Numerical simulations of the cardiovascular system

Anna Maria Lo Presti
annamaria.lopresti01@unipa.it

Università degli Studi di Palermo
dipartimento di ingegneria unipa

Computational hemodynamics

Concept

Atrial fibrillation, a heart rhythm disorder characterized by an irregular and rapid heartbeat, is the leading cause of thromboembolic events, leading to strokes, including transient ischemic attacks (TIAs), and other cardiovascular complications, including dementia.

In the context of atrial fibrillation, it is estimated that approximately 90% of thrombi form in the left atrial appendage (LAA).

The formation of blood clots within the LAA can alter normal blood circulation, compromising blood delivery to affected regions should they migrate into the cardiovascular system.

To enhance understanding of thrombosis in the LAA within patient-specific morphologies, the simulation of the complex interaction between fluid dynamics and structural mechanics will be pursued using an advanced monolithic fluid-structure interaction (FSI) model based on Smoothed Particle Hydrodynamics (SPH), under sinus rhythm and atrial fibrillation conditions.

Scientific approach

To investigate the dynamics of thrombosis within the LAA and simulate the complex interaction between fluid dynamics and structural mechanics, PANORMUS-SPH code, developed at the Engineering Department of the University of Palermo, will be used. SPH, a mesh-free Lagrangian method, discretizes the domain into particles, allowing for a continuous representation of fluid behavior.

The employed approach involves transforming fluid particles into a solid phase by introducing internal spring bounds when a thrombus is expected to develop. This innovative methodology models clot formation by monitoring the concentration dynamics of the main biochemical species involved in the coagulation cascade and platelet aggregation processes. Specifically, the model features four biochemical species – thrombin, prothrombin, fibrin and fibrinogen – along with three types of platelets: resting, activated and bounded.

Research objectives

- Predict the formation, growth, and dissolution of thrombi.
- Assess thromboembolic risks in patient-specific scenarios.
- Improve prevention strategies tailored to individual patient needs.
- Enhance treatment strategies for better management of thromboembolic conditions.
- Design safer medical devices based on risk assessments.

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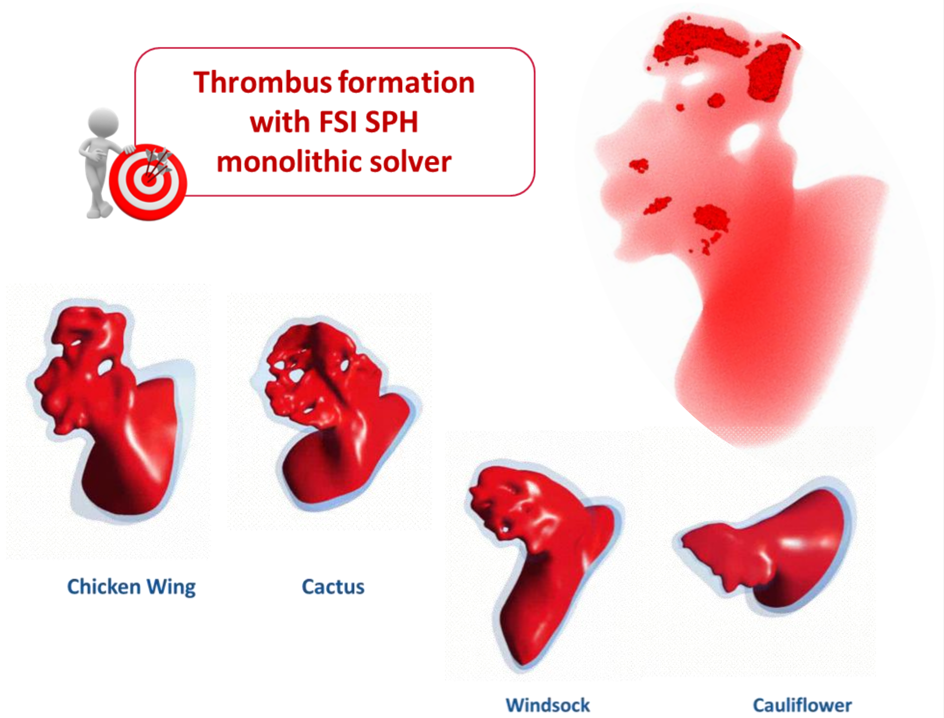

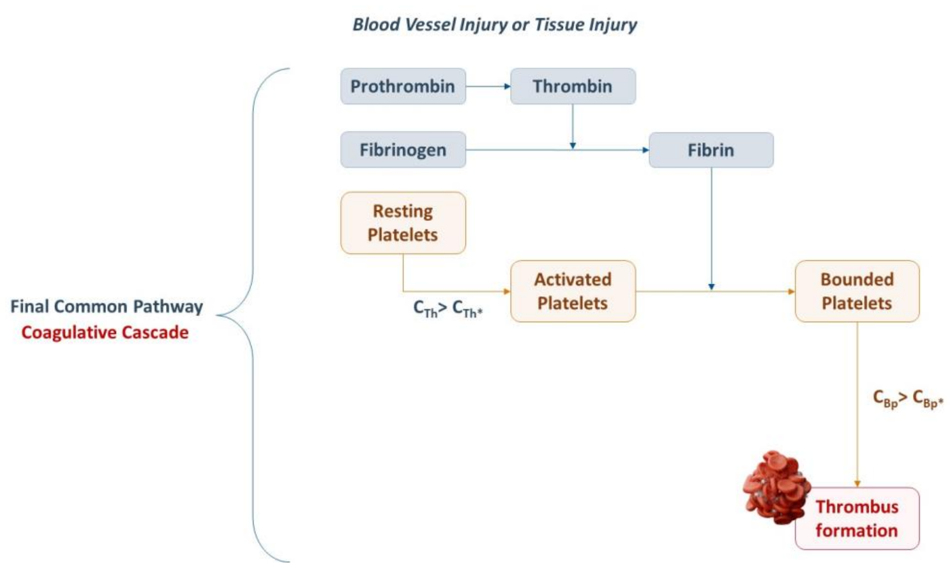

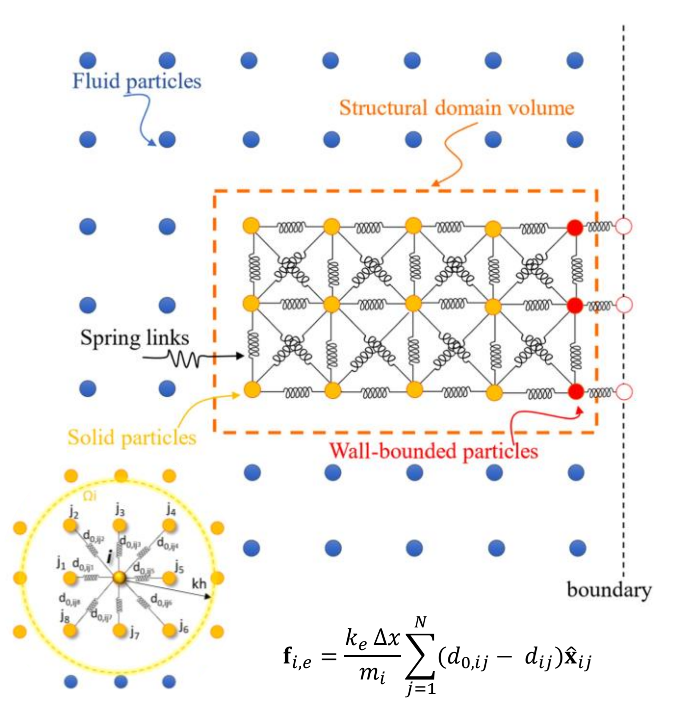

$$\mathbf{f}_{i,e} = \frac{k_e \, \Delta x}{m_i} \sum_{j=1}^{N} (d_{0,ij} - d_{ij}) \hat{\mathbf{x}}_{ij}$$