Chapter 03
Lecture Outline

See separate PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.
Introduction

• All organisms are composed of cells
• Cells are responsible for all structural and functional properties of a living organism
• Important for understanding
  – Workings of human body
  – Mechanisms of disease
  – Rationale of therapy
Concepts of Cellular Structure

• **Expected Learning Outcomes**
  – Discuss the development and modern tenets of the cell theory.
  – Describe cell shapes from their descriptive terms.
  – State the size range of human cells and discuss factors that limit their size.
  – Discuss the way that developments in microscopy have changed our view of cell structure.
  – Outline the major components of a cell.
Development of the Cell Theory

- **Cytology**—scientific study of cells
  - Began when Robert Hooke coined the word *cellulae* to describe empty cell walls of cork in 17th century

- **Theodor Schwann** concluded, about two centuries later, that all animals are made of cells

- **Louis Pasteur** demonstrated in 1859 that “cells arise only from other cells”
  - Refuted idea of *spontaneous generation*—living things arising from nonliving matter
Development of the Cell Theory

• **Cell theory**
  – All organisms composed of cells and cell products
  – Cell is the simplest structural and functional unit of life
  – An organism’s structure and functions are due to activities of cells
  – Cells come only from preexisting cells
  – Cells of all species exhibit biochemical similarities
Cell Shapes and Sizes

- About 200 types of cells in human body with varied shapes
- Squamous—thin, flat, scaly
- Cuboidal—squirish-looking
- Columnar—taller than wide
- Polygonal—irregularly angular shapes, multiple sides
- Stellate—star-like
- Spheroid to ovoid—round to oval
- Discoid—disc-shaped
- Fusiform—thick in middle, tapered toward the ends
- Fibrous—thread-like
- Note: A cell’s shape can appear different if viewed in a different type of section (longitudinal vs. cross section)
Cell Shapes and Sizes

Squamous

Polygonal

Discoid

Cuboidal

Stellate

Fusiform (spindle-shaped)

Columnar

Spheroidal

Fibrous

Figure 3.1
Cell Shapes and Sizes

• Human cell size
  – Most cells about 10–15 micrometers (µm) in diameter
    • Egg cells (very large) 100 µm diameter
    • Some nerve cells over 1 meter long
  – Limit on cell size: an overly large cell cannot support itself, may rupture
    • For a given increase in diameter, volume increases more than surface area
      – Volume proportional to cube of diameter
      – Surface area proportional to square of diameter
Cell Shapes and Sizes

Large cell
Diameter = 20 \( \mu \text{m} \)
Surface area = 20 \( \mu \text{m} \times 20 \mu \text{m} \times 6 = 2,400 \mu \text{m}^2 \)
Volume = 20 \( \mu \text{m} \times 20 \mu \text{m} \times 20 \mu \text{m} = 8,000 \mu \text{m}^3 \)

Small cell
Diameter = 10 \( \mu \text{m} \)
Surface area = 10 \( \mu \text{m} \times 10 \mu \text{m} \times 6 = 600 \mu \text{m}^2 \)
Volume = 10 \( \mu \text{m} \times 10 \mu \text{m} \times 10 \mu \text{m} = 1,000 \mu \text{m}^3 \)

Effect of cell growth:
Diameter \((D)\) increased by a factor of 2
Surface area increased by a factor of 4 \((= D^2)\)
Volume increased by a factor of 8 \((= D^3)\)

Figure 3.2
Basic Components of a Cell

• **Light microscope (LM)** revealed plasma membrane, nucleus, and cytoplasm (fluid between nucleus and surface)

• **Transmission electron microscope (TEM)** improved resolution (ability to reveal detail)

• **Scanning electron microscope (SEM)** improved resolution further, but only for surface features
# Basic Components of a Cell

<table>
<thead>
<tr>
<th>Object</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visible to the Naked Eye (Resolution 70–100 μm)</strong></td>
<td></td>
</tr>
<tr>
<td>Human egg, diameter</td>
<td>100 μm</td>
</tr>
<tr>
<td><strong>Visible with the Light Microscope (Resolution 200 nm)</strong></td>
<td></td>
</tr>
<tr>
<td>Most human cells, diameter</td>
<td>10–15 μm</td>
</tr>
<tr>
<td>Cilia, length</td>
<td>7–10 μm</td>
</tr>
<tr>
<td>Mitochondria, width × length</td>
<td>0.2 × 4 μm</td>
</tr>
<tr>
<td>Bacteria (<em>Escherichia coli</em>), length</td>
<td>1–3 μm</td>
</tr>
<tr>
<td>Microvilli, length</td>
<td>1–2 μm</td>
</tr>
<tr>
<td>Lysosomes, diameter</td>
<td>0.5 μm = 500 nm</td>
</tr>
<tr>
<td><strong>Visible with the Transmission Electron Microscope (Resolution 0.5 nm)</strong></td>
<td></td>
</tr>
<tr>
<td>Nuclear pores, diameter</td>
<td>30–100 nm</td>
</tr>
<tr>
<td>Centriole, diameter × length</td>
<td>20 × 50 nm</td>
</tr>
<tr>
<td>Poliovirus, diameter</td>
<td>30 nm</td>
</tr>
<tr>
<td>Ribosomes, diameter</td>
<td>15 nm</td>
</tr>
<tr>
<td>Globular proteins, diameter</td>
<td>5–10 nm</td>
</tr>
<tr>
<td>Plasma membrane, thickness</td>
<td>7.5 nm</td>
</tr>
<tr>
<td>DNA molecule, diameter</td>
<td>2.0 nm</td>
</tr>
<tr>
<td>Plasma membrane channels, diameter</td>
<td>0.8 nm</td>
</tr>
</tbody>
</table>
Basic Components of a Cell

- **Plasma (cell) membrane**
  - Surrounds cell, defines boundaries
  - Made of proteins and lipids

- **Cytoplasm**
  - Organelles
  - Cytoskeleton
  - Inclusions (stored or foreign particles)
  - Cytosol *(intracellular fluid, ICF)*

- **Extracellular fluid (ECF)**
  - Fluid outside of cells
  - Includes tissue (interstitial) fluid
The Cell Surface

• Expected Learning Outcomes
  – Describe the structure of the plasma membrane.
  – Explain the functions of the lipid, protein, and carbohydrate components of the plasma membrane.
  – Describe a second-messenger system and discuss its importance in human physiology.
  – Describe the composition and functions of the glycocalyx that coats cell surfaces.
  – Describe the structure and functions of microvilli, cilia, and flagella.
The Plasma Membrane

- **Plasma membrane**—border of the cell
  - Appears as pair of dark parallel lines when viewed with electron microscope
  - Has intracellular and extracellular faces

- **Functions**
  - Defines cell boundaries
  - Governs interactions with other cells
  - Controls passage of materials in and out of cell

Figure 3.6a
The Plasma Membrane

Oily film of lipids with embedded proteins

Figure 3.6b
Membrane Lipids

- 98% of membrane molecules are lipids

Phospholipids
- 75% of membrane lipids are phospholipids
- Amphipatic molecules arranged in a bilayer
- Hydrophilic phosphate heads face water on each side of membrane
- Hydrophobic tails—are directed toward the center, avoiding water
- Drift laterally, keeping membrane fluid
Membrane Lipids

• **Cholesterol**
  – 20% of the membrane lipids
  – Holds phospholipids still and can stiffen membrane

• **Glycolipids**
  – 5% of the membrane lipids
  – Phospholipids with short carbohydrate chains on extracellular face
  – Contributes to **glycocalyx**—carbohydrate coating on cell surface
Membrane Proteins

• Membrane proteins
  – 2% of the molecules but 50% of the weight of membrane

• Integral proteins—penetrate membrane
  – Transmembrane proteins pass completely through
  – Hydrophilic regions contact cytoplasm, extracellular fluid
  – Hydrophobic regions pass through lipid of the membrane
  – Some drift in membrane; others are anchored to cytoskeleton

Figure 3.7
Membrane Proteins

• **Peripheral proteins**
  – Adhere to one face of the membrane (do not penetrate it)
  – Usually tethered to the cytoskeleton
Membrane Proteins

- Functions of membrane proteins include:
  - Receptors, second-messenger systems, enzymes, channels, carriers, cell-identity markers, cell-adhesion molecules

Figure 3.8
Membrane Proteins

- **Receptors**—bind chemical signals
- **Second messenger systems**—communicate within cell receiving chemical message
- **Enzymes**—catalyze reactions including digestion of molecules, production of second messengers
- **Channel proteins**—allow hydrophilic solutes and water to pass through membrane
  - Some are always open, some are gated
    - **Ligand-gated channels**—respond to chemical messengers
    - **Voltage-gated channels**—respond to charge changes
    - **Mechanically-gated channels**—respond to physical stress on cell
  - Crucial to nerve and muscle function
Membrane Proteins

- **Carriers**—bind solutes and transfer them across membrane
  - **Pumps**—carriers that consume ATP
- **Cell-identity markers**—glycoproteins acting as identification tags
- **Cell-adhesion molecules**—mechanically link cell to extracellular material
Second Messengers

- Chemical first messenger (epinephrine) binds to a surface receptor
- Receptor activates G protein
  - An intracellular peripheral protein that gets energy from guanosine triphosphate (GTP)
- G protein relays signal to adenylate cyclase which converts ATP to cAMP (second messenger)
- cAMP activates cytoplasmic kinases
- Kinases add phosphate groups to other enzymes turning some on and others off
- Up to 60% of drugs work through G proteins and second messengers
A messenger such as epinephrine (red triangle) binds to a receptor in the plasma membrane. The receptor releases a G protein, which then travels freely in the cytoplasm and can go on to step 3 or have various other effects on the cell. The G protein binds to an enzyme, adenylate cyclase, in the plasma membrane. Adenylate cyclase converts ATP to cyclic AMP (cAMP), the second messenger. cAMP activates a cytoplasmic enzyme called a kinase. Kinases add phosphate groups (P_i) to other cytoplasmic enzymes. This activates some enzymes and deactivates others, leading to varied metabolic effects in the cell.

First messenger

Receptor

Adenylate cyclase

G

ATP

P_i

P_i

cAMP (second messenger)

Inactive kinase

Activated kinase

Inactive enzymes

Activated enzymes

Various metabolic effects
The Glycocalyx

• Fuzzy coat external to plasma membrane
  – Carbohydrate moieties of glycoproteins and glycolipids
  – Unique in everyone but identical twins

• Functions
  – Protection
  – Immunity to infection
  – Defense against cancer
  – Transplant compatibility
  – Cell adhesion
  – Fertilization
  – Embryonic development
Microvilli

• Extensions of membrane (1–2 μm)
  – Gives 15 to 40 times more surface area
  – Best developed in cells specialized in absorption

• On some absorptive cells they are very dense and appear as a fringe—“brush border”
  – Some microvilli contain actin filaments that are tugged toward center of cell to milk absorbed contents into cell
Microvilli

Actin microfilaments are centered in each microvilli
Cilia

- **Cilia**—hairlike processes 7–10 μm long
- Single, nonmotile **primary cilium** found on nearly every cell
  - “Antenna” for monitoring nearby conditions
  - Helps with balance in inner ear; light detection in retina
- **Multiple nonmotile cilia**
  - Found on sensory cells of nose
- **Ciliopathies**—defects in structure and function of cilia
- **Motile cilia**—respiratory tract, uterine tubes, ventricles of brain, ducts of testes
  - 50 to 200 on each cell
  - Beat in waves sweeping material across a surface in one direction
  - Power strokes followed by recovery strokes
Cilia

Figure 3.11a
Cilia inside trachea
Cilia

- **Axoneme**—core of motile cilium
  - Has **9 + 2 structure** of microtubules
  - Two central microtubules surrounded by ring of nine pairs
  - Ring of nine pairs anchors cilium to cell as part of basal body
  - **Dynein arms** “crawl” up adjacent microtubule, bending the cilium
    - Uses energy from ATP

Figure 3.11 b, c, d
• **Cilia beat freely within a saline layer at cell surface**
  • Chloride pumps pump Cl\(^{-}\) into ECF
  • Na\(^{+}\) and H\(_2\)O follow
• **Mucus floats on top of saline layer**

Figure 3.12
Cystic Fibrosis

- **Cystic fibrosis**—hereditary disease in which cells make chloride pumps, but fail to install them in the plasma membrane
  - Chloride pumps fail to create adequate saline layer on cell surface

- **Thick mucus plugs pancreatic ducts and respiratory tract**
  - Inadequate digestion of nutrients and absorption of oxygen
  - Chronic respiratory infections
  - Life expectancy of 30

Figure 3.12a
Flagella

- Tail of a sperm—only functional flagellum in humans

- Whip-like structure with axoneme identical to cilium’s
  - Much longer than cilium
  - Stiffened by coarse fibers that support the tail

- Movement is undulating, snake-like, corkscrew
  - No power stroke and recovery strokes
Pseudopods

- **Pseudopods**—continually changing extensions of the cell that vary in shape and size
  - Can be used for cellular locomotion, capturing foreign particles

Figure 3.13
Membrane Transport

• Expected Learning Outcomes
  – Explain what is meant by a selectively permeable membrane.
  – Describe various mechanisms for transporting material through the plasma membrane.
  – Define osmolarity and tonicity and explain their importance.
Membrane Transport

• Plasma membrane is **selectively permeable**—allowing some things through, but preventing others from passing

• **Passive mechanisms** require no ATP
  – Random molecular motion of particles provides necessary energy
  – Filtration, diffusion, osmosis

• **Active mechanisms** consume ATP
  – Active transport and vesicular transport

• **Carrier-mediated mechanisms** use a membrane protein to transport substances across membrane
Filtration

- **Filtration**—particles are driven through membrane by **physical pressure**

- **Examples**
  - Filtration of water and small solutes through gaps in capillary walls
    - Allows delivery of water and nutrients to tissues
    - Allows removal of waste from capillaries in kidneys

![Image of filtration process](image-url)

**Figure 3.14**

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Simple Diffusion

• **Simple diffusion**—net movement of particles from place of high concentration to place of lower concentration
  – Due to constant, spontaneous molecular motion
  – Molecules collide and bounce off each other

• Substances diffuse down their **concentration gradient**
  – Does not require a membrane
  – Substance can diffuse through a membrane if the membrane is permeable to the substance
Simple Diffusion

- Factors affecting diffusion rate through a membrane
  - Temperature: ↑ temp., ↑ motion of particles
  - Molecular weight: larger molecules move slower
  - Steepness of concentrated gradient: ↑ difference, ↑ rate
  - Membrane surface area: ↑ area, ↑ rate
  - Membrane permeability: ↑ permeability, ↑ rate
Osmosis

- **Osmosis**—net flow of water through a selectively permeable membrane
  - Water moves from the side where it (water) is more concentrated to the side where it is less concentrated
  - Solute particles that cannot pass through the membrane “draw” water from the other side

- **Crucial consideration for I.V. fluids**

- **Osmotic imbalances underlie diarrhea, constipation, edema**

- Water can diffuse through phospholipid bilayers, but osmosis is enhanced by **aquaporins**—channel proteins in membrane specialized for water passage
  - Cells can speed osmosis by installing more aquaporins
Osmosis

Figure 3.15
Osmosis

- **Osmotic pressure**—hydrostatic pressure required to stop osmosis
  - Increases as amount of nonpermeating solute rises

- **Reverse osmosis**—process of applying mechanical pressure to override osmotic pressure
  - Allows purification of water

Figure 3.15b
Osmolarity and Tonicity

• One osmole (osm) = 1 mole of dissolved particles
  – Takes into account whether solute ionizes in water
    • 1 M glucose is 1 osm/L
    • 1 M NaCl is 2 osm/L

• Osmolarity—number of osmoles per liter of solution
  – Body fluids contain a mix of many chemicals, and osmolarity is the total osmotic concentration of all solutes
  – Blood plasma, tissue fluid, and intracellular fluid are 300 milliosmoles per liter (mOsm/L)
  – Osmolality is number of osm per kg of water
    • In physiology osmolality and osmolarity are nearly the same
Osmolarity and Tonicity

- **Tonicity**—ability of a surrounding solution (bath) to affect fluid volume and pressure in a cell
  - Depends on concentration of nonpermeating solutes

- **Hypotonic solution**—causes cell to absorb water and swell
  - Has a lower concentration of nonpermeating solutes than intracellular fluid (ICF)
  - Distilled water is an extreme example

- **Hypertonic solution**—causes cell to lose water and shrivel (crenate)
  - Has a higher concentration of nonpermeating solutes than ICF

- **Isotonic solution**—causes no change in cell volume
  - Concentrations of nonpermeating solutes in bath and ICF are the same
  - Normal saline (0.9% NaCl) is an example
Effects of Tonicity on RBCs

Hypotonic, isotonic, and hypertonic solutions affect the fluid volume of a red blood cell. Notice the crenated and swollen cells.

Figure 3.16a
Figure 3.16b
Figure 3.16c
Carrier-Mediated Transport

• **Transport proteins** in membrane carry solutes into or out of cell (or organelle)

• **Specificity**
  – Transport proteins are specific for particular solutes
  – Solute (ligand) binds to receptor site on carrier protein
  – Solute is released unchanged on other side of membrane

• **Saturation**
  – As solute concentration rises, the rate of transport rises, but only to a point—*transport maximum (Tm)*
Carrier-Mediated Transport

- **Transport maximum**—transport rate at which all carriers are occupied

![Graph showing the relationship between concentration of solute and rate of solute transport through the plasma membrane. The graph reaches a plateau at the transport maximum ($T_m$).]
Carrier-Mediated Transport

• Three kinds of carriers
  – Uniport—carries one type of solute
    • Example: Calcium pump
  – Symport—carries two or more solutes simultaneously in same direction (cotransport)
    • Example: sodium-glucose transporters
  – Antiport—Carries two or more solutes in opposite directions (countertransport)
    • Example: sodium-potassium pump removes Na⁺, brings in K⁺

• Three mechanisms of carrier-mediated transport
  – Facilitated diffusion, primary active transport, secondary active transport
Carrier-Mediated Transport

- **Facilitated diffusion**—carrier moves solute down its concentration gradient
- **Does not consume ATP**
- **Solute attaches to binding site on carrier, carrier changes conformation, then releases solute on other side of membrane**

Figure 3.18

1. A solute particle enters the channel of a membrane protein (carrier).
2. The solute binds to a receptor site on the carrier and the carrier changes conformation.
3. The carrier releases the solute on the other side of the membrane.
Carrier-Mediated Transport

• **Primary active transport**—carrier moves solute through a membrane up its concentration gradient

• **The carrier protein uses ATP for energy**

• **Examples:**
  - **Calcium pump** (uniport) uses ATP while expelling calcium from cell to where it is already more concentrated
  - **Sodium–potassium pump** (antiport) uses ATP while expelling sodium and importing potassium into cell
Carrier-Mediated Transport

- The sodium-potassium pump (Na\(^+\)–K\(^+\) pump)
- Each pump cycle consumes one ATP and exchanges three Na\(^+\) for two K\(^+\)
- Keeps K\(^+\) concentration higher and Na\(^+\) concentration lower within the cell than in ECF
- Necessary because Na\(^+\) and K\(^+\) constantly leak through membrane
  - Half of daily calories utilized for Na\(^+\)–K\(^+\) pump

Figure 3.20
Carrier-Mediated Transport

• **Na⁺–K⁺ pump functions**
  – Maintains steep Na⁺ concentration gradient allowing for **secondary active transport**
  – Regulates solute concentrations and thus osmosis and thus cell volume
  – Maintains negatively charged resting membrane potential
  – Produces heat

Figure 3.20
Carrier-Mediated Transport

• Secondary active transport
  – Carrier moves solute through membrane but only uses ATP indirectly
  – Example: sodium-glucose transporter (SGLT) (symport)
    • Moves glucose into cell while simultaneously carrying sodium down its gradient
    • Depends on the primary transport performed by Na\(^+\)-K\(^+\)pump
    • Does not itself use ATP
• **SGLTs** work in kidney cells that have **Na\(^+\)–K\(^+\) pump** at other end of cell
  – Prevents loss of glucose to urine

Figure 3.19
Vesicular Transport

- **Vesicular transport**—moves large particles, fluid droplets, or numerous molecules at once through the membrane in **vesicles**—bubble-like enclosures of membrane.

- **Endocytosis**—vesicular processes that bring material into cell:
  - **Phagocytosis**—“cell eating,” engulfing large particles
    - Pseudopods; phagosomes; macrophages
  - **Pinocytosis**—“cell drinking,” taking in droplets of ECF containing molecules useful in the cell
    - Membrane caves in, then pinches off pinocytic vesicle
  - **Receptor-mediated endocytosis**—particles bind to specific receptors on plasma membrane
    - Clathrin-coated vesicle

- **Exocytosis**—discharging material from the cell

- Utilizes motor proteins energized by ATP
Vesicular Transport

Phagocytosis keeps tissues free of debris and infectious microbes
Vesicular Transport

• **Receptor-mediated endocytosis**
  – More selective endocytosis
  – Enables cells to take in specific molecules that bind to extracellular receptors

• **Clathrin-coated vesicle in cytoplasm**
  – Uptake of LDL from bloodstream
Vesicular Transport

Figure 3.22
Receptor-mediated endocytosis

1. Extracellular molecules bind to receptors on plasma membrane; receptors cluster together.

2. Plasma membrane sinks inward, forms clathrin-coated pit.

3. Pit separates from plasma membrane, forms clathrin-coated vesicle containing concentrated molecules from ECF.

(all): Company of Biologists, Ltd.
Vesicular Transport

- **Transcytosis**—transport of material across the cell by capturing it on one side and releasing it on the other
- **Receptor-mediated endocytosis** moves it into the cell and **exocytosis** moves it out the other side
Vesicular Transport

• **Exocytosis**
  – Secreting material
  – Replacement of plasma membrane removed by endocytosis

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Figure 3.24 a,b

b: Courtesy of Dr. Birgit Satir, Albert Einstein College of Medicine
The Cell Interior

• Expected Learning Outcomes
  – List the main organelles of a cell, describe their structure, and explain their functions.
  – Describe the cytoskeleton and its functions.
  – Give some examples of cell inclusions and explain how inclusions differ from organelles.
The Cytoskeleton

- **Cytoskeleton**—network of protein filaments and cylinders
  - Determines cell shape, supports structure, organizes cell contents, directs movement of materials within cell, contributes to movements of the cell as a whole

- **Composed of:** microfilaments, intermediate fibers, microtubules
The Cytoskeleton

Figure 3.25a
The Cytoskeleton

• **Microfilaments**
  – 6 nm thick
  – Made of actin protein
  – Forms terminal web

• **Intermediate filaments**
  – 8–10 nm thick
  – Within skin cells, made of protein keratin
  – Give cell shape, resist stress

• **Microtubules**
  – 25 nm thick
  – Consist of protofilaments made of protein tubulin
  – Radiate from centrosome; can come and go
  – Maintain cell shape, hold organelles, act as railroad tracks for walking motor proteins, make axonemes of cilia and flagella, form mitotic spindle
EM and Fluorescent Antibodies Demonstrate Cytoskeleton

Figure 3.25b

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Microtubules

Figure 3.26
Organelles

• **Internal structures** of a cell, carry out specialized metabolic tasks

• **Membranous organelles**
  – Nucleus, mitochondria, lysosomes, peroxisomes, endoplasmic reticulum, and Golgi complex

• **Nonmembranous organelles**
  – Ribosomes, centrosomes, centrioles, basal bodies
The Nucleus

- **Nucleus**—largest organelle (5 μm in diameter)
  - Most cells have one nucleus
  - A few cell types are **anuclear** or **multinucleate**

- **Nuclear envelope**—double membrane around nucleus
  - Perforated by **nuclear pores** formed by rings of proteins
    - Regulate molecular traffic through envelope
    - Hold the two membrane layers together
The Nucleus

• Nuclear envelope is supported by nuclear lamina
  – Web of protein filaments
  – Provides points of attachment for chromatin
  – Helps regulate cell life cycle

• Nucleoplasm—material in nucleus
  – Chromatin (thread-like) composed of DNA and protein
  – Nucleoli—masses where ribosomes are produced
The Nucleus

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(a) Interior of nucleus
(b) Surface of nucleus

Nucleolus
Nucleoplasm
Nuclear envelope

Nuclear pores

Figure 3.27a
Figure 3.27b

(a) Interior of nucleus
2 μm

(b) Surface of nucleus
1.5 μm

a: ©Richard Chao; b: ©E.G. Pollock
Endoplasmic Reticulum

• *Endoplasmic reticulum*—system of channels (*cisternae*) enclosed by membrane

• *Rough endoplasmic reticulum*—parallel, flattened sacs covered with *ribosomes*
  – Continuous with outer membrane of nuclear envelope
  – Produces phospholipids and proteins of the plasma membrane
  – Synthesizes proteins that are packaged in other organelles or secreted from cell
Endoplasmic Reticulum

• **Smooth endoplasmic reticulum**
  – Lack ribosomes
  – Cisternae more tubular and branching
  – Cisternae thought to be continuous with rough ER
  – Synthesizes steroids and other lipids
  – Detoxifies alcohol and other drugs
  – Calcium storage

• **Rough and smooth ER are functionally different parts of the same network**
Endoplasmic Reticulum

Figure 3.28c

Rough endoplasmic reticulum
Ribosomes
Cisternae
Smooth endoplasmic reticulum
Ribosomes

• **Ribosomes**—small granules of **protein and RNA**
  – Found in nucleoli, in cytosol, and on outer surfaces of rough ER, and nuclear envelope

• They “read” coded genetic messages (**messenger RNA**) and assemble amino acids into proteins specified by the code
Golgi Complex

• **Golgi complex**—a system of cisternae that synthesizes carbohydrates and puts finishing touches on protein synthesis
  – Receives newly synthesized proteins from rough ER
  – Sorts proteins, splices some, adds carbohydrate moieties to some, and packages them into membrane-bound **Golgi vesicles**
    • Some vesicles become lysosomes
    • Some vesicles migrate to plasma membrane and fuse to it
    • Some become secretory vesicles that store a protein product for later release
Golgi Complex

Figure 3.29
Lysosomes

- **Lysosomes**—package of enzymes bound by a membrane
  - Generally round, but variable in shape

- **Functions**
  - Intracellular hydrolytic digestion of proteins, nucleic acids, complex carbohydrates, phospholipids, and other substances
  - **Autophagy**—digestion of cell’s surplus organelles
  - **Autolysis**—“cell suicide”: digestion of a surplus cell by itself
Peroxisomes

• **Peroxisomes**—resemble lysosomes but contain different enzymes and are produced by endoplasmic reticulum

• **Function is to use molecular oxygen to oxidize organic molecules**
  – Reactions produce hydrogen peroxide (H$_2$O$_2$)
  – **Catalase** breaks down excess peroxide to H$_2$O and O$_2$
  – Neutralize free radicals, detoxify alcohol, other drugs, and a variety of blood-borne toxins
  – Break down fatty acids into acetyl groups for mitochondrial use in ATP synthesis

• **In all cells, but abundant in liver and kidney**
Lysosome and Peroxisomes

Figure 3.30a

(a) Lysosomes

1 μm

(a-b): ©Don Fawcett/Science Source

Figure 3.30b

(b) Peroxisomes

0.3 μm
Proteosomes

- **Proteosomes**—hollow, cylindrical organelle that disposes of surplus proteins
  - Contain enzymes that break down tagged, targeted proteins into short peptides and amino acids

Figure 3.31
Mitochondria

- **Mitochondria**—organelles specialized for synthesizing **ATP**
- Continually change shape from spheroidal to thread-like
- Surrounded by a double membrane
  - Inner membrane has folds called **cristae**
  - Spaces between cristae called **matrix**
    - Matrix contains ribosomes, enzymes used for ATP synthesis, small circular DNA molecule
      - Mitochondrial DNA (mtDNA)
- "**Powerhouses**" of the cell
  - Energy is extracted from organic molecules and transferred to ATP

Figure 3.32
Mitochondrion

Figure 3.32

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Evolution of Mitochondrion

- Mitochondria evolved from bacteria that invaded another primitive cell, survived in its cytoplasm, and became permanent residents.
  - The bacterium provided inner membrane; host cell’s phagosome provided outer membrane
  - Mitochondrial ribosomes resemble bacterial ribosomes
  - mtDNA resembles circular DNA of bacteria
  - mtDNA is inherited through the mother
  - mtDNA mutates more rapidly than nuclear DNA
    - Responsible for hereditary diseases affecting tissues with high energy demands
Centrioles

- **Centriole**—a short cylindrical assembly of microtubules arranged in nine groups of three microtubules each
- Two centrioles lie perpendicular to each other within the **centrosome**—small clear area in cell
  - Play important role in cell division
- **Form basal bodies of cilia and flagella**
  - Each basal body is a centriole that originated in centriolar organizing center and then migrated to the membrane
Centrioles

Figure 3.33a,b

(a) Cross section (TEM)

(b) Pair of centrioles

Inclusions

• Two kinds of inclusions
  – Stored cellular products
    • Glycogen granules, pigments, and fat droplets
  – Foreign bodies
    • Viruses, intracellular bacteria, dust particles, and other debris phagocytized by a cell

• Never enclosed in a unit membrane
• Not essential for cell survival