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Momentum and Energy Transfer in Cardiac Pumping

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Blood flow processes and energy transfer characteristics in the human left ventricle are studied via a combination of computational fluid dynamics and magnetic resonance imaging. Cardiac imaging from a normal adult is segmented and transformed to generate three-dimensional (3D) moving elements for an arbitrary Lagrangian Eulerian formulation of the Navier-Stokes equations. The pulsating flow processes produced by cardiac pumping are very complicated to analyze and difficult for presentation. They are studied by calculating the Lagrange stream function on several longitudinal planes. Relating these sectional flow patterns with ventricle motion demonstrates the formation, growth and decay of 3D vortices in the ventricle. The mitral valve motion on diastolic flow is studied using a two-dimensional model. During early systole, the momentum produced by cardiac contraction does not interrupt vortices in the ventricle; it follows the vortices to the aortic valve. As the flow rate increases the vortices reduce, reflecting an effective momentum and energy transport from the ventricular wall to the systolic flow. The cardiac pumping can be further characterized by kinetic energy flux from the ventricle to the blood flow, the rate of work done by pressure and that by shear stresses. In terms of the Bernoulli equation, the total energy fluxes are practically balanced by the rate change of kinetic energy in the ventricle. The work done by shear and dissipation of energy in the ventricle are rather small. All these kinematic, dynamic and energy characteristics portray an optimal cardiac pumping of the normal human left ventricle. The wall motion can be expressed by kinetic energy flux though energy delivered to blood flow by the ventricular dilatation is primarily contributed by the rate of work done by pressure. For an inflow to the normal ventricle, the work done by shear stresses and the dissipation of energy are small in both 2D and 3D computational analyses. The results of these two models complement each other. The 2D model remains useful and practical as in most of engineering analyses.