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Flow-induced translocation of vesicles through a narrow pore

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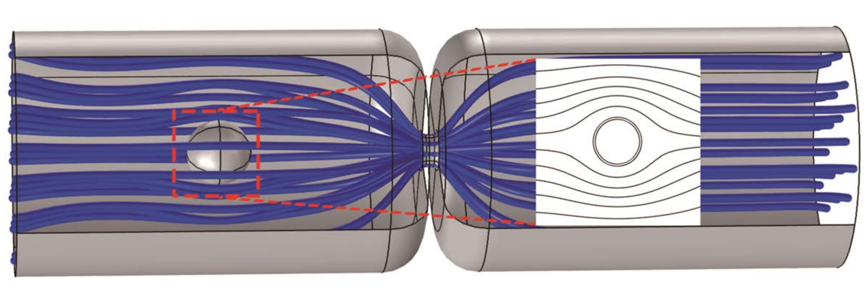
Introduction

Vesicles are very "soft", consisting of a liquid internal medium enclosed by a very thin deformable membrane, which can be deformed easily by external forces. The research on vesicles in microfluidic channels has received increased interest in recent decades, motivated by a wide range of applications, including drug delivery, cell sorting and cell characterization devices, and the determination of membrane properties, on the grounds of their simple structure, which also provides an ideal model system for exploring the structure *versus* function of living cells. Because fluid mechanics (motions of internal and external liquid) and solid mechanics (motions and deformations of membranes) are strongly coupled, the actual flow field may be much more complicated considering the fluid-membrane boundary conditions for the motions and deformations of vesicles. Therefore, the description of flow-induced translocation of vesicles through a narrow pore has not been well established, especially on strain energy, which is essential in various engineering and biomedical applications. In our work, we numerically investigate the flow-induced translocation of vesicles through a narrow pore, in particular from a dynamic point of view, using finite element method, where the fluid–structure interactions are employed to complete the coupling between fluid flow and the vesicle membrane. We aim to monitor the motions and deformations of the vesicles in the narrow pore to yield the mapping between the positions of the vesicles and deformed states.

Model and methods



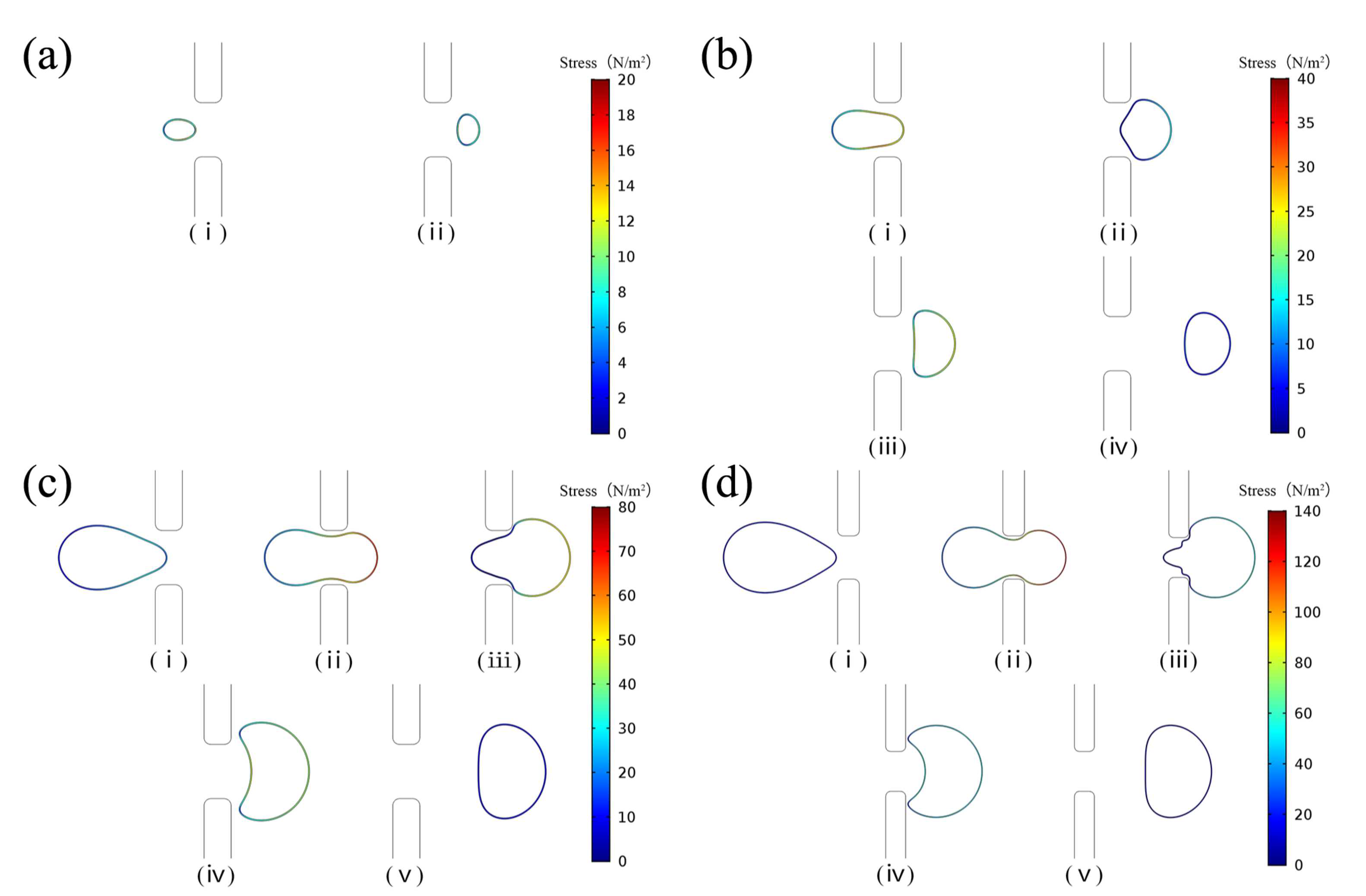
Schematic representation for the model, in which a spherical vesicle is put into a cylindrical, where a narrow pore exists in the middle of the microchannel.

We consider the interior and exterior liquids of vesicle as incompressible Newtonian fluids with a laminar flow;

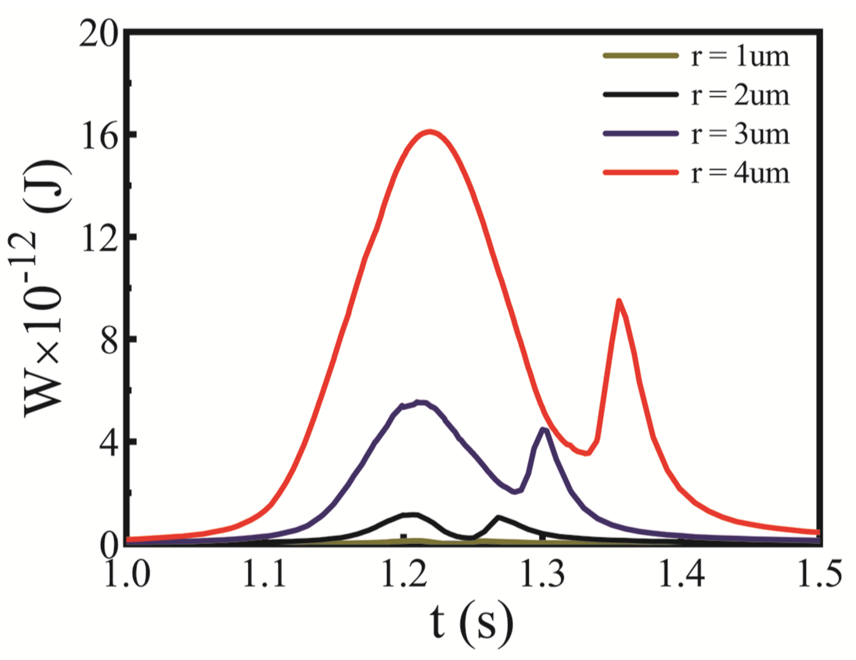
We use the Kelvin–Voigt model to describe the viscoelastic behavior of the membrane;

We employ the finite element method to solve the governing equations on the unstructured meshes, where fluid–structure interactions is employed to couple between fluid flow and the vesicle membrane.

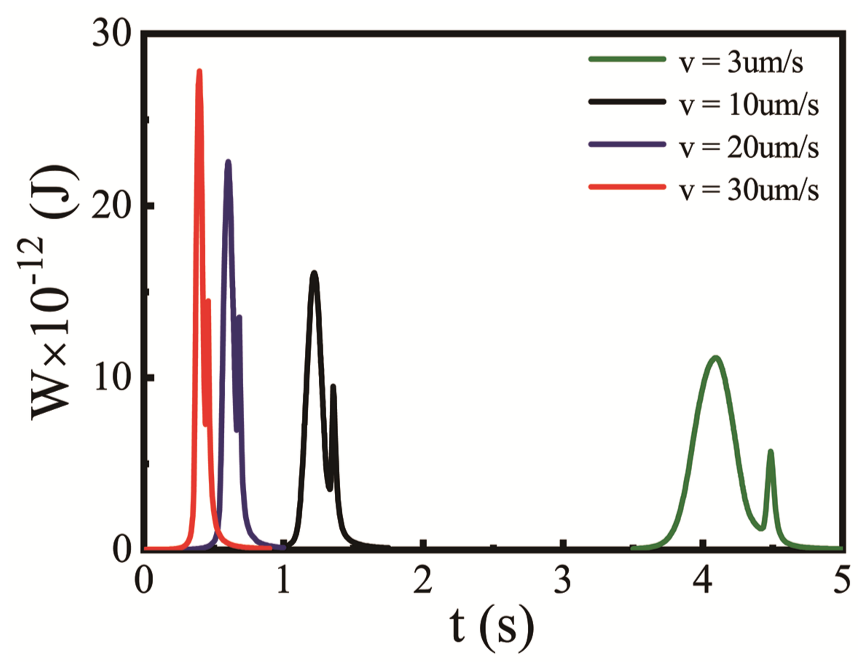
Results



Motions and deformations of vesicles into the narrow pore for the radii of vesicles: (a) 1 mm, (b) 2 mm, (c) 3 mm, and (d) 4 mm.

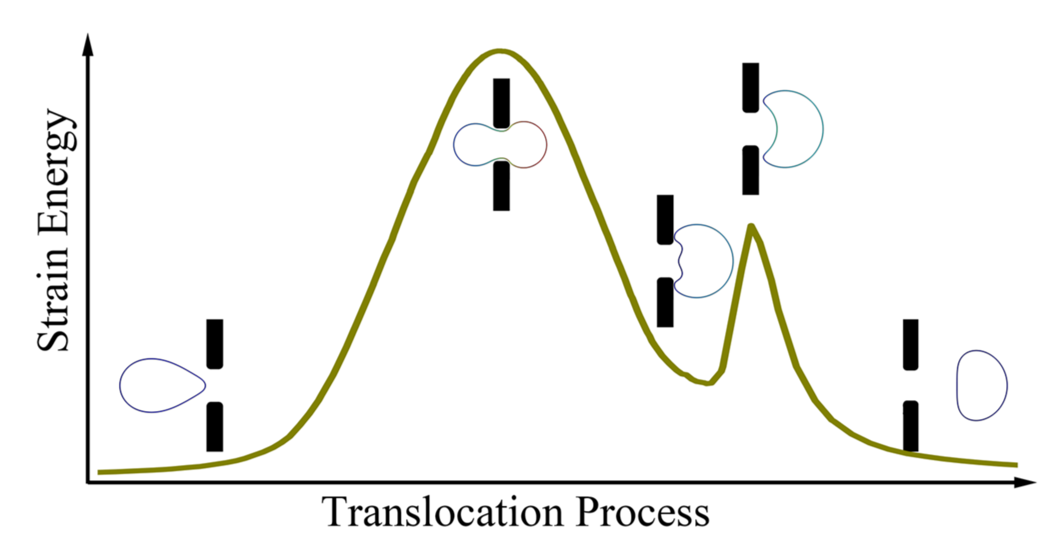


Strain energy with the translocation process from time 1s to 1.5s for different radii of vesicles.



Strain energy for different inlet velocities.

Summary



Our results demonstrate that the vesicle shows similar shape change from bullet-like to dumbbell-like, dumbbell-like to bulb-like, and bulb-like to parachute-like if it is pushed by flow field to pass through a narrow pore smaller than its size. We further find that the strain energy exhibits a higher peak and a lower peak in the whole translocation process, where the higher peak corresponds to the dumbbell-like shape and the lower peak corresponds to the parachute-like shape due to more stretching of the membrane for the dumbbell-like shape than that of the parachute-like shape.

Our work answers the mapping between the positions of the vesicles and deformed states with the stress distribution and change of strain energy, which can provide helpful information on the utilization of vesicles in pharmaceutical, chemical, and physiological processes.

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