Migrating Motion and Deformation of an Oblate Capsule Flowing through a Cylindrical Channel

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ABSTRACT

The dynamic motion and deformation of an oblate capsule flowing in a cylindrical channel are studied by using a coupling method that integrates the boundary integral method and the finite element method. This study is inspired by a long-standing puzzle: why do red blood cells (RBCs) take asymmetric shapes (also known as slipper shape) even in a symmetric flow?

We focus on a simple configuration to examine the appearance and persistence of slipper shapes. The RBC is modeled as an oblate capsule with a thin hyperelastic membrane. Neglecting bending resistance, the membrane deformation follows a Skalak constitutive law, in which the area dilatation modulus is three times the shear surface modulus. The internal and external fluids are incompressible Newtonian fluids with the same physical properties (density and viscosity). The capsule flows inside a narrow cylindrical tube with its center of mass initially positioned off the channel axis, which breaks the natural symmetry of confined Poiseuille flow. Asymmetric motion and deformation of the capsule are thus induced, which are governed by a strong nonlinear coupling between the hydrodynamics stresses, membrane elasticity and the wall confinement.

The three-dimensional simulations reveal that off-centered capsules always assume slipper shapes as they migrate towards the channel axis, contrary to centered capsules, which exhibit axisymmetric parachute shapes. The slipper shape can indeed significantly increase the flow efficiency. We study the influence of the particle initial shape and find that less slender capsules have a shorter characteristic time of migration towards the axis and that the slipper shape persists for shorter times. This can explain why the slipper shape is frequently observed for red blood cells, but not for artificial quasi-spherical capsules.

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