CELL MEMBRANE

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Modern descriptions of the cell are intimately related to the notion of cell membranes. The cell membrane is not only the boundary of the unit of life, it is also a specific compartment that harbors many essential cell functions including communication with the environment, transport of molecules and certain metabolic functions. Nowadays, the consensual model to depict the membrane structure and functions is called the “fluid mosaic model”.

The fluid mosaic hypothesis was formulated by Singer and Nicolson in the early 1970s. According to this model, membranes are made up of lipids, proteins and carbohydrates. The main lipid membrane components are phospholipids. These molecules are amphiphilic, i.e. they have one polar part attracted by water (hydrophilic) and one a-polar component repelled by water (hydrophobic). When they are diluted in water, amphiphiles spontaneously adopt the most thermodynamically stable molecular structure, namely the one that maximizes both hydrophilic and hydrophobic interactions. These interactions may be affected by several parameters, such as the chemical nature of the molecules, their size, the salinity and pH of the solution. In biological conditions, cell phospholipids form a bilayer in which hydrophobic tails face each other in the core of the structure whereas the hydrophilic heads interact with the surrounding water. Since proteins are also amphiphilic molecules, the same constraints apply to them. Some proteins (called intrinsic or integral) are embedded in the lipid bilayer matrix where they are able to establish hydrophobic and hydrophilic interactions with their respective lipid counterparts. Other proteins, called extrinsic or peripheral proteins, can also be transiently associated with membrane surfaces through weaker interactions. Finally, carbohydrates can be linked to either proteins or lipids, resulting in glycoproteins or glycolipids.

The “mosaic” term of this model refers to the mixture of lipids and intrinsic proteins in the membrane. These boundaries are also “fluid” because their components can move laterally, allowing both diffusion of components and local specific gatherings. Other lipids, such as cholesterol, act as membrane fluidity regulators. Phospholipid movements are generally restricted to lateral drift, because the cross of the membrane from one side to the other requires the energetically unfavorable transient contact of their hydrophilic head with the hydrophobic membrane core. Thus, the transfer of molecules from one side of the membrane to the other generally involves the activity of some specific integral membrane proteins, called flippases. For the same reasons, integral proteins can diffuse within the lipid matrix but they seldom switch their polarity from one membrane side to the other. As a result, lipid, protein and carbohydrate composition are different between the two monolayers, a characteristic that is referred to as membrane asymmetry.

Membrane functions are extremely diverse. As cell borders, membranes control the molecular exchanges with the environment, resulting in cell pH regulation and osmotic homeostasis. Membranes are “selective barriers”: They concentrate nutrients within the cell, exclude the cellular waste products, keep the ionic gradients and transform them into chemical energy. Since they allow the transduction of many external stimuli into cell signals, they are also major actors in the responses of the cell to their environment. In addition, their composition also turns membranes into the main apolar compartment of the prominently aqueous cell medium, thus concentrating most lipid pigments (e.g. chlorophyll) and hydrophobic proteins. The presence of these molecules in the membranes doubles their bounding function with essential metabolic and bioenergetic activities.

Except for some rare authors who still envisage the cell as a naked colloid network, there is nowadays little disagreement that membranes are essential parts of all contemporary cells. Despite this basic acceptance concerning modern cells, we have witnessed in recent years a strong debate questioning the presence of similar membranes in the last common ancestor of living organisms, namely the cenancestor. Arguing about the presence or absence of membranes in early organisms–not only the cenancestor, but also previous organisms closer in time to the origins of life–challenges what we consider to be the basic unit of life, i.e. the cell. Unfortunately, because the lack of membranes is generally unquestioned in modern organisms, it is nowadays difficult to come across discussions about the theoretical importance of membranes.

The limited attention currently given to membranes in defining the cell concept contrasts greatly with the importance that this issue had in early cell studies. Indeed, when the Cell Theory was formulated 175 years ago in the XIXth century, the reality of the membrane was unknown. Its universal character was not generally acknowledged until well into the XXth century, and even when the cells were assumed to be bounded by some kind of membrane, the fluid mosaic model was not accepted until as late as the 1970s. The natural question then is: how were the cell boundaries envisioned between the formulation of the Cell Theory around 1839 and the final predominance of the fluid mosaic model in 1972?