Chapter 3: The Cellular Level of Organization

I. An Introduction to Cells, p. 63

- Cell theory (Robert Hooke, 1665)
  - Cells are the building blocks of all plants and animals.
  - All cells come from division of preexisting cells.
  - Cells are the smallest units that perform all vital physiological functions.
  - Each cell maintains homeostasis at the cellular level.

- An organism maintains homeostasis through the coordination of all its cells, working individually and together.

- Cytology: the study of cell structure and function, a division of cell biology.

- Two classes of cells in the human body:
  1. sex cells (germ cells): reproductive cells [male sperm, female oocytes (eggs)]
  2. somatic cells (soma = body): all body cells except sex cells.

Figure 3-1

- Shows the general structure and typical organelles of a body cell.

Table 3-1

- Summarizes the organelles and their functions.

- Human body cells are surrounded by a cell membrane which separates the inside (cytoplasm) from the outside (extracellular) fluid. Fluid between cells is called interstitial fluid. (interstitium = something standing between).

- Cell membrane is more than just a barrier; it selectively transports nutrients into, and cellular products and wastes out of, the cell.

II. The Cell Membrane, p. 63

- Cell membrane or plasma membrane has 4 basic functions:
  1. Physical isolation: forms a physical barrier between the inside and outside of the cell. Keeps things in or out.
  2. Regulate exchange with the environment: controls entry of ions and nutrients, eliminates waste, releases cellular products.
  3. Monitor the environment: detects changes in composition, concentration or pH of extracellular fluid. Contains receptors that respond to chemical signals.
  4. Structural support: keeps cells in place and stabilizes tissues
Membrane Lipids, p. 66

(Figure 3-2)

The cell membrane is made up of a double layer of phospholipid molecules (phospholipid bilayer) with their hydrophilic heads toward the watery environment on both sides.

The hydrophobic fatty-acid tails inside the membrane form a barrier to ions and water soluble compounds, isolating the inside of the cell from the outside.

Membrane Proteins, p. 66

(Figure 3-2) There are two structural classes of membrane proteins:
1. **integral proteins**: embedded within the membrane.
2. **peripheral proteins**: stuck to the inner or outer surface of the membrane.

These large protein molecules are divided into six specialized functions:
1. anchoring proteins (stabilizers): attach cell membrane to inside or outside structures.
2. recognition proteins (identifiers): label cells as normal or abnormal to the immune system.
3. enzymes: catalyze reactions inside or outside the membrane.
4. receptor proteins: bind and respond to extracellular molecules called ligands, (e.g. ions, hormones).
5. carrier proteins: bind specific solutes and transport them through the cell membrane using energy.
6. channels: pores that regulate the flow of water and specific solutes through membrane.

Membrane Carbohydrates, p. 67

Carbohydrates in the cell membrane include proteoglycans, glycoproteins and glycolipids. Parts of these molecules extend outside the cell membrane to form a sticky “sugar coat” or glycocalyx.

Four main functions of the glycocalyx are:
1. Lubrication and protection
2. Anchoring and locomotion
3. Specificity in binding (receptors)
4. Recognition (immune response)
III. The Cytoplasm, p. 68

♣ Cytoplasm includes all materials inside the cell membrane but outside the nucleus. The 2 components of cytoplasm are:
  1. cytosol (intracellular fluid): thick liquid with dissolved nutrients, ions, soluble and insoluble proteins, waste products.
  2. organelles: structures with specific functions inside the cell.

The Cytosol, p. 68

♣ Cytosol differs from extracellular (interstitial) fluid in 3 ways:
  1. Potassium ions are concentrated inside, and sodium ions outside, the cell.
  2. Cytosol has a high concentration of suspended proteins.
  3. Cytosol stores some carbohydrates, large amounts of amino acids and lipids.

♣ Insoluble materials within the cytosol (e.g. glycogen granules, lipid droplets, pigment granules) are called inclusions.

The Organelles, p. 68

♣ Each organelle has a specific function related to cell structure, growth, maintenance or metabolism. Organelles are divided into 2 groups:
  1. nonmembranous organelles: no membrane, in direct contact with cytosol.
  2. membranous organelles: isolated from cytosol, covered with plasma membrane similar to cell membrane.

♣ The 6 types of nonmembranous organelles are: cytoskeleton, microvilli, centrioles, cilia, ribosomes and proteasomes.

Figure 3-3a

1. cytoskeleton: structural proteins for shape, strength, and some metabolic functions. All cells’ cytoskeletons have 3 elements: microfilaments, intermediate filaments, and microtubules.
   (A) microfilaments (thin filaments): the thinnest of all cytoskeleton protein strands, typically composed of the protein actin.
      Three major functions are:
      (1) attachment and mechanical strength
      (2) interact with proteins to determine viscosity
      (3) in muscle cells, actin pairs with thick filaments of the protein myosin to produce motion
   (B) intermediate filaments: the most durable cytoskeleton elements (e.g. collagen), mid-sized between microfilaments and thick filaments.
      Three major functions are:
      (1) strengthen cell and maintain shape
      (2) stabilize organelles
(3) stabilize positions between cells
(C) microtubules: the largest cytoskeleton component; hollow tubes made of the protein tubulin, attach to the centrosome. Five functions of microtubules are:
(1) primary structure of cytoskeleton: cell strength, rigidity, anchor organelles
(2) change shape of cell
(3) form tracks to move vesicles and organelles within the cell (molecular motors kinesin, dynein)
(4) form spindle apparatus during cell division
(5) form structural components of other organelles (e.g. centrioles, cilia)

Figure 3-3b
2. microvilli: finger-shaped projections on the surfaces of some cells, increase surface area for absorption, attached to cytoskeleton.

Figure 3-4a
3. centrioles form spindle apparatus during cell division, only found in cells that divide. Cytoplasm surrounding the centriole is the centrosome, associated with the cytoskeleton.

Figure 3-4b, c
4. cilia: long extensions of cell membrane move fluids across the cell surface (respiratory tract, reproductive tract). Made of microtubules anchored to a basal body below the cell surface.

5. ribosomes: carry out orders from the nucleus for protein synthesis.
- Have 2 separate subunits -- the small ribosomal subunit and the large ribosomal subunit -- which contain special proteins and ribosomal RNA (rRNA).
- Protein synthesis begins when 2 subunits join a strand of messenger RNA (mRNA).
- 2 types of ribosomes in cells are:
  1. free ribosomes: scattered through cytoplasm (make proteins for the cell).
  2. fixed ribosomes: attached to endoplasmic reticulum (make proteins for secretion).

6. proteasomes: contain enzymes (proteases) that disassemble damaged proteins into peptides and amino acids for recycling

• The 5 types of membranous organelles are: endoplasmic reticulum, Golgi apparatus, lysosomes, peroxisomes and mitochondria.

Figure 3-5
1. endoplasmic reticulum (ER, endo = within, plasm = cytoplasm, reticulum =
network): a network of membranes (forming storage chambers called cisternae) connected to the nuclear envelope.

-The 4 major functions of the ER are:
  (1) synthesis of proteins, carbohydrates and lipids
  (2) storage of synthesized molecules and materials
  (3) transport of materials within the ER
  (4) detoxification of drugs or toxins by enzymes

-There are 2 types of endoplasmic reticulum:
  (1) smooth endoplasmic reticulum (SER) has no ribosomes. Its main function is to synthesize lipids and carbohydrates such as:
    - phospholipids and cholesterol for membranes
    - steroid hormones for the reproductive system
    - glycerides for storage in liver and fat cells
    - glycogen for storage in skeletal muscle and liver cells
  (2) rough endoplasmic reticulum (RER) is rough because of ribosomes attached to its surface. Functions in protein and glycoprotein synthesis.
    - ribosomes synthesize polypeptides (primary protein structure) and release them into the cisternae of the RER.
    - inside the RER, polypeptides fold into secondary and tertiary protein structures.
    - most proteins and glycoproteins manufactured in the RER are then enclosed in membrane packages called transport vesicles which carry them to the Golgi apparatus.

Figure 3-6
2. Golgi apparatus: a stack of 5 or 6 flattened membrane containers (cisternae).

Figure 3-7
- The 3 major functions of the Golgi apparatus are:
  (1) modifies and packages proteins and glycoproteins (secretions such as hormones or enzymes) for exocytosis
  (2) modifies the cell membrane
  (3) packages special enzymes used in cytosol

- Vesicles carry proteins from the RER to the forming (cis) face of the Golgi apparatus. The proteins pass through successive layers of the Golgi apparatus (where they are modified or molecular groups added) and exit the maturing (trans) face.

- 3 types of vesicles carry material away from the Golgi apparatus:
  (1) secretory vesicles: vesicle membrane fuses with cell membrane for exocytosis
  (2) membrane renewal vesicles: fuse with cell membrane to add or
remove lipids and proteins
(3) lysosomes: carry enzymes and remain in the cytosol

Figure 3-8
3. Cells clean up their internal environment (break down large molecules, attack bacteria, or recycle damaged organelles) with powerful enzyme-containing vesicles called lysosomes \((lyso = \text{dissolve}, \text{soma} = \text{body})\).
   - Primary lysosomes, formed by the Golgi apparatus, are membranous vesicles containing inactive enzymes.
   - Secondary lysosomes form when lysosomes fuse with damaged organelles and digestive enzymes are activated. Any toxic chemicals produced are isolated within the lysosome.
   - The lysosome returns useful nutrients to the cytosol, and ejects wastes by exocytosis.
   - If a cell is damaged, its own lysosomes disintegrate and digest the cell by autolysis \((auto = \text{self})\).

4. Peroxisomes are enzyme-containing vesicles that break down fatty acids and other organic compounds, producing the dangerous free radical hydrogen peroxide \((\text{H}_2\text{O}_2)\).
   - Peroxisome enzymes are produced by free ribosomes
   - Peroxisomes replicate by division

• All membranous organelles (except mitochondria), including the nucleus and the cell membrane, communicate and exchange membrane parts through vesicle movement. This continuous movement and exchange, called membrane flow, allows cellular membranes to adapt and change.

• (*) A cell is the basic structural and functional unit of life. Cells respond to their environment and maintain homeostasis at the cellular level. Cells can modify their structure and function over time.

Figure 3-9
5. Cells require energy to function. Mitochondria \((\text{singular: mitochondrion})\) produce energy in the form of ATP.
   - Mitochondria have a smooth outer membrane and a folded inner membrane.
   - The inner folds are called cristae. Enzyme-containing fluid surrounding the cristae is the matrix.
   - Mitochondria produce energy by breaking down foods, such as the sugar glucose.
   - The breakdown of glucose begins in the cytosol with glycolysis.
   - The resulting pyruvic acid molecules enter the matrix and are further broken down by the tricarboxylic acid cycle (TCA cycle), using oxygen and releasing carbon dioxide. This process is called aerobic metabolism or cellular respiration.
(*) Mitochondria provide most of the energy needed to keep your cells alive. Aerobic respiration requires oxygen and organic substrates, and generates carbon dioxide and ATP.

IV. The Nucleus, p.77

Figure 3-10
♣ The cell’s control center, the nucleus, is the largest organelle in the cell. It’s surrounded by a double membrane (the nuclear envelope) with communication passages called nuclear pores. The small space between the two layers of the nuclear envelope is the perinuclear space.
- The nucleus contains all of our DNA, all the information needed to reproduce and run our bodies.
- Also found in the nucleus are ions, enzymes, nucleotides and some RNA, all suspended in a fluid nucleoplasm, and supported by filaments of nuclear matrix.

♣ Other organelles within the nucleus include:
A. nucleoli: active in protein production
   - composed of RNA, enzymes and histone proteins
   - synthesize rRNA and assemble ribosomal subunits

Figure 3-11  B. nucleosomes: structure formed when DNA coils around histones
- chromatin: loosely coiled DNA (cells not dividing)
- chromosomes: tightly coiled DNA (cells dividing)

♣ (*) The nucleus contains genetic instructions for proteins that determine cell structure and function. Information is stored in chromosomes made of DNA and various proteins.

Information Storage in the Nucleus, p. 79

♣ How is genetic information stored?
- DNA carries instructions to produce every protein in the body. Each protein is a unique sequence of amino acids.
- The DNA instructions for one protein make up a gene. The chemical language of DNA instructions is the genetic code.
- Genetic code is the order (sequence) of the nitrogenous bases (A, T, C and G) in the DNA molecule. Every group of three bases (the triplet code) represents one amino acid. (Table 3-2)
- There is more than 1 code for each amino acid, e.g. TGT and TGC are both genetic code for the amino acid cysteine.
- Not every gene codes for a protein, some code for RNA, or have unknown functions.
Figure 3-12

1. The first step in protein production is gene activation (uncoils DNA and removes histones). Complementary strands of DNA uncoil in the specific area of one gene (marked by start or promoter codes and stop codes).

2. The gene is read by an enzyme called RNA polymerase.
   - One half of the DNA (the coding strand) codes for the protein.
   - The complementary half (the template strand), like a reverse mold, is used by the RNA polymerase molecule.

3. RNA polymerase copies the complete code for the protein (gene) onto a strand of messenger RNA (mRNA) in the process of transcription.
   - Starting with the promoter or start sequence, RNA polymerase binds free nucleotides together to form a strand of mRNA, duplicating the DNA coding strand, but substituting uracil nucleotides for thymine nucleotides.
   - In the resulting mRNA strand, each group of 3 nucleotides (triplet) is a codon representing one amino acid.

4. At the stop signal, the mRNA strand detaches from the DNA molecule and its code is edited (RNA processing). Unnecessary codes (introns) are removed and the rest (exons) spliced together.

Figure 3-13 (part 1)

5. The mRNA leaves the nucleus through a nuclear pore and carries the instructions to a ribosome in the cytoplasm, where protein synthesis occurs.
   - Translation begins when an mRNA strand is bound between a small and a large ribosomal unit.
   - Each mRNA codon (sequence of 3 nitrogenous bases) translates to one amino acid in a polypeptide chain.
   - In the cytoplasm, transfer RNA (tRNA) delivers free amino acids to the mRNA. Each t-RNA is identified by a specific anticodon, which identifies the type of amino acid it carries. The anticodon binds to a specific mRNA codon, creating the correct sequence of amino acids for a specific protein.
   - Enzymes join the amino acids together in a polypeptide chain.
   - One mRNA can be read by many ribosomes (polyribosome) to synthesize multiple copies of the same polypeptide.

• (*) Genes are functional units of DNA containing instructions for one or more proteins. Protein synthesis requires several enzymes, ribosomes, and 3 types of RNA.
• (*) A mutation is a change in the nucleotide sequence of a gene, caused by chemical or radiation exposure or by mistakes during DNA replication, and can change gene function.

*How the Nucleus Controls Cell Structure and Function*, p. 84

1. *Direct control* over synthesis of structural proteins and secretions to control the cell’s internal structure and responses to the environment (e.g. secretions).
2. *Indirect control* over all aspects of cellular metabolism through enzyme production.

V. *How Things Get Into and Out of Cells*, p. 84

• The cell membrane is a barrier -- but nutrients must get in, and products and wastes must get out.

• Permeability determines which materials move in and out of a cell.
  - A membrane which lets nothing in or out is **impermeable**.
  - A membrane that lets anything pass is **freely permeable**.
  - A membrane that restricts movement is **selectively permeable**.
  - Selectively permeable membranes allow some materials to move freely and restrict others, depending on size, electrical charge, molecular shape, lipid solubility, or other factors.

• Transport through a cell membrane can be **active** (requiring energy/ATP) or **passive** (no energy required).
  - The 3 major categories of transport are **diffusion** (passive), **carrier-mediated transport** (passive or active), and **vesicular transport** (active).

*Figure 3-14*

1. **Diffusion**, p. 85
   - All atoms are constantly in motion. Random motion causes mixing. When a solute (e.g. sugar) is added to a solvent (e.g. water), and there are more molecules of solute in one part of the solvent than in another, that is a **concentration**.
   - As molecules of concentrated solute begin mixing through random molecular motion, the concentration of the solute gets lower and lower. This range of concentrations is a **concentration gradient**.
   - Concentration gradients always move in one direction, from high concentration to low concentration.
   - 5 factors affect the speed of diffusion (diffusion rate):
     1. *Distance* the solute particle has to move.
     2. *Molecule* size: small molecules move faster than large molecules.
3. **Temperature**: More heat energy means faster molecular motion.
4. **Gradient size**: The difference in concentration from beginning to end of concentration gradient.
5. **Electrical forces**: Opposite charges attract, like charges repel. The combination of a concentration gradient and an electrical gradient is an electrochemical gradient.

**Figure 3-15**
- Diffusion across a cell membrane can be *simple* or *channel-mediated*.

**Simple Diffusion**: 2 kinds of materials can diffuse across a cell membrane simply by concentration gradient.
1. Lipid-soluble compounds such as alcohol, fatty acids, steroids and lipid-soluble drugs
2. Dissolved gases such as oxygen and carbon dioxide

**Channel-Mediated Diffusion**: water soluble compounds, such as ions, must pass through membrane channels (transmembrane proteins).
- The ability of an ion to pass through a membrane channel depends on its size, charge, and interactions with the channel itself.

**Figure 3-16**
- **Osmosis** refers to the diffusion of water across the cell membrane.
  - The more solutes in an aqueous solution, the lower the concentration of water molecules.
  - To maintain equilibrium, water molecules tend to diffuse across a membrane *toward* the side with a higher concentration of solutes (lower concentration of water), increasing the volume of fluid on the side with more solutes.
  - The membrane must be freely permeable to water but selectively permeable to solutes.
  - The force of a concentration gradient of water is its *osmotic pressure*.
  - The osmotic pressure can be measured by pushing against the flow of water (hydrostatic pressure) until the volume is equal on both sides.

**Figure 3-17**
- The total solute concentration in an aqueous solution is its *osmolarity* or *osmotic concentration*.
  - The way different solutes affect the cell is called *tonicity*.
  - A solution that does not cause osmotic flow of water in or out of a cell is *isotonic* (*iso* = same, *tonos* = tension).
  - Two fluids may have equal osmolarity, but different tonicity.
  - A *hypertonic* solution has more solutes, and *gains* water by
osmosis. A cell in a hypertonic solution loses water and shrinks (e.g. crenation of red blood cells).

- A hypotonic solution has less solutes, and loses water through osmosis. A cell in a hypotonic solution gains water and can rupture (e.g. hemolysis of red blood cells).

(*) Concentration gradients tend to even out. In the absence of a membrane, diffusion eliminates concentration gradients. When different solute concentrations exist on either side of a selectively permeable membrane, osmosis moves water through the membrane to equalize the concentration gradients.

2. **Carrier-Mediated Transport**, p. 89

- In carrier-mediated transport, integral proteins bind ions and organic substrates and carry them across the cell membrane.
  
  - The 3 characteristics of carrier-mediated transport are:
    1. **Specificity**: one transport protein carries only specific substances
    2. **Saturation limits**: The rate of transport depends on the number of available transport proteins, not concentration.
    3. **Regulation**: cofactors such as hormones can regulate transport.
  
  - **Cotransport**: one carrier transports 2 substances in the same direction at the same time.
  
  - **Countertransport**: one substance is moved in while another is moved out.

- The 2 main examples of carrier-mediated transport are facilitated diffusion and active transport.

**Figure 3-18**

- Molecules that are too large to fit through a channel protein (e.g. glucose, amino acids) can be passively transported across the cell membrane by facilitated diffusion.
  
  - The molecule binds to a receptor site on the carrier protein, which changes shape to allow the molecule to pass through. The receptor site on each carrier protein is specific to certain molecules.

**Figure 3-19**

- **Active transport** moves specific substances across the cell membrane regardless of their concentrations. Moving against a concentration gradient requires energy, such as ATP.
  
  - active transport proteins called **ion pumps** move ions (Na+, K+, Ca+, Mg++) across cell membranes
  
  - an ion pump that countertransports two ions at the same time is
called an exchange pump.

- An example is the **sodium-potassium exchange pump** (*sodium-potassium ATPase*), which constantly pumps sodium ions (Na+) out of the cell and potassium (K+) ions into the cell (up to 40% of a cell’s ATP use).
  - The energy of 1 ATP moves 3 Na+ out and 2 K+ into the cell.

**Figure 3-20**

- In *secondary active transport*, the concentration gradient of one substance drives the active transport of another substance in the same direction, without the immediate use of ATP.
  - In the case of glucose transport, the resulting concentration of Na+ within the cell later requires ATP energy to pump the Na+ back out.

3. **Vesicular Transport**, p. 92

- **Vesicles** are membrane sacs that move large volumes of substances (*bulk transport*) into and out of the cell, or between organelles within the cell. The 2 main categories of vesicular transport are **endocytosis** (*endo* = into) and **exocytosis** (*exo* = out of).

  (1) **Endocytosis:**
  - The 3 major types of endocytosis are **receptor-mediated**, **pinocytosis**, and **phagocytosis**. Endocytosis is active transport using ATP

**Figure 3-21**

(1) In **receptor-mediated endocytosis**, receptors (glycoproteins) on the surface of the cell bind specific target molecules (ligands) such as iron ions or cholesterol.
  - receptors bound to ligands cluster together to form a **coated vesicle** (*endosome*) which carries ligands and receptors into the cell.
  - coated vesicles fuse with lysosomes to separate the ligands from their receptors.
  - coated vesicles return the empty receptors to the cell surface.

**Figure 3-22a**

(2) In **pinocytosis** (*cell drinking*) endosomes open and “drink” extracellular fluid, not specific to any substance.

**Figure 3-22b**

(3) In **phagocytosis** (*cell eating*) membrane extensions called **pseudopodia** (*pseudo* = false, *podia* = feet) reach out and grab large, solid objects (bacteria, cell debris) and engulf them in vesicles (phagosomes).
  - Phagosomes fuse with lysosomes which digest the material and expel wastes through exocytosis.
(II.) **Exocytosis:** *(Figure 3-22b)*

- **Exocytosis** is the reverse of **endocytosis**.
  - Membranous vesicles within the cell (formed from other membranous organelles such as Golgi apparatus, phagosomes or lysosomes) merge with the cellular membrane to expel their contents (cellular products or wastes).

**Table 3-3** Review the 7 methods of transport through cell membranes.

**The Transmembrane Potential**, p. 94

- The electrical charge inside the cell membrane is slightly negative, and the outside slightly positive (more positive ions outside, more negative ions inside).
  - this unequal charge produces a difference in electrical potential *(potential difference)* across the cell membrane *(transmembrane potential)*.
  - transmembrane potential is expressed in **millivolts** *(mV)*
  - the **resting potential** of an undisturbed cell ranges from -10 mV to -100 mV, depending on the type of cell.
  - the ability of the cell membrane to keep electrical charges separated results in **potential energy** across the membrane.
  - transmembrane potential provides electrical energy to muscles, the nervous system and some glands.

**VI. The Cell Life Cycle**, p. 95

**Figure 3-23**

- A human being grows from 1 cell to 75 trillion cells by **cell division**.
  - cells grow, age and die at a genetically determined rate *(apoptosis)*
  - most of a cell’s life is spent in a non-dividing state *(interphase)*
  - for body *(somatic)* cells to divide, their genetic material must be duplicated exactly *(DNA replication)* and divided equally *(mitosis)*
  - **cytokinesis** divides the cytoplasm and all the duplicated organelles into 2 daughter cells
  - the entire life cycle of a cell from one division to another is the **cell cycle**.
  - production of sex cells is a different process *(meiosis)* which will be discussed in Chapter 28.

**Interphase**, p. 95

- Body cells spend more time working than dividing. The working period is called **interphase**.
  - **Interphase** begins with a period when the cell performs only its specialized cell functions *(G-zero phase)*. This time varies by cell type.
  - An interphase cell preparing for cell division goes through 3 more stages.
    1. **G1 phase**: cell growth, organelle duplication, protein synthesis
2. **S phase**: DNA replication, histone synthesis  
3. **G2 phase**: finishes protein synthesis and centriole replication

**Figure 3-24**  
- In DNA replication, DNA strands unwind and **DNA polymerase** begins attaching complementary nucleotides along each strand.  
  - DNA polymerase can only work in one direction. Smaller segments are tied together by **ligases**.

**Mitosis**, p. 97

**Figure 3-25**  
- After the G2 stage of interphase, the duplication and division of the nucleus (M phase or mitosis) begins. Mitosis occurs in 4 stages: **prophase, metaphase, anaphase, telophase**.

**Stage 1. Prophase:**  
- *(Figure 3-11)* The 2 DNA copies coil tightly into chromatids, connected at a **centromere**. The protein complex around the centromere is the **kinetochore**. This visible structure is a **chromosome**.  
  - nucleoli disappear  
  - centriole pairs move to cell poles  
  - microtubules (**spindle fibers**) extend between centriole pairs  
  - nuclear envelope disappears  
  - spindle fibers attach to the kinetochore of each chromatid (**chromosomal microtubules**)  

**Stage 2. Metaphase:**  
- chromosomes align in a plane between the centrioles (**metaphase plate**)  

**Stage 3. Anaphase:**  
- chromosomal microtubules pull chromosomes apart into 2 **daughter chromosomes**  
  - daughter chromosomes are divided into 2 groups near the centrioles.

**Stage 4. Telophase:**  
- nuclear membranes reform  
- chromosomes uncoil  
- nucleoli reappear  
- cell has 2 complete nuclei

- (*) Mitosis is the duplication of chromosomes in the nucleus in preparation for cell division.
Cytokinesis, p. 98

- **Cytokinesis** is the division of the cytoplasm of the cell into 2 daughter cells.
  - Cleavage furrow appears around the metaphase plate.
  - Cell membrane closes and 2 separate cells created (end of cell division).

The Mitotic Rate and Energy Use, p. 98

- Because the condensed chromosomes of mitosis are easy to see, the rate of cell division is also called mitotic rate.
  - The slower the mitotic rate, the longer the cell life.
  - Muscle cells and neurons rarely divide, are long-lived.
  - Exposed cells (skin, digestive tract) may live only a few days or hours.
  - Unspecialized cells (stem cells) maintain cell populations by producing both new stem cells and specialized cells.
  - Cell division requires large amounts of energy (ATP). Lack of energy slows cell growth and repair.

Regulation of the Cell Life Cycle, p. 98

- Normally, cell division balances cell loss.

Table 3-4

- Some factors trigger cell division:
  1. Internal factors such as M-phase promoting factor (MPF), which appears when levels of the protein **cyclin** rise.
  2. Extracellular chemical factors, including hormones and growth factors
- Other factors prevent cell division:
  1. Repressor genes inhibit cell division. Many cancers are associated with faulty repressor genes.
  2. Telomeres (terminal segments of DNA) wear out, preventing cell division.

Cell Division and Cancer, p. 99

- A tumor or neoplasm is an enlarged mass of cells produced by abnormal cell growth and division.
- A benign tumor is contained and not life threatening.
- Cells in a malignant tumor spread into surrounding tissues (invasion) and start new tumors (metastasis).
- An illness that disrupts normal cellular controls and produces malignant cells is cancer.
- Mutated genes that disrupt normal cellular controls are **oncogenes**.

**Figure 3-26**
- Cancer develops in series of steps:
  - abnormal cell
  - primary tumor
  - metastasis
  - secondary tumor

- (*) Cancer results from mutations that disrupt normal controls over cell growth and division. Cancers often begin where stem cells are dividing rapidly. More chromosome copies mean greater chance of error.

*Cell Diversity and Differentiation*, p. 100

- All cells carry a complete set of DNA, with instructions for all bodily functions.
  - In order for tissues to form, cells must specialize or **differentiate** (e.g. liver cells, fat cells, neurons).
  - This requires turning off all the genes not needed by that cell.

- (*) All your body cells (except sex cells) contain the same 46 chromosomes. What makes cells different from one another is which genes are active, and which genes are inactive.

**SUMMARY**

In Chapter 3 we learned:

- The structures and functions of human cells.
- The structures and functions of membranous and nonmembranous organelles within the cytoplasm.
- The special functions of ATP, mitochondria and the process of aerobic cellular respiration.
- The special structures and functions of the nucleus
  - The control functions of nucleic acids.
  - The structures and replication of the DNA molecule.
  - The roles of DNA and RNA in protein synthesis.
- The structures and chemical activities of the cell membrane.
  - The mechanical processes of diffusion and osmosis.
  - The active processes of transport proteins.
  - The role of vesicles in endocytosis and exocytosis
  - The electrical properties of plasma membrane.
- The stages and processes of cell division
  - DNA replication
  - Mitosis
  - Cytokinesis
• The relationship between cell division, energy use and cancer.