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Modeling and simulation of the motion of deformable interfaces in a confined geometry: application to the study of the flow of red blood cells in microcirculation

It is known since long that understanding the underlying mechanisms of red blood cells aggregation and blood flow may be a keystone explaining the etiology of certain pathological situations. Some of these diseases are closely related to the functioning of red blood cells. It is important to recall the main function of red cells, oxygen transport from the lungs to the rest of the body. Organs like the heart, the kidney and the brain have a high demand on oxygen. Oxygen is released by the red cells in the microcirculation, and more precisely in small and tiny vessels called the capillaries. The capillaries often have a diameter smaller than the one of the red blood cells themselves. Therefor the red blood cells are subject to severe deformations during their flow in these small vessels. In the microcirculation, it is often observed that the red cells flow in single or multiple files forming small trains of cells called clusters. The arrangement and organization of the red cells depend on the diameter of the vessel and the concentration of red cells (hematocrit). Each red blood cell interacts hydrodynamically with the other cells, and when the cells are in a close range from one another depletion and/or bridging interactions take place between the surrounding plasma proteins and the red cells leading to more persistent clusters. At physiological levels of the different plasma proteins, and for healthy red cells, clustering is a reversible process. However that might lead to a partial or total occlusion of the small vessels (ischemia). The tissues deprivation from oxygen might induce a severe pain (due to the lack of oxygen) and may lead to irreversible damages in these regions. When it occurs in the brain, it might cause a stroke (cerebrovascular accident), whereas in the heart, it might lead to congestive heart failures as a consequence of an overpressure due to the augmentation of blood volume and an incapacity to pump it through the obstructed (or narrowed in case of partial occlusions) capillaries. Surprisingly, the physics of the microcirculation is still unclear. This might be explained by the complexity of the interaction between different sciences leading to the understanding of the necessary minimal ingredients to build a starting model that can be used to describe the non-trivial coupling between the red cells and the geometry of the vessels from one side, and the interaction with the plasma proteins from the other side. Our approach is based on the study of vesicles which are extensively used as a model for understanding dynamics and deformation of red blood cells at the individual level but also regarding collective phenomena and rheology. Vesicles' membranes withstand to bending but do not have a shear resistance, unlike red blood cells, but they still share several

dynamical properties with red blood cells, like tank-treading and tumbling under linear shear flow, or parachute and slipper shapes under Poiseuille flow. We investigate numerically several kind of problems such as: (i) the dynamics of isolated cells **[1]**; (ii) the hydrodynamic coupling between the red blood cells (by using vesicles as a model) subject to a Poiseuille flow under different confinements **[5]**; (iii) the aggregation of red blood cells and formation of rouleaux **[4]**; and (iv) the contribution of macromolecules in the formation of clusters under flow condition **[2,3]**. The obtained results give a new insight into the physics of deformable objects under confinement that are transposable to the flow of red blood cells in the microcirculation.

Keywords: Vesicles, red blood cells, boundary integral method, poiseuille flow, chaotic dynamics, aggregation, cluster formation, hydrodynamic interactions, basin of attraction, macromolecules-induced interactions.

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