INTRACRANIAL ANEURYSMS: WHAT ARE YOU MISSING IF YOU CONSIDER FULLY RIGID ARTERIAL TISSUE?

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Introduction

The simulation of Intracranial Aneurysms (IAs) using Computational Fluid Dynamics (CFD) has been thoroughly studied over the past few years. The aim generally revolves around rupture risk assessment in order to aid physicians in their medical decisions. CFD patient-specific results should contribute to a better diagnosis and improve the relevance of a potential clinical intervention. While CFD has been widely applied for simulating IAs, the literature covering Fluid-Structure Interaction (FSI) remains scarce. Arterial tissue is commonly modelled as fully rigid, although publications have emphasized the wide range of mechanical properties and thickness profiles aneurysmal tissue can feature [1]. Among the few research works covering FSI in IAs, a large majority investigates complex patient-specific geometries [2]. This, along with different modelling hypotheses, impedes direct comparisons between studies, hampering the field's progress. Idealized aneurysm geometries are still missing for studying the FSI-related phenomena in a more controlled manner.

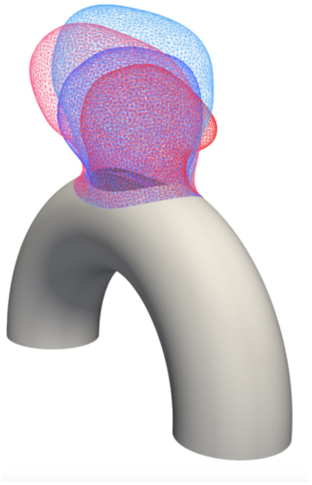

Figure 1: View of the simplified artery with various superimposed aneurysm shapes.

Methods

To bridge the gap between existing studies, we propose an idealized sidewall aneurysm geometry, composed of a toroidal artery intersected by a spherical aneurysm. The aneurysm membrane can be exchanged for more complex shapes, making the case extremely versatile (cf. Figure 1). It provides an adequate environment to assess the system's sensitivity with respect to a large span of physical parameters, such as the stiffness and thickness of the walls. We present our FSI simulation framework, which couples an Arbitrary Lagrangian-Eulerian (ALE) formulation for the fluid and an updated Lagrangian solid solver (described in [3]). The two solvers are strongly coupled, iterating between solving the incompressible Navier-Stokes equations and assessing the solid's hyperelastic response to fluid stresses. A non-Newtonian blood rheology model is applied for the fluid and haemodynamic metrics such as the Wall Shear Stress (WSS) and the Oscillatory Shear Index (OSI) are evaluated in the different simulated configurations.

Results

Using the introduced idealized aneurysm geometry, we study the impact of physical and geometrical parameters on the WSS and OSI. As these metrics are classically employed as risk indicators for IAs, we use them to quantify the discrepancies between different configurations. We also simulate a case with static arterial tissue as a reference in order to evaluate the limits of the rigid-wall assumption. Our findings demonstrate the relevance of FSI modelling depending on the prescribed physical parameters and aneurysm phenotypes.

Discussion

The few studies presenting FSI simulations of IAs explore intricate patient-specific structures and make use of a broad spectrum of physical parameters, whose impact on the obtained results remains largely unexplored. This research work paves the way towards a more unified view of FSI-related phenomena in IAs. Although the analysis of patient-specific geometries is our ultimate goal, we believe that simple trends must be highlighted in basic test cases like the one presented here.

References

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