Chapter 6

A Tour of the Cell

Chapter Outline

Concept 6.1 Biologists use microscopes and the tools of biochemistry to study cells

• In a light microscope (LM), visible light passes through the specimen and then through glass lenses.

• Although an LM can resolve individual cells, it cannot resolve much of the internal anatomy, especially the organelles, membrane-enclosed structures within eukaryotic cells.

• To resolve smaller structures, scientists use an electron microscope (EM), which focuses a beam of electrons through the specimen or onto its surface.

• SEMs) are useful for studying the surface structure or topography of a specimen.

• Transmission electron microscopes (TEMs) are used to study the internal structure of cells.

Cell biologists can isolate organelles to study their functions.

• Cell structure and function can be studied by cell fractionation, a technique that takes cells apart and separates major organelles and other subcellular structures from one another.

• Cell fractionation can be used to isolate specific cell components so that the functions of these organelles can be studied.

Concept 6.2 Eukaryotic cells have internal membranes that compartmentalize their functions

Prokaryotic and eukaryotic cells differ in size and complexity.

• Organisms of the domains Bacteria and Archaea consist of prokaryotic cells. Protists, fungi, animals, and plants consist of eukaryotic cells.

• All cells are surrounded by a selective barrier, the plasma membrane.

• The semifluid substance within the membrane is the cytosol, in which subcellular components are suspended.

• All cells contain chromosomes that carry genes in the form of DNA.

• All cells have ribosomes, tiny complexes that make proteins based on instructions contained in genes.

• A major difference between prokaryotic and eukaryotic cells is the location of the DNA.

  o In a eukaryotic cell, most of the DNA is in an organelle bounded by a double membrane, the nucleus.

  o In a prokaryotic cell, the DNA is concentrated in the nucleoid, without a membrane separating it from the rest of the cell.

• The interior of a prokaryotic cell and the region between the nucleus and the plasma membrane of a eukaryotic cell is the cytoplasm.
Eukaryotic cells are generally much larger than prokaryotic cells.

The plasma membrane functions as a selective barrier that allows the passage of oxygen, nutrients, and wastes for the whole volume of the cell.

As a cell increases in size, its volume increases faster than its surface area.
  ○ As a result, smaller objects have a higher ratio of surface area to volume.
  ○ Rates of chemical exchange across the plasma membrane may be inadequate to maintain a cell with a very large cytoplasm.

The need for a surface sufficiently large to accommodate the volume explains the microscopic size of most cells.

Cells that exchange a lot of material with their surroundings, such as intestinal cells, may have long, thin projections from the cell surface called microvilli, which increase the surface area without significantly increasing the cell volume.

**Internal membranes compartmentalize the functions of a eukaryotic cell.**

• The general structure of a biological membrane is a double layer of phospholipids.

• Other lipids and diverse proteins are embedded in the lipid bilayer or attached to its surface.

• Each type of membrane has a unique combination of lipids and proteins for its specific functions.

**Concept 6.3 The eukaryotic cell’s genetic instructions are housed in the nucleus and carried out by the ribosomes**

• The nucleus contains most of the genes in a eukaryotic cell.
  ○ Additional genes are located in mitochondria and chloroplasts.

• The nucleus is separated from the cytoplasm by a double membrane called the nuclear envelope.

• Within the nucleus, the DNA and associated proteins are organized into discrete units called chromosomes, structures that carry the genetic information.
  ○ Each chromosome contains one long DNA molecule associated with many proteins. This complex of DNA and protein is called chromatin.

• Each eukaryotic species has a characteristic number of chromosomes.
  ○ A typical human cell has 46 chromosomes.
  ○ A human sex cell (egg or sperm) has only 23 chromosomes.

• In the nucleus is a region of densely stained fibers and granules adjoining chromatin, the nucleolus.

• The nucleus directs protein synthesis by synthesizing messenger RNA (mRNA).

• The mRNA is transported to the cytoplasm through the nuclear pores.

• DNA --- RNA ---- Protein --- Physical characteristic

**Ribosomes are protein factories.**

• Ribosomes, containing rRNA and protein, are the cellular components that carry out protein synthesis.

• Free ribosomes are suspended in the cytosol and synthesize proteins that function within the cytosol.

• Bound ribosomes are attached to the outside of the endoplasmic reticulum or nuclear envelope.
Concept 6.4 The endomembrane system regulates protein traffic and performs metabolic functions in the cell

- Many of the internal membranes in a eukaryotic cell are part of the endomembrane system, which includes the nuclear envelope, endoplasmic reticulum, Golgi apparatus, lysosomes, vesicles, vacuoles, and plasma membrane.

The endoplasmic reticulum manufactures membranes and performs many other biosynthetic functions.

- The endoplasmic reticulum (ER) accounts for more than half the membranes in a eukaryotic cell.
- There are two connected regions of ER that differ in structure and function.
  - Smooth ER looks smooth because it lacks ribosomes.
  - Rough ER looks rough because ribosomes are attached to the outside, including the outside of the nuclear envelope.
- Smooth ER is rich in enzymes and plays a role in a variety of metabolic processes, including synthesis of lipids, metabolism of carbohydrates, detoxification of drugs and poisons, and storage of calcium ions.
- Enzymes of smooth ER synthesize lipids, including oils, phospholipids, and steroids.
- Rough ER is especially abundant in cells that secrete proteins.
  - As a polypeptide chain grows from a bound ribosome, it is threaded into the ER lumen through a pore formed by a protein complex in the ER membrane.
  - As the new polypeptide enters the ER lumen, it folds into its native shape.
- Most secretory polypeptides are glycoproteins, proteins to which a carbohydrate is covalently bonded.
- Secretory proteins are packaged in transport vesicles that bud from a specialized region called transitional ER.
- Transport vesicles carry proteins from one part of the cell to another.
- Rough ER is also a membrane factory for the cell.
- Enzymes in rough ER also synthesize phospholipids from precursors in the cytosol.

The Golgi apparatus is the shipping and receiving center for cell products.

- Many transport vesicles from the ER travel to the Golgi apparatus for modification of their contents.
- The Golgi apparatus is a center of manufacturing, warehousing, sorting, and shipping.
- The Golgi apparatus consists of flattened membranous sacs—cisternae—that look like a stack of pita bread.

- One side of the Golgi apparatus, the cis face, is located near the ER. The cis face receives material by fusing with transport vesicles from the ER.
  - The other side, the trans face, buds off vesicles that travel to other sites.
  - Products from the ER are usually modified during their transit from the cis to the trans region of the Golgi apparatus.
• Transport vesicles budded from the Golgi may have external molecules on their membranes that recognize “docking sites” on the surface of specific organelles or on the plasma membrane, thus targeting them appropriately.

**Lysosomes are digestive compartments.**
• A **lysosome** is a membrane-bound sac of hydrolytic enzymes that an animal cell uses to digest macromolecules.
• Proteins on the inner surface of the lysosomal membrane are spared by digestion by their three-dimensional conformations, which protect vulnerable bonds from hydrolysis.
• Lysosomes carry out intracellular digestion in a variety of circumstances.
  o Amoebas eat by engulfing smaller organisms by **phagocytosis**.
  o The **food vacuole** formed by phagocytosis fuses with a lysosome, whose enzymes digest the food.
• Lysosomes can play a role in recycling the cell’s organelles and macromolecules. This recycling, or **autophagy**, renews the cell.

**Vacuoles have diverse functions in cell maintenance.**
• Vacuoles are large vesicles derived from the ER and Golgi apparatus.
• These membrane-bound sacs have a variety of functions.
• **Food vacuoles** are formed by phagocytosis and fuse with lysosomes.
• **Contractile vacuoles**, found in freshwater protists, pump excess water out of the cell to maintain the appropriate concentration of ions and molecules inside the cell.
• A large **central vacuole** is found in many mature plant cells.

**Concept 6.5 Mitochondria and chloroplasts change energy from one form to another**
• Mitochondria and chloroplasts are the organelles that convert energy to forms that cells can use for work.
• **Mitochondria** are the sites of cellular respiration, using oxygen to generate ATP by extracting energy from sugars, fats, and other fuels.
• **Chloroplasts**, found in plants and algae, are the sites of photosynthesis.
  o Chloroplasts convert solar energy to chemical energy by absorbing sunshine and using it to synthesize new organic compounds such as sugars from CO₂ and H₂O.

**Mitochondria and chloroplasts have a similar evolutionary origin.**
• The **endosymbiont theory** states that an early ancestor of eukaryotic cells engulfed an oxygen-using nonphotosynthetic prokaryotic cell.
  o The engulfed cell became an **endosymbiont** within its host cell.
  o Over the course of evolution, the host cell and its endosymbiont merged into a single organism, a eukaryotic cell with a mitochondrion.
  o One of these cells engulfed a photosynthetic prokaryote and evolved into a eukaryotic cell containing chloroplasts.
• There is considerable evidence to support the endosymbiont theory for the origin of mitochondria and chloroplasts.
  o In contrast to organelles of the endomembrane system, each mitochondrion or chloroplast has two membranes separating the innermost space from the cytosol.
  o Mitochondria and chloroplasts contain ribosomes and circular DNA molecules that are attached to their inner membranes.
Mitochondria convert chemical energy within eukaryotic cells.

- Almost all eukaryotic cells have mitochondria.
  - Cells may have one very large mitochondrion or hundreds to thousands of individual mitochondria.
  - The number of mitochondria is correlated with aerobic metabolic activity.
  - Mitochondria have a smooth outer membrane and a convoluted inner membrane with infoldings called cristae.

- The inner membrane divides the mitochondrion into two internal compartments.
  - The first compartment is the intermembrane space, a narrow region between the inner and outer membranes.
  - The inner membrane encloses the mitochondrial matrix, a fluid-filled space with mitochondrial DNA, ribosomes, and enzymes.

Chloroplasts capture light energy and convert it to chemical energy.

- Chloroplasts contain the green pigment chlorophyll as well as enzymes and other molecules that function in the photosynthetic production of sugar.

- Inside the innermost membrane is a fluid-filled space, the stroma, in which float membranous sacs, the thylakoids.
  - The stroma contains chloroplast DNA, ribosomes, and enzymes.
  - The thylakoids are flattened sacs that play a critical role in converting light to chemical energy. In some regions, thylakoids are stacked like poker chips into grana.

- The chloroplast belongs to a family of plant structures called plastids.
  - Amyloplasts are colorless plastids that store starch in roots and tubers.
  - Chromoplasts store pigments for fruits and flowers.

The peroxisome is an oxidative organelle.

- Peroxisomes, bound by a single membrane, contain enzymes that transfer hydrogen from various substrates to oxygen, producing hydrogen peroxide (H\textsubscript{2}O\textsubscript{2}) as a byproduct.

- Some peroxisomes use oxygen to break fatty acids down to smaller molecules that are transported to mitochondria as fuel for cellular respiration.

- The H\textsubscript{2}O\textsubscript{2} formed by peroxisomes is itself toxic, but peroxisomes also contain an enzyme that converts H\textsubscript{2}O\textsubscript{2} to water.

Concept 6.6 The cytoskeleton is a network of fibers that organizes structures and activities in the cell

The cytoskeleton provides support, motility, and regulation.

- The cytoskeleton is a network of fibers extending through the cytoplasm that provides mechanical support and maintains the cell’s shape.
  - This function is especially important in animal cells, which lack walls.

- The cytoskeleton interacts with motor proteins to produce motility.
  - Cytoskeleton elements and motor proteins work together with plasma membrane molecules to move the whole cell along fibers outside the cell.

- Inside the cell, vesicles use motor protein “feet” to “walk” to destinations along a track provided by the cytoskeleton.

- The vesicles that bud off from the ER travel to the Golgi apparatus along tracks built of cytoskeletal elements.
Three main types of fibers make up the cytoskeleton: microtubules, microfilaments, and intermediate filaments.

- **Microtubules** are the thickest of the three types of fibers; microfilaments (or actin filaments) are the thinnest; and intermediate filaments are fibers with diameters in a middle range.
- **Microtubules** are hollow rods constructed of the globular protein tubulin.
- Microtubule fibers are constructed of the globular protein tubulin.
  - Each tubulin molecule is a dimer consisting of two subunits.
- A microtubule changes in length by adding or removing tubulin dimers.
- Microtubules shape and support the cell and serve as tracks to guide motor proteins carrying organelles to their destination.
- In many animal cells, microtubules grow out from a centrosome near the nucleus.
- Within the centrosome is a pair of centrioles, each with nine triplets of microtubules arranged in a ring.
- A specialized arrangement of microtubules is responsible for the beating of cilia and flagella.
- Cilia usually occur in large numbers on the cell surface.
- Flagella are the same diameter as cilia, but are 10–200 μm long.
  - There are usually just one or a few flagella per cell.
- **Microfilaments** or actin filaments are solid rods about 7 nm in diameter, present in all eukaryotic cells.
- Localized contraction brought about by actin and myosin also drives amoeboid movement.
  - Pseudopodia, cellular extensions, extend and contract through the reversible assembly and contraction of actin subunits into microfilaments.

**Concept 6.7 Extracellular components and connections between cells help coordinate cellular activities**

**Plant cells are encased by cell walls.**

- In plants, the cell wall protects the cell, maintains its shape, prevents excessive uptake of water, and supports the plant against the force of gravity.

- A young plant cell secretes a relatively thin and flexible wall called the primary cell wall.

- Between the primary walls of adjacent cells is a middle lamella, a thin layer with sticky polysaccharides called pectins that glues cells together.
- When a plant cell stops growing, it strengthens its wall by secreting hardening substances into the primary wall or by adding a secondary cell wall between the plasma membrane and the primary wall.
  - The secondary wall may be deposited in several layers.
  - It has a strong and durable matrix that provides support and protection.
  - Wood consists mainly of secondary walls.

**The extracellular matrix of animal cells provides support, adhesion, movement, and regulation.**

- Though lacking cell walls, animal cells do have an elaborate extracellular matrix (ECM).
**Cell junctions**

- Neighboring cells in tissues, organs, and organ systems often adhere, interact, and communicate through direct physical contact.

- Plant cells are perforated with *plasmodesmata*, channels allowing cytosol to pass between cells.

- Animals have three main types of intercellular links: *tight junctions*, *desmosomes*, and *gap junctions*.

- In **tight junctions**, membranes of adjacent cells are fused, forming continuous belts around cells that prevent leakage of extracellular fluid.

- **Desmosomes** (or anchoring junctions) fasten cells together into strong sheets, much like rivets.

- **Gap junctions** (or communicating junctions) provide cytoplasmic channels between adjacent cells.