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Learning Outcomes 1

1. Explain why it is important to know the cellular basis of a disease.
2. Distinguish somatic cells from germ cells, and diploid and haploid.
3. Explain how cells differentiate.
4. List the four major chemicals in cells.
5. Describe how organelles interact to secrete, use energy, and clean up debris.
6. Describe the structure and function of a biological membrane.
7. List the components of the cytoskeleton.
8. Describe the main events of the cell cycle.

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Learning Outcomes 2

9. Indicate how chromosomes change and interact during mitosis.
10. Discuss control of the cell cycle.
11. List the events of apoptosis.
12. List the characteristics of a stem cell and a progenitor cell.
13. Describe the three main sources of human stem cells.
14. Describe the components of the human microbiome.
15. List factors that can alter the human microbiome.

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Introducing Cells 1

Inherited traits, quirks and illnesses arise from the activities of cells.

Cells are the basic units of life and comprise the human body.

- Our bodies include more than 290 specialized, or differentiated, cell types
- These aggregate and interact to form the four basic tissue types: epithelial, connective, muscle, and nervous tissue

All cells share certain features, but they are also specialized because they express different subsets of genes.

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Introducing Cells 2

Table 2.1 Tissue Types	
Tissue	Function/Location/Description
Connective tissues	A variety of cell types and surrounding materials protect, support, bind to cells, and fill spaces throughout the body; include cartilage, bone, blood, and fat
Epithelium	Tight cell layers form linings that protect, secrete, absorb, and excrete
Muscle	Cells contract, providing movement
Nervous	Neurons transmit information as electrochemical impulses that coordinate movement and also sense and respond to environmental stimuli; neuroglia support and nourish neurons

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Introducing Cells 3

Somatic cells are also called body cells.

- Have two copies of the genome and are said to be **diploid**

Germ cells are the sperm and egg cells

- Have one copy of the genome and are **haploid**.

The meeting of sperm and egg restores the diploid state

Stem cells are diploid cells that divide to give rise to differentiated cells, and to other stem cells in a process called **self-renewal**

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Domains of Life

Biologists recognize three basic types of cells that define three major "domains" of life:

- **Archaea** and **Bacteria**—Unicellular prokaryotes

Eukarya—Includes both unicellular and multicellular eukaryotes

Cells of domains contain globular assemblies of RNA and protein called **ribosomes**.

- Essential for protein synthesis

The eukaryotes may have arisen from an ancient fusion of a bacterium with an archaean.

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Eukaryotic and Prokaryotic Cells



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Cell Chemical Constituents

The major macromolecules that make up cells are **carbohydrates** (sugars and starches), **lipids** (fats and oils), **proteins**, and **nucleic acids** (DNA and RNA).

- **Carbohydrates** provide energy and contribute to cell structure.
- **Lipids** form the basis of some hormones, form membranes, provide insulation, and store energy.
- **Proteins** have many diverse functions such as forming the contractile fibers of muscle cells, enabling blood to clot, and forming the bulk of connective tissues.
- **Enzymes** are especially important proteins because they facilitate, or catalyze, biochemical reactions.
- **Nucleic acids** (DNA and RNA) are most the most important macromolecules to the study of genetics.

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A Generalized Animal Cell 1

Surrounded by the **plasma membrane** (also called the cell membrane)

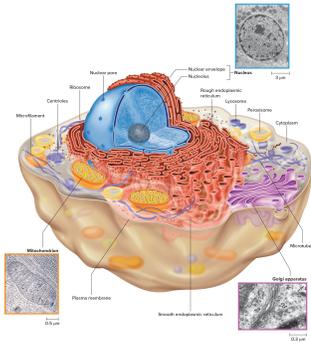
Contains intracellular **organelles**

Contains:

- **Cytoplasm**
- Stored proteins, carbohydrates, and lipids
- Pigment molecules
- Other small chemicals

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A Generalized Animal Cell 2



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Organelles

Divide labor by partitioning certain areas or serving specific functions

Keep related biochemicals and structures close to one another to interact efficiently

Functions:

- Enable a cell to retain and use its genetic instructions
- Acquire energy, secrete substances, and dismantle debris

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The Nucleus 1

The most prominent organelle

Surrounded by a layer called the nuclear envelope

Contains:

- Nuclear pores that allow movement of biochemicals
- Nuclear lamina provides mechanical support and holds nuclear pores in place
- **Nucleolus** produces ribosomes
- Other contents —Chromosomes, RNA and nucleoplasm

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The Nucleus 2

Labels: Cytoplasm, Nuclear envelope, Nuclear pore, Inside nucleus

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Secretion: Making Milk 1

Secretion illustrates how organelles function together to coordinate the basic life functions.

Labels: Ribosome, Lysosome, Mitochondrion, Smooth ER, Lipid droplet, Golgi apparatus, Plasma membrane, Lipid droplet, Nuclear pore, Nuclear envelope, mRNA, Rough ER, Sugar, Protein, Vesicle

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Secretion: Making Milk 2

1. Genes that encode milk proteins and certain enzymes are transcribed into mRNA.
2. mRNA exits through nuclear pores.
3. mRNA moves to surface of rough ER, where proteins are synthesized on ribosomes using amino acids in the cytoplasm.
4. Lipids are synthesized in the smooth ER.
5. Sugars are synthesized and proteins folded in the Golgi apparatus, then both are released in vesicles that bud off of the Golgi apparatus.
6. Protein- and sugar-laden vesicles move to the plasma membrane for release. Fat droplets pick up a layer of lipid from the plasma membrane as they exit the cell.

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Endoplasmic Reticulum (ER)

Interconnected membranous tubules and sacs

The ER winds from the nuclear envelope to the plasma membrane

- Rough ER contains ribosomes and is involved in protein synthesis
- Smooth ER does not contain ribosomes and is important in lipid synthesis

Proteins exit the ER in membrane-bounded, sac-like organelles called **vesicles**

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Golgi Apparatus

- Stack of interconnected flat, membrane-enclosed sacs
- Processing center that adds sugars forming glycoproteins and glycolipids
- Products are released into vesicles that bud off to the plasma membrane
- Some cell types have just a few Golgi apparatuses, but those that secrete may have hundreds

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Lysosomes 1

Membrane-bound sacs containing 43 types of digestive enzymes

Dismantle bacterial remnants, worn-out organelles, and excess cholesterol

Engage in **autophagy**

Endosomes are vesicles derived from the plasma membrane that ferry materials to lysosomes.

- Example: low-density lipoprotein (LDL) cholesterol

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Lysosomes 2

Labels in diagram: Plasma membrane, Extracellular debris, Lysosomal enzymes, Golgi apparatus, Lysosomes: Budding vesicles containing lysosomal enzymes, Intracellular debris, damaged mitochondria, Mitochondrion fragment, Digestion, Peroxisome fragment, Lysosome membrane.

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Lysosomes 3

Cells differ in the number of lysosomes they contain.

- Macrophages require many to digest bacteria
- Liver cells require many to break down cholesterol, toxins, and drugs

Absence or malfunction of an enzyme causes a lysosomal storage disease.

- Tay-Sachs is an inherited disorder
- Nervous system becomes buried in lipid, causing death within 3 years of age

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Peroxisomes

Sacs with outer membranes studded with several types of enzymes

Break down lipids, rare biochemicals

Synthesize bile acids

Detoxify compounds from exposure to oxygen free radicals

- Abundant in liver and kidney cells

Adrenoleukodystrophy is an example of a genetic disease caused by an absent peroxisomal enzyme.

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Mitochondria 1

Provide energy by breaking chemical bonds that hold together nutrient molecules in food

Freed energy is stored in **adenosine triphosphate (ATP)**

A mitochondrion is surrounded by 2 membranes

- Inner membrane forms folds called cristae
- Hold enzymes that catalyze biochemical reactions

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Mitochondria 2

Labels in diagram: Cristae, Outer membrane, Inner membrane, Matrix, DNA, Ribosomes.

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Organelles of An Animal Cell

Table 2.2 Structures and Functions of Organelles

Organelle	Structure	Function
Endoplasmic reticulum	Membrane network; rough ER has ribosomes, smooth ER does not	Site of protein synthesis and folding; lipid synthesis
Golgi apparatus	Stacks of membrane-enclosed sacs	Site where sugars are made and linked into starches or joined to lipids or proteins; proteins finish folding; secretions stored
Lysosome	Sac containing digestive enzymes	Degrades debris; recycles cell contents
Mitochondrion	Two membranes; inner membrane enzyme-studded	Releases energy from nutrients
Nucleus	Porous, double-membraned sac containing DNA	Separates DNA within cell
Peroxisome	Sac containing enzymes	Breaks down and detoxifies various molecules
Ribosome	Two associated globular subunits of RNA and protein	Scaffold and catalyst for protein synthesis
Vesicle	Membrane-bounded sac	Temporarily stores or transports substances

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Biological Membranes 1

A biological membrane has a distinctive structure.

Composed of a double layer (bilayer) of molecules called phospholipids.

- Phosphate: hydrophilic ("water loving")
- 2 fatty acid chains: hydrophobic ("water hating")

Proteins are embedded in the phospholipid bilayer.

It contains carbohydrate molecules on the external surface.

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Biological Membranes 2

Proteins aboard lipids

- Contribute to cell's identity
- Transport molecules
- Keep out toxins and pathogens

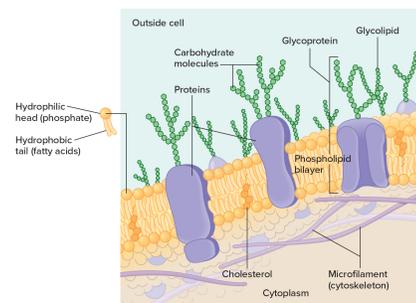
Some membrane proteins form channels for ions

"Channelopathies" are diseases that stem from faulty ion channels.

- Example: Cystic fibrosis

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Biological Membranes 3



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Plasma Membrane — Cell-to-Cell Communication

Many molecules that extend from the plasma membrane are receptors

- Bind ligands that may set into motion a cascade of chemical reactions inside the cell

Signal transduction

- Molecules form pathways that detect signals from outside the cell and transmit them inward

Cellular adhesion

- Plasma membrane helps cells attach to certain other cells

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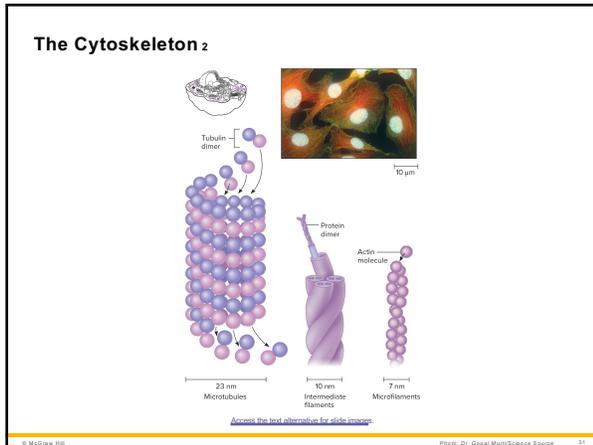
The Cytoskeleton 1

A meshwork of protein rods and tubules that serves as the cell's architecture, positioning organelles and providing overall 3D shapes.

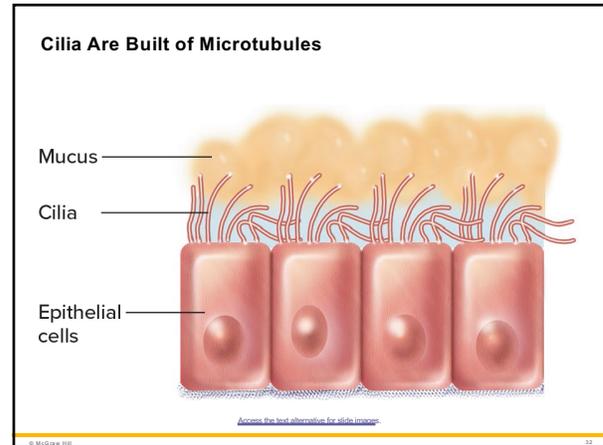
Includes three major types of elements

- Hollow **microtubules**, made of tubulin
- Solid **microfilaments**, which consist of actin
- **Intermediate filaments** are made of more than one protein type.

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Cell Division and Death

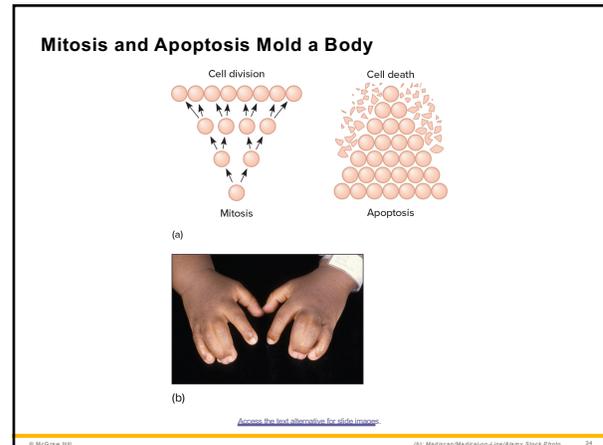
An adult human body consists of about 30 trillion cells

- New cells form as old ones die, at different rates in different tissues.

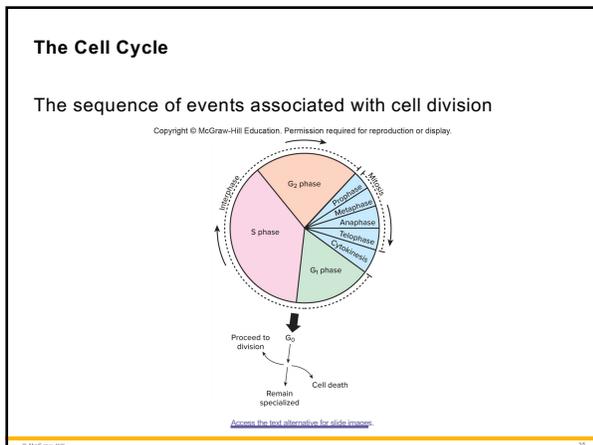
Growth, development, maintaining health, and healing from disease or injury require an intricate interplay between the rates of:

- **Mitosis** and **cytokinesis**—Division of DNA and rest of the cell
- **Apoptosis**—Cell death
- Precise, genetically programmed sequence of events

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Stages of the Cell Cycle—Interphase 1

- Prepares for cell division
- Replicates DNA and subcellular structures
- Composed of **G₁**, **S**, and **G₂** phases
- Cells may exit the cell cycle at G₁ or enter G₀, a quiet phase

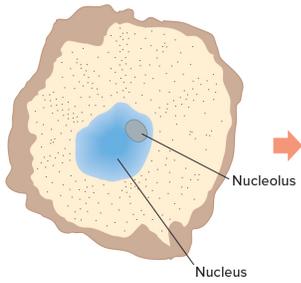
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Stages of the Cell Cycle—Interphase 2

- Chromosomes are replicated during S phase prior to mitosis
- Result in each chromosome consisting of two copies joined at the **centromere**
- Proteins forming the mitotic **spindle** are synthesized
- Microtubules form **centrioles** near the nucleus

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Interphase



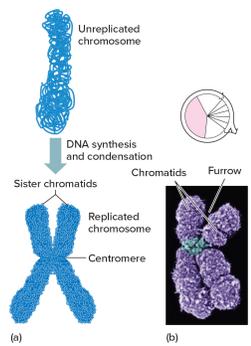
The diagram shows a cell with a large, light-colored nucleus containing a smaller, darker nucleolus. An orange arrow points to the right, indicating the progression of the cell cycle.

Interphase

- Chromosomes are uncondensed.

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Replicated and Unreplicated Chromosomes



The diagram illustrates the transition from an unreplicated chromosome (a single blue thread) to a replicated chromosome (two blue threads joined at a central point). Labels include: Unreplicated chromosome, DNA synthesis and condensation, Sister chromatids, Replicated chromosome, Centromere, Chromatids, and Furrow. Two sub-diagrams, (a) and (b), show the process of DNA replication and chromosome condensation.

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Mitosis—Prophase 1

DNA coils tightly.

- Chromosomes are thus shortened and thickened

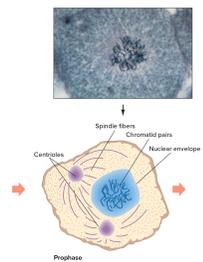
Microtubules organize into a spindle.

Nuclear membrane breaks down.

Nucleolus is no longer visible.

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Mitosis—Prophase 2



The top part is a micrograph showing a cell in prophase 2 with condensed chromosomes. The bottom part is a diagram of a cell in prophase 2, showing spindle fibers, chromatid pairs, and centrioles. Labels include: Spindle fibers, Chromatid pairs, Nuclear envelope, Centrioles, and Prophase. Photo: E.G. Raabe.

Prophase

- Condensed chromosomes take up stain. The spindle assembles, centrioles appear, and the nuclear envelope breaks down.

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Mitosis—Metaphase 1

Chromosomes attach to the spindle at their centromeres.

- Align along the cell's equator

Metaphase chromosomes are under great tension

- But they appear motionless because they are pulled with equal force on both sides.

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Mitosis—Metaphase 2

Metaphase

- Chromosome align.

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Mitosis—Anaphase 1

Plasma membrane indents at the center

Centromeres divide, which releases the tension

Chromatids separate and become independent chromosomes.

- Move to opposite ends of the cell

During this very brief phase, a cell fleetingly contains twice the normal number of chromosomes

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Mitosis—Anaphase 2

Anaphase

- Anaphase**
- Centromeres part and chromatids separate.

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Mitosis—Telophase 1

- The cell looks like a dumbbell with a set of chromosomes at each end.
- Spindle falls apart.
- Nucleoli and membranes around the nuclei re-form at each end of the elongated cell.
- Division of the genetic material is now complete.

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Mitosis—Telophase 2

Telophase

- Telophase**
- The spindle disassembles and the nuclear envelope re-forms.

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Mitosis—Cytokinesis

- Cytoplasmic division occurs after nuclear division is complete.
- Organelles and macromolecules are distributed between the two daughter cells.
- Microfilament band contracts, separating the two cells.

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Control of the Cell Cycle

Control of mitosis is a daunting task.

- Too little, and an injury goes unrepaired
- Too much, and an abnormal growth forms

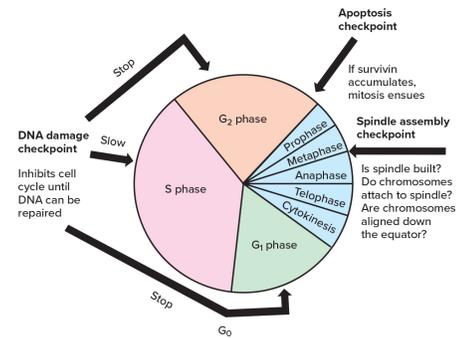
Groups of interacting proteins function at specific times in the cell cycle, called **checkpoints**

- Ensure that chromosomes are correctly replicated and apportioned into daughter cells

Internal and external factors can affect a cell's mitotic clock.

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Cell Cycle Checkpoints



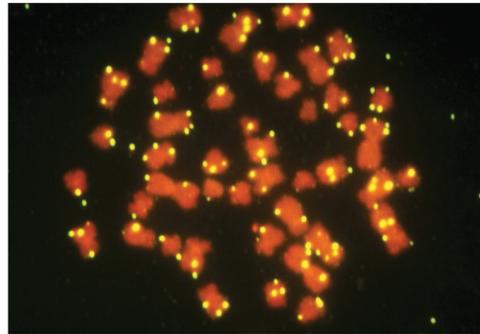
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Telomeres 1

- Located at the ends of the chromosomes
- Contain hundreds to thousands of repeats of a 6-base DNA sequence (TTAGGG)
- Lose 50 to 200 endmost bases after each cell division
- After 50 divisions, shortened telomeres signal the cell to stop dividing
- Sperm, eggs, bone marrow, and cancer cells produce **telomerase** that prevent shortening of telomeres

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Telomeres 2



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Hormones and Growth Factors

Hormone is made in a gland and transported in the bloodstream to another part of the body.

- Exerts a specific effect

A **growth factor** acts locally.

- Epidermal growth factor (EGF) stimulates cell division in the skin beneath a scab.

Two types of proteins, the **cyclins** and **kinases**, interact inside cells, activating the genes whose products carry out mitosis.

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Apoptosis

Begins when a "death receptor" on the plasma membrane receives a signal to die

Killer enzymes called caspases are activated

- Destroy enzymes that replicate and repair DNA
- Tear apart the cytoskeleton
- Abolish cell's ability to adhere to other cells
- Attract phagocytes that digest the cell remnants

Dying cell forms bulges called blebs

Membrane surrounds the pieces, preventing inflammation.

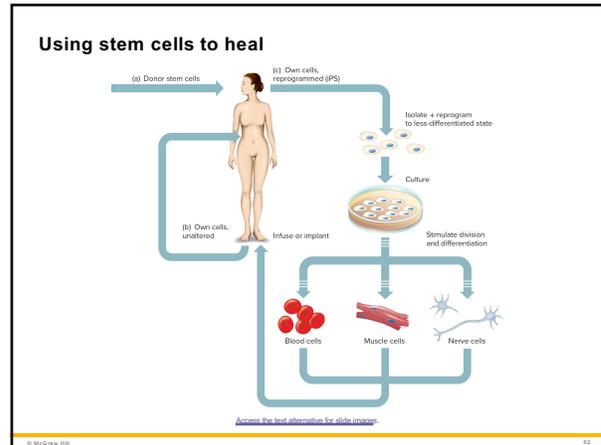
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Stem Cell Sources :

Table 2.3 Stem Cell Sources

Stem Cell Type	Source
Embryonic stem cell	Inner cell mass of very early embryo; somatic cell nuclear transfer into egg cell
Induced pluripotent stem cell	Genes or other chemicals reprogram somatic cell nucleus; no embryos required
"Adult" stem cell	Somatic cells that normally function as stem cells, from any stage of development from fertilized ovum through elderly

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Stem Cell Applications

Stem cells are being used in four basic ways:

- Discovery and development of drugs
- Observing the earliest sign of disease
- Create tissues and organs, for use in implants and transplants, or to study
- Stimulating stem cells in the body via the introduction of reprogramming proteins

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The Human Microbiome :

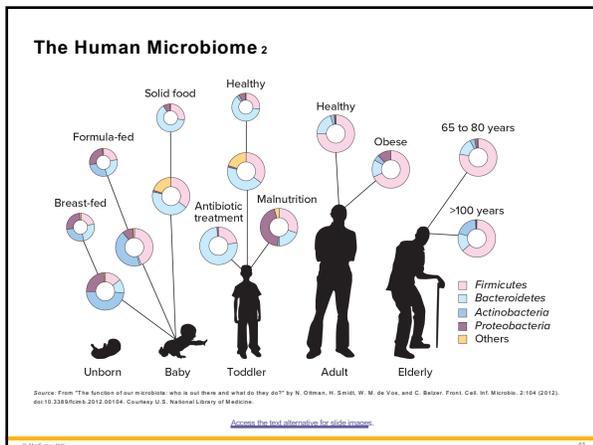
About 60 percent of the cells in a human body are microorganisms (bacteria, fungi, protozoan, as well as viruses)

- The cells within and on us that are not actually of us constitute the human **microbiome**.

Different body parts house different communities of microbes.

The microbiome changes with experience and environmental exposures

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The Human Microbiome :

Human microbiome studies have revealed that:

- Certain skin bacteria cause acne, but others keep skin clear.
- Circumcision protects against viral infections such as HIV.
- Lowered blood sugar following weight-loss surgery is partly due to a changed gut microbiome.
- An altered microbiome hastens starvation in malnourished children.
- Antibiotics temporarily alter the gut microbiome.
- Microbiome imbalances may contribute to or cause asthma, cancers, obesity, psoriasis, Crohn's disease, and gum disease.
- Babies born by Cesarean section (surgically) have different microbiomes than babies born vaginally.
- People living in isolated areas have different microbiomes than city residents.

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