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Bending compliance of lipid bilayer regulates the curvature threshold and pathway of membrane structural stability loss

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Motivation and Aim: Membrane fission and fusion generally involve highly curved membrane intermediates. Membrane bending not only allows to confine the membrane rearrangement sites but also creates the elastic stress widely regarded as a trigger of local lipid rearrangements. The experimental and theoretical analyses have revealed various lipid rearrangements induced by the critical bending stress pathways. However, it remains unclear which molecular and force factors control the pathways choice and enable leakage-free membrane rearrangements.

Methods and Algorithms: Here, we modeled the stress action experimentally and theoretically using a simple 1D model, the membrane nanotube (NT) constricted by proteins and physical forces. We used the electric field to measure the ionic conductance of the NT lumen and, at the same time, assess, in real-time, changes of the material parameters of the NT membrane during the NT constriction and scission.

Results: We found that the NT membrane retained linear bending elasticity up to the moment of scission. The scission, seen as an abrupt loss of the luminal connectivity, happened spontaneously upon reaching a certain critical curvature, a function of the lipid composition of the NT membrane. The theoretical analysis demonstrated that the corresponding instability was associated with a threshold value of elastic stress, the bending rigidity function, and the NT monolayers' intrinsic curvature. Analysis of the NT constriction dynamics by proteins revealed that the proteins sense the lipid elastic response and generally create subcritical or transient critical stresses, thus effectively avoiding causing membrane leakage.

Conclusion: We conclude that the nanoscale deformations of highly bent intermediates of membrane fusion and fission could be described in terms of linear macroscopic elasticity with the embedded elastic moduli ascribed to bilayer midplane. We further speculate that the material properties of the lipid bilayer are reflected in the functional design of proteins mediating cellular membrane remodeling: the membrane constriction action of the protein machinery is adapted to the lipidome.

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