PhD Proposal

Biomimetic modeling of thoracic aortic dissections and Biomechanical markers

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Clinical Context

Aortic dissection is a vascular pathology affecting the thoracic aorta. It is characterized by the appearance of a tear in the aortic wall, leading to the formation of a second circulation channel opposite the arterial lumen (Figure 1). The two channels are separated by a mobile wall known as the flap. The result is gradually remodeling of the arterial wall, which can lead to distension of the aorta. Thrombus, the product of blood coagulation, can also partially or totally obstruct the second circulation channel.

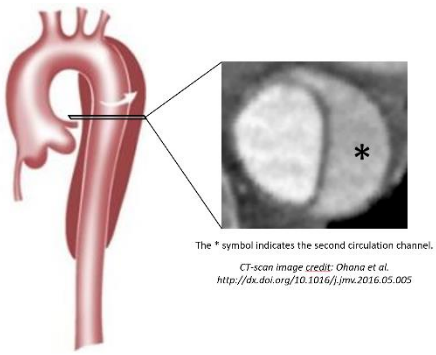

Figure 1 : Dissection of the descending thoracic aorta (left) and CT-scan imaging (right). The difference in contrast between the two channels indicates partial obstruction by thrombus in the second channel.

Ultimately, the major risk is rupture of the artery, which can be fatal without emergency intervention. To anticipate any unfavorable evolution that could lead to rupture, patients are regularly monitored by medical imaging (MRI and/or CT-scan).

Mainly morphological and epidemiological criteria (maximum diameter, second-channel patency, etc.) can now be used to estimate the evolution of pathology and, consequently, to help in the therapeutic decision, mainly involving stenting. However, at present, these criteria are not sufficiently discriminating to determine early on the risk of an unfavorable evolution. Taking into account the morpho-biomechanical specificities of each patient and better anticipation could enable optimal clinical management.

Objectives

The long-term aim of this research is to provide new, more reliable and earlier quantifiable indicators through biomechanical studies of pathological aortic remodeling. The goal is to identify correlations between morphology, hemodynamics and mechanical behavior of the aorta, providing clinicians with a simple, rapid diagnostic tool.

More specifically, the aim is to develop biomimetic numerical models of pathology based on quantitative data obtained from medical imaging. Models incorporating fluid-structure interactions

(FSI) have already been implemented in our group (1). However, they have the major drawback of requiring a relatively long computation time for clinical use. In addition, the mechanical properties of the aortic wall are rarely implemented in these models in a patient-specific manner. To address these two issues, we have developed an imposed displacement approach to overcome the coupling between fluid and structure (2) and propose a biomimetic model of the pathology. The proposed protocol is based on the processing of MRI images, from which we reconstruct the movements of the aorta over time before imposing them as boundary conditions in a CFD (Computational Fluid Dynamics) numerical model, reducing the problem to the resolution of the Navier-Stokes equations.

The developments carried out have demonstrated the feasibility and validity of the protocol established on healthy volunteers and patients with thoracic aneurysms. Further developments, including image processing, are required to adapt this protocol to aortic dissections and the integration of the flap as a moving wall in the flow.

More specifically, work will focus on (i) integrating CT-scan data to obtain a reference geometry with better resolution than MRI imaging, and (ii) adapting the “imposed displacement” method to the integration of the thrombus in CFD models. This will be based on the team's thesis work on characterizing the 3D microstructure of thrombi and the permeability values obtained at macroscopic and microscopic scales (3, 4).

Candidate profile

The candidate should have academic knowledge of the relevant disciplines: fluid and structural mechanics, biomechanics, numerical modeling. He/she must have a proven appetite for interdisciplinarity and master CFD and scientific calculation tools.

Application

Candidates should send their application by e-mail to the supervisors, which should include a Curriculum Vitae, a letter of motivation, transcripts of Master's grades (M1 and M2) and a letter of recommendation from a previous internship.

The thesis will start on October 1st, 2025.

Thesis funding

ED 353 doctoral school grant if accepted

Lab axis

This project is part of the Living and Bio-inspired Systems axis of the IRPHE UMR 7342 laboratory.

More information: https://irphe.univ-amu.fr/en/research-axes/living-and-bio-inspired-systems

The proposed thesis will be carried out in collaboration with the Vascular Surgery Department (MCU-PH M. Gaudry) and the Radiology and General and Vascular Medical Imaging Department (PU-PH Alexis Jacquier) at Hôpital de la Timone, Marseille.

References

1. Deplano et al, (2024) Fluid Structure Interaction in aortic dissections in Biomechanics of the Aorta: Modelling for Patient Care. Elsevier Science, Editors T.C. Gasser, S. Avril, J.A. Elefteriades. https://hal.science/hal-04232191
2. Baudouard et al, (2025) Assessing the displacement of thoracic aortic aneurysms with magnetic resonance imaging for a biomimetic numerical modeling. Submitted to Biomechanics and Modeling in mechanobiology. Preprint https://www.researchsquare.com/article/rs-6157089/v1
3. Léonet et al, (2025) Morphological and Mechanical Characterization of Thrombi in Abdominal Aortic Aneurysms. Accepted in Heliyon. Preprint https://hal.science/hal-04999007
4. Léonet et al, (2025) Aortic thrombi microstructure through contrast-enhanced X-ray microtomography. Accepted in Scientific Reports. Preprint https://hal.science/hal-04999047