PhD Position: Cross-modality and In-vitro Validation of a High-fidelity Framework for the Simulation of Intracranial Aneurysms Hemodynamics augmented by 4D flow MRI

Context

Intracranial aneurysms are balloonings of blood vessels in the brain, thought to affect nearly 1 out of 30 adults worldwide. Most never rupture, but those who do have disastrous consequences. The fatality rate is 50%, and many survivors are permanently disabled, not to mention the significant economic burden on the patient and the healthcare system.

Numerical simulation of blood flow in unruptured intracranial aneurysms has been widely used to non-invasively study hemodynamics in realistic models reconstructed from patient-specific vascular volumes. This allows to calculate a variety of determinant factors contributing to the risk of growth and rupture (i.e., wall shear stress, oscillatory shear index, relative residence time) that are otherwise difficult to measure in vivo. One challenge to improve clinical relevance lies in the need to adapt the simulations to the physiology of each patient, to faithfully simulate the way blood circulates in the sac and the forces it exerts on the vessel walls and avoid poor interpretation of risk areas and pathological mechanisms.

Developing new numerical capabilities enriched with individualized clinical data to accurately assess the individual risk of intracranial aneurysm rupture and optimize treatment outcomes in the follow-up of endovascular repair is thus of tremendous medical and societal interest, both to support decision-making and assessment of treatment options by doctors, and to improve the life quality and expectancy of patients.

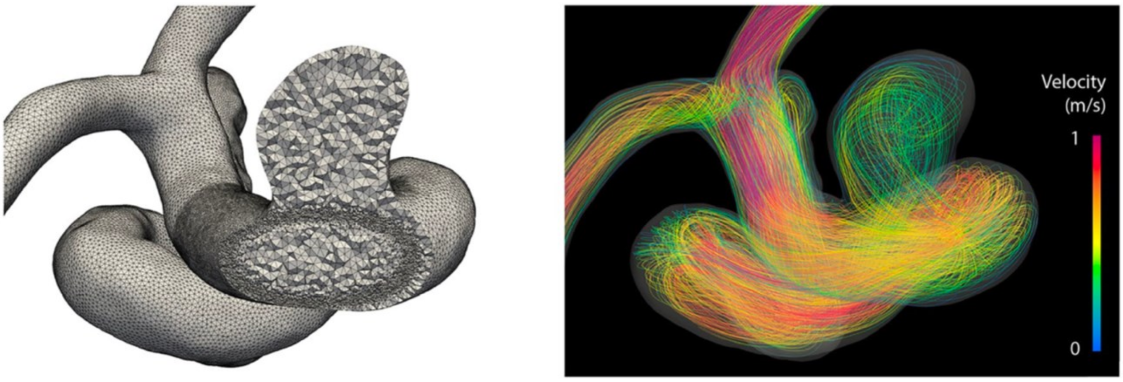

Fig. 1: Patient specific aneurysm computational model and velocity patterns obtained by numerical simulation of the associated blood flow dynamics.

Objective

The PhD builds on the emergence of three-dimensional, time-resolved, three-directional MR flow imaging (4D-flow), a promising method of investigation for cardiovascular and neurovascular physiology, that has been extensively validated in the aorta and carotid arteries and has shown relevant to measure intra-aneurysmal flow modifications in stented aneurysms. We aim at enriching our current CFD simulation framework from experimental 4D flow data to improve accuracy and reliability in predicting aneurysmal rupture risk, which is all the more important as the tradeoff between image quality and scan time limits the widespread use of current 4D-flow acquisition schemes in patient studies and the clinic.

Work is structured around the following main tasks:

- acquire relevant input 4D flow data before and after stent implantation on hollow models of aneurysm flow consisting in a spherical cavity mounted on flexible tubes,
- post-process the obtained results to reduce noise, eliminate errors, and fix missing data and ultimately deliver smooth flow fields and hemodynamic indices,
- compare with simulated 4d flow data obtained by fluid-structure interaction simulation of the same aneurysm flow models,
- augment the computational results by designing a deep reinforcement learning agent for data assimilation purposes of the experimental data to, using the cardiac frequency, pulsatile inflow rate, as well as the parameters of the blood rheology and hyperelastic material models as free variables to optimize,
- integrate all numerical developments into an automated workflow for large-scale hemodynamic simulations,
- assess feasibility in a patient-specific context.

Participants

This work is conducted as part of CURE, a 5-year ERC-funded project, that seeks to leverage advanced modeling approaches combining computational fluid dynamics (CFD) and artificial intelligence (AI) to develop data-informed optimization tools for intracranial aneurysm management. CURE is currently ongoing at CEMEF , an internationally-recognized research center of Mines Paris PSL and CNRS located in Sophia-Antipolis (on the French riviera), and is implemented in close collaboration with the doctors of the Neuroradiology and Intervention Institute at University Hospital Munich (LMU), one of the largest university hospitals in Europe and a center of high-end medicine, medical innovation, and research.

The successful candidate will be part of the Computing and Fluids (CFL) group of CEMEF, whose research is focused at the intersection of fluid dynamics and major societal challenges in energy, environment and health (biofluids). CFL comprises of 50+ scientists with expertise across the full range of fluid mechanics disciplines, who benefit from cutting edge facilities in high-performance computing, cloud platforms and 3D printing technology to integrate advanced computational tools and theory with laboratory experiments and bring innovative, science-based solutions to real-world fluid-flow problems. The group is deeply committed to goal-oriented, collaborative research as closely integrated with industry as possible. It also offers exhaustive training opportunities for high-level professionals and academics through master’s and doctoral programs in core areas linked to mechanics, computer engineering and artificial intelligence, and provides top-class students an opportunity to pursue their training in a dynamic, high-quality research environment, while developing their network and allowing them to connect with the world of science in entertaining and exciting ways.

With a tight collaboration with LMU, the PhD therefore provides a unique multidisciplinary environment to carry out new challenging research machine learning biomedical engineering, as well as an outstanding opportunity to work on real-world healthcare applications.

Applicants

The duration of the PhD is 3 years, to start to start in the fall of 2024. Applicants will have (or be in the process of obtaining) a master's degree in fluid mechanics, applied mathematics, or a related field, with an outstanding academic record (at or near the top of their class) at master’s level. Preferred candidates will possess demonstrable experience in the numerical modelling and simulation of flow transport phenomena, a working knowledge of finite element analysis, numerical programming ability using C++ and python, professional command of English, good presentation skills, and the ability and willingness to work collaboratively within a multi-disciplinary team. Prior experience in collaborative projects using git would be appreciated.

Contact

Formal applications should include a detailed cv, letter of motivation, list of publications (in case of joint authorship, please clearly indicate your own contribution), official transcript of grades for the qualifying degree, and the names, affiliations, and email addresses of two academic referees who can provide details about your academic profile in relation to this position (please do not include any reference letters in your application). Applicants must also provide samples of research papers or sections of dissertation demonstrating their ability to engage in doctoral level academic writing.

Applications should be directed to Prof. Elie Hachem : elie.hachem[at]minesparis.psl.eu