APPLICATION OF THE PFEM TO THE STUDY OF BLOOD FLOWS AND THEIR INTERACTIONS WITH ARTERY WALLS

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1. Introduction

Cardiovascular diseases are the leading cause of mortality worldwide, with projections indicating a concerning rise in related deaths. Understanding the hemodynamics and biomechanical mechanisms underlying vascular failure is essential for advancing diagnostic and therapeutic strategies. In this context, computational models offer promising tools that can really improve patient care. The current study aims at demonstrating the relevance of the Particle Finite Element Method (PFEM) to model fluid-structure interactions between artery walls and blood flows, and assess the corresponding biomechanical aspects.

2. Materials and Methods

The fluid-structure interaction problem is addressed using a partitioned approach with a strong coupling between a PFEM model of the fluid [1] and Metafor, an in-house non-linear large deformation finite element model, for the solid [2,3]. Blood is either treated as a Newtonian or Casson fluid. Different modeling approaches are used for the deformation of blood vessels, with either linear elastic, Neo-Hookean, or Mooney-Rivlin hyperelastic models incorporated into either a single or a three-layer structure (intima - media - adventitia) of the blood vessel wall.

3. Results

The numerical simulations successfully describe a wide range of situations, from the ejection of blood from the left ventricle (Fig.1), the blood flow in the healthy aortic artery, to the dynamics of an (axisymmetric) abdominal aortic aneurysm and, ultimately, its rupture. The analysis of the results suggests that, although the flow rates and deformation of the aortic wall are only weakly sensitive to the constitutive laws, these assumptions do have a significant influence on some physiologically relevant parameters. In particular, the wall shear stress, which can hardly be measured *in vivo* but is of high clinical significance in atherosclerosis diagnosis, appears to be strongly sensitive to the modeling approach. The simulations also demonstrate the limitation of the current practice of using aneurysm size as sole criterion for surgical intervention and explain the importance of biological remodeling processes (with the replacement of elastin by stiffer collagen) in preventing the development and rupture of an aneurysm.

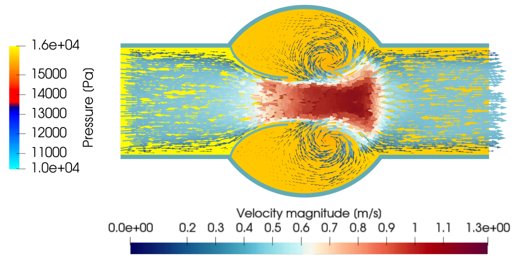

Figure 1: Pressure (background) and velocity (arrows) fields in a 2D model of the aortic valve during systole.

4. Discussion and Conclusions

To the best of our knowledge, this work describes the very first applications of the PFEM to the study of blood flows. Although the model should be improved, for instance by introducing a turbulence model to deal with high-speed flow through the aortic valve, the results demonstrate the high potential of this method for describing the interactions of blood flows with the deforming artery walls.

5. References

1. Février S et al., Comput Mech (2024).
2. Ponthot JP, *Metafor*, http://metafor.ltas.ulg.ac.be
3. Lacroix M et al., Comput Math Appl;155:51-65 (2024).