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A Dissipative Particle Dynamics Study of a Capsule in Microfluidic Intracellular Delivery System

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Abstract : Intracellular delivery of materials has always proved to be a challenge in research and therapeutic applications. Usually, vector-based methods, such as liposomes and polymeric materials, and physical methods, such as electroporation and sonoporation have been used for introducing nucleic acids or proteins. Reliance on exogenous materials, toxicity, off-target effects was the short-comings of these methods. Microinjection was an alternative process which addressed the above drawbacks. However, its low throughput had hindered its adoption widely. Mechanical deformation of cells by squeezing them through constriction channel can cause the temporary development of pores that would facilitate non-targeted diffusion of materials. Advantages of this method include high efficiency in intracellular delivery, a wide choice of materials, improved viability and high throughput. This cell squeezing process can be studied deeper by employing simple models and efficient computational procedures. In our current work, we present a finite sized dissipative particle dynamics (FDPD) model to simulate the dynamics of the cell flowing through a constricted channel. The cell is modeled as a capsule with FDPD particles connected through a spring network to represent the membrane. The total energy of the capsule is associated with linear and radial springs in addition to constraint of the fixed area. By performing detailed simulations, we studied the strain on the membrane of the capsule for channels with varying constriction heights. The strain on the capsule membrane was found to be similar though the constriction heights vary. When strain on the membrane was correlated to the development of pores, we found higher porosity in capsule flowing in wider channel. This is due to localization of strain to a smaller region in the narrow constriction channel. But the residence time of the capsule increased as the channel constriction narrowed indicating that strain for an increased time will cause less cell viability.

Keywords : capsule, cell squeezing, dissipative particle dynamics, intracellular delivery, microfluidics, numerical simulations
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