SMOOTHED PARTICLE HYDRODYNAMICS METHOD APPLIED TO CARDIOVASCULAR FLOWS

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INTRODUCTION

Investigation of blood flow behavior in the left ventricle (LV) during the filling phase (diastolic phase) is of great interest to biomedical engineering and cardiology. In the process of detection/ refinement of heart diseases, physicians can only rely on the clinical data and their personal experience. It is important, therefore, to develop decision tools that can help surgeons testing, in silico, hemodynamic conditions of a patient. Following this idea, there was, during the last decades, a growing interest in computational modeling of the flow in the circulatory system under normal and pathological conditions. The most significant difficulty in traditional Computational Fluid Dynamics (CFD) methods is related to the mesh generation and re-meshing process required in problems with deformable boundaries like for the simulation of cardiovascular flows. Moreover, these methods generate some data that do not contribute in direct clinical decisions. An alternative to overcome these limitations can be the new generation of numerical methods called meshfree methods.

Smoothed Particle Hydrodynamics (SPH) is a Lagrangian meshfree method created originally to simulate compressible flows in astrophysics [1]. Most of the incompressible flow simulations using SPH are dealing with free surface or low Reynolds number cases. As a primary approach, we performed 2D modeling of the flow inside a simplified model of the LV with rigid walls during diastolic phase [2]. The present work is the first attempt to demonstrate the ability and the accuracy of our home-made code to simulate pulsatile flows using SPH method.

METHODS

SPH considers a continuum medium as a set of number of particles. Each particle has its own properties such as pressure and velocity. Numerical discretization involves interpolating the value of a physical property (A) at given particle (a) based on an interpolating function (W), using the properties of neighboring particles of particle (a) (Figure 1).

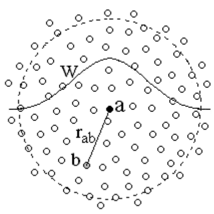

Figure 1: Principle of SPH and neighbors of particle (a)

This concept is interpreted numerically as [1],

$$A(\vec{r}_a) = \sum_b m_b \frac{A_b}{\rho_b} W(\vec{r}_{ab}, h)$$

Using this equation, the physical governing equations of the flow can be rewritten in the form of SPH formulation.

RESULTS AND DISCUSSION

Simplified LV geometry with initial distribution of the fluid particles and unsteady inlet velocity are shown in Figure (2).

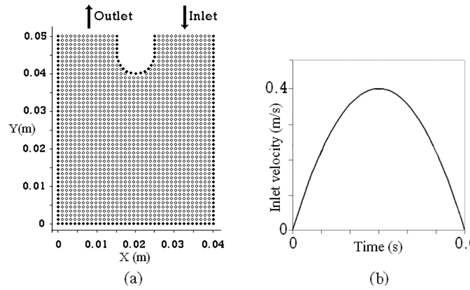

Figure 2: **(a)** Initial distribution of particles, **(b)** Inlet velocity.

The simulated velocity vector fields for three different instants during an inlet velocity cycle are shown in Figure (3).

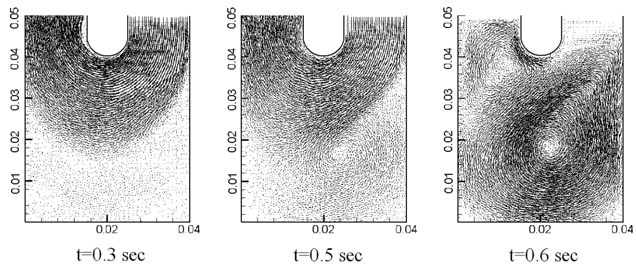

Figure 3: Velocity vectors at different instants of the inlet velocity cycle.

In acceleration phase the inlet jet penetrates in the LV and in deceleration phase, a coherent structure appears (t=0.5 s) and then is convected towards the centre of LV cavity (t=0.6 s). The main vortex structure is very close to the one observed in the LV during filling phase [3]. The velocity profiles at different cross sections at t=0.3 (s) have been compared with the results of finite volume (FV) method in Figure 4.

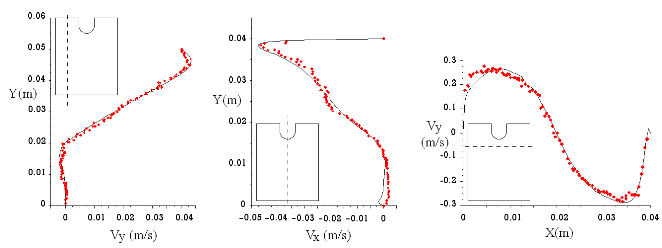

Figure 4: Comparison of velocity profiles at different cross sections of the LV obtained with SPH (•) and FV (—).

CONCLUSIONS

As a conclusion, the close agreement between our results with the ones obtained using FV method shows that SPH represents a very good approximation to model unsteady flow in the LV. To reach physiological conditions, several improvements are still needed, such as using a realistic geometry and considering myocardial deformation.

REFERENCES

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