Level set methods to build moving meshes for patient specific blood flow simulations

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Introduction

The hemodynamic factor in the thoracic aorta is believed to play an important role in the initiation and the progress of endovascular injuries. Most reported studies are dealing with averaged physiological geometries and rigid arterial boundaries. However, for diseases such as the aortic dissection, the geometrical changes are very patient specific and the wall motions over the cardiac cycle influence the blood flow drastically. There is a need to generalize the patient specific studies where the actual inlet/outlet boundary conditions and wall motions are accounted for. In the most general approach, the geometrical changes during the cardiac cycle result from the coupled fluid-structure interaction problem. This path is very challenging because the density of blood and tissues are of the same order, the rheology of the vessels is far from well understood and because the actual answer depends on the interaction of the arteries with the surrounding organs. Another option is to study the response of the blood flow submitted to prescribed wall motions and geometry changes. In this study we propose a method to build patient specific geometric data and boundary conditions for unsteady CFD runs with variable meshes valid over the cardiac cycle.

Materials and methods

Recently, the anatomical surfaces have been extracted by means of Level Set methods (Sethian, 1999) that accurately model the complex surfaces of pathological objects (T. Deschamps, 2004).

Level set methods offer a highly robust and accurate method for tracking the interface motion in a volume of interest coming from MRI sequences. Given an initial position for an interface Γ, where Γ is a closed surface in R^3, and a speed function F which gives the speed of Γ in its normal direction, the level set method takes the perspective of viewing Γ as a zero level set of a function $\phi(x,t)$ from R^3 to R whose evolution equation is :

$$\phi_t + F|\nabla\phi| = 0,$$
$$\phi(x, t=0) = given$$

Our main contribution is twofold:

1- develop a specific MRI (Balanced-TFE – Philips Intera 1.5 T) sequence in order to extract the full geometric data at several phases over the cardiac cycle,

2- develop a noise reduction strategy by improving the anisotropic diffusion algorithm of Perona and Malik (1990) in 3D.

Finally, the level-set/fast marching method is applied to each set of geometric data on a phase by phase basis. This results in a set of independent meshes that can be used to describe the geometry evolution of the cardiac cycle.

Results and discussion

Six human aortic volumes according to the the six most representative phases of the cardiac cycle were extracted. The moving mesh was made by means of a spatial transformation from the first mesh towards the template samples. The whole cardiac cycle was reconstructed by the interpolation between each phase. Figure 1 displays the intersection of a plane with the extracted volumes, at two different phases.

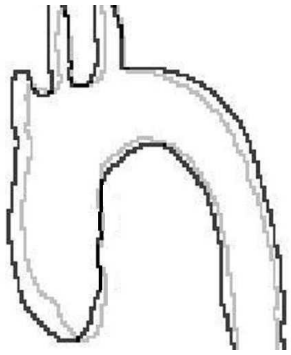

Fig. 1: Intersection of interfaces with a plane at 67ms (systole = black) and at 402ms (diastole = gray).

Conclusion

The proposed approach permits the computation of the blood flow under realistic *in vivo* time evolving conditions. It is much simpler than the full coupled fluid-structure problem and has the potential to provide a better picture of the hemodynamic status of specific patients. Insights about the physiopathology of some arterial diseases are also expected.

References

T. Deschamps (2004), Vessel segmentation and blood flow simulation using Level-Sets and Embedded boundary methods. International Congress Series 1268 (2004) 75– 80.

P. Perona and J. Malik (1990), Scale-space and edge detection using ansotropic diffusion, IEEE Transactions on Pattern Analysis and Machine Intelligence, 12(7):629-639.

J.A. Sethian (1999): Level Set Methods and Fast Marching Methods. Cambridge University Press