Controlled Modulation of Lipid Bilayer State by a Photosensitive Membrane Effector

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Amino Acids and Peptides Stabilize Fatty Acid Membranes against Salt-Induced Flocculation
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The prebiotic formation of biopolymers (specifically DNA, RNA, and proteins) has long been a mystery and is important for understanding the origin of life on earth. These bio-molecules are composed of building blocks that would have been dispersed in early oceans. Our previous work has shown that RNA bases and ribose bind to and stabilize fatty acid vesicles [Black et al. PNAS 110, 13272 (2013)]. Our results implied that the building blocks of a biological polymer could have spontaneously associated with components of the first membranes to form stable structures. We have now shown that protein building blocks, peptides synergize with fatty acid vesicles against salt-induced flocculation. Using spectrophotometry, we measured the presence of flocs (and other structures) in fatty acid solutions, with and without amino acids and over a range of temperatures. Using fluorescence microscopy, we identified the structures that caused changes in absorbance in our spectrophotometric assays. We found that the two most hydrophobic prebiotic amino acids, leucine and isoleucine, prevent salt-induced flocculation. Moreover, although alanine and glycine, which are less hydrophobic, had little effect on flocculation, dipeptides composed of these two amino acids significantly inhibited protein-induced flocculation. The values of viscosity measured for the plasma membrane of E.coli in this study are higher than those measured previously in E.coli lipid extracts or in model membranes. They were also further characterized with other surface-sensitive techniques such as fluorescence microscopy to assess the phospholipid mobility.

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Measurement of the Viscosity of E. coli Membranes using Molecular Rotors and Film
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We have employed molecular rotors, small organic molecules whose fluorescence lifetime is sensitive to the viscosity of the environment, to assess the viscosity of the E.coli plasma membrane. We used Fluorescence Lifetime Imaging Microscopy (FLIM) which allows us to measure the fluorescence lifetimes (and thus viscosities) on the level of single cells. We probed the viscosity of membranes both in live cells and in spheroplasts, where the outer membrane was removed by lysozyme treatment. Viscosity values obtained for both environments were similar implying that the molecular rotor used indeed localized to the plasma membrane and measured previously described differences in the membrane viscosities. Measurements on live cells show a rather broad spread of viscosities between individual cells in population; such heterogeneity of physical parameters of the cell has been reported previously for the diffusion of protein in the cytoplasm of bacteria. The viscosity of membranes was temperature dependent as we have observed a change in viscosity when cells grown at 37 degrees Celsius were measured at lower temperatures than the growth. Subjecting the cells to a hypotonic shock by increasing the medium osmolarity by adding NaCl also elicited a change in viscosity and yet a larger spread of viscosity values between individual cells, which is consistent with previous observations that a fraction of cell within a population seems to respond to the osmotic shock more strongly than the others.

The values of viscosity measured for the plasma membrane of E.coli in this study are higher than those measured previously in E.coli lipid extracts or in the plasma membrane of life eukaryotic cells but slightly lower than what was reported previously for the Gram-positive bacterium Bacillus subtilis.

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Polydopamine as an Efficient Polymer to Prepare Biologically Relevant Supported Lipid Bilayers
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Solid-supported lipid bilayers (s-SLBs) are widely used as versatile biological membrane mimics. However, lipid-solid surface interactions and ensuing frictions lead to a decrease in lipid mobility. To address this issue, we prepared polymer-supported lipid membranes using a soft polymer cushion as a lubricating layer. A bioinspired polymer, polydopamine was chosen due to its ability to easily form thin coatings onto a wide range of surfaces, with a control of the thickness depending on the immersion time of the substrate. Polydopamine coated-mica was used to support zwitterionic phospholipid bilayers of dimyristoylphosphatidylcholine (DMPC) or dioleoylphosphatidylcholine (DOPC). Atomic Force Microscopy (AFM) was performed to verify the deposition of DMPC and DOPC bilayers, revealing the presence of lipid patches on the polymer surface. The addition of positively charged cholesterol (DC-Chol) in the membrane composition greatly improved the lipid surface coverage (up to 90%). Best results were obtained for 20 and 30% DC-Chol containing membranes. They were also further characterized with other surface-sensitive techniques such as fluorescence microscopy to assess the phospholipid mobility. Surface Plasma Resonance (SPR) and Quartz Crystal Microbalance with Dissipation (QCM-D) results showed the irreversible deposition of the lipid bilayers on the polymer surface. The polydopamine polymer film proved to be efficient to maintain fluidity of the phospholipid bilayers, thus enhancing this class of membrane model. We will present practical application of our s-SLBs onto porous filters as an improved model of Parallel Artificial Membrane Permeability Assay (PAMPA) to better predict passive permeation of orally administered drugs.
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The lipid membrane matrix represents a 2-D liquid-crystal, the properties of which, at fixed other conditions, are locally modulated by the presence of effectors as e.g. cholesterol (passive) or proteins (passive and active). Not only does the incorporation of effectors into the host matrix locally or even globally modify the initial state of the host per se, most probably the state of the matrix in turn serves as a control tool for regulating the work of functional units (e.g. proteins).

Results presented on a membrane model system that was inoculated with a photosensitive and thus active variety of cholesterol. Azobenzene-cholesterol (azo-chol) exhibits a reversible trans-cis transition (365nm: trans- to cis-; 455nm: cis- to trans-). In a membrane, the azobenzene group, covalently connected to the cholesterol by an ester bond, is confined into the headgroup region. The system was explored by a combination of spectroscopic (UV-vis, NMR, mass spectroscopy), thermodynamic (Langmuir compression, calorimetry) and structural studies (X-ray/neutron reflectometry, grazing incidence X-ray diffraction). The conformational change of the guest upon illumination is coupled into the host system, inducing a transition of the whole membrane. The increased demand of headgroup area for the cis-azo-group pushes the membrane into a more compressed state, and vice versa for trans-azo-chol. The switching process between the two final states exhibits first-order kinetics. The state of the host bilayer is modulated as a response to the conformational switching of the guest effector via external light illumination. In a more general context, similar behavior may be found upon the conformational changes of membrane proteins during work.

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Creating Fluid Supported Lipid Bilayers with High Amounts of Phosphatidylethanolamine

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Phosphatidylethanolamine (PE) comprises 20-50% of overall phospholipid content in human cell membranes and constitutes 70-80% of the membranes in gram-negative bacteria. The presence is specifically required for the proper folding of numerous membrane proteins, the function of active transport systems, cell division, fusion, blood coagulation, and may play a role in neurodegenerative diseases. Unfortunately, it is hard to work with this lipid in model systems like supported lipid bilayers and there is correspondingly less information known about its basic physical properties in bilayers. Specifically, the role of PE in lipid raft formation, vesicle fusion, cholesterol interaction, ion binding, and lipid flip-flop needs to be elucidated to understand its part in cell membrane function and disease pathways. To this end, my research has two goals. First, I have developed supported lipid bilayer systems that can operate with high mole percentages of PE. Second, I have begun to exploit such systems to explore the properties and functions of PE in membranes.

2751-Pos Board B181

Biophysical Analysis of a Successful Protocol to Reconstitute Tetramers of the M2 Muscarinic Receptor

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The human G protein-coupled receptor M2 muscarinic receptor has been functionally reconstituted in its tetrameric state into mixed lipid bilayers (Redka et al. 2013). This is achieved by first solubilizing the receptor in mixed detergent micelles composed of digitonin and sodium cholate, then reconstituting it into vesicles composed of phosphatidylcholine, phosphatidylserine and cholesterol, followed by detergent removal. To understand how the individual detergent and lipid components used in this empirical protocol contribute to the stability and activity of the receptor, we used isothermal titration calorimetry (ITC) to study the self-assembly of the mixed surfactant system; differential scanning calorimetry and pressure perturbation calorimetry to probe the phase behavior of the membrane; ITC, fluorescence (time-resolved) leakage assays and dynamic light scattering to characterize detergent-lipid interactions. The results suggest ideal mixing between digitonin and sodium cholate in the formation of mixed micelles that stabilize the receptor. Differences in membrane-partitioning behavior between the two detergents and the presence of a significant fraction of gel phase at the temperature used in the protocol contribute to non-equilibration of the detergents in the bilayer. Insights gained from this biophysical approach will aid in the mechanistic selection of detergents and conditions that influence function, oligomeric state, orientation, and accessibility of membrane proteins in future studies.

2752-Pos Board B182

Ion-Mobility Mass Spectrometry Assay for Incorporation of Phytanic Acid into Myscel Phospholipids

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Human dysferlinopathies (Limb-Girdle Muscular Dystrophy 2b, Myoshi Myopathy) are muscle-wasting syndromes caused by mutations in the dysferlin protein. Muscle fiber loss impairs sarcolemmal repair that may contribute to disease progression. One therapeutic approach is to treat subjects with compounds that fortify the natural membrane tendency to reseal after damage, and to minimize the inflammation that impedes regeneration and amplifies tissue destruction. Phytic acid is a saturated branched chain fatty acid comprised of a 16 carbon aliphatic chain with 4 methyl groups (4ME; 16:0); it is incorporated into phospholipids and triglycerides. Model phospholipid bilayers containing phytic acid exhibit greater electrical stability than bilayers composed of straight-chain phospholipids. Phytic acid-containing phospholipids may improve the resistance of the muscle fiber sarcolemma to stretch-induced damage. To measure phytic acid incorporation into muscle phospholipids, dysferlin-deficient A/J mice were maintained on a defined diet supplemented with 2% phytol for three weeks; control animals received the defined diet without phytol. Muscle tissue lipids were analyzed by mass spectrometry. The muscle phosphatidylcholine species profiled after 1 month of phytol and control diet, except that some additional species were detected in the phytol diet muscle. The two most abundant novel species (m/z 790.7 and 862.7) are tentatively identified as PC 16:0-16:0 and PC 20:0-22:6. To confirm the presence of phytic acid, the ion mobility of these species was compared with diphytanoyl PC standard and endogenous straight chain PC phospholipids. The ion mobility is intermediate between PC species containing either zero or two phytanic acid chains, consistent with having one phytic acid chain. We estimate that these species represent 5% of PC. Using this methodology, we will identify phytic acid containing species in the other classes, in order to determine the total amount of phytic acid-containing phopholipid incorporated in the muscle.

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Fluctuation-Induced Interactions between Membrane-Bound Proteins

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The spatial organization of membrane-bound proteins is in part determined by interactions that originate from long-range correlations due to the membrane’s elastic behavior. Even basic geometric mechanisms, such as the suppression of membrane height fluctuations near protein binding sites, can lead to nontrivial interactions between proteins that might result in their aggregation. To study the effect of such membrane-induced interactions, we devise a simple model that captures (a) a nonspecific repulsion between proteins, (b) elastic properties of the membrane, and (c) a local harmonic coupling between proteins and membrane shape. The model’s dynamics is governed by Langevin equations to faithfully capture entropic effects and the importance of rare fluctuations. We find that the membrane induces an attractive interaction between the proteins, which aggregate to mitigate the entropic cost of suppressing membrane fluctuations. This generic mechanism might help explain the spatial patterns induced by membrane sculpting proteins.

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Effect of Phosphatidylinositol-Bisphosphate (PIP2) Lipids on Membrane Structure and Forces

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It is widely accepted that the interaction between lipid bilayers at closest separation is dominated by a repulsive hydration force arising from the structuring of water molecules on the lipid bilayer surface. This force has been recognized as a major activation energy barrier preventing fusion of bilayers. Our working hypothesis is that the orientation of the hydrogen bond network on the bilayer surface determines the amplitude of the hydration force. We are testing this hypothesis using the 1,2-diioleoyl-sn-glycero-3-phospho-[1'-myo-inositol-4,5'-bisphosphate][P4(4,5)P2] lipid and its isomers which differ in the position of phosphate groups on the inositol ring. Phosphatidylinositol-bisphosphate (PIP2) lipids are pivotal in signaling and play an important role in exocytosis. Specifically, we have utilized small angle X-ray diffraction (SAXS) and monitored the structural consequences of osmotic pressure in multilamellar suspensions of dioleoylphosphatidylcholine (DOPC) in the presence of P(4,5)P2. Our preliminary data (powder X-ray diffraction and reconstructed electron density profiles) show that there are notable changes in bilayer structure, particularly the lamellar repeat distance, thickness, and forces in the presence of P(4,5)P2.