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Continuum modeling of deformation and aggregation of red blood cells

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Abstract

In order to gain better understanding for rheology of an isolated red blood cell (RBC) and a group of multiple RBCs, new continuum models for describing mechanical properties of cellular structures of an RBC and inter-cellular interactions among multiple RBCs are developed. The viscous property of an RBC membrane, which characterizes dynamic behaviors of an RBC under stress loading and unloading processes, is determined using a generalized Maxwell model. The present model is capable of predicting stress relaxation and stress-strain hysteresis, of which prediction is not possible using the commonly used Kelvin-Voigt model. Nonlinear elasticity of an RBC is determined using the Yeoh hyperelastic material model in a framework of continuum mechanics using finite-element approximation. A novel method to model inter-cellular interactions among multiple adjacent RBCs is also developed. Unlike the previous modeling approaches for aggregation of RBCs, where interaction energy for aggregation is curve-fitted using a Morse-type potential function, the interaction energy is analytically determined. The present aggregation model, therefore, allows to predict various effects of physical parameters such as the osmotic pressure, the thickness of a glycocalyx layer, the penetration depth, and the permittivity, on the depletion and electrostatic energy among RBCs. Simulations for elongation and recovery deformation of an RBC and for aggregation of multiple RBCs are conducted to evaluate the efficacy of the present continuum

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