11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

Dynamic states of red blood cell in simple shear flow

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Key Words: *red blood cell; deformability; shape; low Reynolds number;Lattice Boltzmann; immersed boundary*

We investigate the effects of flow on RBC motion in micro-capillaries.The shape and motion of red blood cells (RBC) in blood flow play important roles in many physiological activities including oxygen transport, inflammation, thrombosis, etc. Understanding RBC dynamics for a broad range of flow condition and RBC material properties would not only provide insight to the complex activity of individual RBC but also advance the design of microfluidic diagnostic devices.

We use a combined immersed boundary-lattice Boltzmann[1] method with a multi-scale RBC model[2] that captures the experimentally measured elastic modulus and bending rigidity. The RBC is modelled as a 2-dimensional surface with total area constraints, membrane bending rigidity and elasticity. The model captures the properties of RBC lipid bi-layer membrane and the cytoskeleton anchored on it. At rest, the surface encloses a bi-concave region with viscous haemoglobin liquid. Depending on the fluid shear force, RBC can undergo tumbling, tank-treading, and other complex motion. Dynamic states under different shear rate γ and viscosity ratio($\lambda=\eta_{in}/\eta_{out}$) of the inner and outer fluid are investigated. The RBC dynamics are characterized by the capillary number Ca, which is the ratio between fluid shear force and elastic restoring force $Ca=\eta_{out}\gamma R/G$, R is the RBC diameter and G is the two dimensional shear modulus. The range of Ca and λ is chosen to correspond to previous experimental measurements.

At low Ca, RBC tumbling is accompanied with lateral “flipping” motion. The dynamics approaches Jeffery orbit for rigid ellipsoid moving in three dimensional simple shear flow [3]. The stability of the lateral flipping is coupled with the viscosity ratio and the slight oscillation of the RBC shape aspect ratio.

At high Ca, two characteristically different tank-treading dynamics are found. The first kind approaches that predicted by modified Kellar-Skalak theory[4]. The second kind of tank-treading involves lateral shifts of the membrane material points. Higher Ca can trigger a transition from type I to type II that depends on the viscosity ratio.

At medium Ca, a rich state diagram with sever shape change are found as λ gets higher in addition to swing[4]. Complex states including knizocyte、Frisbee-like motion and bell shape as observed in experiment[5] are captured. We also find dynamic states that have robust oscillatory period and states reveal long transient behavior (over $2000\gamma^{-1}$) .

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