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Optimisation of lower limb bypass surgery hemodynamics with a patient specific 1D-OD model

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ABSTRACT

Atherosclerosis is the most common type of cardiovascular disease in the western countries. It gives rise to the thickening of large- and medium- size arteries. When the arteries narrow until occlusion, bypass remains the only surgical procedure to overcome the lesion. Bypass surgery indication and planning are commonly based on morphological data's provided from radiological exams and on clinical studies from the literature. Nowadays, no predictive hemodynamic tool is available to choose for the best surgical option in order to avoid long-term obstruction of bypasses.

In the context of the NHEMO (Numerical HEMOdynamics) project [5], we aim to develop a efficient tool for surgeons that predict rapidly patient-specific hemodynamic features. The method is based on the resolution of the one-dimensional governing equations of blood flow. We have chosen a discontinuous Galerkin method to discretize those equations in the peripheral arterial network and have coupled the 1D model with a zero-dimensional model (RCR windkessel model) that takes into account the smaller vessels [1,3,4].

In this work, we focus more specifically on two patients that underwent femoro-politeal bypass surgery (femoral artery replaced by a homograft). Pre- and post-surgery medical examinations (duplex ultrasound, MRI, angiography scan, arterial pressure measurements and pulse wave velocity measurement) permit us to estimate the patient specific parameters of our model: morphological data's (length and diameter of the arteries), velocity profile at the inlet, material specifications (elasticity of the arteries and prosthesis), resistance and compliance of the distal network.

However, uncertainty exists in the value of parameters associated with the model. Indeed, mathematical models serve as simplified and reduced representations of complex biological processes, that are constrained by the difficulty of assigning numerical values to the parameters. Furthermore, there exists a large amount of uncertainty related to the variability in human body conditions and measurements [2].

The present study aims to analyze the sensitivity of these parameters through the 1D-0D model for patient-specific simulations. We aim to emphasize the influence of each of them on the results of the simulation, by analyzing the variation in magnitude and shape of the pressure and velocity waves.

The results show that the parameters having a great sensitivity and that affect the wave magnitude a lot are the windkessel R,C parameters of the outlets and the elasticity parameter β (Fig. 1) [6].

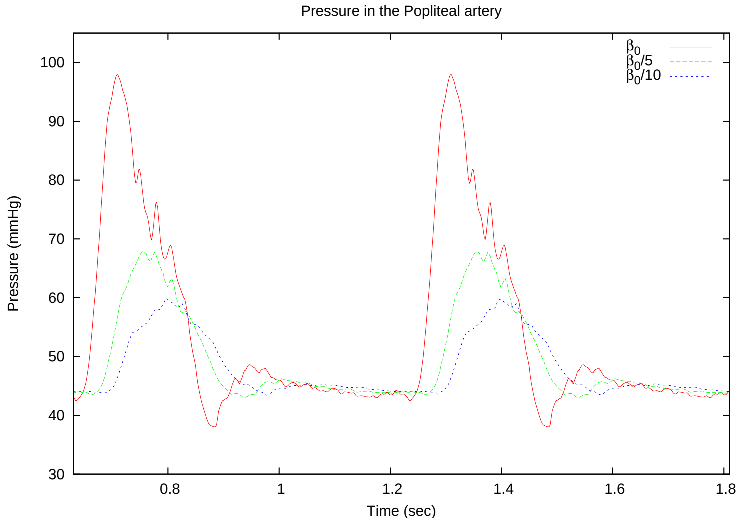

Figure 1: Pressure time history for different β parameters of the arteries: $\beta_0 \simeq 8.10^{-6}\ g\, cm^{-2}\, s^{-2}$

On the opposite, we show that a variation of the blood viscosity and a geometrical 1D complexity does not introduce noticeable variations of the results.

Focusing on the parameters showing great sensitivity, we have computed the parametric model for two clinical cases of femoro-popliteal surgery. The results of the simulation (pressure and velocity waveforms) show a good agreement with the waveforms observed in post operative measurements.

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