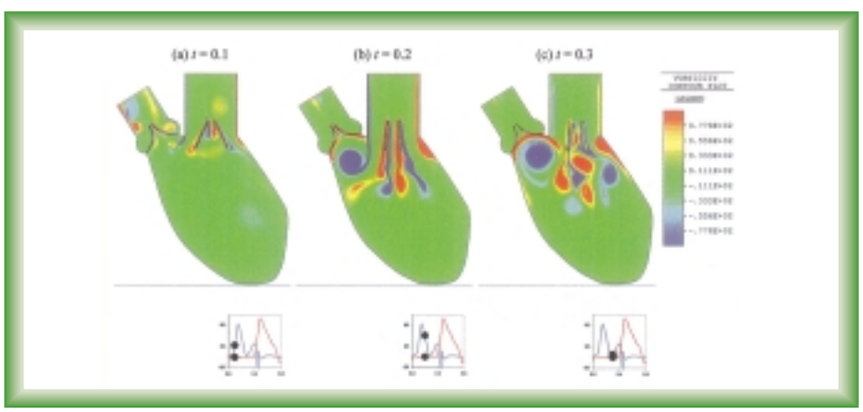
Modeling the Heart

The tough, excitable muscular tissue that forms our steadily beating heart is wondrous indeed.

The heart of the tiny tree shrew beats about 780 times per minute, while that of the massive elephant beats about 30 times per minute. Despite these differences, almost all healthy mammals tend to live about the same number of heartbeats per lifetime, about 25 to 35 million beats in the case of humans, although there are variations. Given the heart's complexity, it is a wonder that this hardworking organ – really two separate organs contracting in unison – doesn't give out sooner. Oxygenated blood from the lungs enters the left atrium and then through the open mitral (bicuspid) valve into the left ventricle (LV). When the LV contracts, the mitral valve slams shut, and its blood is forced out into the body, through the aortic valve under pressure. Deoxygenated blood returns through the right atrium, and then through the tricuspid valve, into the right ventricle (RV). When the RV contracts, in synchrony with the LV, the tricuspid valve closes, and the RV's blood is forced back out to the lungs, through yet another valve.

The mitral and aortic valves are the most likely to fail, and every year more than 170,000 mechanical (MHV) or biological heart valves are implanted to correct these and other failures. Current MHVs produce non-ideal fluid flow, and better understanding the complex fluid mechanics of blood in response to MHV and LV operation is crucial for MHV improvement. Although the problem is too complex for a full 3-dimensional solution using current computers, Prof. Shmuel Einav and Dr. Moshe Rosenfeld have tackled a simplified 2-dimensional version of this problem, modeling the LV with a 20,000-50,000 point mesh (a more realistic 3-dimensional LV model would require over 500,000 points). Since the researchers were primarily interested in the fluid flow field in the vicinity of the mitral valve itself, the motion of the LV walls was ignored. The incompressible, time-dependent Navier-Stokes equations were solved, using the imposed, time-dependent mitral and aortic flow rates described respectively by the blue and red curves in the figures below.

In calculations with a fixed mitral MHV and either steady or physiological incoming flow, a large vortex was found in the LV. Adding valve motion, using a single disk valve or a bileaflet valve, introduced major differences in the closing phase of the mitral valve. Strong shear layers developed in the small gap between the valve tips and the LV walls, creating strong vortices that altered the global flow in the LV, especially near the valve, a result that warrants considerable further study. Further refinements, include calculating the valve motion itself using convergence methods, changed the fine details (e.g., of vortex formation) but not the global flow. The investigators' computer models thus seem useful for studying many important aspects of blood flow across mechanical mitral heart valves.



The investigators also experimentally observed and measured the flow of a water-glycerin mixture, seeded with small silver-coated microspheres, in a transparent heart valve model. The system was attached to an electronically controlled pulsating pump. Light from an argon-ion laser, an electronic shutter and a video camera helped capture images of the particles' motion in the stream. These complementary studies should increase our understanding of the fluid mechanics of heart-MHV systems and how to improve their operation.