Computational Simulation in a Left Ventricle During Filling

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1. Introduction

The flow inside a model left ventricle during filling represents one of the most interesting problems of the blood flow in the heart. The diastolic dysfunction can be defined as the inability of the left ventricle to fill and to maintain its stroke volume without abnormal increase of the atrial filling pressure. The diastolic dysfunction during filling is often early indicators of the heart failure and the diastolic dysfunction appears a primary cause of the morbidity from heart failure. The early clinical diagnosis pays particular attention to the features of the fluid dynamics during diastolic filling. Thus the biological fluid dynamics plays an important role to understand and interpret the early clinical diagnosis to the features of the diastolic filling.

The interesting feature of the flow phenomena in the left ventricle is the occurrence of the diastolic vortices inside the ventricular chamber. The objective of the present study is to investigate the presence of the vortex structures that develop at the tip of the mitral valve during the unsteady filling period. The flow phenomena in this study are studied under healthy conditions using data adapted from clinical measurements.

2. Mathematical Formulation of the Problem

The flow inside a model left ventricle of an incompressible fluid with density r and the dynamic viscosity m is considered. The left ventricle is modeled as the truncated prolate spheroid as shown in Fig. 1 and the mitral valve is assumed as the ellipsoid at the inlet. To construct the left ventricle chamber in Fig. 1 the equatorial- and polar-axis dimensions are used from the apex to the base. The equations to be solved are the continuity and Navier-Stokes equations.

$$\nabla \bullet \vec{u} = 0 \qquad (1)$$

$$\frac{\partial \vec{u}}{\partial t} + (\vec{u} \bullet \nabla)\vec{u} = -\frac{1}{\rho}\nabla P + \nu\nabla^2\vec{u} \qquad (2)$$

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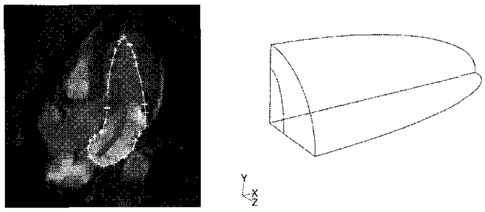

Fig. 1 The heart using the MR imaging technique and the model geometry of the left ventricle

The no-slip condition is imposed at the ventricle wall and the symmetry conditions are given at the y- and z-plane. The inlet velocity profile at the mitral valve is specified with the temporal waveform during the filling phase as shown in Fig. 2. The inflow at the mitral valve accelerates early in the inlet velocity temporal waveform and reaches a maximum of 0.5864 m/sec by 61 msec. After this point, the velocity magnitude begins to decrease and drops 0.1014 m/sec at 163 msec.

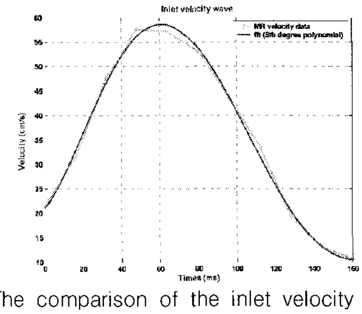

Fig. 2 The comparison of the inlet velocity waveform at the mitral valve between MR velocity data and curve fit

3. Results and Discussion

Fig. 3 illustrates the development of the vortex structures which move toward the ventricle apex during the diastolic phase. Immediately after the vortex structure is born at the edge of the mitral valve, the vortex sheet rolls-up and forms a well organized vortex structure. The vortex structure is attached to the edge of the mitral valve, and grows the size and intensity. It translates toward the ventricle apex with time. This vortex induces the formation of an opposite sign boundary layer vorticity at the ventricle wall.

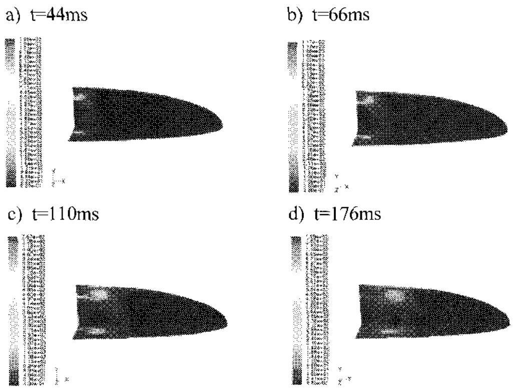

Fig. 3. Vorticity contour in the symmetric plane at R=1

Fig. 4 depicts the pressure contours in the symmetric planes of the left ventricle. The pressure field is dominated by the inertia during the initial accelerating phase and by the convection after the maximum inlet velcotiy. As show in Fig. 3 (a) the pressure distribution inside the left ventricle has the negative values and the local minimum value of the pressure field occurs at the region of corresponding to the birth of the vortex structure. At the early stage of the decelerating phase, there are positive values of the intraventricular pressure.

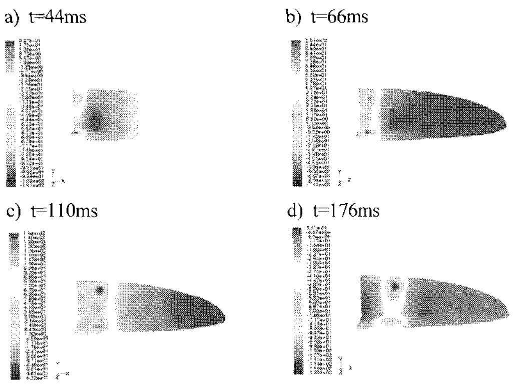

Fig. 4. Pressure contours in the symmetric plane at R=1

Fig. 5 illustrates the time evolution of the pressure difference between the mitral valve and the ventricle apex during the inlet velocity temporal waveform. The R is defined as the ratio of the cross-sectional area of the partial opening to the full opening of the mitral valve. The minimum pressure drop occurs at the maximum acceleration of the inlet flow while the maximum pressure drop gains at the maximum decelerating of the inlet flow.

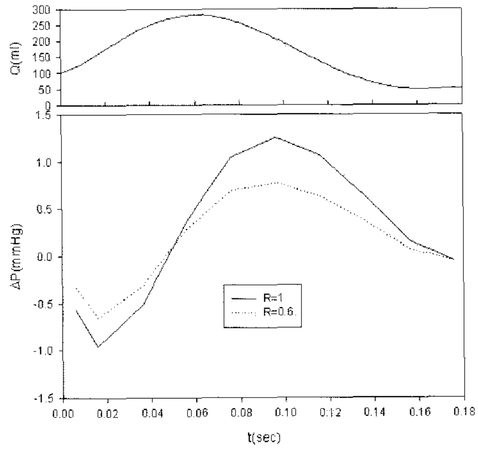

Fig. 5. The time evolution of the pressure difference between the mitral valve and the apex

4. Concluding Remarks

The ventricular filling problem has been numerically studied by solving the equations of motion in a prolate spheroid geometry. During the early filling phase the velocity profile with the temporal waveform at the mitral valve is given by the clinical data. The vortex structure originates and develops at the edge of the mitral valve. The vortex sheet immediately rolls-up to form a well organized vortex structure. When the inlet flow decelerates, the vortex structure moves toward the ventricle apex. Intraventricular pressure is dominated by inertia during the early acceleration while it is dominated by the convection during the deceleration phase.

Acknowledgement

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