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The squeezing of red blood cells though capillaries with near-minimal diameters. (English)

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Summary: An analysis is presented of the mechanics of red blood cells flowing in very narrow tubes. Mammalian red cells are highly flexible, but their deformations satisfy two significant constraints. They must deform at constant volume, because the contents of the cell are incompressible, and also at nearly constant surface area, because the red cell membrane strongly resists dilation. Consequently, there exists a minimal tube diameter below which passage of intact cells is not possible. A cell in a tube with this diameter has its critical shape: a cylinder with hemispherical ends. Here, flow of red cells in tubes with near-minimal diameters is analysed using lubrication theory. When the tube diameter is slightly larger than the minimal value, the cell shape is close to its shape in the critical case. However, the rear end of the cell becomes flattened and then concave with a relatively small further increase in the diameter.

The changes in cell shape and the resulting rheological parameters are analysed using matched asymptotic expansions for the high-velocity limit and using numerical solutions. Predictions of rheological parameters are also obtained using the assumption that the cell is effectively rigid with its critical shape, yielding very similar results. A rapid decrease in the apparent viscosity of red cell suspensions with increasing tube diameter is predicted over the range of diameters considered. The red cell velocity is found to exceed the mean bulk velocity by an amount that increases with increasing tube diameter.

MSC:

76Z05 Physiological flows
92Cxx Physiological, cellular and medical topics

Keywords:

red blood cells; Mammalian red cells; rheological parameters; matched asymptotic expansions; high-velocity limit

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