4th Micro and Nano Flows Conference
UCL, London, UK, 7-10 September 2014

Blood Flow *in silico*: From Single Cells to Blood Rheology

Gerhard GOMPPER [1,*]

* Corresponding author: Tel.: ++49 2461 61 4012; Fax: ++49 2461 61 3180; Email: g.gompper@fz-juelich.de
1 Theoretical Soft Matter and Biophysics, Institute of Complex Systems and Institute for Advanced Simulation, Forschungszentrum Jülich, D-52425 Jülich, Germany

Keywords: Microcirculation, Capillary Flow, Red Blood Cells

The flow behavior of vesicles and blood cells is important in many applications in biology and medicine. For example, the flow properties of blood in micro-vessels is determined by the rheological properties of red blood cells (RBCs). Blood flow is therefore strongly affected by diseases such as malaria or diabetes, where RBC deformability is strongly reduced. Furthermore, microfluidic devices have been developed recently, which allow the manipulation of small amounts of suspensions of particles or cells.

Of fundamental interest is here the relation between the flow behavior and the elasticity and deformability of the blood cells, their long-range hydrodynamic interactions in microchannels, and thermal membrane undulations [1]. We study these mechanisms by combination of particle-based mesoscale simulation techniques [2] for the fluid hydrodynamics with triangulated-surface models [3-5] for the membrane. The essential control parameters are the volume fraction of RBCs (tube hematocrit), the flow velocity, and the capillary radius.

In narrow channels, single red blood cells in capillary flow show a transition from the biconcave disk shape at low flow velocities to a parachute shape at high flow velocities [4,6]. For somewhat wider channels, other shapes such as slippers intervene between these states [6]. At higher volume fractions, hydrodynamic interactions are responsible for a strong deformation-mediated clustering tendency at low hematocrits, as well as several distinct flow phases at higher hematocrits, such as a zig-zag arrangement of slipper shapes [7]. For large vessels, blood behaves like a continuum fluid, which displays a strong shear-thinning behavior; our simulations show quantitatively how this behavior arises due to RBC deformability and cell-cell attraction [8]. Finally, the dynamics of RBCs is demonstrated to lead to a margination of white blood cells at intermediate hematocrits and not too large flow rates [9].

References

[1] D.A. Fedosov, H. Noguchi, and G. Gompper. *Multiscale Modeling of Blood Flow: From Single Cells to Blood Rheology.* Biomech. Model. Mechanobiol., advance online publication (2013). DOI: 10.1007/s10237-013-0497-9.

[2] G. Gompper, T. Ihle, D.M. Kroll, and R.G. Winkler. *Multi-Particle Collision Dynamics -- a Particle-Based Mesoscale Simulation Approach to the Hydrodynamics of Complex Fluids.* Adv. Polymer Sci. **221**,1 (2009).

[3] G. Gompper and D.M. Kroll. Triangulated-Surface *Models of Fluctuating Membranes.* In *Statistical Mechanics of Membranes and Surfaces*, 2nd edition, edited by D.R. Nelson and T. Piran and S. Weinberg (World Scientific, Singapore, 2004).

[4] H. Noguchi and G. Gompper. *Shape Transitions of Fluid Vesicles and Red Blood Cells in Capillary Flows.* Proc. Natl. Acad. Sci. USA **102**, 14159 (2005).

[5] D.A. Fedosov, B. Caswell, and G.E. Karniadakis. *A multiscale red blood cell model with accurate mechanics, rheology, and dynamics.* Biophys. J. **98**, 2215 (2010).

[6] D.A. Fedosov, M. Peltomäki, and G. Gompper. *Shapes and Deformation of Red Blood Cells in Microvessel Flows.* submitted (2013).

[7] J.L. McWhirter, H. Noguchi, and G. Gompper. *Flow-Induced Clustering and Alignment of Red Blood Cells in Microchannels.* Proc. Natl. Acad. Sci. USA **106**, 6039 (2009).

[8] D.A. Fedosov, W. Pan, B. Caswell, G. Gompper, and G.E. Karniadakis. *Predicting blood rheology in silico.* Proc. Natl. Acad. Sci. USA **108**, 11772 (2011).

[9] D.A. Fedosov, J. Fornleitner, and G. Gompper. *Margination of White Blood Cells in Microcapillary Flow.* Phys. Rev. Lett. **108**, 028104 (2012).