Abstract

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Adhesion of cells and extracellular vesicles (EVs) is ubiquitous in nature and plays an important biological role in the functioning and sustenance of cells and the multi-cellular organism as a whole. Shape transformations of cells, for example, as observed during the fission and fusion processes, or during the morphological changes in the red blood cell (RBC) structure while passing through the capillaries, or during the interaction of cell with it's environment, etc., are crucial to their functions.
Thus, the biological importance of adhesion and shape transformation makes it imperative to probe for adhesion-induced shape changes of cells. Cell membranes are complex and diverse structures with complex mechanisms of shape regulation, but a relatively simple elastic theory has been found to be successful in describing red blood cell shape and their transformations. In the thesis, we use a theoretical approach to study shape transformations using a simple vesicle model system that can effectively describe the necessary characteristics of a cell membrane.

In the thesis, we primarily study the shape transformations of lipid vesicles with spherical topology induced by their adhesion to a flat surface. The aim is to investigate the shapes of vesicles stabilized by adhesion and study the shape transformations between different classes of vesicles. Apart from the study of vesicle where the vesicle membrane is composed of a single kind of membrane component (single component vesicle), we also investigate the adhesion of vesicle systems where the vesicle membrane is composed of two kinds of membrane components (multi-component vesicle), and the membrane components are characterized by their intrinsic spontaneous curvatures. Experiments have suggested that the lateral distribution of membrane components can influence the shape of the vesicle, and conversely, the shape of the membrane can induce lateral segregation, with the components migrating to the membrane regions which are more favourable to their intrinsic curvature. The main aim here is to further our understanding of this hypothesis -- which assumes a coupling between the shape and the lateral distribution of components under the context of adhesion. We study the vesicle system within the spontaneous curvature model and numerically minimize the energy functional to obtain the equilibrium shapes and the distribution of the components simultaneously. We have performed a detailed study of the shape transformations between vesicles adhered to a flat surface. It was shown that the most stable configuration of an adhered vesicle with the membrane composed of a single kind of component and characterized by a relatively small spontaneous curvature was oblate with the increase in adhesion. This situation can be more complex with the multi-component vesicle membrane, where there is an extra degree of freedom in the form of a non-homogeneous lateral distribution of components over the vesicle surface. From the calculations, it followed that budding can be induced by adhesion, and even a slight change in adhesion strength was found to be enough to promote or suppress it. It has been shown that an increase in spontaneous curvature of the vesicle membrane could encourage an easy adhesion of vesicles and that this effect was different in concave oblate vesicles (vesicles that curve inwards on their surface) than in the convex oblate vesicles (vesicles that curve outwards on their surface). The relationship between the shape and the corresponding lateral distribution of membrane components of the adhered vesicles has been investigated, and it has been shown that a budded vesicle like a pear-shaped vesicle can support the mixing of components, and a non-budded vesicle shape like oblate can support lateral segregation of membrane components. Our calculations have suggested that an increase in adhesion can promote both mixing and segregation of components, and this depends strongly on the shape of the vesicle under adhesion. Similar behaviour was observed when the vesicles were elongated by growing inner microtubule or when the vesicle volume was changed by the change of trans-membrane osmotic pressure [1].