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How the heart works when it fills: what every fluid mechanician needs to know

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The two principles that govern the diastolic (filling) phase of all human hearts are: "constant volume pump" and "suction pump." The $\approx$ 850 ml volume of the pericardial sack decreases by only $\approx$ 40 ml by end systole. This requires that atrial-ventricular volumes simultaneously reciprocate and it underscores the pressure pump (systolic) and volume pump (diastolic) roles of the chambers. Of the 4 heart chambers – ONLY the left ventricle actually serves as a systolic pressure pump. When the normal left ventricle initiates filling after mitral valve opening, it generates only a small (4mmHg) maximum atrioventricular pressure gradient (LVP$<$ LAP) while its pressure continues to decrease for about 100 msec while its volume increases (dP/dV$<$ 0). Because the chamber recoils faster than it can fill it is a suction (volume) pump. The purpose of diastole is to fill the chamber (mass transfer) in the fraction of a second available in order to maintain cardiac output. The streamlines entering through the 5cm^2 mitral valve initially have a blunt velocity profile and because mitral valve plane alignment is off-center relative to LV long axis, blood rapidly forms an asymmetric toroidal vortex whose formation time has been shown to depend on LV chamber parameters of stiffness, relaxation and load. Recent Lagrangian coherent structure (LCS) analysis of vortex ring growth in the LV reveals nature's elegant fluid mechanics based solution to the diastolic mass transfer problem. The intraventricular vortex also "rinses" the trabeculated inner surface of the heart thereby preventing formation of blood clots and facilitates mitral leaflet coaptation to minimize mitral valve regurgitation.

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