Deformation of vesicle and red blood cell in flow

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単純せん断流と細管流におけるベシクル及び、赤血球の変形をシミュレーションを用いて研究した。運動モードの変化に関係して様々な形態変化（円盤状ー棒状、円盤状ーパラシュート状など）が起こることを発表する。

Introduction

We study the deformation of vesicles and red blood cells in shear flow and in capillary flow. A new simulation technique is presented, which combines a three-dimensional mesoscale simulation technique, multi-particle collision dynamics [1] for the solvent with a dynamically-triangulated surface model for the membrane. The deformation of vesicles is an important subject not only of fundamental research but also in medical applications. For example, in microcirculation, the deformation of red blood cells reduces the flow resistance of microvessels. In diseases such as diabetes mellitus and sickle cell anemia, red blood cells have reduced deformability and often block microvascular flow. We focus the effects of membrane viscosity in shear flow and the effects of the shear elasticity and bending modulus of membrane in capillary flow.

Simple shear flow

In simple shear flow, a fluid vesicle is found to transit from steady tank-treading to unsteady tumbling motion with increasing membrane viscosity [2,3]. The shear induces a transformation from discocyte to prolate ellipsoid at low membrane viscosity. On the other hand, at high membrane viscosity, the shear induces a transformation from prolate to discocyte, or tumbling motion accompanied with oscillations between these two morphologies. This dynamical behavior can be understood from a simplified model.

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Capillary flow

Both fluid and elastic (red-blood-cell model) vesicles retain their discoidal shapes in slow capillary flows (Fig. 1A). We have found that coaxial orientation with the capillary axis is unstable in slow flows [4]. Instead, the vesicles align the longest axis of the moment-of-inertia tensor with the flow direction. In most previous theoretical and numerical studies, axisymmetric shapes which are coaxial with the center of the capillary were assumed and cylindrical coordinates were employed. Our results show that this assumption is justified only for high fluid velocity.

At larger mean fluid velocity, the fluid vesicle transits into a prolate ellipsoidal shape (Fig. 1B). On the other hand, the elastic vesicle transits into a parachute shape (Fig. 1C), because the shear elasticity prevents large shear deformations. Both shape transitions reduce the flow resistance. We have found that the transition velocities are linearly dependent on the bending rigidity and on the shear modulus of the membrane. Our results are in good agreement with experiments on red blood cells.

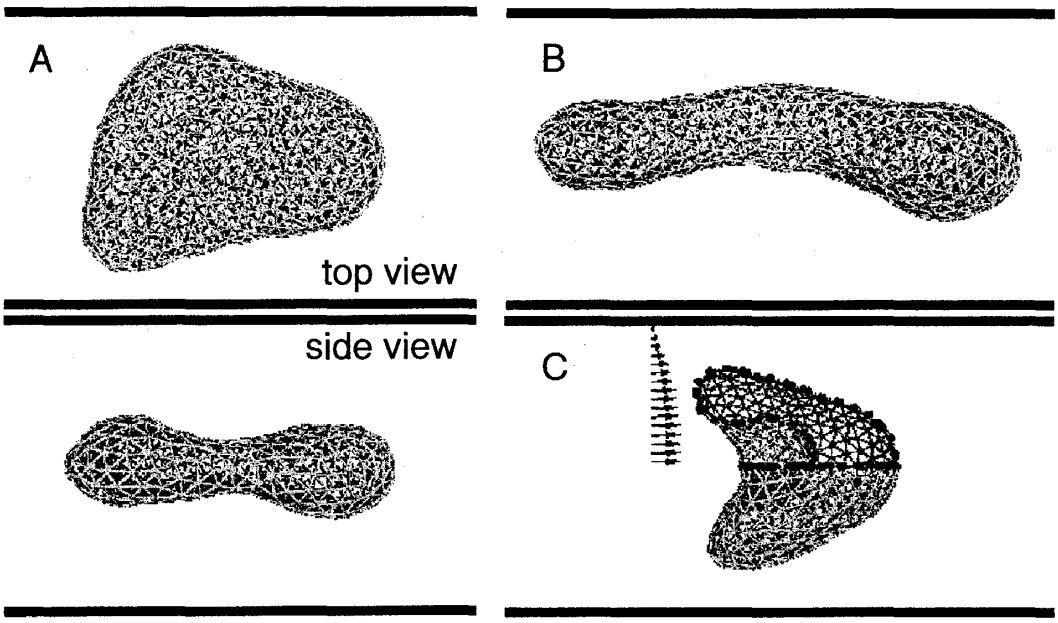

Fig. 1. snapshots of vesicles in capillary flow. Fluid vesicles in (A) slow and (B) fast flows. (C) Elastic (red-blood-cell model) vesicle in fast flow. Thick lines indicate the walls of cylindrical capillary. The arrows represent the flow velocities. Upper front quarter of the vesicle in (C) is removed to allow a look into the interior.

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