Numerical Investigation of Worm-like Drug Carriers in Stenotic Microvessels

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Abstract

The shape of drug carriers is a critical factor in drug formulation, and worm-like drug carriers have recently gained significant interest. This research focuses on the efficacy of these carriers for targeted drug delivery in stenosis. We aim to investigate their behavior within the narrowed blood vessels characteristic of this condition and assess their ability to navigate complex blood flow dynamics. Key factors influencing delivery performance in stenotic conditions include carrier stiffness, red blood cell (RBC) deformability, and the severity of stenosis. To explore these aspects, we utilized a plasma-cell-carrier system to replicate multiphase blood flow. Blood plasma was modeled as an incompressible Newtonian fluid, while drug carriers were represented as one-dimensional (1D) worm-like structures composed of deformable spherical beads. A constant pressure gradient was applied between the inlet and outlet of the vessel to induce flow. To mimic the properties of RBC membranes, we employed a spring model for both RBCs and drug carriers. Interactions between cells and fluid, as well as carriers and fluid, were analyzed using the immersed boundary method. Our findings indicated that the velocity of RBCs surpassed that of drug carriers, with the latter being propelled by RBCs and migrating toward the vessel walls in micro blood flow. We observed tumbling of drug carriers near the endothelial walls and their attachment to RBC membranes. The rheological behavior of drug carriers was influenced by factors such as stenosis severity, RBC deformability, and carrier stiffness. Notably, increasing the stiffness of drug carriers significantly reduced their attachment to the walls. Furthermore, changes in RBC deformability showed that stiffer RBCs promoted margination and decreased attachment of worm-like drug particles. Our results suggest that the stiffness contrast between RBCs and drug carriers plays a crucial role in carrier margination and cell-drug interactions. The numerical simulations conducted in this study provide insights into the mechanisms governing drug transport and distribution within stenotic vessels. By modeling the complex interactions among drugs, blood flow, and tissue dynamics, we can better understand how various factors influence drug delivery outcomes, potentially guiding the design of more targeted and efficient drug delivery systems.

Keywords

Drug Delivery, Worm-like Drug Carriers, Stenosis, Red Blood Cells, Margination, Numerical Simulation