Numerical Fluid-Structure Interaction Model for the Connection of Outflow Cannula of LVAD to the Aorta

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Abstract

Purpose: *Connecting outflow cannula of LVAD to the aorta is an underexplored issue but may have considerable impact. In fact the hemodynamic modifications due to implantation in this region can cause thromboembolic events. It is therefore important to understand the flow pattern in this region and the way device interacts with the cardiovascular system. We present here the mathematical settings and results of a numerical model of the anastomosis between the outflow cannula of LVAD and the aorta.*

Methods: *The geometry of the aorta and that of nearby large arteries is obtained from MRI and CT-scan data. The geometry of the arterial wall and that of the cannula is obtained by extruding the fluid surface based on a relation between wall thickness and local radius. Simulations are run using the parallel Finite Element library LifeV, which can address 3D Fluid-Structure Interaction (FSI). The interaction with the entire cardiovascular system is modeled by a multiscale model. The latter allows the coupling between the 3D model and a 1D tree model of the rest of the cardiovascular system.*

Results: *Our numerical model allows the understanding of the behavior of the blood flow near the anastomosis and the interaction between LVAD and the cardiovascular system. Besides, relevant parameters from the haemodynamical standpoint are identified in order to propose a general mathematical approach to identify an optimal configuration of the anastomosis between LVAD and aorta.*

1. Geometry & Mesh

1.1 Geometry Reconstruction

The geometry is reconstructed from DICOM images (mainly CT-scan) and consists in the aorta (from the aortic root to the descending aorta, including pre-cerebral vessels) and the outflow cannula. This is done using the InsightToolKit library (`www.itk.org`).

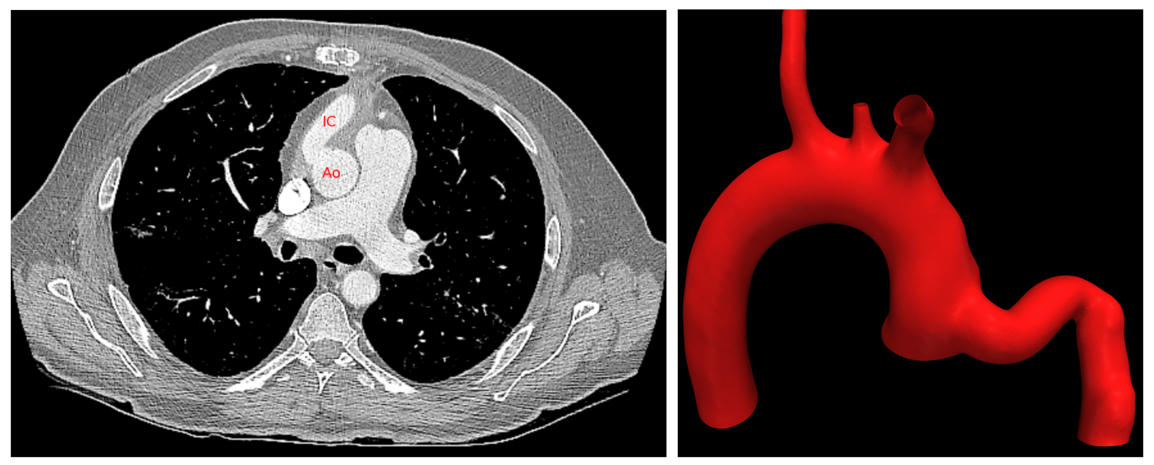

Figure 1: *Left: CT-scan slice at the anastomosis site between outflow cannula of the LVAD (IC) and the aorta (Ao), Right: Reconstructed geometry.*

1.2 Mesh generation

The mesh, created from the geometry, is composed of two parts: the fluid (blood) and the structure (arterial wall). The geometry allows to create the mesh that corresponds to fluid, but the entire arterial wall is not visible on CT-scan so that the mesh for the structure is constructed as a function of the local diameter of the vessel. The software used are the Vascular Modeling ToolKit (`www.vmtk.org`) and gmsh (`www.geuz.org/gmsh`).

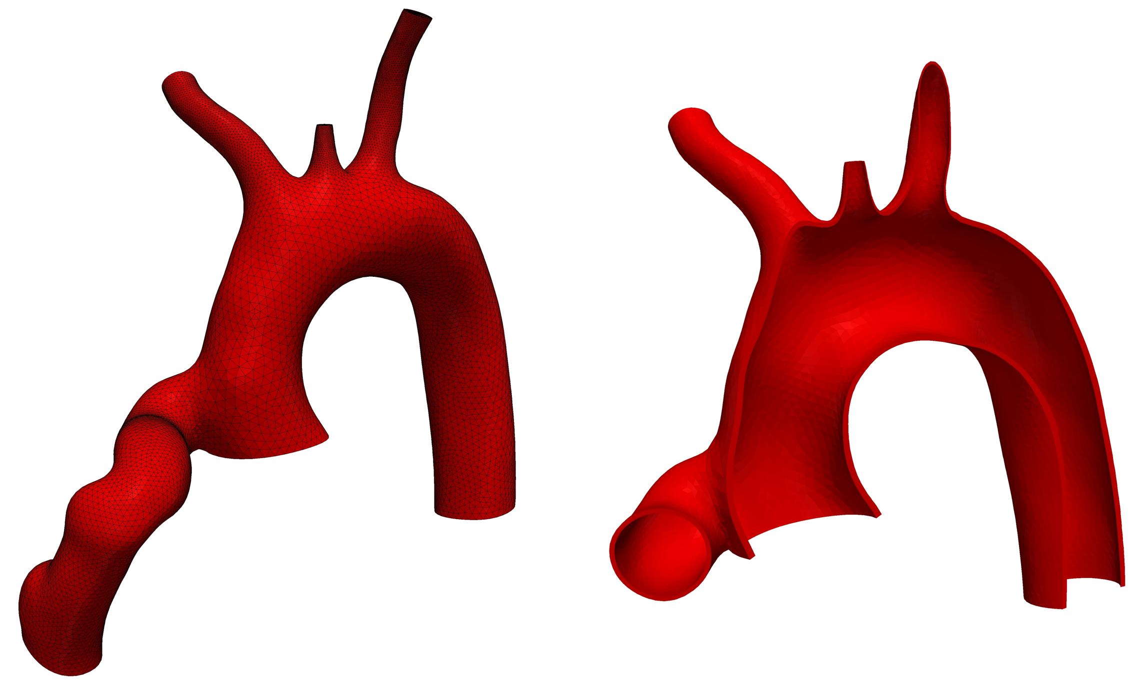

Figure 2: *Left: Fluid mesh, Right: Solid mesh.*

2. Simulations

2.1 Simulation Settings

Simulations are run using LifeV (`www.lifev.org`), a parallel Finite Element library that allows to solve the 3D Navier-Stokes equations and to take into account Fluid-Structure Interactions. The model for the structure is composed by a linear elasticity equation. Simulations are performed on clusters, e.g. Blue Gene/P (IBM) or Cray XT4 (Cray Inc.).

In this particular case the aortic valve is closed and all the inflow comes from the cannula of the LVAD. Boundary conditions are obtained from a 1D model previously developed and validated (see [1], [2]). This allows to couple the 3D model with the entire cardiovascular system.

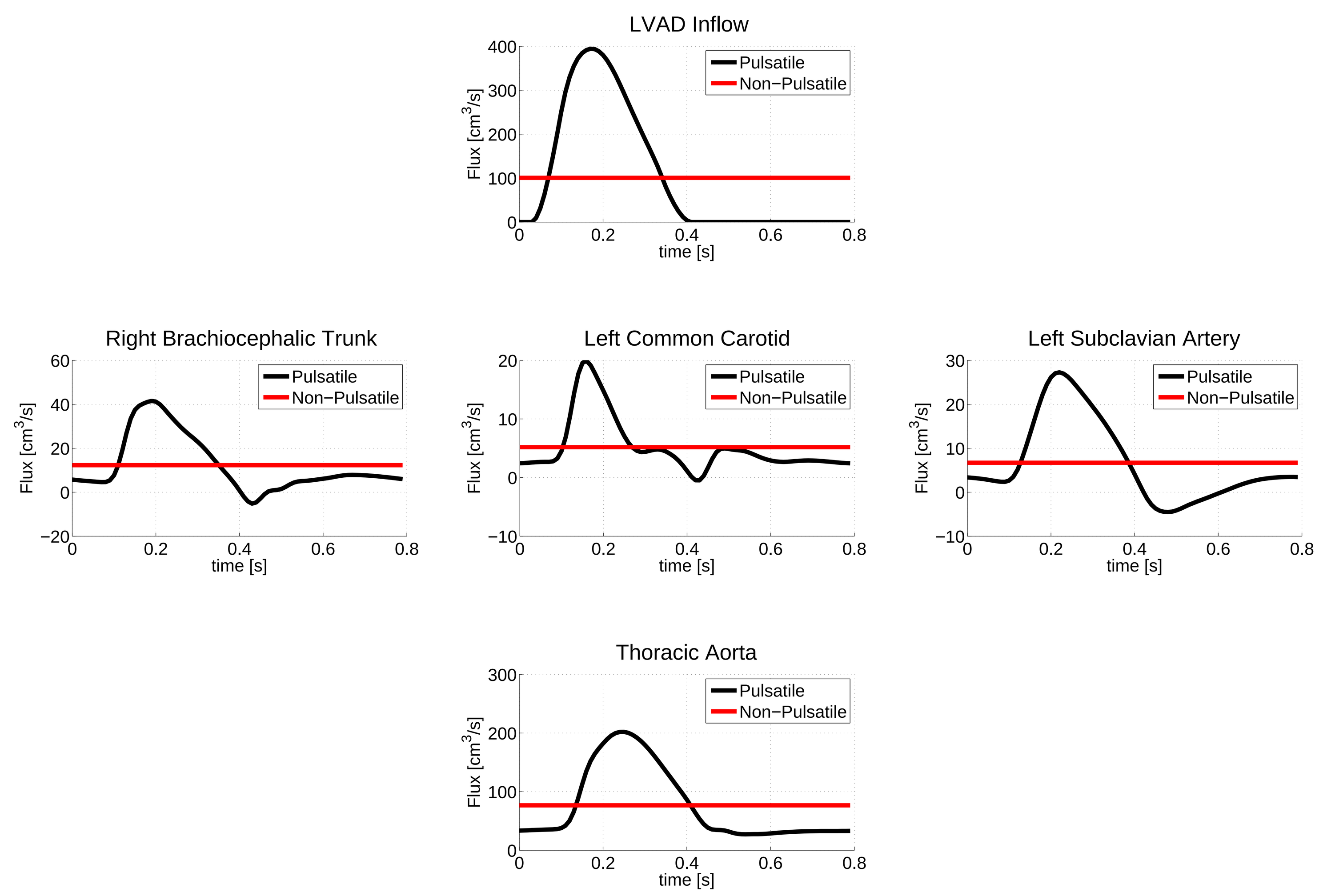

Figure 3: *Boundary Conditions. Fluxes imposed at inlet and outlets.*

2.2 Numerical Results

The following figures represent the results of numerical simulations that modelize a continuous flow LVAD over one heart beat. These figures highlight recirculating zones, wall shear stress abnormal distribution and velocity distribution of the blood.

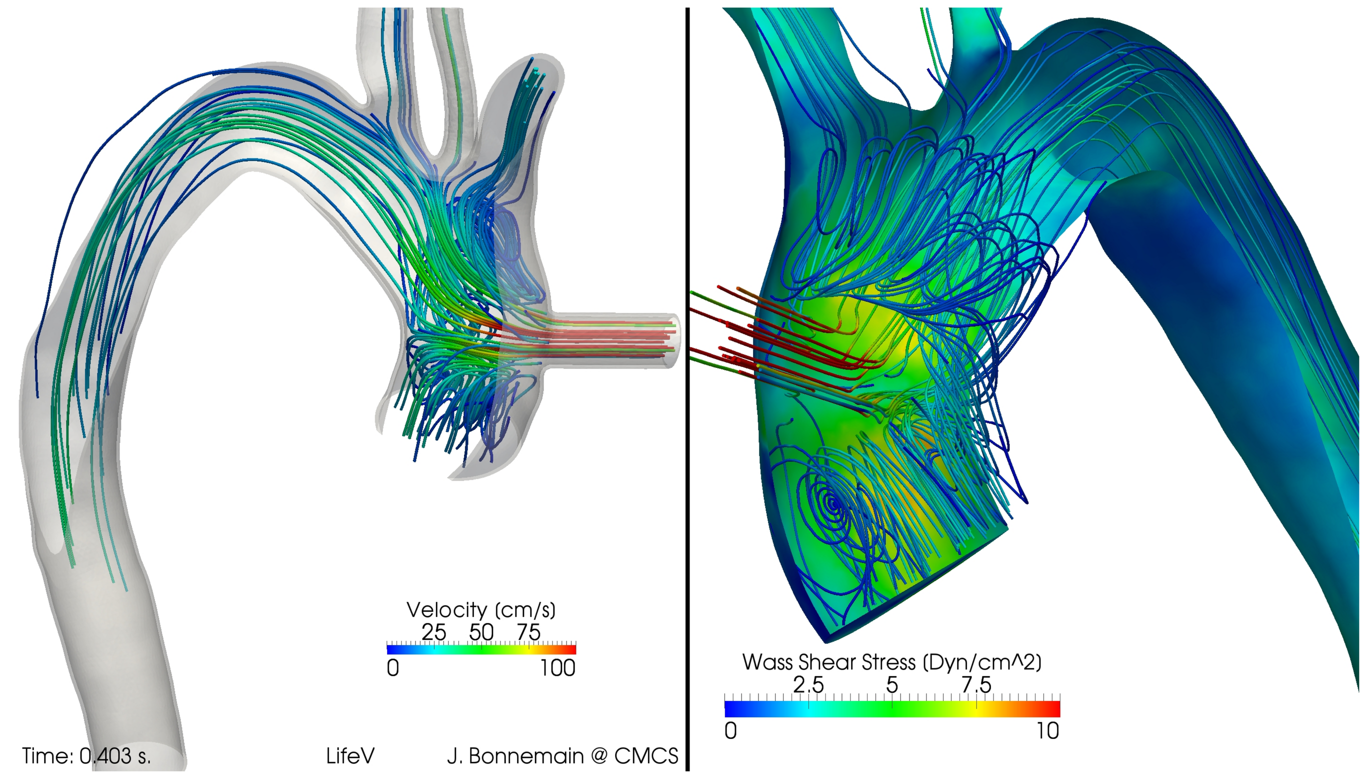

Figure 4: *Streamlines. Left: Streamlines are colored for the velocity, Right: Wall shear stress is displayed on the arterial wall.*

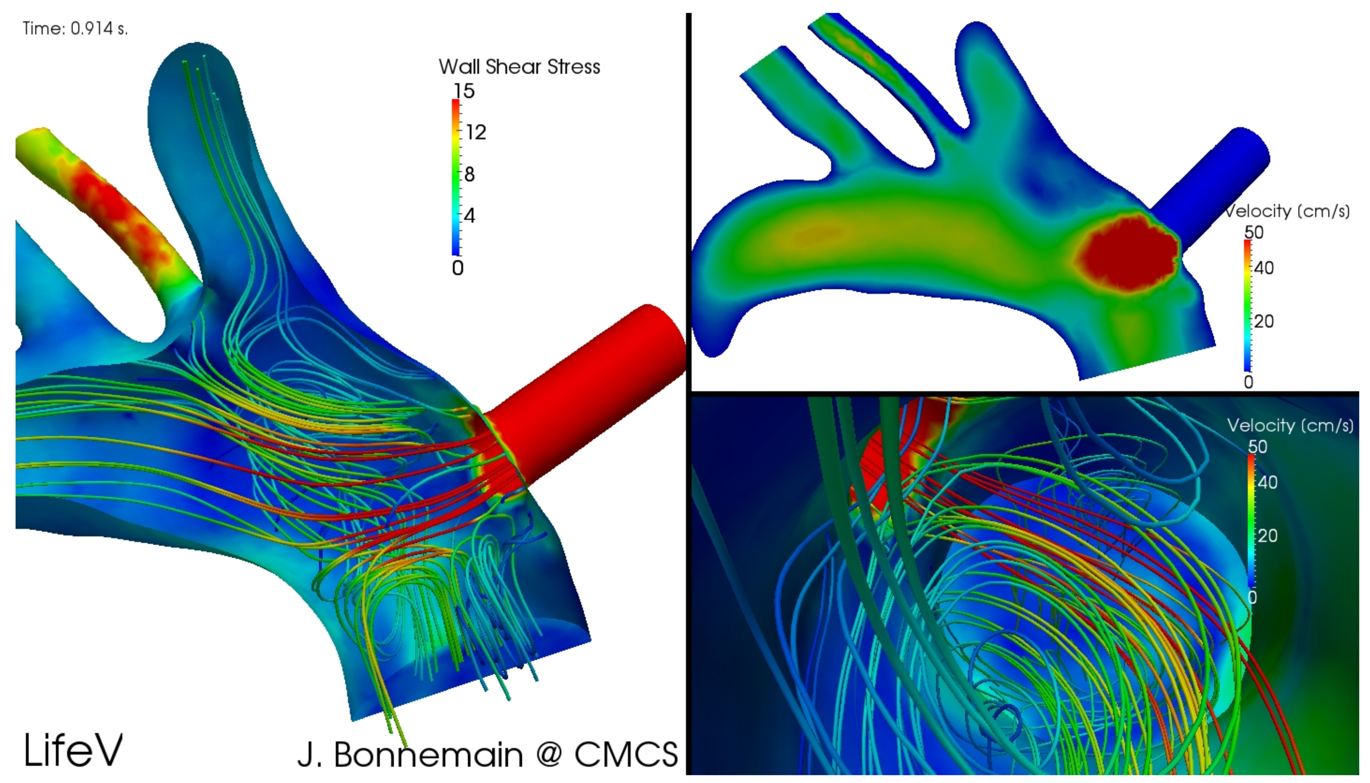

Figure 5: *Left: Streamlines and wall shear stress. Upper right: Velocity of the blood. Lower right: Streamlines inside the aorta, inferior view from the aortic root.*

References

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[2] P. Reymond, F. Merenda, F. Perren, D. Rufenacht, and N. Stergiopulos. Validation of a one-dimensional model of the systemic arterial tree. *Am J Physiol Heart Circ Physiol*, 297(1):H208–222, 2009.

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