Dynamics of Red Blood Cells and Fluid Vesicle in flows

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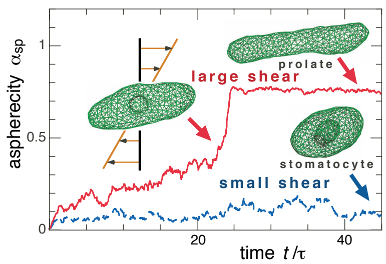
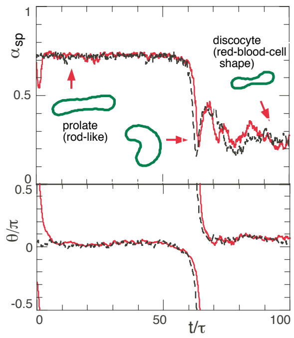
Red blood cells and lipid vesicles exhibit rich behaviors in flows. We have studied their dynamics using a particle-based hydrodynamic simulation method, multi-particle collision (MPC) dynamics. Several transitions of their shapes and dynamic modes are discovered. In simple shear flow, three types of dynamic modes, tank-treading, tumbling, swinging, occur. They are coupled with shape deformation. In capillary flow, shape transition to parachute shape and alignments of cells are observed. These results show good agreement with experiments.

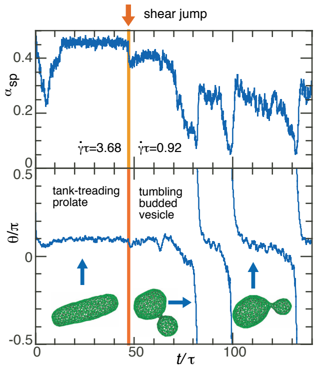
Lipid vesicle in simple shear flow



Stomatocyte to prolate



Prolate to discocyte
Dashed lines: simple theoretical model

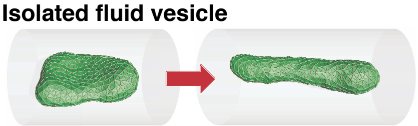


Budded vesicle to prolate (tumbling) (tank-treading)

Shear induces not only elongational shape transitions but also shrinking transition.

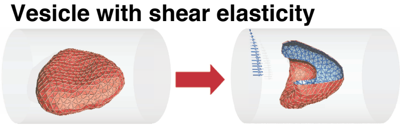
capillary flow

Isolated fluid vesicle

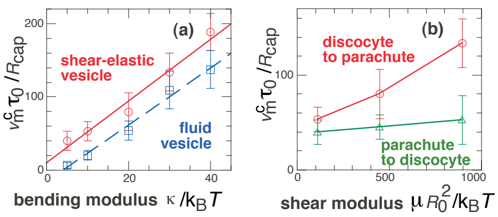


slow flow fast flow

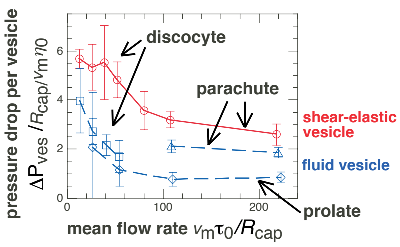
Vesicle with shear elasticity



slow flow fast flow

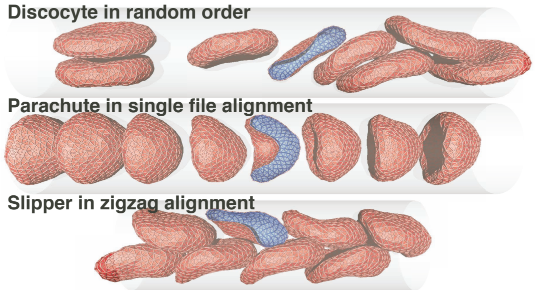


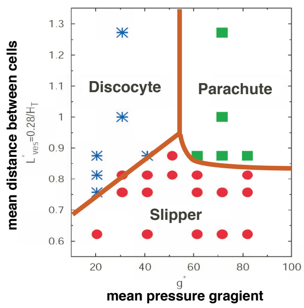
Linear dependence of transition velocities v_m^c.
(a) fluid and shear-elastic vesicles at $\mu R_0^2/k_BT$=112.
(b) shear-elastic vesicles at κ/k_BT=10.



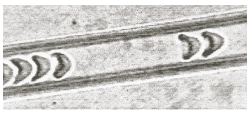
These shape transitions reduce the flow resistance.

Dense system (L.J. McWhirter)





Hydrodynamic interactions between cells induce alignments.



Red blood cells in glass capillary
tsukada et al. Microvasc. Res.61, 231 (2001).

Red blood cells in microvessel
Skalak et al. Science 164, 717 (1969).

CONCLUSION

- Simple shear flow [1-4]
  Fluid vesicles exhibit transitions of their shapes and dynamics modes. Elongational transitions (from discocyte, stomatotye, or buded shape to prolate) and shrinking transition (prolate to discocyte) are found.

- Capillary flow [5-7]
  As flow velocity increases, shear-elastic vesicles transit from a non-axisymmetric discocyte to an axisymmetric parachute shape, while fluid vesicles transit from a discocyte to a prolate ellipsoid.
  In dense suspensions, the hydrodynamic interacitions induce ordered alignmens: single-file parchute and two-file.

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