NUMERICAL ANALYSIS OF THE DEFORMATION OF A RED BLOOD CELL

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KEYWORDS:
Main subjects: biological flow, red blood cell
Fluid: biphasic flow
Visualization method(s): computer simulation
Other keywords: shear, strain, deformation

ABSTRACT: Hemolysis, the the breaking open of red blood cells (RBCs) results from their excessive deformation when exposed to a high shear flow. Although the quantitive evaluation of hemolysis is highly demanded by engineers wokring for designing artificial organs, predictive accuracy of the methods developed so far has not reached a satisfactory level required for practical applications. The talk will describe our recent work on making a new hemolysis simulator that considers the deformation of each RBC. The RBC is modeled as a closed shell membrane consisting of triangular meshes where neighboring meshes and nodal points are connected with springs. Area and volume constraints are imposed by enenergy funcions in order to assure incompressibility. Fluid forces exerted by external plasma flow and internal hemoglobin flow are estimated based on the momentum conservation and Newton's friction law. Given the fluid forces, the dynamic motion of an RBC in a flow field is calculated based on the minimum energy principle. When the RBC model was put in a steady shear flow, it tank-treaded, tumbled or did both, depending on the shear rate. The plot of the deformation index L/W (a length ratio of the long axis L to the short axis W when the RBC is approximated as an ellipsoidal body) against the external fluid shear stres showed a linear incrase in L/W until τ = 50 Pa and later a convergence to approximately ~5 Pa at τ =200 Pa. The RBC in a cyclically reversing unsteady shear flow showed a phase difference between the fluid shear stress and L/W. The results for steady and unsteady shear flows well agreed with experimental results, corroborating the proposed RBC model. We then simulated the RBC in bifurcated flows where an RBC was experimentally observed to lyse when impinging against the apex of bifurcation. The simulation results are presented in Fig. 1, demonstrating significantly dynamic deformation of an RBC as it approached to the apex of bifurcation. A comparison of the maximum of the area strain over the RBC membrane with conventional hemolysis indices showed no consistent tendencies between them. Thus, it is basically impossible to estimate the amount of hemolysis solely from a flow field. A careful investigation of the RBC deformation revealed buckling of the membrane upon collision against the wall. It was found that the area strain reached 1.81 at maximum, larger than the reported value at which a pore is formed in the lipid bilayer membrane. Those results suggested the possibility of estimating hemolysis by the evaluation of the area strain. In conclusion, the results address the necessity to consider deformation of RBCs for better evaluation of hemolysis and the present model would be useful to build the RBC-based hemolysis simulator.

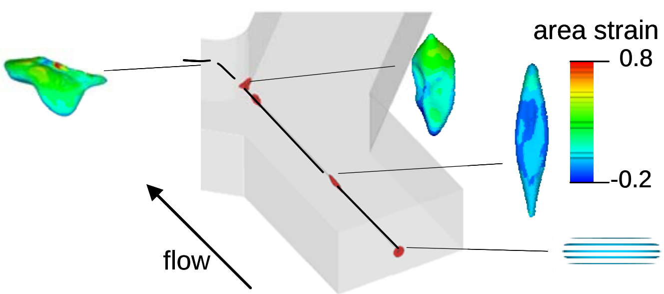

Fig. 1 Snapshots of RBCs in bifurcation flow.