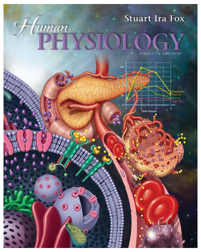
Connect Learn Succeed



Chapter 3

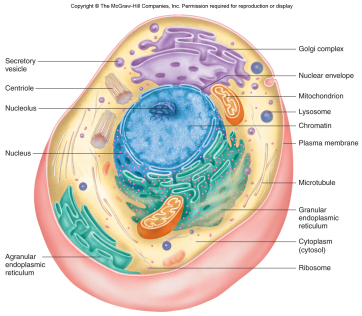
Cell Structure and Genetic Control

Lecture PowerPoint

Cells

- Cells are the basic functional units of the body.
- They come in a variety of shapes and sizes. This diversity reflects their diverse functions.
- Cells do share some common features:
  - Plasma membrane and associated proteins
  - Cytoplasm and organelles
  - Nucleus (not all cells have one)

A Typical Cell



Summary of Cell Components

Table 3.1 | Cellular Components: Structure and Function

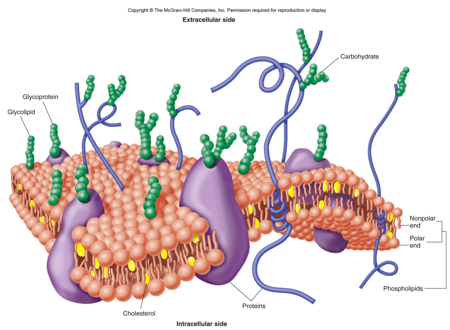
Component	Structure	Function
Plasma (cell) membrane	Membrane composed of double layer of phospholipids in which proteins are embedded	Gives form to cell and controls passage of materials into and out of cell
Cytoplasm	Fluid, jellylike substance between the cell membrane and the nucleus in which organelles are suspended	Serves as matrix substance in which chemical reactions occur
Endoplasmic reticulum	System of interconnected membrane-forming canals and tubules	Agranular (smooth) endoplasmic reticulum metabolizes nonpolar compounds and stores Ca^{2+} in striated muscle cells, granular (rough) endoplasmic reticulum assists in protein synthesis
Ribosomes	Granular particles composed of protein and RNA	Synthesize proteins
Golgi complex	Cluster of flattened membranous sacs	Synthesizes carbohydrates and packages molecules for secretion, secretes lipids and glycoproteins
Mitochondria	Membranous sacs with folded inner partitions	Release energy from food molecules and transform energy into usable ATP
Lysosomes	Membranous sacs	Digest foreign molecules and worn and damaged organelles
Peroxisomes	Spherical membranous vesicles	Contain enzymes that detoxify harmful molecules and break down hydrogen peroxide
Centrosome	Nonmembranous mass of two rodlike centrioles	Helps to organize spindle fibers and distribute chromosomes during mitosis
Vacuoles	Membranous sacs	Store and release various substances within the cytoplasm
Microfilaments and microtubules	Thin, hollow tubes	Support cytoplasm and transport materials within the cytoplasm
Cilia and flagella	Minute cytoplasmic projections that extend from the cell surface	Move particles along cell surface or move the cell
Nuclear envelope	Double-layered membrane that surrounds the nucleus, composed of protein and lipid molecules	Supports nucleus and controls passage of materials between nucleus and cytoplasm
Nucleolus	Dense nonmembranous mass composed of protein and RNA molecules	Produces ribosomal RNA for ribosomes
Chromatin	Fibrous strands composed of protein and DNA	Contains genetic code that determines which proteins (including enzymes) will be manufactured by the cell

I. Plasma Membrane and Associated Structures

Plasma Membrane

- Phospholipid barrier between the intracellular and extracellular environments
  - Hydrophobic center of the double membrane restricts the movement of water, water-soluble molecules, and ions.
  - Many substances are selectively allowed to pass through protein channels.
  - Proteins and phospholipids are not trapped in the membrane but move laterally = fluid mosaic model.

Plasma Membrane



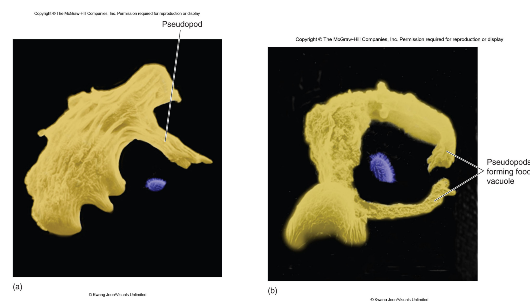
Membrane Proteins

- Integral proteins span the membrane.
- Peripheral proteins are embedded on just one side of the membrane.
- Functions:
  - Structural support
  - Transport
  - Enzymatic control of cell processes
  - Receptors for hormones and other molecules
  - "Self" markers for the immune system

Phagocytosis

- Some white blood cells can perform amoeboid movement by extending pseudopods to pull the cell forward.
- Pseudopods engulf bacteria, dead cells, or other organic materials and then fuse together to form a food vacuole.
- The food vacuole fuses with a lysosome, and the bacterium is digested.

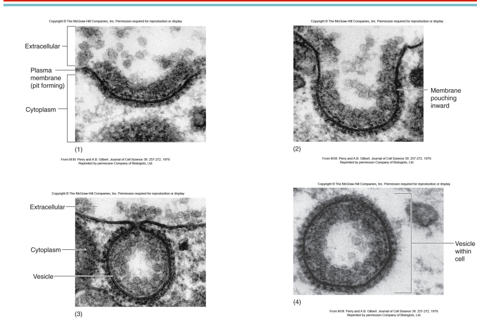
Phagocytosis



Endocytosis

- Another strategy for bringing large materials into the cell
- The plasma membrane furrows inward rather than extending outward. A small part of the membrane surrounding the substance pinches off and is brought in as a vesicle.
  - Pinocytosis: nonspecific
  - Receptor-mediated endocytosis: specific

Endocytosis



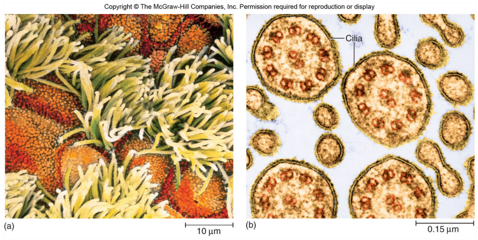
Exocytosis

- Large cellular products (proteins) are moved out of the cell.
  - The Golgi apparatus packages proteins into vesicles that fuse to the plasma membrane, and the contents spill out of the cell.

Cilia

- Tiny, hairlike structures composed of microtubules that project from the plasma membrane
  - Motile cilia beat in unison to move substances through hollow organs.
    - Found in respiratory tract and uterine tubes
  - Primary cilium may have a sensory function.
    - Found on almost every cell in the body

Cilia



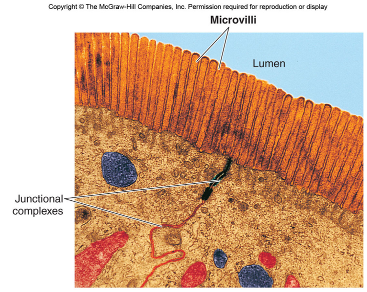
Flagellum

- A single whiplike structure that can propel a cell forward
- Composed of microtubules
- Sperm is the only cell in the human body with a flagellum.

Microvilli

- Folds in the plasma membrane that increase the surface area for rapid diffusion
  - Examples: intestines and kidney tubules

Microvilli



II. Cytoplasm and Organelles

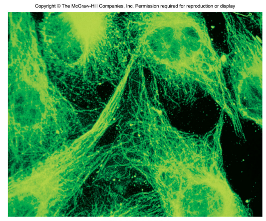
Cytoplasm

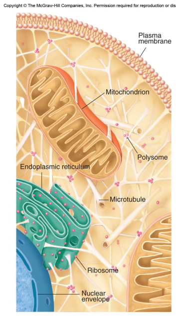
- Material within a cell
  - Includes organelles, a fluid called cytosol, and an organized system of microtubules and microfilaments called the cytoskeleton

Cytoskeletal Proteins

- Proteins of the cytoskeleton are not immobile.
- They organize the intracellular environment and allow movement of muscle cells and phagocytic cells.
- They form the spindle apparatus that pulls chromosomes apart in mitosis.
- They also serve as a "railway" system for vesicles and organelles to move along.

Cytoskeleton





Lysosomes

- Organelles filled with digestive enzymes
  - Fuse with food vacuoles after an immune cell engulfs a bacterium or dead cell
  - Primary lysosome: only contains digestive enzymes
  - Secondary lysosome: contains the partially digested contents of the food vacuole or worn-out organelles
  - Residual body: a lysosome filled with waste, which can be expelled through exocytosis

Lysosomes

- Besides digesting bacteria, lysosomes are responsible for:
  - Autophagy: process of digesting worn-out organelles and proteins in the cell
  - Apoptosis: programmed cell death. The lysosome spills its contents, killing the cell.

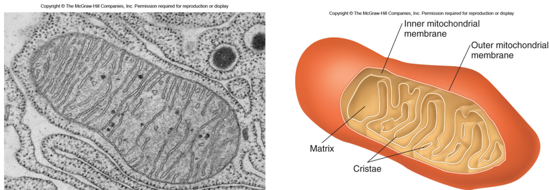
Peroxisomes

- Contain enzymes specific to certain oxidative reactions
  - Found in most cells but most numerous in the liver; often oxidize toxic molecules (such as alcohol)
  - Enzymes used to remove hydrogen from a molecule and transfer it to O_2, forming hydrogen peroxide
  - Also contain the enzyme catalase, which converts hydrogen peroxide into water and O_2

Mitochondria

- Sites of energy production
- Have an inner membrane and an outer membrane separated by an intermembranous space
- Inner membrane is folded into cristae

Mitochondria



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Courtesy Keith R. Porter Endowment

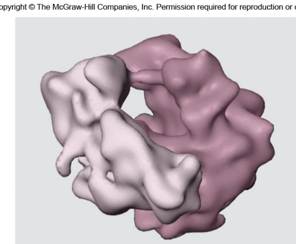
Mitochondria

- Most cells have mitochondria, and there can be thousands of mitochondria in a single cell.
- Mitochondria can migrate around the cell and can make copies of themselves.
  - Have their own DNA, all derived from mom

Ribosomes

- Protein factories of the cell
  - Messenger RNA takes genetic information to the ribosome so a protein can be assembled.
  - Very small
  - Found free in the cytoplasm or associated with the rough ER
  - Broken into 2 subunits composed of proteins and ribosomal RNA while not in use

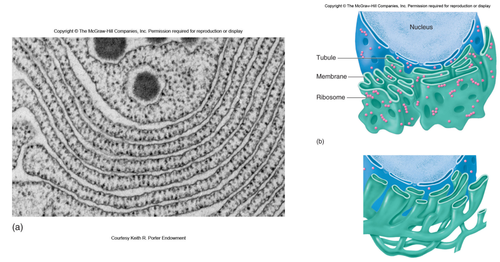
Ribosomes



Endoplasmic Reticulum

- Rough ER is also called granular ER.
  - Has ribosomes
  - Functions in protein modification
- Smooth ER is also called agranular ER.
  - Has many functions, depending on the cell

Endoplasmic Reticulum

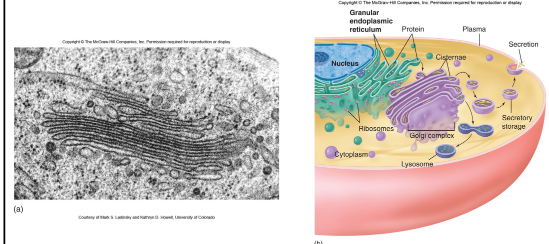


Courtesy Keith R. Porter Endowment

Golgi Complex (Apparatus)

- Consists of stacks of flattened sacs
  - One side receives proteins from the ER.
  - These are packaged in vesicles and bud off to fuse with the plasma membrane for exocytosis.

Golgi Complex (Apparatus)



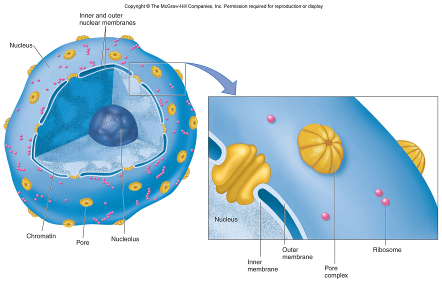
Courtesy of Mark S. Ladinsky and Kathryn D. Howell, University of Colorado

III. Cell Nucleus and Gene Expression

Cell Nucleus

- Most cells have one nucleus.
  - Muscle cells have hundreds; RBCs have none.
- The nucleus is enclosed by the nuclear envelope made of two membranes:
  - Outer membrane continuous with rough ER
  - Inner membrane often fused to outer by nuclear pore complexes, which allow small molecules and RNA to move into/out of the cell

Cell Nucleus



DNA and Genes

- The nucleus contains DNA. A *gene* is a length of DNA that codes for a specific protein.
  - The gene on the DNA is transcribed as messenger RNA, which can leave the cell.
  - The messenger RNA is then translated at the ribosome to assemble the proper amino acid sequence.
  - These two steps can be called genetic expression.

Nucleoli

- The nucleus also has one or more darker regions not surrounded by a membrane; these are called *nucleoli.*
- The nucleoli contain the DNA that codes for the production of ribosomal RNA.

Genome and Proteome

- The genome is all the genes in a particular individual or all the genes of a particular species.
  - Researchers believe humans have ~25,000 genes.
- The proteome is all the proteins that are produced from the genome.
  - More than 150,000 proteins are produced in the human body.

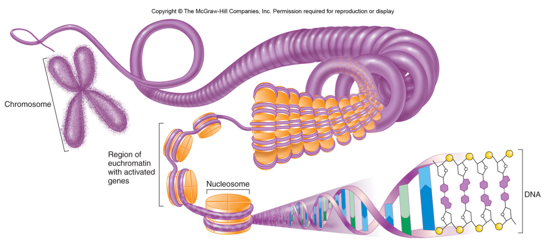
Genome and Proteome

- How can a gene code for more than one protein?
  - mRNA is altered after transcription.
  - Proteins are made of many polypeptide chains.
  - Protein modification occurs by:
    - Adding a lipid or carbohydrate
    - Adding a phosphate group
    - Cutting into small units

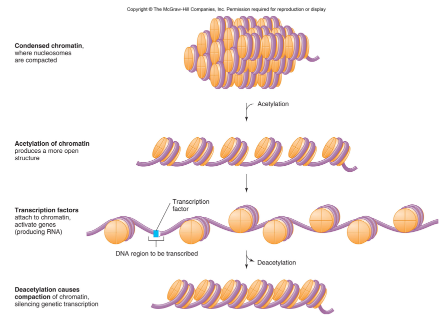
Chromatin

- DNA in the nucleus is packaged with proteins called histones to form chromatin.
  - Euchromatin: active in transcription, looser. Changes in histones allow molecules access to the DNA during gene expression.
  - Heterochromatin: inactive regions, highly condensed. Much of the DNA is inactive.

Chromatin



Chromatin and Gene Expression

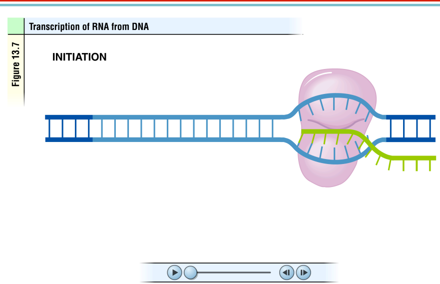


RNA Synthesis

- Also called *transcription.* Involves:
  - Start and stop regions at the beginning and end of the gene
  - Promoters, areas of DNA that are not part of the gene but tell enzymes involved where to begin
  - Transcription factors that bind to the promoter to begin transcription

RNA Synthesis

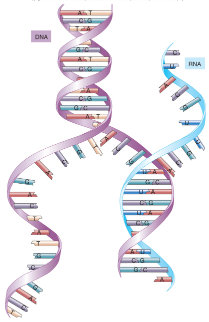
- Also called *transcription.* Involves:
  - RNA polymerase, the enzyme that "reads" the DNA and assembles the appropriate RNA nucleotide
    - Assembly is complementary. If the DNA is GCTA, the RNA will be CGAU.
    - RNA has uracil instead of thymine.
- Forms precursor messenger RNA

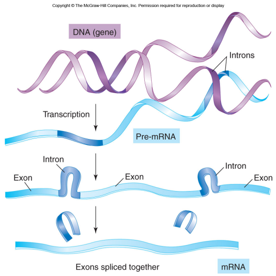


RNA Synthesis

- Precursor messenger RNA is altered in the nucleus before it leaves as messenger RNA (mRNA).
  - Portions of the gene do not actually code for anything. They are called introns and must be spliced out.
  - The portions that are kept are called exons.
  - Alternative splicing allows one precursor mRNA to be used to make multiple proteins.
  - Exons are joined together by snRNPs.

Messenger RNA Synthesis and Splicing





RNA Interference

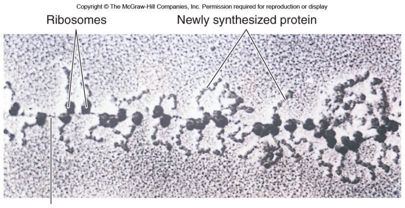
- RNA molecules that don't code for proteins may prevent some mRNA molecules from being translated.
  - Two types: siRNA and miRNA
  - The expression of at least 30% of genes is regulated in this way.

IV. Protein Synthesis and Excretion

Protein Synthesis

- Also called *translation*
- mRNA attaches to a string of ribosomes to form a polyribosome.

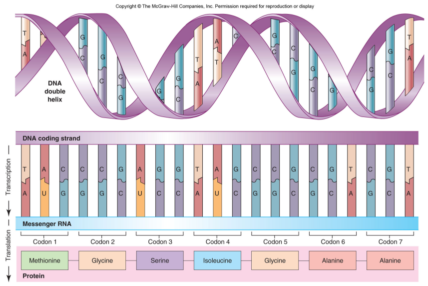
Protein Synthesis



Protein Synthesis

- The proper amino acids in a polypeptide chain are coded for by regions of 3 nucleotides on the mRNA called a codon.

Protein Synthesis



Codons

Table 3.2 | Selected DNA Base Triplets and mRNA Codons*

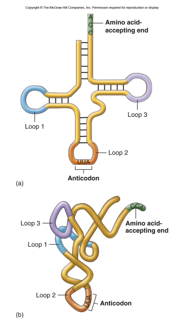
DNA Triplet	RNA Codon	Amino Acid
TAC	AUG	“Start” (Methionine)
ATC	UAG	“Stop”
AAA	UUU	Phenylalanine
AGG	UCC	Serine
ACA	UGU	Cysteine
GGG	CCC	Proline
GAA	CUU	Leucine
GCT	CGA	Arginine
TTT	AAA	Lysine
TGC	ACG	Threonine
CCG	GGC	Glycine
CTC	GAG	Glutamic acid

*In most cases there is actually more than one codon for each of the different amino acids, although only one codon per amino acid is shown in this table. Also, there are three different “stop” codons, for a total of 64 different codons.

Transfer RNA (tRNA)

- Bent into a cloverleaf shape
  - One end has the anticodon, which is three nucleotides that will be complementary to the proper codon.
  - The other end has the appropriate amino acid.

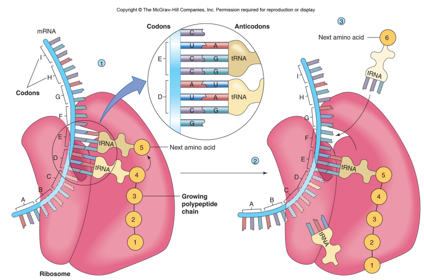
Transfer RNA (tRNA)



Formation of a Polypeptide

- The mRNA moves through the ribosome, with the proper tRNA attaching at each codon.
- Amino acids attached to the tRNAs form peptide bonds to each other and disassociate from the tRNA.
- tRNAs disassociate from the mRNA as they lose their amino acids.
- This continues until a stop codon is encountered and the whole complex disassociates.

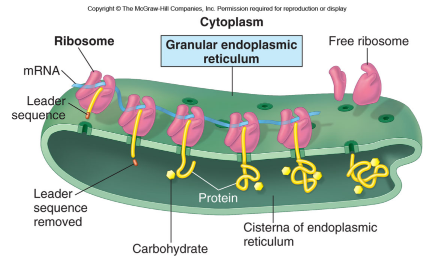
Translation



Rough ER Revisited

- Newly formed proteins destined to leave the cell enter the rough ER.
  - The first ~30 amino acids are hydrophobic and are attracted to the membrane of the rough ER.

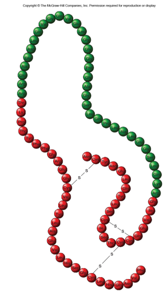
Rough ER Revisited



Rough ER Revisited

- The hydrophobic leader sequence is removed. Other portions may be removed as well.
  - In the conversion of preproinsulin to insulin, the middle region is removed and the ends bonded together.

Rough ER Revisited



Golgi Complex Revisited

- Secretory proteins are next sent to the Golgi complex.
  - Proteins may be further modified, including the production of glycoproteins.
  - Proteins are separated according to destination.
  - Proteins are packaged and shipped in vesicles to their destinations.

Protein Degradation

- Regulatory proteins are rapidly degraded, making their effects short-lived. This allows for greater control of cell functions.
  - Proteases in the lysosome digest proteins.
  - They are tagged by a molecule called ubiquitin, which marks them for degradation by a proteasome.

V. DNA Synthesis and Cell Division

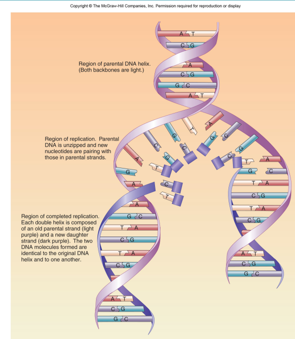
DNA Replication

- Before cell division, each DNA molecule must replicate itself so that one of each copy can be distributed to the two new cells.
- Involves many enzymes:
  - Helicases break hydrogen bonds between the DNA strands. This creates a fork in the double-stranded molecule where nucleotides can be added to both strands.

DNA Replication

- Involves many enzymes:
  - DNA polymerase attaches complementary nucleotides to the exposed strand.
    - Two new molecules are being made from the original one, each with half old and half new DNA.
    - This is called semiconservative replication.

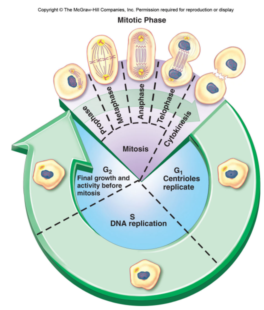
DNA Replication



The Cell Cycle

- Divided into interphase and mitosis
- Interphase is divided into:
  - G_1
  - S
  - G_2
- Mitosis is divided into:
  - Prophase
  - Metaphase
  - Anaphase
  - Telophase

The Cell Cycle



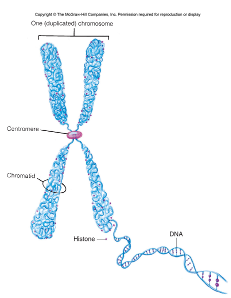
Interphase

- Nondividing cell. Some cells never divide so are always in interphase.
  - Lots of RNA synthesis occurring
  - G_1phase: The cell is performing the functions characteristic of cells in that tissue.
    - Cyclin D moves the cell through G_1.
    - Overactivity of the gene for cyclin D has been implicated in some cancers.
    - p53 is a transcription factor that can stall a gene at the G_1/S checkpoint

Interphase

- S phase: If a cell is going to divide, it performs DNA replication in the S phase.
- G_2 phase: Chromosomes start to condense.
  - Consist of two strands called sister chromatids joined by a centromere.

Interphase



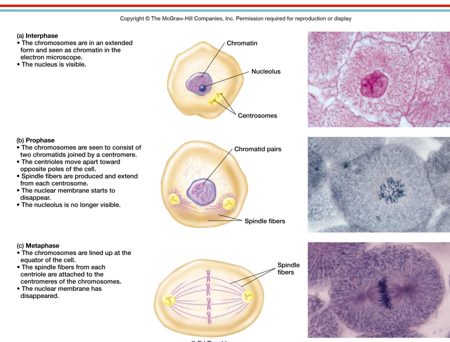
Cell Death

- Necrosis: Cell dies pathologically due to deprivation of blood supply.
- Apoptosis: Programmed cell death is performed by enzymes called caspases.
  - Extrinsic: "Death ligands" attach to the cell and mark it for destruction.
  - Intrinsic: Intercellular signals trigger death due to DNA damage, cancer, infection, or oxidative stress.

Mitosis

- Prophase: Chromosomes become visible.
- Metaphase: Chromatids line up in the center of the cell.
  - Attached to spindle fibers

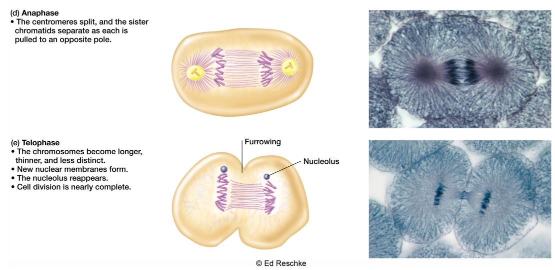
Mitosis



Mitosis

- Anaphase: Centromeres split as the spindle fibers shorten and pull chromatids to opposite sides.
- Telophase: Cytoplasm is divided and cells separate.

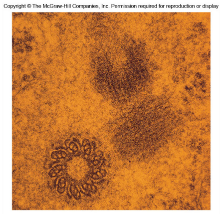
Mitosis



Centrosome

- Is a structure located near the nucleus of a nondividing cell. At the center are two centrioles. They replicate in interphase and move away from each other in prophase. Spindle fibers form.

Centrosome



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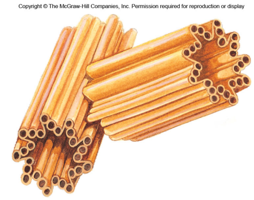

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Telomeres

- Cells can only divide for so long. Loss of the ability to divide may be due to the loss of regions at the end of the DNA called *telomeres*.
  - Each time DNA is replicated, a little more telomere is lost.
  - Cells that can divide indefinitely, such as those in bone marrow, have an enzyme called telomerase that replicates the telomere.

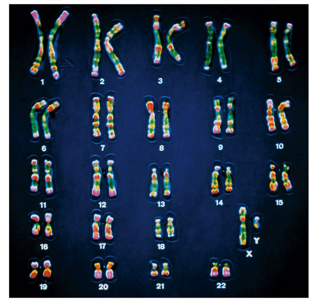
Hypertrophy and Hyperplasia

- Hyperplasia: growth due to an increase in the number of cells
  - Responsible for the growth of most body regions
- Hypertrophy: growth due to an increase in cell size
  - Responsible for increase in skeletal muscle size

Homologous Chromosomes

- Humans have 23 pairs of chromosomes, one set from each parent.
- Each pair is called homologous chromosomes, and they have the same genes on them (but not identical DNA).

Homologous Chromosomes



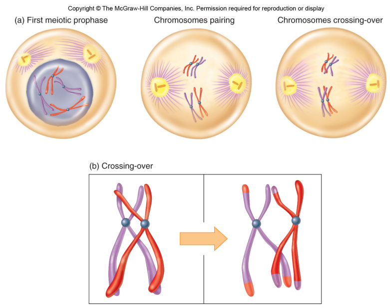
Meiosis

- Process by which two cell division steps produce gametes (ova and sperm)
  - Only occurs in the gonads (ovaries and testes)

Meiosis I

- Prophase I: Homologous chromosomes pair up.
  - Parts are often swapped in a process called *crossover*.
- Metaphase I: Homologous chromosomes line up in the center of the cell.
  - Cells line up at random; maternal and paternal chromosomes are shuffled.
- Crossover and shuffling result in genetic diversity.

Crossover



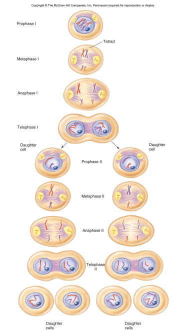
Meiosis I

- Anaphase I: Homologous chromosomes are pulled apart.
- Telophase I: Homologous chromosomes are separated. This results in two daughter cells with 23 chromosomes each.
  - This is reduction division since each cell now has half as many chromosomes.
  - Necessary for sexual reproduction

Meiosis II

- Meiosis II proceeds like mitosis with phases prophase II through telophase II.
- Sister chromatids line up in the center of the cell. Centromeres are broken and pulled to opposite poles.
- Results in 4 cells with 23 chromosomes each.

Meiosis



Meiosis

Table 3.3 | Stages of Meiosis

Stage	Events
First Meiotic Division	
Prophase I	Chromosomes appear double-stranded.
	Each strand, called a chromatid, contains duplicate DNA joined together by a structure known as a centromere.
	Homologous chromosomes pair up side by side.
Metaphase I	Homologous chromosome pairs line up at equator.
	Spindle apparatus is complete.
Anaphase I	Homologous chromosomes separate; the two members of a homologous pair move to opposite poles.
Telophase I	Cytoplasm divides to produce two haploid cells.
Second Meiotic Division	
Prophase II	Chromosomes appear, each containing two chromatids.
Metaphase II	Chromosomes line up single file along equator as spindle formation is completed.
Anaphase II	Centromeres split and chromatids move to opposite poles.
Telophase II	Cytoplasm divides to produce two haploid cells from each of the haploid cells formed at telophase I.