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Department of Biochemistry /Second Stage

Lecture-2: Structure and Composition of Biological Membranes

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1. Introduction to Membrane Structure

Biological membranes are fundamental structural elements of all living cells. They define cellular boundaries, compartmentalize intracellular organelles, and create distinct microenvironments necessary for specialized biochemical reactions. The structural organization of membranes is directly linked to their diverse biological functions.

Modern understanding of membrane structure integrates biochemical, biophysical, and molecular perspectives, emphasizing the dynamic nature of membranes rather than viewing them as static barriers.

2. Chemical Composition of Biological Membranes

Biological membranes are primarily composed of **lipids, proteins, and carbohydrates**, each contributing specific structural and functional properties.

2.1 Membrane Lipids

Lipids form the structural backbone of membranes. The major classes include:

- **Phospholipids** (phosphatidylcholine, phosphatidylethanolamine, phosphatidylserine)
- **Glycolipids**
- **Sterols** (cholesterol in eukaryotes)

The amphipathic nature of membrane lipids drives spontaneous bilayer formation in aqueous environments.

Phospholipids are compound/complex lipids containing lipid molecules attached to a phosphate group. Phospholipids are derivatives of glycerol-3-phosphate in which the glycerol backbone is attached to two fatty acids on one end and esterified phosphoric acid and an organic alcoholic group on the other.

Lipid Bilayer Organization

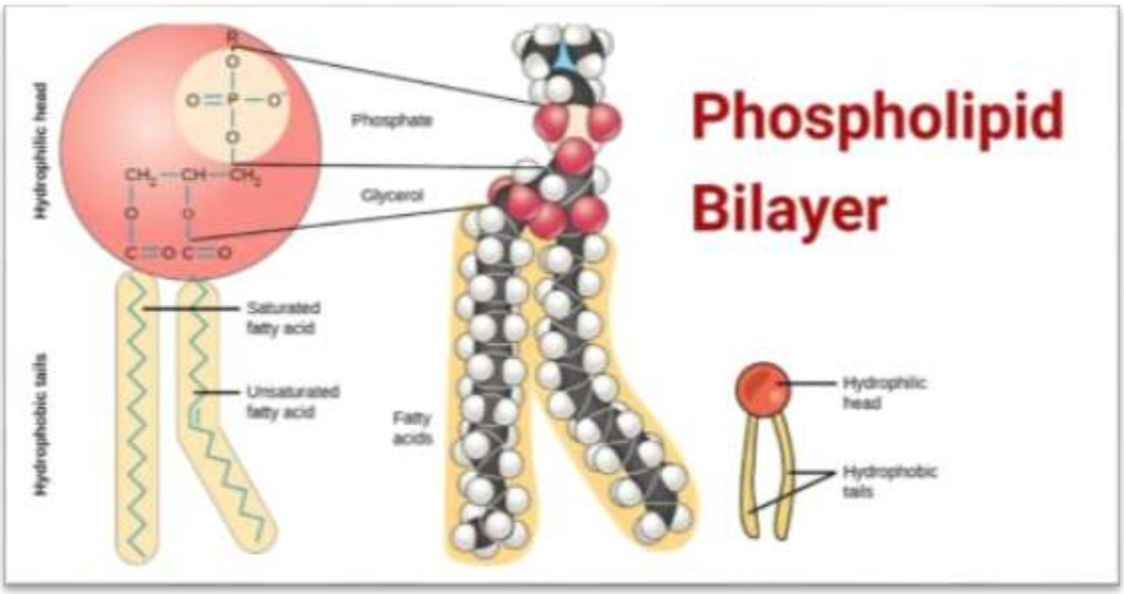

Figure: Phospholipid bilayer depicting hydrophobic tails of fatty acid chains and hydrophilic head of glycerol backbone, phosphate, and polar head group.

Structure of phospholipid bilayer

The phospholipid bilayer consists of phospholipids arranged in two layers with exterior facing hydrophilic polar heads and interior hydrophobic non-polar tails. This imparts the amphiphilic nature to phospholipids. Structurally, a phospholipid molecule comprises two fatty acid tails and a head with glycerol (3-carbon alcohol) and a phosphate molecule. The two fatty acyl chains are esterified to the two hydroxyl groups in glycerol, while the phosphate group is esterified to the terminal hydroxyl group in glycerol. The two fatty acyl chains differ in the number of C atoms (commonly 16 or 18) and their degree of saturation, i.e., the presence of 0, 1 or 2 double bonds. Surprisingly, the phospholipid fatty acids are of two types where one is saturated and the other unsaturated, which is responsible for membrane fluidity and flexibility of the phospholipid membrane.

3. Membrane Proteins: Structure and Classification

Membrane proteins account for the majority of membrane functions.

3.1 Integral (Transmembrane) Proteins

- Span the lipid bilayer
- Often α-helical or β-barrel in structure
- Function as channels, transporters, and receptors

3.2 Peripheral Membrane Proteins

- Loosely associated with membrane surfaces
- Involved in signaling and cytoskeletal attachment

3.3. Lipid-Anchored Proteins

Lipid-anchored proteins are covalently attached to lipid molecules embedded in the cell membrane.

Features of Lipid-Anchored Proteins

These proteins are linked to the membrane via lipid groups like GPI anchors (glycosylphosphatidylinositol) or prenyl groups. The lipid anchors allow the protein to attach firmly to the membrane.

Types of Membrane Proteins

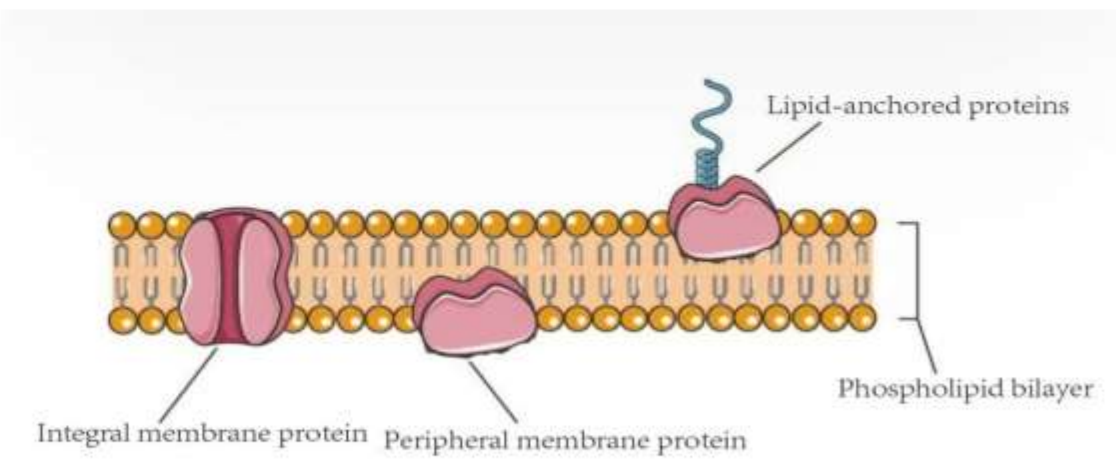

Figure 1. Three types of membrane proteins.

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4. Carbohydrates and Membrane Asymmetry

Carbohydrates are present exclusively on the extracellular surface of membranes as:

- **Glycoproteins**
- **Glycolipids**

Together, they form the **glycocalyx**, which plays a crucial role in:

- Cell–cell recognition
- Immune response
- Cell adhesion

Membrane asymmetry is a fundamental feature essential for normal cellular function.

5. The Fluid Mosaic Model

The **Fluid Mosaic Model**, proposed by Singer and Nicolson (1972), describes membranes as two-dimensional fluids where proteins are embedded within a lipid bilayer.

Features

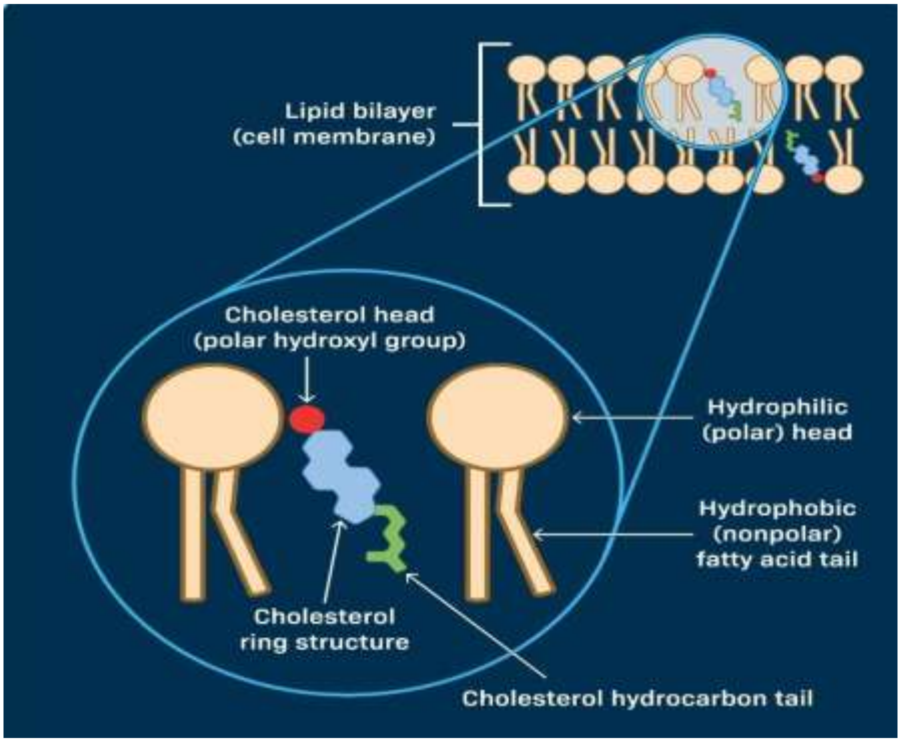
- Lateral mobility of lipids and proteins
- Heterogeneous protein distribution
- Dynamic structural organization

6. Membrane Fluidity and Its Regulation

Membrane fluidity is critical for membrane function and is influenced by:

- Fatty acid saturation
- Fatty acid chain length
- Cholesterol content
- Temperature

Cholesterol acts as a fluidity buffer, stabilizing membranes across temperature ranges.



Cholesterol affects the fluidity of cell membranes (the lipid bilayer) by interacting with phospholipid fatty acid chains. Similar to phospholipids, cholesterol in the membrane aligns itself so that its polar head group faces the aqueous environment, and its nonpolar hydrocarbon tail faces toward the inside of the membrane

7. Specialized Membrane Domains

Biological membranes are not uniform. Specialized domains include:

- **Lipid rafts** (cholesterol- and sphingolipid-rich microdomains)
- Caveolae :These domains serve as platforms for signaling and protein sorting.

8. Functional Implications of Membrane Structure

Membrane composition directly affects:

- Transport efficiency
- Signal transduction
- Energy metabolism
- Membrane protein activity

Structural alterations can profoundly influence cellular physiology.

Short Essay Questions

Q1. Discuss the molecular basis of membrane asymmetry and explain its functional significance in eukaryotic cells.

Q2. Explain how lipid composition influences membrane fluidity and how cells adapt membrane structure to temperature changes.

Q3. Describe the Fluid Mosaic Model and critically evaluate its relevance in light of modern discoveries such as lipid rafts.

Q4. Compare integral and peripheral membrane proteins in terms of structure, membrane association, and biological function.

References

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