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Patient-specific CFD simulations using MPTT rheological model: a type B aortic dissection case study

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Abstract

Cardiovascular diseases are the leading cause of mortality in the industrialized world. Among these diseases, aortic dissection is relatively unknown and difficult to treat, with a survival rate for most severe cases not exceeding 10%. This pathology occurs when an injury leads to a localized tear of the innermost layer of the aorta, called the entry port. It allows blood to flow between the layers of the aortic wall, forcing the layers apart and creating a false lumen. The dissection of these layers may extend over a long portion of the thoracic and abdominal aorta.

While type A dissection is a clinical emergency and associated with a high mortality, type B dissection differs in that the surgeons must choose the method of intervention. This type is more conducive to endovascular treatment, which seeks to obliterate the entrances to the false lumen with a stent. Poor redistribution of flow can be harmful for the health of the patient and the implementation of a stent in the aortic cross region has significant technical difficulties due to the angulation and the extent of the diseased area.

Surgical planning for this procedure is based on medical imaging carried out before the intervention. Therefore, it does not consider the deformation of the vascular structure during the operation, which can lead to both a bad sizing but also poor positioning of the stent. The objective of this research project is to develop a numerical tool to predict the consequences of these changes in terms of flow, hence to provide assistance to the surgical planning process.

Computational Fluid Dynamic simulations of blood flow in a type B aortic dissection were performed. Navier-Stokes equations for an incompressible fluid were solved using the OpenFOAM solver. Rigid wall and laminar flow were considered in a first step. The Windkessel model was applied to account for flow resistance encountered by the blood and a Poiseuille velocity profile at the inlet was based on a patient pulsatile flow rate. Modified Phan-Thien and Tanner model, which considers blood as a viscous and shear thinning fluid, was used to compare to the Newtonian model. A future step includes Fluid/Structure Interaction simulations compared to the acquisition and segmentation of dynamic 4D MRI data, with the use of the open source FOAM Extend software. Simulations must take into account the nonlinear behavior of the different materials composing the arterial wall layers.

The characterization of blood behavior with the deformability of the arterial wall is a first step into the surgical procedure simulation. Numerical predictions will allow the surgical team to make an appropriate choice of stent and to identify its most suitable positioning for each patient.