Numerical simulation of blood flow through a patient specific stented cerebral aneurysm using an immersed boundary approach.

M. Mendina*, G. Usera*
Corresponding author: mmendina@fing.edu.uy

Universidad de la República, Uruguay

Abstract: Blood flow through a patient specific cerebral aneurysm is simulated using an immersed boundary approach, under different treatment options using stents. Open source flow solver caffa3d.MBRi provides the framework in which the aneurysm boundaries and the stents boundaries, described in STL format, are represented using the immersed boundary approach over a block structured cartesian grid. The grid block structure is automatically built, optimised to reduce the void cell overhead, and to promote a nearly balanced load distribution in parallel computations. This strategy provides a fully automated and hassel free gridding approach, which preserves the efficiency of structured grids.

Keywords: Immersed boundary, finite volume, cerebral aneurysm, domain decomposition, open source

1 Introduction

A cerebral aneurysm is a cerebrovascular disease that affects the wall of a vessel which dilates and, eventually, breaks. Different treatments have been proposed, among which endovascular embolization is a technique that does not requires invasive surgery and involves placing coils and stents at the aneurysm location, that ultimately exclude the aneurysm from blood circulation. Accurate CFD predictions of local hemodynamics in patient specific geometries would provide clinicians with valuable pre-treatment and post-treatment data. The particular case considered in this work was proposed within the Virtual Intracranial Stenting Challenge 2011 [1], aimed at assessing the accuracy of CFD simulations of blood flow through patient specific aneurysm geometries.

2 Method

The caffa3d.MBRi open source F90 flow solver is used in this work, which is an evolution of caffa3d.MB [2], featuring full multi-grid, immersed boundary approach, domain decomposition based parallelism at block grid level using MPI, and several other extensions. The block structured grid strategy inherent to caffa3d.MBRi provides the basis for tailoring the overall cartesian grid to the aneurysm geometry in such a way that the void cell overhead is minimized. Figure 1 shows the result of this approach, where the Cartesian grid is composed of 143 cube grid blocks, of side 5mm. Each grid block is formed by $32^3$ (coarse grid) or $64^3$ (fine grid) uniform cells, yielding about 5 and 40 million cells respectively. The boundaries of each grid block are either one-to-one interfaces with another grid block, or non-slip boundary conditions at void spaces, outside the aneurysm geometry, with the exception of grid block boundary cells at the inlets and outlets, where specified flow conditions were applied. The geometry of the aneurysm itself is not enforced at the grid level, but represented through a scalar field which contains the signed distance from each grid cell to the aneurysm boundary, being negative inside the vessels and positive outside it. Immersed boundary approach followed the direct forcing strategy with interpolation as proposed in [3]. Vessels walls were considered rigid and flow conditions stationary, as stated in the Challenge procedures to easier allow
intercomparision of results among different teams.

Figure 1: Block-structured cartesian grid tailored to the aneurysm geometry, minimising the void cell space and promoting near balanced parallel work distribution among blocks.

3 Results

Grid independent results were achieved for the non-treated case with both the coarse ($\delta=0.150\text{mm}$) and fine grids ($\delta=0.075\text{mm}$), while the fine grid was used for the stented cases, due to the small diameter of the stents wires. Blood was assumed to behave as a Newtonian fluid, with $\text{Re}\sim 50$ for the provided stationary flow conditions. Figure 2 presents partial results for the flow field at the aneurysm cavity.

Figure 2: a) Velocity module contour slice through $z=0$ section across the aneurysm cavity showing interaction with one type of stented treatment. b) X-Velocity profile across section ($z=0$, $x=0.01$), showing the effect of different treatment options onto the strength of the jet that enters the aneurysm cavity.

4 Conclusions and future work

Open source flow solver caffa3d.MBRi showed capable of predicting blood flow through an stented patient specific aneurysm geometry under idealized stationary conditions and rigid walls, stablished under the VISC11 Challenge. Block-structured cartesian grids, coupled with immersed boundary approach and MPI parallelization provided a cost effective strategy with very low gridding effort. Future plans aim at incorporating vessels walls dynamics, which under the immersed boundary approach require no modification of the grid, but recalculation of the scalar field that keeps track of the signed distance to the vessel wall.

References