Computer simulation of blood cell motion based on viscoelastic deformation

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Abstract

A motion of blood cell is indispensable for function of a living organism. For example, an erythrocyte is deformed passively by a fluid force due to the blood flow. The deformation is not only necessary for an erythrocyte to pass through a narrow blood vessel, but also important for a local mechanical environment that may affect micro vascular remodeling [Murfee al. (2015)]. On the other hand, a leukocyte actively deforms its entire shape during the spreading and crawling on a substrate, which results from active changes in cellular microstructures, such as a compressive microtubule network and a tensile actin-filament network. In this study, we investigated a role of viscoelastic deformation of cellular structure in cellular motions by means of computer simulation. A capsule, defined as a fluid drop encapsulated by a viscoelastic surface membrane, was used as a mechanical model of an erythrocyte. The in-plane tensile deformation of the membrane was expressed by a strain-hardening model, while the out of membrane deformation by an isotropic bending model [Tsubota et al. (2014); Tsubota (2014)]. The natural state of the membrane with respect to in-plane shear deformation was modeled as either of a sphere, biconcave disk shape, or their intermediate shapes, while the natural state with respect to out-of-plane bending deformation was modeled as a uniform geometric shape. The in-plane membrane viscosity was modeled by a two-dimensional Newtonian fluid. Assuming Stokes flow, a boundary element method was used to couple membrane's viscoelastic deformation and its surrounding fluid flow. According to the numerical simulations at an experimentally measured viscoelastic constants of the cell membrane, the experimentally measured fluid shear stress at the transition between tumbling and tank-treading motions under shear flow was reproduced for an intermediate natural state of the cell membrane. A shear thinning behavior of the membrane was necessary to reproduce experimentally measured tank-treading periods as a function of shear rate. On the other hand, the mechanical model of erythrocyte was applied to the shape mechanics of a fibrosarcoma, as a representative adhesive cell. Numerical results indicated that given a fixed boundary condition at positions of measured focal adhesions, elastic deformation successfully reproduced a cellular shape measured in an *in vitro* experiment. These numerical results demonstrate that details of viscoelastic deformation mechanics of the blood cell, such as a membrane's natural state, non-Newtonian properties, and boundary conditions, should be taken into account to quantify RBC mechanics with a sophisticated numerical simulation. In an undergoing work, mechanical structures inside a cell and their changes due to biochemical events are taken into account to quantitatively predict a reaction force at a focal adhesion, as well as interrelation between the reaction forces and assembly/disassembly of the focal adhesions as an important factor in a leukocyte locomotion [Miyoshi et al. (2013)].

Keywords: Biomechanics, Blood cell, Locomotion, Natural state, Boundary condition

References

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