Viscoelastic properties of vesicles

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Blood is a complex fluid whose viscoelastic properties are basically dominated by the elasticity and interactions of the cells that it contains. Blood is composed of a newtonian fluid, the blood plasma, representing some 55% of the total blood volume, while the remaining volume is occupied by blood cells. Among the wide variety of corpuscles usually found in blood, around 99% are red blood cells (RBCs), an anucleated cell whose shape and mechanical properties are entirely determined by its membrane. Consequently, the study of the viscoelastic behaviour of RBCs immersed in water could be relevant to improve our understanding of the macroscopic behaviour of blood[1].

The blood resistance to flow through thin capillaries is governed by the deformability of the RBCs, which in turn depends on the rigidity of its membrane. Experimental evidence shows that at high shear rates RBCs adopt an asymmetric shape, usually known as slipper, which seems to minimize blood resistance favouring fluid circulation. How this and other intriguing phenomena affect to the viscoelasticity of blood remains under debate[3].

The RBC membrane is a complex structure formed by a lipid bilayer with a spectrin cytoskeleton anchored to its inner leaflet, which prevents from pinching and vesiculization. The cytoskeleton is relaxed when the cell is close to its equilibrium shape, the so-called discocyte, and its stress energy is then negligible. Accordingly, the unique contribution to the elastic energy of the membrane is due to the presence of the bilayer, and usually represented by the Helfrich free energy[2]:

$$\mathrm{F_{mem}} = \frac{\kappa_\mathrm{b}}{2}\int(\mathrm{H}-\mathrm{c_o})^2\mathrm{dA}, \tag{1}$$

where κ_b is the bending rigidity, H is the mean curvature of the cell shape and c_o reflects any asymmetry in the membrane. We use this energy to simulate the elastic behaviour of the cell membrane via a phase-field model, coupled to the Navier-Stokes equation which describes the hydrodynamics of the surrounding fluid. The model has proven to capture the essential physics of the system.

Linear viscoelasticity is a useful way to characterize and understand the complex behaviour of the fluid, since it relates the macroscopic response of the fluid with the microscopic mechanical properties of the cells that introduce the elasticity. In our simulations, vesicles immersed in water are externally forced by a oscillatory forcement, similar to the mechanism used in a rheometer. The dynamic and stress modulii can be easily computed and hence the fluid could be characterized by a macroscopic model such as the one-relaxational time Maxwell model.

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