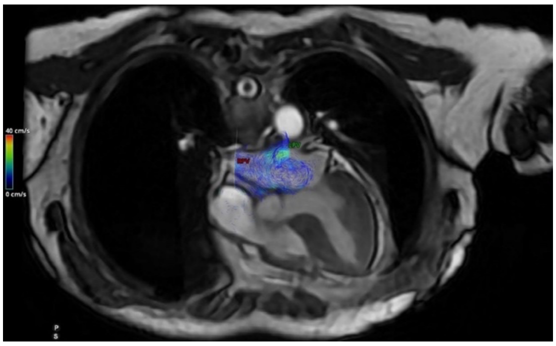
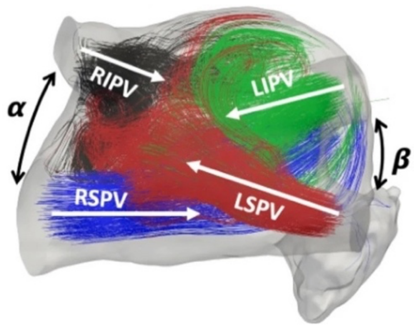
Cardioembolic Stroke Risk Stratification using AI Accelerated Patient-Specific Blood Flow Simulation

Context

With over 6 million victims every year, stroke is the second-leading cause of mortality worldwide. The 20 million patients that survive their stroke often suffer from long-term disability. 20 to 30% of ischemic strokes are cardio-embolic, an incidence that increases with age. These strokes are more severe than others, 40% more costly, and victims share high rates of early and long-term recurrence. In developed countries, the absolute number of cardio-embolic strokes has tripled during the past three decades and projections anticipate it will triple again by 2050. Meanwhile, the economic burden of stroke worldwide is expected to reach a staggering US $ 1 trillion by 2030. The paradox of this situation is that treatments are available: oral anticoagulation is an effective preventive therapy, but current strategies to identify patients in whom it will be beneficial lack efficiency.





Aim

The main goal of this project is to develop innovative point of care tools for the prediction and prevention of cardioembolic stroke based on patient-specific simulations. Currently, detection of Atrial Fibrillation (AF) serves as the sole entry point for prevention, despite not being the exclusive cause of cardioembolic stroke and exhibiting considerable diversity in associated risks. Furthermore, the CHA2DS2-VASC score, which guides anticoagulation therapy, is derived from retrospective cohorts predicting ischemic stroke rather than specifically cardioembolic events. This weakens its rationale, as patients with non-cardioembolic stroke do not benefit from anticoagulation. Cardiac biomarkers, such as left atrial (LA) appendage shape or LA morphology, have recently emerged as valuable predictors of stroke risk. However, they do not integrate blood flow characteristics responsible for thrombogenesis.

Methods

Two main methods non-invasively quantify LA 3D flow. First, 4D flow MRI captures 3D+t blood velocities without radiation, but limited resolution hinders analysis of wall shear stress and vortices, especially in the left atrial appendage. Second, CFD simulates high-resolution hemodynamics but requires patient-specific geometry, wall mechanics, and boundary conditions, as well as demanding advanced imaging and expertise.

The LA is highly responsive to mechanical stresses due to its role as a reservoir, conduit, and pressure sensor. Excessive stresses drive diseases like AF by activating mechano-sensitive channels and calcium release. However, links between mechanical stresses and LA structure, function, and hemodynamics remain unclear, as does the impact of myocardial fibrosis on LA hemodynamics and thrombogenesis.

In this PhD project at Inria, in collaboration with the iCV team from Laboratoire d'Imagerie Biomédicale-LIB (Sorbonne University, Inserm), and the M2P2 team (Aix-Marseille University), we will combine advanced imaging with high-resolution CFD to create validated, patient-specific LA hemodynamics maps in order to ultimately improve stroke prevention. The objective is to simulate physiological aspects of atrial function and hemodynamics through cardiac motion and blood flows. This will enable to better understand the mechanisms of thrombogenesis and develop new biomarkers for stroke risk stratification. Then, AI-based surrogate models will be developed in order to obtain fast simulations for large-scale risk stratification.

The CFD model of the LA and the AI-based surrogate models will be validated using 4D flow MRI provided by the iCV team. Data will be drawn from 50 patients with first-episode AF from the CTstrain-AF study (NCT04281329 with CT and MRI imaging), a collaboration between LIB and Pitié-Salpêtrière Hospital, for which ethics approval for further analysis has already been obtained. Accurate 3D LA reconstructions have already been generated from CT scans using 3D Slicer. LA wall motion will be extracted from dynamic 4D flow MRI (20 phases per cycle) via an in-house deep learning-based segmentation tool. Mean flow velocities in the pulmonary veins have been also measured by an experienced technician from 4D flow MRI images.

The CFD solver, incorporating sufficient grid resolution and realistic wall motion with appropriate boundary conditions, will be developed with the M2P2 team. M2P2 activities using methods such as the Lattice Boltzmann Method (LBM) focus on complex biological flows, including blood circulation, aortic valve replacement, cellular transport, and tissue mechanics. These approaches allow for precise simulations of fluid mechanics applied to physiological processes, contributing to a better understanding of diseases and the development of innovative medical technologies, such as biomedical devices.

The AI methods will leverage recent work performed at Inria in order to replace equation solvers with deep neural networks when simulating the cardiac function. The challenge is to capture the important phenomena for stroke risk prediction while ensuring generalisation to new patients. The CFD solver will use a differentiable physics approach (leveraging automatic differentiation) so that it can be readily integrated with deep learning frameworks. Combination of physics-based learning and statistical shape models will be explored in order to integrate the impact of anatomy on flows.

This is therefore a truly interdisciplinary project at the intersection of artificial intelligence, medical imaging, mathematical modelling, and patient-specific simulation.

Practical Information
This 3-year PhD thesis will be based at Inria and co-supervised by Dr Maxime Sermesant (3IA Côte d'Azur Chair, Epione team, Inria, Sophia Antipolis), Dr Nadjia Kachenoura (Biomedical Imaging Laboratory, Sorbonne University, Paris), and Dr Isabelle Cheylan (M2P2, Aix-Marseille University).
Competitive salary with comprehensive social benefits (national healthcare, health insurance, annual leaves, etc.), along with a dynamic and stimulating work environment.

Searched Profile
- MSc Level in data science, applied mathematics or biomedical engineering.
- Motivated by mathematical modelling and AI
- Eager to work in the medical field
- Good coding skills in Python
- Fluent in English (Reading, Writing, Speaking)

Contact People
Send a CV and motivation letter to:
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