Molecular model of phospholipid bilayer
Effect of external ion concentration on water flow across the plasma membrane of an animal cell

However, the pant cell has cellulose (cell wall) can prevented the swelling or shrinking
Fluid mosaic model of biomembrane

- Cytosol
- Lipid-anchored protein
- Integral membrane protein
- Peripheral membrane protein
- Exoplasm
- Peripheral membrane protein
- Hydrophilic phospholipid head group
- Phospholipid bilayer
- Hydrophilic fatty acyl side chains

3nm
Plasma membrane

1. Affect shape and function
2. Anchor protein to the membrane
3. Modify membrane protein activities
4. Transducing signals to the cytoplasm

“A living cell is a self-reproducing system of molecules held inside a container - the plasma membrane”

Membrane comprised of lipid sheet (5 nm thick)
Primary purpose - barrier to prevent cell contents spilling out
BUT, must be selective barrier
Prokaryotes still have plasma membrane, but contain no internal membrane limited subcompartments

**Chemical reaction vs. compartment**

Each organelle is surrounded by biomembranes.

Cytoplasm: The part of the cell outside the largest organelle, the nucleus.

Cytosol: The aqueous part of the cytoplasm outside of the organelle, contain its own distinctive protein.

**Lumen:** A space between outside and inside of membrane or surrounding by membrane.

Biomembrane are bilayer structure.

the area of internal membrane was tenfold of surface outside membrane; The internal membrane is important than outside.

The internal membrane formed organelle and provide a separating space for specific chemical or biological reaction.
The major components of eukaryotic cell architecture

 Plasma membrane

 Nucleus

 Golgi

 ER

 Mitochondrion

 Lysosome

 Endosome

 Multivesicular body

 Plasma membrane

 (700 μm²)

 Internal membranes

 (7000 μm²)

 Cytoskeleton

 (94,000 μm²)
Eukaryotic membranes are dynamic.

Stacked membranes of the Golgi complex.
Biomembrane: lipid composition and structural organization

Three classes of lipids are found in biomembrane

1. **Phosphoglycerides; most abundant**
2. **Sphingolipids**
3. **Steroid: stable lipid bilayer**

There are amphipathic

PE: phosphatidylethanolamine
PC: phosphatidylcholine
PS: phosphatidylserine
PI: phosphatidylinositol
SM: sphingomyelins
GlcCer: glycolipid glucosylcerebroside

(c) Cholesterol

Hydrophobic tail

Acyl group: c16 or c18, 0, 1 or 2 double bond
Phospholipid structure

PL = glycerol attached to 2 FA phosphate and different side groups (PE, PS, PC)
SM = serine attached to 2FA phosphate and choline side group
PI = minor phospholipid critical for signaling; inositol ring can be phosphorylated
Cholesterol = complex hydrocarbon ring structure
The bilayer structure of biomembrane

Phospholipid bilayers: two molecule thick, formed the cell membrane
Two important of lipid bilayers: 1. hydrophobic core: prevent the diffusion of water-soluble. It regulated by specific membrane proteins; 2. stability by hydrophobic and van der Waals interactions between the lipid chains.

Lipid Bilayer

1. Impermeable barrier prevent diffusion of water soluble solute
2. Membrane protein mediate transport of specific molecule
3. Maintained by hydrophobic interaction
Phospholipid spontaneously form bilayers
Phospholipid bilayers form a sealed compartment surrounding an internal aqueous space

Micelle

Liposome
Due to the amphipathic nature of phospholipids, these molecules *spontaneously* assemble to form closed bilayers.
Formation of and study of pure phospholipid bilayer

Chloroform and methanol (3:1)

Phospholipids in solution
Evaporate solvent
Dissolve phospholipids in solvent and apply to small hole in partition

Planar bilayer
Plastic partition

Liposome

Phospholipid spontaneously form bilayers
Cell membranes are asymmetric

Cellular membranes have a cytosolic face (exposed to the cytosol) and an exoplasmic face (directed away from the cytosol)

Organelles with two membranes, the exoplasmic surface faces the lumen between the membranes
Faces of cellular membranes

The faces of cellular membrane
1. **Internal faces**
   - Surface orient toward the **interior** of the compartment
2. **External faces**
   - The surface presented to the **environment**

**Green: internal cytosol**

Nucleus, mitochondria and chloroplast are enclosed by two membrane separated by a small intermembrane space

- **Internal face**: surface toward the interior of the compartment
- **External face**: surface presented to the environment
- **Cytosolic face**: internal cytosol
- **Exoplastic face**: external cytosol

**Diagram:**
- Endoplasmic reticulum
- Golgi
- Lysosome
- Mitochondrion
- Vesicle
- Matrix
- Intermembrane space
- Cytosol
- Exterior
- Plasma membrane
- Inner membrane
- Outer membrane
- Nuclear membrane

**Legend:**
- **Mitochondrial membranes**
- **Cytosolic face**
- **Exoplastic face**
- **Intermembrane space**
Faces of cellular membranes are conserved during membrane budding and fusion

Endocytosis: red membrane is face to cytosol
Exocytosis: red membrane is also face to cytosol (exoplasmic face)

面對細胞質的，就會面對細胞質
Variation in biomembrane in different cell types

Biomembrane had different function and shape in different cell type

RBC
Smooth and flexible

Multiple layers of modified plasma membrane: formed by adjacent glial cells

Cilia project from the ependymal cells that line the brain ventricles

Long, slender extension
Biomembrane contain three principal classes of lipids

Lipid composition influence the physical properties

Different cell type → different composition of lipids

<table>
<thead>
<tr>
<th>TABLE 10-1 Major Lipid Components of Selected Biomembranes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOURCE/LOCATION</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Plasma membrane (human erythrocytes)</td>
</tr>
<tr>
<td>Myelin membrane (human neurons)</td>
</tr>
<tr>
<td>Plasma membrane (E. coli)</td>
</tr>
<tr>
<td>Endoplasmic reticulum membrane (rat)</td>
</tr>
<tr>
<td>Golgi membrane (rat)</td>
</tr>
<tr>
<td>Inner mitochondrial membrane (rat)</td>
</tr>
<tr>
<td>Outer mitochondrial membrane (rat)</td>
</tr>
<tr>
<td><strong>Primary leaflet location</strong></td>
</tr>
<tr>
<td>PC = phosphatidylcholine; PE = phosphatidylethanolamine; PS = phosphatidylserine; SM = sphingomyelin.</td>
</tr>
</tbody>
</table>
Why does membrane need to be fluid?

Enables rapid diffusion of membrane proteins within plane of bilayer and permits interaction (important for cell signalling)

Facilitates distribution of membrane lipids and proteins from insertion site (following synthesis) to other regions of cell

Allows membranes to fuse and mix molecules

Ensures even distribution of membrane molecules between daughter cells following division
Most lipid many proteins are laterally mobile in biomembrane. Thermal effect and dependent. Two dimensional plane of a bilayer move rotate.

“The Fluid Mosaic Model”

**FRAP:** Fluorescent Recovery After Photobleaching

![Diagram of FRAP process]

- **1.** Label the membrane protein
- **2.** Bleach with laser
- **3.** Record fluorescent recovery after photobleaching
Mobility (diffusion) of a given membrane components depends on:

- the size of the molecule
- its interactions with other molecules
- temperature
- lipid composition (tails, cholesterol)
Most lipoid and many protein are laterally mobile in biomembrane

Gel and fluid forms of the phospholipid bilayer

Below the phase transition temperature, fatty acyl chains are in a gel-like (crystalline) state.

Above the phase transition temperature, fatty acyl chains are in rapid motion.

Heat disorders the nonpolar tail and induces a transition form gel to fluid
Lipid composition influence physical properties of membrane:

1. Different composition of organs
2. Specialized membrane function
   i.e. apical surface if intestinal lumen
   sphingolipids: phosphoglycerides: cholesterol
   basolateral  0.5  1  1
   apical 1 1 1
3. Affects membrane fluidity
   a. short C-H chain are more fluid
   b. kinks in C-H: less stable
4. Influence thickness of membrane
5. Local curvature (彎曲)
Heat disorders the nonpolar tail and induces a transition form gel to fluid.

Cholesterol is important in maintaining the fluidity, but cannot form a bilayer. It restricts the random movement of phospholipid head groups at the surfaces of the leaflets, and concentration depend.

Heat disorders the nonpolar tail and induces a transition form gel to fluid.
Cholesterol can increase membrane (PC) thickness, but no effect of SM

Exoplasmic leaflet has enrich PC
Cytosolic face has enrich PE, so more curvature

bilayer enriched with PC in the exoplasmic leaflet and with PE in the cytoplasmic face would cause the natural curvature
Biomembrane: lipid composition and structural organization

Three classes of lipids are found in biomembrane

<table>
<thead>
<tr>
<th>Phosphoglycerides</th>
<th>Acyl group:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>c16 or c18,</td>
</tr>
<tr>
<td></td>
<td>0, 1 or 2 double bond</td>
</tr>
</tbody>
</table>

1. **Phosphoglycerides; most abundant**
2. **Sphingolipids**
3. **Steroid: stable lipid bilayer**

There are amphipathic

PE: phosphatidylethanolamine
PC: phosphatidylcholine
PS: phosphatidylserine
PI: phosphatidylinositol
SM: sphingomyelins
GlcCer: glycolipid glucosylcerebroside

(c) Cholesterol

**Head group**

Hydrophobic tail

Plasmalogen

Sphingolipids

Choline head

(c) Cholesterol
Cholesterol $\rightarrow$ Membrane fluidity $\downarrow$

In animal cells, cholesterol used to modulate membrane fluidity - fills gaps between kinks of unsaturated tails

Used particularly in plasma membrane $\Rightarrow$ closer packing $\Rightarrow$ less fluidity/permeability

phospholipid cholesterol

Adapted from ECB Fig 11-16

Figure 10–10. Molecular Biology of the Cell, 4th Edition.
Membrane fluidity

Membrane fluidity important for membrane function; determined by phospholipid composition.

Close packing of hydrocarbon tails ⇒ less fluidity (increased viscosity).

Length and unsaturation (no of double bonds) determine closeness of packing.

Length varies from 14-24 C atoms; shorter chain length ⇒ less interaction ⇒ increased fluidity.

One tail of molecule has one or more double bonds - unsaturated (H atoms); other tail has no double bonds - saturated.

Double bonds ⇒ kinks (曲) ⇒ less packing.

Adapted from ECB Fig 11-6.
Van der Waals interactions between fatty acyl chains are the main determinants of acyl chain mobility. Double bonds reduce the number of potential van der Walls interactions between fatty acyl chains.
Phospholipids can rapidly diffuse along the plane of the membrane
  – Nearest neighbor replacement rate is \(~10^{-8}/\text{sec}\)
Flip-flop is a rare process –
  – leaflet exchange rate is 6 - > 20 h

6- 20 hours for flip-flop
Flippases move phospholipids from one membrane leaflet to the opposite leaflet

asymmetric distribution of phospholipids

senescence or apoptosis – disturb the asymmetric distribution

Phosphatidylserine (PS) and phosphatidylethanolamine: cytosolic leaflet

exposure of these anionic phospholipids on the exoplasmic face – signal for scavenger cells to remove and destroy

Annexin V – a protein that specifically binds to PS phospholipids

fluorescently labeled annexin V– to detect apoptotic cells

flippase: ABC superfamily of small molecule pumps
Lipid bilayer asymmetry (mechanism?)

Two layers of bilayer have **different compositions**

- different **phospholipid/glycolipid** inside vs outside
- membrane proteins embedded into membrane with specific orientation

Phosphatidylcholine (PC)
Sphingomyelin (SM)
Cholesterol

Phosphatidylserine (PS)
Phosphatidylinositol (PI)
Phosphatidylethanolamine (PE)
Glycolipid

Adapted from ECB Fig 11-17
Flipasees move phospholipids from one membrane leaflet to opposite leaflet

Cell membrane move

lateral diffusion

flexion rotation

flip-flop (rarely occurs)

Figure 10–8. Molecular Biology of the Cell, 4th Edition.
Lipid asymmetry occurs during manufacture

To permit membrane growth, newly synthesised membrane must be evenly (均匀) distributed between both monolayers

Asymmetry distribution of bi-layer, Requires enzyme assistance - *flippases*

*Flippases* selectively transfer specific phospholipids ⇒ asymmetric distribution in each monolayer

**Membrane synthesis occurs in endoplasmic reticulum (ER)**

New membrane exported to other membranes by vesicles (budding and fusion)
**Flip-flop of lipids** (from one half of a bilayer to the other) is normally very **slow**.

Flip-flop would require the polar head-group of a lipid to traverse the hydrophobic core of the membrane. **Need large energy**

The **two leaflets** of a bilayer membrane tend to **differ** in their lipid composition. **Flippases** catalyze flip-flop in membranes where lipid synthesis occurs.

Some membranes contain enzymes that **actively transport** particular lipids from one monolayer to the other.
Membrane lipids are usually **distributed unequally** in the exoplasmic and cytosolic leaflets.

**Membrane asymmetry Affects:**

**Enzyme cleavage**
- phospholipase cleaves phospholipids at exoplasmic sides
- cytosolic sides are resist to phospholipase cleavage

Membrane is an asymmetry in lipid composition across the bilayer.

But cholesterol is relative evenly distributed.

Phospholipase can regulated the composition of phospholipid in membrane. It can cut off the hydrophobic tail and can not across membrane.

Specific of phospholipases
Cholesterol and sphingolipids cluster with specific proteins in membrane microdomain

Lipid raft (筏流): high cholesterol and sphingomyelin and more order → less fluid bilayer → formed special micro domain

Proteins with covalently attached lipid anchors (fatty acid or GPI) tend to associate with raft domains.

Exp: some membrane lipids (GM1, glycosphingolipid) and protein (placental alkaline phosphatase PLAP) colocalize in lipid rafts
Lipid rafts

- Glycosylphosphatidyl inositol anchored protein
- Sphingomyelin
- Dioleoyl-phosphatidylcholine

Cholesterol and sphingomyelin form microdomains; lipid rafts
- Cholesterol inhibitor methyl b-cyclodextrin (cholesterol depletion) or filipin (cholesterol sequester) breaks lipid rafts
- Lipid rafts are enriched for many receptors, signaling proteins
Lipid rafts:

**Sphingolipids** (particularly glycosphingolipids) in the plasma membrane outer leaflet tend to separate out from glycerophospholipids, & co-localize with **cholesterol** in microdomains called **lipid rafts**.

Lipid rafts are **resistant to detergent solubilization**, which has facilitated their isolation and characterization.

**Close packing** of sphingolipids in association with cholesterol has been attributed to **lack of double bonds** in sphingolipid hydrocarbon chains.

Glycerophospholipids often include at least one fatty acid that is kinked, due to one or more double bonds.

Proteins with covalently attached **lipid anchors** (fatty acid or GPI) tend to associate with raft domains.
Function:
1. Signal transduction
2. More strong
Biomembranes: protein components and basic functions

Proteins interact with membrane in three different ways:

**Integral protein**: three part and across membrane, has hydrophobic and hydrophilic part.

**Lipid anchored**: cannot cross membrane. It is bound to one or more lipid molecules.

**Peripheral protein**: cannot interact with the hydrophobic core. Indirectly bound to membrane, via integral protein connect to membrane or cell. May have support.
Three categories of membrane protein

1. Integral membrane protein (transmembrane protein)
   a. Exoplasmic domain
   b. Membrane spanning domain: hydrophobic
   c. Glycosylated

2. Lipid anchored membrane protein covalently bound to lipid

3. Peripheral membrane protein bound to membrane by interaction with integral membrane protein
   Normally non-covalent interaction with integral membrane proteins or with lipid head groups
Membrane-embedded $\alpha$ helices are the primary secondary structures in most transmembrane protein.

Membrane protein: Helices can expose the hydrophobic residue. It can interact with membrane hydrophobic part.

$\alpha$-helices:
20-25 hydrophobic amino acids
Interact with fattyacyl of lipid by van-der-waals
Structural models of two multipass membrane protein

bacteriorhodopsin  Glycerol channel

Covalently attach to one helix

Hydrophilic core

Photo → retinal → change structure → signal transduction
Structural model of bacteriorhodopsin, a multipass (7) transmembrane protein that functions as a photoreceptor in certain bacteria. Like G-coupled receptor
Gly: most small
Green par: hydrophobic amino acid
Blue: hydropholic amino acid
Phospholipid interact with membrane protein

Polar lipid head

Exterior

Membrane

Interior

A aquaporin homotetramer (membrane protein)
Multiple β strands in porins (孔蛋白) form membrane-spanning “barrels” (桶狀)

Porins:
Integral membrane protein
Permit the uptake and disposal of small hydrophilic molecules, has regulation and prevent chemical damage…
Inside is hydropholic part — Can pass chemical
Outside is hydrophobic part — Integrate to membrane
All porins are trimeric transmembrane protein

Hydrophobic part

Yellow: aliphatic side (脂肪) chain
Red: aromatic side chain
HYDROPHOBIC AMINO ACIDS

Alanine (Ala or A)
Valine (Val or V)
Isoleucine (Ile or I)
Leucine (Leu or L)

Methionine (Met or M)
Phenylalanine (Phe or F)
Tyrosine (Tyr or Y)
Tryptophan (Trp or W)
Lipid-anchored membrane proteins

Modes of attachment to:

Cytosolic leaflet:
- fatty acyl group (e.g. myristate (C14) or palmitate (C16)) attached to the N-terminal glycine residue
- unsaturated fatty acyl (farnesyl (C15) or geranylgeranyl (C20)) group attached by thioether bond to C-terminal cysteine. In some cases a second fatty acyl group is linked to another cysteine.

Exoplasmic leaflet:
- Glycosylphosphatidylinositol (GPI) anchor:
  - phosphatidylinositol (PI): two fatty acid chains inserted in membrane
  - several sugar residues
  - phosphoethanolamine: links to C-terminus of protein
Covalently attached hydrocarbon chains anchor some protein to membrane

Acylation attached: attached to the N-terminal glycine residue
Prenylation: to C-terminal cysteine residue
GPI (glycosylphosphatidylinositol): such as proteoglycans.

Acylation involves the generation of the acyl group  R-C=O

All transmembrane proteins and glycolipids are asymmetrically oriented in the bilayer
Possible modifications to Man$_3$GlcN oligosaccharide core:

- $R_1 = \text{Man} \alpha$-(1-2)
- $R_2 = \text{Phosphoethanolamine}$
- $R_3 = \text{Phosphoethanolamine}$
- $R_4 = \text{Gal}$
- $R_5 = \text{GalNAc} \beta$-(1-4)
- $R_6 = \text{Fatty Acid at } C_2 \text{ or } C_3 \text{ of inositol}$
All transmembrane proteins and glycolipids are asymmetrically oriented in the bilayer

Many transmembrane protein contain carbohydrate chain covalently linked to serine, threonine, or asparagine.

Chapter 14. glycosylation for membrane protein and transport.
Human RBC type depend on the surfaces expressed different glycoproteins and glycolipids. All human had enzyme for synthesis O antigen. A type human: has GalNAc transferase. B type human: has Gal transferase. AB type human: both enzyme has.

Glc = Glucose
Gal = Galactose
GlcNAc = N-Acetylglucosamine
GalNAc = N-Acetylgalactosamine
Fuc = Fucose
### TABLE 10-2  ABO Blood Groups

<table>
<thead>
<tr>
<th>BLOOD GROUP</th>
<th>ANTIGENS ON RBCS*</th>
<th>SERUM ANTIBODIES</th>
<th>CAN RECEIVE BLOOD TYPES</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>Anti-B</td>
<td>A and O</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>Anti-A</td>
<td>B and O</td>
</tr>
<tr>
<td>AB</td>
<td>A and B</td>
<td>None</td>
<td>All</td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>Anti-A and anti-B</td>
<td>O</td>
</tr>
</tbody>
</table>

*See Figure 10-20 for antigen structures.*

Table 10-2  
*Molecular Cell Biology, Sixth Edition*  
© 2008 W.H. Freeman and Company
Lipid binding motifs help target peripheral proteins to the membrane

Inter-facial binding surface and mechanism of action of phospholipase A2
It can degradation of damage or aged cell membrane
Protein can be removed from membrane by detergents or high-salt solutions.
Phospholipids and sphingolipids: synthesis and intracellular movement

Cell division need more membrane
New membrane not old membrane extension, but new synthesis

Fatty acids are precursors for phospholipids, sphingolipids, and other membrane components:

Fatty acid synthesis: – regulation of membrane synthesis
saturated fatty acids, unsaturated fatty acids,
C14, C16, C18(stearate, oleate, linoleate, linolenate)
C20(arachidonate)

C14, C16 – synthesized in cytosol from acetyl CoA by acetyl-CoA carboxylase & fatty acid synthetase

Palmitoyl CoA – elongated to 18-24 in ER or mitochondria

De saturase – located in ER, introduce double bonds, kink - unsaturated fatty acids – more fluid

Essential polyunsaturated FAs – linoleic acid, linolenic acids (亞麻油酸)
Unesterified FAs move within cells bound to small cytosolic proteins

Fatty acid-binding proteins: FABP

$\text{FABP (†): } \text{FA} \rightarrow \text{glucose in cardiac muscle}$

FABP expression is regulated for release or uptake FA

FABP levels are high in active muscles\(\rightarrow\) using fatty acids for energy

In adipocytes\(\rightarrow\) + fatty acid \(\rightarrow\) stored as TG

\(\rightarrow\) - fatty acid \(\rightarrow\) use by other cells

In liver\(\rightarrow\) 5% of all cytosolic proteins

Binding of a FA to the hydrophobic pocket of a fatty acid-binding protein (FABP)
Fatty acids synthesis is mediated by several important enzymes.

Glucose, fatty acids, amino acids → acetyl group → linked to acetyl Co A
Acetyl CoA → acetyl CoA carboxylase and fatty acid synthase (in cytosol) → Saturated FA (14, 16C)
Palmitoyl CoA (16C FA acyl group linked to CoA) → 18-24C FA → + 2 carbon in ER or mitochondria
Desaturase enzyme → in ER, produced double bond in FA
Chemical structures of FAs and some of their derivatives

TG → 3 FFA (free fatty acid) + 1 glycerol

Fatty acid are precursor for phospholipids and other membrane components

Arachidonate, platelet activating factor….; Synthesized in peroxisomes

14, 16, 18, 20 C; saturated and unsaturated FA
Incorporation of FAs into membrane lipids takes place on organelle membranes.

Fatty acid didn’t directly pass membrane

\[ \text{Acetyl CoA} \rightarrow \text{saturated fatty acid} \]

\[ \text{acetyl-CoA carboxylase} \]

\[ \text{fatty acid synthase} \]

Annexin V : binds to anionic phospholipids

\[ \rightarrow \text{long exposure of exoplasmic face of plasma memb.} \]

\[ \rightarrow \text{signal for scavenger cells to remove dying cells} \]

**Phospholipid synthesis**
Cholesterol is synthesized by enzymes in the cytosol and ER

HMG-CoA: β-hydroxy-β-methylglutaryl CoA
Drugs used to inhibit cholesterol synthesis include competitive inhibitors of HMG-CoA Reductase.

Examples include various statin drugs such as lovastatin (Mevacor) and derivatives (e.g., Zocor), Lipitor, etc.

A portion of each statin is analogous in structure to mevalonate or to the postulated mevaldehyde intermediate.

Extensive clinical trials have shown that the statin drugs decrease blood cholesterol and diminish risk of cardiovascular disease.
many bioactive molecules are made from cholesterol and its biosynthetic precursors

Cholesterol and phospholipids are transported between organelle by Golgi-independent mechanisms: three hypothesis

Classic secretory pathway disruption (chemical inhibitor, mutation) – do not prevent cholesterol or phospholipid transport between membranes although do disrupt transport of proteins and sphingolipids

lipid in the ER – can not move to mitochondrial membrane by classic secretory vesicle transport
Proposed mechanism of Golgi-independent transport of cholesterol and phospholipids between membranes

Pathway I

Vesicles transfer lipids, did not across Golgi

Cholesterol and phospholipids are transported between organelles by golgi-independent (non-classic secreted transport systems)-three pathway

Proposed mechanism of Golgi-independent transport of cholesterol and phospholipids between membranes
Proposed mechanism of Golgi-independent transport of cholesterol and phospholipids between membranes

**Pathway II**

- ER membrane extension for organelle
- Hypothetical proteins
- Cytosol

**Pathway III**

- Binding protein
- Cytosol

Membrane-embedded proteins
Small lipid-transfer proteins
ATHEROSCLEROSIS (粥狀硬化)

Atheroma
Plaque rupture

Thinning of fibrous cap

Hemorrhage from plaque microvessels
This is a normal coronary artery with no atherosclerosis and a widely patent lumen that can carry as much blood as the myocardium requires.
Atherosclerosis in the coronary artery.
The lumen is narrowed by half. A small area of calcification is seen in the plaque at the right.
A coronary thrombosis is occluding the lumen of this coronary artery.
The Matrix Skeleton of Unstable Coronary Artery Plaque

end