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Abstract

How nanoparticles interact with biomembranes is central for understanding their bioactivity. Biomembranes wrap around nanoparticles if the adhesive interaction between the nanoparticles and membranes is sufficiently strong to compensate for the cost of membrane bending. In this article, we review recent results from theory and simulations that provide new insights on the interplay of bending and adhesion energies during the wrapping of nanoparticles by membranes. These results indicate that the interplay of bending and adhesion during wrapping is strongly affected by the interaction range of the particle-membrane adhesion potential, by the shape of the nanoparticles, and by shape changes of membrane vesicles during wrapping. The interaction range of the particle-membrane adhesion potential is crucial both for the wrapping process of single nanoparticles and the cooperative wrapping of nanoparticles by membrane tubules.

1. Introduction

Recent advances in nanotechnology have led to an increasing interest in how nanoparticles interact with living organisms [1]. On the one hand, biomedically designed nanoparticles are promising delivery vehicles or vectors in drug treatments [2–6]. On the other hand, nanoparticles are frequently incorporated into smart materials, in food packing, as anti-fouling agents or to keep surfaces sterile [7]. This wide application of industrial nanoparticles has also led to concerns about their safety [3, 8, 9] and has triggered intense activities to investigate and understand nanotoxicity [10–12].

Since nanoparticles have to cross biomembranes to enter the cells and organelles of living organisms, a current focus is on understanding the interactions of nanoparticles with membranes. Nanoparticles that are larger than the membrane thickness cross the membrane by wrapping and subsequent fission of a membrane neck. The wrapping of the nanoparticles by the membranes can either occur spontaneously from an interplay of adhesive and elastic energies, or can be assisted by the curvature-inducing proteins and protein machineries of cellular membranes [13–16].

The topic of this review is the spontaneous wrapping of nanoparticles by membranes. Spontaneous wrapping occurs if the adhesive interaction between the nanoparticles and the membrane is sufficiently strong to compensate for the cost of membrane bending. The spontaneous wrapping of nanoparticles has been observed in experiments with lipid vesicles [17–21], polymersomes [22, 23], and cells [24, 25], and has been investigated by theoretical calculations [26–39] and simulations [40–62]. In this review article, our focus is on recent results from theory and simulations that provide new insights on how the wrapping process is affected (i) by the interaction range of the particle-membrane adhesion potential, (ii) by the shape of the nanoparticles, and (iii) by shape changes of membrane vesicles during wrapping.

Previous theoretical investigations have been largely focused on particle-membrane adhesion potentials with