NUMERICAL SIMULATION OF PLATELETS ADHESION ON STRUCTURED ARTIFICIAL SURFACES

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Context

As cardiovascular diseases are the first cause of death worldwide, providing efficient medical devices to treat these diseases is a main concern in the biomedical engineering field. However, because these devices are directly interacting with the blood, their hemocompatibility must be ensured. This is one of the most important challenges to their development and side treatment with anti-coagulant is currently needed to prevent thrombus formation at the surface of the blood contacting devices. In an effort towards increased hemocompatibility of such devices, artificial surface structures in the micrometer range have been shown to influence the thrombogenicity of the surface although this effect is not well characterized and understood [1].
This abstract presents the preliminary outcomes of an on-going computational study aiming at better understanding how the platelets adhesion, the key mechanism in thrombus initiation, can be affected by the presence of micro-structurations over the material surface. This is a joint effort including an experimental component addressed in the companion paper by Schadow et al. 2024 [2].

Methods

The numerical model is implemented in the YALES2BIO solver developed at IMAG (https://imag.umontpellier.fr/~yales2bio/) and dedicated to the simulation of blood flows [3].
The fluid movement is described by the incompressible Navier-Stokes continuity and momentum equations:

$$\nabla\cdot\mathbf{u} = 0 \qquad (1)$$

$$\rho\frac{\mathrm{Du}}{\mathrm{Dt}} = -\nabla p + \mu\nabla^2\mathbf{u} + \mathbf{f}(\mathbf{x},t) \qquad (2)$$

$$f_i(\mathbf{x},t) = F_i\Delta\big(\mathbf{x}\text{-}\mathbf{Y}(t)\big) + G_{ij}\frac{\partial}{\partial x_j}\Delta_d(\mathbf{x}\text{-}\mathbf{Y}(t)) \qquad (3)$$

The force $\mathbf{f}(\mathbf{x},t)$ present in the momentum equation (2) and detailed in equation (3) accounts for the presence of a particle in the flow as prescribed by the Force Coupling Method [4]. The external forces and torque as well as the incompressibility constraint are transmitted from the particle to the fluid via two ellipsoidal Gaussian envelopes Δ and Δ_d, centered at the particle center of mass $\mathbf{Y}$, whose width are related to the particle dimensions to match chosen physical properties of the particle.
The linear velocity of each particle is measured as the average velocity under the Gaussian envelope (4) and is used to update the position of the particle at each numerical time step by integration of equation (5):

$$\mathbf{u}_p = \int_\Omega \mathbf{u}(\mathbf{x},t)\Delta(\mathbf{x}\text{-}\mathbf{Y}(t))dV \qquad (4)$$

$$\frac{d\mathbf{Y}}{dt} = \mathbf{u}_p \qquad (5)$$

A similar work is done to update the particle orientation by measuring the angular velocity of the particle from the fluid vorticity.

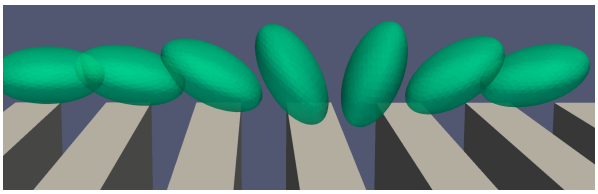

Figure 1: Numerical model of platelet transport over grooves implemented in YALESBIO. A surface of the particle dimensions is used for visualization.

Results

The numerical model has been validated against results from the literature regarding the dynamics of ellipsoidal particles in shear flows. In absence of solid boundary wall, the model reproduces the rotation of the particle in a way fully consistent with the theoretical Jeffery's orbit [4]. Close to a planar wall, results obtained for an aspect ratio equal to 0.5 are in good agreement with the computational results from Hsu & Ganatos [5]. The methodology is now applied to cases where the wall is micro-structured (see Figure 1) and short-range adhesion forces are present. Our results show differences in flow characteristics depending on surface structures that might be responsible for positive and negative effects on the hemocompatibility of structured surfaces. The corresponding results will be presented at the conference, should the paper be accepted.

References

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