

Chapter 2

Cell Physiology

CHAPTER OUTLINE

CELL THEORY AND DISCOVERY

The cell is the smallest structural and functional unit capable of carrying out life processes. Cells are the building blocks for all multicellular organisms including humans.

Cells of a hummingbird, a human, and a whale are all about the same size. Larger species have more cells, not larger cells.

The human body has about 200 different types of cells based on structure and specialization.

AN OVERVIEW OF CELL STRUCTURE

Most of the trillions of cells making up the human body share three major subdivisions:

-The **plasma membrane** is composed of a bilayer of phospholipids containing proteins, carbohydrates, and cholesterol and functions to provide a semipermeable barrier around the cell. The membrane functions to prevent intracellular fluid from mixing with extracellular fluid (which separates the cell's contents from its surroundings), yet it functions to assist in the transport of life-sustaining substances into the cell and waste materials out of the cell.

-The nucleus is bounded by the double-layer membrane (**nuclear envelope**) and contains deoxyribonucleic acid (DNA). The nucleus is the site for the synthesis of all types of RNA (transcription). The nuclear envelope is pierced by many **nuclear pores** that allow necessary traffic to move between the nucleus and the cytoplasm.

-The cytoplasm consists of the cytosol and both membranous and non-membranous organelles.

ENDOPLASMIC RETICULUM AND SEGREGATED SYNTHESIS

The endoplasmic reticulum (ER) is a complex membrane system with two distinct, but connected, regions: rough (RER) and smooth endoplasmic reticulae (SER). The RER membrane is studded with ribosomes, which are the “workbenches” where protein synthesis takes place. In addition to these attached ribosomes, there are “free” ribosomes dispersed throughout the cytosol. Proteins synthesized in the RER are destined for export or used in construction of new cellular membrane. RER membranes contain enzymes necessary for lipid synthesis.

The SER packages new proteins in portions of the SER membrane that have budded off to form **transport vesicles**, which are utilized to move newly synthesized protein to the Golgi complex. In some specialized cells, the SER is extensive and functions in lipid metabolism, aiding the RER in synthesizing steroids. Another function of SER is to detoxify harmful substances produced in the body by metabolism or substances that enter the body from the outside. These substances can include drugs or other foreign compounds.

GOLGI COMPLEX AND EXOCYTOSIS

Transport vesicles carry their cargo to the Golgi complex for further processing.

The Golgi complex packages secretory vesicles for release by exocytosis. The Golgi complex is responsible for sorting and segregating products according to their function and final destination. This segregation of destination is accomplished by packaging the various products in membranes containing different surface proteins called **docking markers**. As a result of the specific docking marker, the vesicle can “dock” and unload its cargo only at the appropriate **docking-marker acceptor** proteins located at specific destinations within the cell—like a house address.

LYSOSOMES AND ENDOCYTOSIS

Lysosomes are small (0.2–0.5 μm) oval or spherical vesicles contain hydrolytic enzymes and serve as the “intracellular digestive system.” Cells normally contain about 300 lysosomes. Lysosomes remove aged or damaged organelles (cellular debris) and foreign/extracellular materials (such as bacteria) brought into the cell by phagocytosis, pinocytosis, or receptor-mediated endocytosis.

PEROXISOMES AND DETOXIFICATION

Peroxisomes are membranous organelles that produce and decompose hydrogen peroxide (H_2O_2). H_2O_2 is produced when the peroxisome's oxidative enzymes interact with various wastes produced in the cell or toxins such as alcohol that may have entered the cell. H_2O_2 is potentially destructive to the cell if allowed to accumulate; therefore, peroxisomes contain *catalase* to decompose the H_2O_2 into H_2O and O_2 .

MITOCHONDRIA AND ATP PRODUCTION

Mitochondria are the *energy organelles* or "*power plants*" and generate about 90 percent of the ATP needed by the cells for survival. Mitochondria are rod-shaped or oval, and are about the size of bacteria. Mitochondria are thought to have originated as ancient bacteria that were engulfed, or invaded, by primitive cells early in evolutionary history, thus accounting for them possessing their own distinct DNA. In some cells mitochondria form interconnected networks, called the **mitochondrial reticulum**, increase the efficiency of distribution of substrates needed for ATP synthesis.

Mitochondria generate ATP using by-products from **glycolysis** (10 sequential enzyme-catalyzed reactions occurring in the cytosol) as substrates for the citric acid cycle (CAC; occurs in the mitochondrial matrix) and oxidative phosphorylation (occurs along the membrane of the cristae). The process involves oxidation of NADH and $FADH_2$ molecules via the **electron transport system**. ATP synthesis is powered by **chemiosmosis**. The cell generates more ATP in aerobic than in anaerobic conditions. The energy stored in ATP is used for synthesis, transport, and mechanical work. In addition to the role in ATP synthesis, mitochondria are essential for **apoptosis** (programmed cell death) as they rupture and leak **cytochrome c** into the cytosol, thus activating specific enzymes and causing them to slice the cell into small, disposable pieces.

RIBOSOMES CARRY OUT PROTEIN SYNTHESIS

Ribosomes coordinate the components that participate in translation of mRNA, allowing synthesis of proteins. Ribosomes are "free" in the cytosol or attached to the membrane of the RER.

VAULTS AS CELLULAR TRUCKS

Vaults may serve as cellular transport vehicles, moving specific substances from the nucleus to their destinations in the cell.

CENTROSOME, CENTRIOLES, AND MICROTUBULE ORGANIZATION

The centrosome consists of the centrioles surrounded by a mass of proteins. This structure functions as the cell's main microtubule-organizing center. Microtubules are components of the cytoskeleton. Microtubules are important in moving vesicles throughout the cytosol and function in the formation of cilia, flagella, and mitotic spindles.

CYTOSOL: CELL GEL

The cytosol is important in intermediary metabolism, ribosomal protein synthesis, and nutrient storage.

CYTOSKELETON: CELL "BONE AND MUSCLE"

Microtubules help maintain asymmetrical cell shapes and play a role in complex cell movements.

Microfilaments are important to cellular contractile systems and as mechanical stiffeners.

Intermediate filaments are important in cell regions subject to mechanical stress.

The cytoskeleton functions as an integral whole and links other parts of the cell together.

LIST OF KEY TERMS

Cell structure

- cell/plasma membrane
- cytoplasm
- cytosol
- ectoplasm
- glycogen
- inclusions

Organelles

- nucleus
- nuclear envelope
- nuclear pores

- deoxyribonucleic acid (DNA)
- ribonucleic acid (RNA)
- vaults
- endoplasmic reticulum
- rough ER
- smooth ER
- Golgi bodies
- mitochondria
- matrix
- cristae

- lysosomes
- peroxisomes
- basal body
- transport vesicles

Cytoskeleton

- tubulin
- microtubules
- microfilaments
- actin

Cellular extensions

- flagellum

- microvilli	endocytosis	- NAD ⁺
- cilia	- endocytic vesicles	- FAD
- amoeboid movement	- guanosine diphosphate (GDP)	- kinesin
- pseudopod	- guanosine triphosphate (GTP)	- dynamin
Cellular processes	- adenosine diphosphate (ADP)	- clathrin
- metabolism	- adenosine triphosphate (ATP)	Disease states of cellular origin
- aerobic	- molecular motors	- amyotrophic lateral sclerosis (ALS)
- anaerobic	Cellular molecules	- Lou Gehrig's disease
- oxidative enzymes	- ATP synthase	- cancers
- oxidative phosphorylation	- messenger RNA (mRNA)	- Tay-Sachs disease
- chemiosmotic mechanism	- transfer RNA (tRNA)	- Charcot-Marie-Tooth type 2a
- autophagy	- ribosomal RNA (rRNA)	
- phagocytosis	- hydrogen peroxide	
- pinocytosis	- catalase	
- exocytosis		
- endocytosis		
- receptor-mediated		

LECTURE HINTS AND SUGGESTIONS

1. Slides, transparencies, and electron micrographs are very useful for pointing out the major features of cells and organelles. These can be obtained from Carolina Biological Supply Company, Burlington, NC. Numerous online resources are also available, such as <http://www.cellbio.com>.
2. Demonstrate a model of a cell and the different organelles. Encourage students to think of cells as highly dynamic, three-dimensional entities.
3. Use online animations of active cellular events to drive home the concept of cellular functions.
4. Use a video microscope to show living cells or preserved specimens.
5. If you have an internet connection in the classroom, a variety of video clips and slides are available at the sites listed below.
6. Students enjoy the "Cell Game" available from Carolina Biological Supply.
7. The importance of ATP in living systems can be easily demonstrated using fireflies. Kits are available from biological supply companies.
8. Have a student volunteer to do some form of physical exertion (e.g., jumping jacks or squat-thrusts) until they show signs of increased body heat, flushing of face, or sweat production. Use this as a demonstration of the use of cellular energy.
9. Be sure to remind students of the learning resources available on the textbook website and of the literature-searching capability of InfoTrac®.

AUDIOVISUAL AIDS

Videos/Films

The following are films that may be suitable for presentation in your class.

<http://www.ffh.films.com>

Cells – The Inside and Out, 2 parts, 29–33 min each.

These information-rich programs take an entertaining route in examining both the inner workings of the cell and the ways intercellular reactions occur. With extremely clear graphics and a witty narrative, the whole array of cellular organelles is presented, as well as the structure and function of the cell membrane.

Inside Cells: Cells and Their Organelles, 29 min.

Using electron microscope images and entertaining graphics, this program walks viewers through the basic components of a cell. The tour looks in detail at the structure and function of cellular organelles, including cell membranes, nuclei, mitochondria, chloroplasts, smooth and rough endoplasmic reticula, ribosomes, lysosomes, vacuoles, cytoplasm, cytosol and cytoskeleton, microtubules and microfilaments, and the Golgi complex. The program also covers the importance of internal cellular membranes and compares the relative sizes of the different organelles.

The Cell and Energy, 10 min.

The cell's energy molecule, glucose, is examined, and the process of extracting energy from glucose and transferring it to ATP in specific organelles—called mitochondria—is discussed. The structure, function, and evolution of these organelles are illustrated in relation to their role in cellular respiration.

<http://www.ffh.films.com>

Glycolysis I, 10 min.

This program begins with the discovery of the energy role played by the cell cytosol, the starting point of cellular respiration. Computer animation is used to follow the sequential breakdown of glucose through the process of glycolysis that leads to the production of ATP molecules.

Glycolysis II, 10 min.

Continuing with the second half of the glycolysis process, the energy intermediate molecule NADH is introduced. The glycolytic breakdown of glucose continues, ending with the production of the molecule pyruvate. The program also looks at how simple life-forms produce alcohol.

The Krebs Cycle, 10 min.

The chemical process known as the Krebs cycle is examined in detail. The cyclical metabolism of pyruvate and the subsequent generation of NADH inside the cell mitochondrion are illustrated in three-dimensional computer animation.

Oxidative Phosphorylation, 10 min.

Occurring across the inner membrane of the mitochondrion organelle, this process is shown to depend on the creation of a hydrogen gradient, which in turn drives the synthesis of ATP molecules. The program totals the ATPs produced from a single glucose molecule through the combined process of glycolysis, the Krebs cycle, and oxidative phosphorylation.

<http://cambridge.films.com/>

The Cell, 14 min.

This program explains the structure and function of the cell—the basic unit of life—and how it is studied using the compound and electron microscopes.

An Introduction to the Living Cell, 29 min.

This program shows subcellular organelles working together to meet the cell's needs. Full-motion computer animation, art, and microscopic images help guide students' understanding of the cell's inner workings.

Cancer Cell Research: The Way of All Flesh, 60 min.

This program examines the history of using HeLa cells in the study of cancer biology.

Cell Biology in the Cellular City, 30 min.

This DVD explores the membrane of the cell and of the organelles.

<http://www.carolina.com>

Glycolysis and Cellular Respiration: The Biology of Energy, 27 min.

This DVD explores the processes of glycolysis, fermentation, CAC, and oxidative phosphorylation, and the endosymbiotic theory of the origin of mitochondria.

Visualizing Cell Processes, 5 videos, each 15 min.

These VHS video explore: (1) the biochemistry of the chloroplast and the mitochondria; (2) the structures and processes of cell movement and transport of materials in the cell; (3) cellular anatomy and the molecules of the cell; (4) replication, mitosis, and cellular reproduction; and (5) the genetic code.

<http://www.evndirect.com>

Understanding the Cell, 17 min.

This DVD/VHS program uses computer animation and videomicroscopy to detail the structure of prokaryotic and eukaryotic cells.

Understanding Cell Membranes, 32 min.

This DVD/VHS provides computer animation for the study of the basic anatomy of the cell membrane.

DNA: The Amazing Double Helix, 21 min.

This DVD/VHS provides students with state-of-the-art computer animations for the study of the structure and function of DNA and practical application of genetic engineering.

The Cell: Basic Unit of Life, 18 min.

This DVD provides a basic overview of the structure of the cell and an explanation of the function of organelles.

Software

Cells: An Interactive Exploration. (http://ffh.films.com/id/11557/Cells_An_Interactive_Exploration.htm)

-an interactive CD exploring the structures and functions common to all cell types.

Cells alive! QG, a CD that explores cell structure in video and animations.

Cell Biology Biodiscs CD, BIO, a series of 13 CDs on cell biology.

Cell City, CE, an innovative CD that explains the operations of a cell.

Cell Structure and Function, EI, presents an overview of the animal cell.

Cell Structure and Function, CY, an interactive CD.

Cell Structure and Specialization Set, CBS, five CDs covering cells.

Cells, CBS, covers the cell theory and differences between plant and animal cells.

Cellular Respiration, CY, an interactive CD.

Cellular Respiration, PLP, an interactive CD.

Energy and the Chemistry of Life, CBS, CD Mac/Win.

Inside the Cell, Cyber Ed, <http://www.cyber-ed.com>.

Learning about Cells and Biology, EDI, an illustrated CD on cell structure and function.

The Plasma Membrane & Cellular Transport, CY, an interactive CD.

The Study of the Cell, PLP, an interactive CD.

Relevant Educational Websites

http://www.biology.arizona.edu/cell_bio/tutorials/cytoskeleton/main.html

This jump-off page lists links for tutorials and images dealing with cellular movements.

<http://ajpcon.physiology.org/>

Home page for the American Journal of Physiology. Provides essays on the APS classic papers.

<http://www.nrcam.uchc.edu/> (National Resource for Cell Analysis and Modeling)

Home page for the Virtual Cell, an online cell-modeling program.

<http://www.interscience.wiley.com/jpages/0021-9541/>

Interface for the Journal of Cellular Physiology.

<http://www.cellsalive.com>

Jump-off page for interactive study of cells, mitosis, meiosis, etc. Also available are downloads of videos and photographic images of cells.

<http://www.cell.com>

Jump-off page for downloadable papers and animations of cellular processes.

<http://www.cellbio.com> (Cell and Molecular Biology Online)

Homepage for Cell and Molecular Biology Online. Provides hyperlinks to videos, papers, books, and interactive demonstrations of the function of cells.

http://www.biology.arizona.edu/cell_bio/cell_bio.html

Hyperlinks to The Biology Project. Activities include animations and online problem sets designed to help the student learn cell biology.

Relevant Organizations Providing Educational Resources

American Society for Biochemistry and Molecular Biology

9650 Rockville Pike

Bethesda, MD 20814-3996

<http://www.asbmb.org>

American Society for Cell Biology

8120 Woodmont Ave, Suite 750

Bethesda, MD 20814-2762

<http://www.ascb.org>

American Society of Cytopathology

400 West 9th Street, Suite 201

Wilmington, Delaware 19801

<http://www.cytopathology.org/>

British Society for Cell Biology

c/o M. Clements, Department of Zoology

Downing St., Cambridge CB2 3EJ, UK

<http://www.bsbc.org>

Canadian Society of Biochemistry and Molecular and Cell Biology

<http://www.csbmcb.ca/>

International Federation for Cell Biology

<http://www.ifcbiol.org/>

International Society for Analytical Cytology

60 Revere Drive, Suite 500

Northbrook, IL 60062-1577

(847) 205-4722

<http://www.isac-net.org/>

Answers to End of Chapter Essays

1. A cell's three major subdivisions are the plasma membrane, which encloses the cell; the nucleus, which contains the genetic material; and the cytoplasm, which is the interior portion of the cell outside the nucleus.
2. An advantage of organelle compartmentalization is that it allows organelles to have a distinct internal compartment that contains specialized chemicals for carrying out particular functions.
3. Membranous organelles include: endoplasmic reticulum, Golgi complex, lysosomes, peroxisomes, and mitochondria. Non-membranous organelles include: ribosomes, vaults, and centrioles.

4. Endoplasmic reticulum (ER) is a fluid-filled membranous system distributed throughout the cytosol. Rough ER consists of flattened interconnected sacs, and the outer surface of the rough ER contains ribosomes. These ribosomes synthesize and release proteins into the ER lumen, where they undergo transport within or outside the cell. Smooth ER is a meshwork of interconnected tubules and lacks ribosomes, thus the name *smooth*. The smooth ER collects proteins and lipids from the rough ER and packages them for distribution throughout the cell.
5. Exocytosis is the mechanism by which materials from the inside of the cell are released to the exterior. During exocytosis cells secrete materials into the ECF. Endocytosis is the opposite of exocytosis. It is the internalization of extracellular material by the cell. There are three forms of endocytosis depending on what is being internalized. Pinocytosis is a process by which a droplet of ECF is non-selectively internalized. Phagocytosis is a process by which large multi-molecular particles are internalized. Receptor-mediated endocytosis is a selective process that enables cells to internalize specific large molecules from its environment.
6. Lysosomes serve as the intracellular digestive system. They contain hydrolytic enzymes and, in addition to breaking down raw ingredients, they also remove worn-out organelles.
7. Peroxisomes contain oxidative enzymes and perform detoxifying activities by removing hydrogen atoms from certain organic molecules. Lysosomes serve as the intracellular digestive system. They contain hydrolytic enzymes, and in addition to breaking down raw ingredients, they also remove worn-out organelles.
8. Cellular respiration refers to the collection of intracellular reactions in which nutrient molecules are broken down to form ATP. During the process, oxygen is utilized and carbon dioxide is produced. Oxidative phosphorylation is the process by which ATP is synthesized using the energy released by electrons as they are transferred to oxygen; it takes place at the mitochondrial inner membrane. Chemiosmosis encompasses the last steps of oxidative phosphorylation and involves the production of ATP via the activation of ATP synthase. This enzyme is activated as H⁺ moves into the mitochondrial matrix.
9. Mitochondria are enclosed by a double membrane—an outer membrane that surrounds the organelle, itself, and an inner membrane that contains numerous folds, called cristae. The innermost cavity formed by the cristae is called the matrix and is filled with a gel-like solution. These organelles play a major role in ATP production. Citric acid cycle reactions occur in the matrix, and oxidative phosphorylation reactions take place on the inner membrane.
10. Oxidative enzymes in the peroxisome utilize oxygen for detoxification. Oxidative enzymes in the mitochondria utilize oxygen in the process of synthesizing ATP.
11. Cells expend energy on synthesis of new chemical compounds, membrane transport processes, and mechanical work.
12. The cytoskeleton is composed of microtubules, microfilaments, and intermediate filaments. Microtubules serve a variety of functions including maintaining the shape of cells, coordinating complex intracellular movements, and serving as the main structural component of cilia and flagella. Microfilaments play a major role in cellular contractile systems, including muscle contraction. Intermediate filaments resist mechanical stress placed on cells.

