Dehydration damage in biological membranes: mechanisms, structure and kinetics.

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The ability of some organisms to survive severe dehydration has been of scientific interest since the pioneering work of Antony van Leeuwenhoek in 1702. Dehydration, whether via desiccation or freezing, leads to severe physical and biochemical stresses on biological structures which are, for most organisms, fatal. There are however a significant number of organisms and organelles which are capable of withstanding varying degrees of dehydration.

The mechanisms which enable this dehydration tolerance have been the subject of considerable interest, and active research, for the past few decades. As the primary indicator of cell damage, the cell membrane has naturally been the focus of much of this research. Severe dehydration can lead to irreversible changes to lipid membranes, such as the transition from the fluid bilayer phase to the gel bilayer phase, and even to lethal non-bilayer phases. Such changes have been observed in both model and real biological systems.

However, it has emerged that it is the composition of the aqueous environment, rather than the membrane itself, which is largely responsible for differential dehydration tolerance of different species. It is now well established that dehydration tolerance is often correlated with the presence of high concentrations of sugars, including but not limited to, trehalose and sucrose. For many years it was believed that these sugars, and in particular trehalose, had some unique property which enabled them to protect membranes during dehydration.

However, over the past decade it has emerged that membrane protection is not specific, but rather a general property of all solutes. The degree of protection is due to a combination of the volumetric, osmotic, and vitrifying properties of the aqueous solution. In this talk I will review our understanding of the physical mechanisms of membrane damage due to dehydration, and the role of solutes in reducing this damage. I will present a model which quantitatively explains the effect of solutes on membrane phase transitions. Finally, I will present the results of recent experiments designed to study both the structural and kinetic effects of solutes on bilayer to non-bilayer transitions.