Tank-treading, swinging, and transition to tumbling of erythrocytes in strong shear flows

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Introduction

The motion of erythrocytes (or red blood cells) through vascular vessels has long been recognized as a fundamental problem in physiology and biomechanics owing to the main function of these cells to exchange oxygen and carbon dioxide with the tissues. Undeformed mammalian erythrocytes are biconcave capsules whose interior hemoglobin solution (or cytoplasm) is enclosed by a multi-layered membrane which is composed by an area-incompressible lipid bilayer underlined by a thin elastic cytoskeleton which exhibits resistance to shearing deformation.

Results

The erythrocyte behavior in shearing flows (which affects its physiological role in both health and disease) is still not well understood owing to the coupling of the fluid dynamics with the nonlinear elastic mechanics of the multi-layered membrane. Recent investigation based on cell imaging parallel to the shear plane has revealed that at moderate shear stress (about 0.1 Pa), erythrocytes present an oscillation of their inclination (called swinging motion) superimposed to the long-observed steady tank-treading motion (Abkarian et al, Physical Review Letters, 98, 2007). However, the cell behavior at high shear stress (about 3-5 Pa) is still not clear. We emphasize that moderate and high flow rates represent two different deformation regimes; in the former the cell appears as a biconcave disc while in the latter it obtains a ellipsoidal-like shape.

To investigate the erythrocyte dynamics in strong shear flows, we employ our interfacial spectral boundary element algorithm for elastic membranes properly extended to model the erythrocyte's biconcave disc reference shape and surface-area incompressibility. Our computational results for the cell deformation are in excellent agreement with experimental findings from ektacytometry. We note that in strong flows the relationship between flow rate and cell deformation is logarithmic; such behavior is not observed for droplets or for spherical capsules. To the best of our knowledge, no previous numerical methodology has been able to reproduce accurately real ektacytometry data at high flow rates.

Conclusions

In addition, our computational work allows analysis of the erythrocyte dynamics beyond the capabilities of ektacytometry and other experimental techniques which see the cell from one view-angle only. In this talk we will discuss the swinging motion of the erythrocytes observed (for the first time) at high shear rates and how it is affected by the flow rate and the viscosity ratio. We also discuss the transition of the erythrocyte motion from tank-treading to tumbling.