamber view (D) shows a transient low velocity vortex (blue arrow) formed before the opening of mitral valve. Transesophageal views of the descending thoracic aorta in short axis (E) and long axis (F) reveals presence of retrograde flow in diastole (blue arrow). See Online Videos 1, 2, and 3.

Figure 2. Left Ventricular Flow During the Early Diastolic Filling Phase

Multiplanar snapshots of 3 time frames showing blood flow vorticity, which corresponds to the local rotation of fluid particles (red, counterclockwise rotation, and blue, clockwise rotation). The velocities of the tracked contrast particles are represented with arrows. In a normal heart, the shear layer that emerges from the mitral valve leaflets rolls up into a nearly circular vortex ring whose rotary motion is visible on both planes (left). The vortex propagates away from the mitral valve’s leaflets and entrains the ambient fluid inside the left ventricular cavity (middle), becoming a nonuniform ring structure, with a predominant clockwise rotation component on the long axis plane. Eventually, the clockwise rotating flow dominates the blood motion, and washed out into the apex, while the 3-dimensional ring-shaped vortex is no longer recognizable (right). See Online Videos 4 and 5. Schematic drawings by Craig Skaggs.
Figure 3. Left Ventricular Flow During Ejection

Blood is ejected out of the left ventricle with formation of a central jet surrounded by shear layers on the long axis (left). The shear layer with clockwise rotation is displaced towards the submtrial region and the counter-clockwise shear layer, at the wall of the left ventricular outflow tract, increases progressively when the flow develops an outflow jet surrounded by a 3-dimensional shear structure recognizable on the orthogonal plane (middle), during end ejection the 3-dimensional flow jet and shear extends toward the apex that is washed out (right). Schematic drawings by Craig Skaggs.

Figure 4. Visualization of Flow in the Left Atrium

Flow from the right pulmonary veins follows the contour of the atrial wall with formation of clockwise shear layers on both planes (left, blue). Transient 3-dimensional counterclockwise motion (red) fills the left atrial cavity (left, middle) and disappears with the opening of mitral valve (right). See Online Video 6. Schematic drawings by Craig Skaggs.
Figure 5. Visualization of Diastolic Flow in the Descending Thoracic Aorta

Secondary flows are seen in the aorta in diastole and characterized with formation of transient clockwise (blue) and counterclockwise (red) vortices associated to retrograde blood flow. See Online Video 7. Schematic drawings by Craig Skaggs.

REFERENCES


APPENDIX

For supplementary videos and their legends, please see the online version of this article.