A three-dimensional interfacial spectral boundary element algorithm for capsules and erythrocytes in strong flows

Walter R. Dodson III
Fischell Department of Bioengineering
University of Maryland
College Park, MD, USA

Panagiotis Dimitrakopoulos
Department of Chemical and Biomolecular Engineering,
Bioengineering Graduate Program
University of Maryland
College Park, MD, USA

Introduction

The study of the interfacial dynamics of artificial or physiological capsules (i.e. membrane-enclosed fluid volumes) in Stokes flow has seen an increased interest during the last few decades due to their numerous engineering and biomedical applications. In this work we restrict our interest to elastic membranes with shearing and area-dilatation resistance but negligible bending resistance. This class represents a wide range of artificial capsules as well as the human red blood cells. To solve this problem, several computational methodologies based on low-order interpolation schemes have been employed (e.g. immersed boundary and boundary integral algorithms). While these methodologies are able to study the capsule deformation at low and moderate flow rates, they are unable to determine the capsule dynamics at strong flows where the interfacial deformation is large.

Results

To overcome this, we have developed a spectral boundary element algorithm for interfacial dynamics of three-dimensional capsules in Stokes flow. Our methodology preserves the main characteristic of the spectral methods, i.e. the exponential convergence in the interfacial accuracy as the number of spectral points increases, but without creating denser systems as spectral methods used in volume discretization do. Owing to its spectral nature, our interfacial algorithm has the significant advantage of the accurate determination of any interfacial property, including geometric derivatives and membrane tensions. We believe that this is an important issue for the correct and accurate determination of very deformed capsule shapes made from membranes obeying non-linear elastic laws such as the Skalak and neo-Hookean (or Mooney-Rivlin) laws.

Conclusions

In contrast to the existing low-order methodologies which are unable to study interfacial dynamics at high flow rates, our spectral algorithm predicts stable transient and steady-state capsule shapes in these flows. The pointed profiles of these shapes are in qualitative agreement with experimental findings. Our results for erythrocytes in strong shear flows are also in excellent agreement with experimental findings from ektacytometry.