Biomechanics of red blood cells and related diseases

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We investigate the biomechanics of red blood cells (RBCs) and related diseases by applying a two-component model using the Dissipative Particle Dynamics. We modeled the lipid bilayer and the cytoskeleton as two separate components. The lipid bilayer is considered as area incompressible with zero shear modulus and significant bending, and the cytoskeleton with finite shear modulus but no bending stiffness. We incorporated the real number of the spectrins in the cytoskeleton and modeled the normal elastic interaction and the tangential viscous friction between the lipid bilayer and the cytoskeleton in the molecular level. First, we validated our model by simulating the cytoskeleton deformation in micropipette aspiration and got consistent results with experiments. Second, we simulated tank-treading motion of RBCs in shear flow, passage of RBCs through microfluidic channels and bilayer tethering of RBCs on a substrate under shear flow, and predicted the critical conditions of bilayer-cytoskeletal sliding and detachment in these experiment. We found that the bilayer-cytoskeletal sliding is small for healthy RBCs but can be significant for diseased RBCs. Our predicted bilayer-cytoskeletal interaction strength agrees with the adhesion energy theory in the continuum level. Thirdly, we modeled the membrane fluctuation and torque rheometry experiments, and explored the effect of bilayer-cytoskeletal interactions on the fluctuation amplitude and membrane viscoelasticity. We found that using an appropriate bilayer-cytoskeletal elastic interaction parameter, the two-component model matches the experiment better than the one-component model. Finally, we simulated the critical conditions of RBCs passing the interendothelial slits in the human spleen, and predicted the retention rates of malaria-infected RBCs in the spleen. By comparison with the ex-vivo spleen perfusion experiments, we found that both the increased membrane stiffness shear modulus and cell shape sphericity play important roles in the retention of malaria-infected RBCs.