French Polytech network form for PhD Research Grants from the China Scholarship Council

This document describes one of the PhD subjects proposed by the French Polytech network. The network is composed of engineering schools/universities. The document also provides information about the supervisor.

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PhD information	
Title	Development of a Predictive Model for Atherosclerotic Plaque Rupture, Thrombosis, and Infarction Risk in Complex Vascular Geometries
Main topics regards to CSC list (3 topics at maximum)	III-7. Ingénierie biomédicale Biomedical engineering III-13. Vieillissement : prévention et traitement des maladies des personnes âgées Ageing: prevention and treatment of illnesses of the senior citizen

Required skills in science and engineering	fluid and structural mechanics, numerical modeling and simulation particularly CFD and strong interest in experimental development is desirable.

Subject description (two pages maximum including biblio)

Background and context

Atherosclerosis, marked by plaque accumulation within arterial walls, is the primary cause of cardiovascular diseases and a leading contributor to global mortality. Plaque rupture can initiate thrombus formation, potentially resulting in myocardial infarction. Complex vascular geometries—such as arterial bifurcations or collateral vessel development—profoundly alter hemodynamic patterns, making accurate risk prediction particularly challenging.

Current clinical tools, such as the Fractional Flow Reserve (FFR), though widely used, do not fully account for these intricate geometric and dynamic factors. There is thus a critical need for more comprehensive and accurate assessment tools, capable of supporting clinical decisions in anatomically complex patient cases.

Project Objectives

The aim of this project is to develop a predictive model that can quantify the risk of plaque rupture, thrombosis, and infarction in patient-specific vascular networks featuring complex geometries (e.g., bifurcations, collaterals).

The initial step involves constructing numerical simulations based on patient imaging data, enabling the analysis of key hemodynamic indicators such as Oscillatory Shear Index (OSI), Wall Shear Stress (WSS), and others. These parameters will be used to build a novel risk index that is more robust and clinically relevant than the standard FFR.

While traditional models (such as Computational Fluid Dynamics - CFD, and Fluid-Structure Interaction - FSI) offer precision, they are computationally intensive. By training artificial intelligence (AI) algorithms—such as neural networks or ensemble models—on a validated database of simulations (input geometries + parameters + outputs like OSI, WSS), we can bypass time-consuming simulations and achieve near-instantaneous predictions for new patient geometries.

Working in collaboration with an AI expert, we will develop a predictive AI model tailored for clinical contexts, with response times compatible with surgical planning workflows.

Concurrently, we will expand our existing experimental platform to replicate realistic hemodynamic conditions in physical models derived from patient data. This platform already allows for velocity field measurements in coronary artery phantoms using advanced optical methods. Additional sensors (for pressure, temperature, etc.) and improved acquisition systems (higher sampling rates, faster electronics) will be integrated to enhance its capabilities.

The ultimate goal is to deliver a powerful, clinician-friendly decision-support tool that enables more personalized management of patients with complex vascular anatomies. The project will be conducted in close collaboration with cardiologists, mechanical engineers, and AI specialists.

Methodology

The project will begin with the development of multiphysics numerical simulations. Computational Fluid Dynamics (CFD) models will be employed to simulate blood flow and estimate the distributions of key parameters such as Wall Shear Stress (WSS), Oscillatory Shear Index (OSI), and others. Fluid-structure interaction, involving both the arterial wall and the plaque, will be considered to evaluate local distributions of quantities that are critical for surgical decision-making. These simulations will be based on medical imaging

data, including angiography, MRI, and CT scans, to reconstruct realistic 3D models of vascular regions featuring bifurcations and collaterals.

Following the simulations, statistical and correlation analyses will be conducted between the computed hemodynamic parameters and documented clinical events. This will allow for an evaluation of commonly used risk indices. Based on these results, and in close collaboration with cardiologists, a new composite risk index will be proposed. This index will integrate both geometric and dynamic factors and is expected to provide a more precise and specific alternative to the Fractional Flow Reserve (FFR). The index will then be applied and tested on real patient cases.

The experimental component of the project will involve enhancing an existing platform to replicate pulsatile blood flow conditions in physical models of arterial bifurcations and collateral vessels. This setup already uses Particle Image Velocimetry (PIV) to accurately measure velocity profiles and shear stresses. These measurements will be used to validate the numerical simulations and refine the models. Further upgrades will enable the acquisition of additional data, such as pressure and temperature, thereby improving the fidelity of experimental validation.

For clinical validation, the proposed composite index will be tested and refined in collaboration with clinical teams using complex patient cases. Eventually, a simple and intuitive software interface will be developed to allow physicians to use the tool in routine clinical practice. This interface will support the customization of models according to individual patient anatomy.

Scientific and Clinical Impact

This project will make a substantial contribution to the understanding of the interplay between vascular geometry, hemodynamics, and cardiovascular risk. By incorporating parameters that are still underutilized in clinical practice, it aims to enhance diagnostic precision and enable more personalized treatment strategies. In doing so, it will help reduce the mortality and morbidity associated with cardiovascular diseases.

Required Skills

The ideal candidate should have a strong background in fluid and structural mechanics, preferably with applications in biological or biomedical systems. They should also possess skills in numerical modeling and simulation—particularly CFD—for analyzing blood flow and fluid-structure interactions. Experience or a strong interest in experimental development is desirable, along with the ability to work collaboratively within a multidisciplinary team that includes clinicians. Given the broad, interdisciplinary scope of the project, the candidate may be directed preferentially toward either the modeling, experimental, or clinical integration aspects, depending on their profile and interests.

Références :

[1] M. Lagache, R. Coppel, G. Finet, R.I. Pettigrew and J. Ohayon.
Chapter 13: Measuring the FFR: Clinical measurements and experimental bench. Book entitled “Biomechanics of Coronary Atherosclerotic Plaques: From Model to patients”, Elsevier (2020).,(https://www.elsevier.com/books/biomechanics-of-coronary-atherosclerotic plaque/ohayon/978-0-12-817195-0)

[2] Mauro Malve, Gerard Finet, Manuel Lagache, Ricardo Coppel, Roderic I. Pettigrew, Jacques Ohayon.
Chapter 11: Hemodynamic disturbance due to serial stenosis in human coronary bifurcations: A computational fluid dynamics study. Book entitled “Biomechanics of Coronary Atherosclerotic Plaques: From Model to patients”, Elsevier (2020). (https://www.elsevier.com/books/biomechanics-of-coronary-atherosclerotic plaque/ ohayon/978-0-12-817195-0)

[3] R. Coppel, J. Ohayon, G. Finet, G. Rioufol, A. Gomez, F. Dérimay, M. Malvé, S.K. Yazdani, R.I. Pettigrew and M. Lagache." Influence of collaterals on true FFR prediction for a left main stenosis with concomitant lesions: An In vitro study", An. Biomed Eng 47, 1409–1421 (2019). https://doi.org/10.1007/s10439-019-02235-y

[4] R. Coppel, J. Ohayon, G. Finet, G. Rioufol, A. Gomez, F. Dérimay, M. Malvé, S.K. Yazdani, R.I. Pettigrew and M. Lagache." Influence of collaterals on true FFR prediction for a left main stenosis with concomitant lesions: An In vitro study", Ann Biomed Eng 47, 1409–1421 (2019). https://doi.org/10.1007/s10439-019-02235-y

[5] R. Coppel, AL. Gomez, G. Finet, M. Mauro, RI. Pettigrew, J. Ohayon & M. Lagache (2017) Experimental Bench for Hemodynamic Study of Coronary Artery with Serial Stenoses: Fractional Flow Reserve Assessment, Computer Methods in Biomechanics and Biomedical Engineering, 20:sup1, 45-46. https://doi.org/10.1080/10255842.2017.1382853