Chapter 4: Functional Anatomy of Procaryotic and Eucaryotic Cells

Distinguishing Features of Procaryotic Cells:
1. DNA is:
   - Not enclosed within a nuclear membrane.
   - A single circular chromosome.
   - Not associated with histone proteins.
2. Lack membrane-enclosed organelles like mitochondria, chloroplasts, Golgi, etc.
3. Cell walls usually contain peptidoglycan, a complex polysaccharide.
4. Divide by binary fission.

Distinguishing Features of Eucaryotic Cells:
1. DNA is:
   - Enclosed within a nuclear membrane.
   - Several linear chromosomes.
   - Associated with histones and other proteins.
2. Have membrane-enclosed organelles like mitochondria, chloroplasts, Golgi, endoplasmic reticulum etc.
3. Divide by mitosis.

The Procaryotic Cell: Size, Shape, and Arrangement of Bacterial Cells

Cell Size:
- Dimensions of most bacterial cells:
  - Diameter: 0.2 to 2.0 µm.
  - Human red blood cell is about 7.5-10 µm in diameter.
  - Length: 2 to 8 µm.
  - Some cyanobacteria are up to 60 µm long.

Bacterial Cell Size Compared to Eucaryotic Cells and Viruses

Bacterial Cell Shapes & Arrangements:
  - May have the following arrangements:
    - Diplococci: A pair of attached cocci. Remain attached after dividing.
    - Streptococci: Chainlike arrangement.
    - Tetrad: Groups of four. Divide in two planes.
    - Sarcinae: Groups of eight. Divide in three planes.
    - Staphylococci: Grapelike clusters. Divide in multiple planes.
Common Arrangements of Cocci

**Bacterial Cell Shapes & Arrangements:**
- **Bacillus** (plural: bacilli): Rod-shaped. Most bacilli appear as single rods but may see:
  - **Diplobacilli**: A pair of attached bacilli. Remain attached after dividing.
  - **Streptobacilli**: Chainlike arrangement.
- **Coccobacillus**: Intermediate shape between coccus and bacillus. Oval rods.

Different Types of Bacilli

**Bacterial Cell Shapes & Arrangements:**
- **Spiral Bacteria** Have one or more twists:
  - **Vibrio**: A comma shaped cell. Look like curved rods.
  - **Spirilla**: Helical, corkscrew shaped bacteria with rigid bodies.
    - Use whiplike external flagella to move.
  - **Spirochetes**: Helical bacteria with flexible bodies.
    - Use axial filaments (internal flagella) to move.

Spiral Shaped Bacteria

**Bacterial Cell Shapes & Arrangements:**
- Other less common shapes:
  - Star
  - Flat and square
  - Triangular
- **Pleomorphic bacteria**: Have several possible shapes. Found in a few groups:
  - Corynebacterium
  - Rhizobium

Most bacteria are **monomorphic**: Maintain a single shape. However environmental factors may affect cell shape.
The Procaryotic Cell Structure

I. Structures External to the Cell Wall

1. Glycocalyx: “Sugar coat”.
   - All polysaccharide containing substances found external to the cell wall, from the thickest capsules to the thinnest slime layers.
   - All bacteria have at least a thin slime layer.
   - Chemical composition varies widely with species.
   - A glycocalyx made of sugars is called an extracellular polysaccharide (EPS).
   - The glycocalyx may have several functions:
     - Attachment to host cells.
     - Source of nutrition.
     - Prevent dehydration.
     - Escape host immune system.

Procaryotic Cell Structure

I. Structures External to the Cell Wall

1. Glycocalyx: “Sugar coat”.
   - A. Capsules: Organized polysaccharide substance that is firmly attached to the cell wall.
     - Not formed by all bacteria.
     - Important in virulence.
       - Anthrax bacteria only cause anthrax if have protein capsule.
       - Only Streptococcus pneumoniae with capsule cause pneumonia.
     - Help bacteria escape the host immune system, by preventing destruction by phagocytosis.
     - When bacteria lose their capsules they become less likely to cause disease and more susceptible to destruction.

Procaryotic Cell Structure

I. Structures External to the Cell Wall

1. Glycocalyx: “Sugar coat”.
   - B. Slime Layer: Thin polysaccharide substance that is loosely attached to the cell wall.
     - Not formed by all bacteria.
     - Important for virulence.
     - Oral bacteria stick to teeth due to slime layer and with time produce dental plaque.
     - Allow bacteria to adhere to objects in their environment so they can remain near sources of nutrients or oxygen.
     - Rock surfaces
     - Plant roots
     - Help bacteria trap nutrients near cell and prevent dehydration.

Procaryotic Cell Structure

I. Structures External to the Cell Wall

2. Flagella (Sing. Flagellum):
   - About half of all known bacteria are motile, most use flagella.
   - Long, thin, helical appendages.
   - A bacterium may have one or several flagella, which can be in the following arrangements:
     - Monotrichous: Single polar flagellum at one end.
     - Amphitrichous: Two polar flagella, one at each end.
     - Lophotrichous: Two or more flagella at one or both ends.
     - Peritrichous: Many flagella over entire cell surface.

Procaryotic Cell Structure

I. Structures External to the Cell Wall

2. Flagella (Sing. Flagellum):
   - Flagella have three basic parts:
     - 1. Filament: Outermost region.
        - Contains globular protein flagellin.
        - Not covered by a sheath like eucaryotic filaments.
     - 2. Hook: Wider segment that anchors filament to basal body.
     - 3. Basal Body: Complex structure with a central rod surrounded by a set of rings.
        - Gram negative bacteria have 2 pairs of rings.
        - Gram positive bacteria only have one pair of rings.
**Procaryotic Cell Structure**

I. Structures **External** to the Cell Wall

2. Flagella (Sing. Flagellum):
   - Bacterial flagella move by **rotation** from basal body.
   - Flagellar movement may be either clockwise or counterclockwise.
   - Bacteria may be capable of several patterns of motility.
     - **Runs or swims**: Bacterium moves in one direction.
     - **Tumbles**: Bacterium changes direction. Caused by reversal of flagellar rotation.

Patterns of Bacterial Motility

1. **Taxis**: Movement of a cell toward or away from a particular stimulus.
2. **Chemotaxis**: Movement in response to a chemical stimulus.
3. **Phototaxis**: Movement in response to a light stimulus.
4. **Flagellar protein H antigens** are used to identify important pathogens.
   - **E. coli O157:H7**: Causes bloody diarrhea associated with foodborne epidemics. Causes 200-500 deaths per year.

**Procaryotic Cell Structure**

I. Structures **External** to the Cell Wall

3. Axial Filaments (Endoflagella):
   - Bundles of fibers that are anchored at ends of the cell beneath the outer sheath.
   - Spiral around the cells.
   - Have similar structure to flagella.
   - Rotation of endoflagella produces a **corkscrew** motion.
   - May enable bacteria to penetrate body tissues.
   - Found in **spirochetes**:
     - **Treponema pallidum**: Cause of syphilis.
     - **Borrelia burgdorferi**: Cause of Lyme disease.

**Axial Filaments in Spirochetes**
Procaryotic Cell Structure
I. Structures \textbf{External} to the Cell Wall
4. Fimbriae and Pili:
- Hairlike appendages that are shorter, straighter, and thinner than flagella.
- Used for \textit{attachment} rather than motility.
- Found in Gram-negative bacteria.

\textbf{A. Fimbriae} (Sing: fimbria)
- May occur at poles or over entire cell surface.
- Like glycocalyx, enable bacteria to \textit{adhere} to surfaces. Important for \textit{colonization} of host tissue.
- \textit{Neisseria gonorrhoeae} Causes gonorehea. Attach to sperm cells and mucous membranes through fimbriae.
- Bacteria can attach to broth surface via fimbriae, forming a film-like layer called \textit{pellicle}.

\textbf{B. Pili} (Sing: pilus): Conjugation or sex pili
- Only found in certain groups of bacteria.
- Longer than fimbriae.
- Cells only have one or two sex pili.
- Attach two cells together, and allow the \textit{transfer} of \textit{genetic material} (DNA) between cells.
- Medically important because allow for the transfer of antibiotic resistance genes from one cell to another.
Procaryotic Cell Structure
II. The Cell Wall
Composition:

- **Peptidoglycan (Murein):**
  - Adjacent disaccharide rows are linked together by polypeptide chains which vary in composition, but always contain tetrapeptide side chains.
  - Parallel tetrapeptide side chains may be directly linked together or linked by a polypeptide cross-bridge.
  - **Penicillin** interferes with the final linking of peptidoglycan rows by peptide cross bridges. As a result, the cell wall is greatly weakened and cell undergoes lysis.

A. Peptidoglycan Structure
B. Gram-Positive Cell Wall Structure

- **Gram-Positive Cell Walls:**
  - Consist of several layers of peptidoglycan, which form a thick, rigid structure (20-80 nm).
  - Also contain teichoic acids, which are made up of an alcohol and a phosphate group. Two types:
    - **Lipoteichoic acids**: Span cell wall, linked to cell membrane.
    - **Wall teichoic acids**: Linked to peptidoglycan layer.
  - Teichoic acids are negatively charged and:
    - Bind to and regulate movement of cations into cell.
    - Regulate cell growth and prevent cell lysis.
    - Can be used to identify bacteria.

- **Gram-Negative Cell Walls:**
  - Cell wall is thinner, more complex and more susceptible to mechanical breakage than that of Gram-positive bacteria.
  - Consist of one or a few peptidoglycan layers and an outer membrane.
  - Peptidoglycan is bonded to lipoproteins, in:
    - **Outer membrane**
    - **Periplasmic space**: Region between outer membrane and plasma membrane.
  - Periplasmic space contains degradative enzymes and transport proteins.

Gram-Negative Cell Wall Structure

**Outer Membrane (OM):**
- Consists of:
  - Phospholipid bilayer
  - Lipopolysaccharides (LPS) with two components:
    - **O polysaccharides**: Antigens, used to identify bacteria.
    - **Lipid A**: Endotoxin causes fever and shock.
  - **Porins**: Membrane proteins that allow the passage of nucleotides, disaccharides, peptides, amino acids, vitamins, and iron.
  - **Lipoproteins**

- **Functions of Outer Membrane:**
  - Evade phagocytosis and complement due to strong negative charge.
  - Barrier to antibiotics (penicillin), digestive enzymes (lysozyme), detergents, heavy metals, dyes, and bile salts.
II. The Cell Wall
Atypical Cell Walls:
1. Acid-Fast Bacteria:
   - Cell wall is thick like that of Gram-positive bacteria.
   - Contains 60% lipids and much less peptidoglycan. Has a waxy consistency.
   - Lipids make cells impermeable to many stains, and protect them from acids, alkalis, and antibiotics.
   - Organisms grow slowly because nutrients penetrate inefficiently and cells spend a lot of energy making lipids.
   - Stain as Gram-positive.

2. Mycoplasmas:
   - Smallest known bacteria that can grow and reproduce outside of host cells.
   - They have no cell wall.
   - Pass through most bacterial filters. Originally mistaken for viruses.
   - Unique plasma membrane contains lipids called sterols, which protect them from osmotic lysis.

3. Archaeabacteria
   - May lack cell walls or have cell walls without peptidoglycan.
   - Instead of peptidoglycan, may have pseudomurein.

Procaryotic Cell Structure
III. Structures Internal to the Cell Wall
1. The Plasma (Cytoplasmic) Membrane:
   - Thin structure inside of cell wall that surrounds the cytoplasm.
   - Phospholipid bilayer with proteins (Fluid mosaic model).
     - Integral membrane proteins: Penetrate membrane completely.
     - Peripheral membrane proteins: On inner or outer membrane surface.
   - Lack sterols and are less rigid than eucaryotic membranes.
     - Exception: Mycoplasmas

Functions of the Plasma (Cytoplasmic) Membrane:
1. Selective barrier that regulates the passage of materials in and out of the cell.
   - Impermeable to large proteins, ions, and most polar molecules.
   - Permeable to water, oxygen, carbon dioxide, some simple sugars, and small nonpolar substances.
2. Nutrient breakdown and energy (ATP) production: Site of cellular respiration.
3. Synthesis of cell wall components
4. Assists with DNA replication
5. Site of photosynthesis: Photosynthetic bacteria have membrane extensions called thylakoids, where photosynthesis occurs.
6. Secretes proteins
7. Contains bases of flagella
8. Responds to chemical substances in the environment
Procaryotic Cell Structure
III. Structures Internal to the Cell Wall

Destruction of the Plasma Membrane:
Several antimicrobial agents damage the integrity of the plasma membrane. They commonly cause leakage of intracellular contents and cell death:
1. Alcohols
2. Quaternary ammonium compounds
3. Antibiotics (Polymyxins)

Movement of Materials Across Membranes:
Can be either a passive or an active process.

Passive Transport Processes:
- Substances move spontaneously from an area of high concentration to one of low concentration.
- Do not require energy expenditure (ATP) by the cell.
- Include the following processes:
  - Simple diffusion
  - Facilitated Diffusion
  - Osmosis

Active versus Passive Transport

Passive Transport Processes:
1. Simple diffusion:
   - Net movement of molecules or ions from an area of high concentration to one of low concentration.
   - Equilibrium: Net movement stops when molecules are evenly distributed.
   - Used by cells to transport small molecules (oxygen, carbon dioxide) across their membranes.
   - Example: Diffusion of perfume into the air after the bottle is opened.

2. Facilitated diffusion:
   - Net movement of molecules or ions from an area of high concentration to one of low concentration.
   - Substance to be transported combines with a carrier protein in plasma membrane.
   - Extracellular enzymes may be used to break down large substances before they can be moved into the cell by facilitated diffusion.
Facilitated Diffusion Requires a Membrane Carrier Protein

Osmosis: The diffusion of water across a semipermeable membrane

Effects of Osmosis on Cells

Procaryotic Cell Structure
III. Structures Internal to the Cell Wall
Movement of Materials Across Membranes:
Passive Transport Processes:
3. Osmosis:
- Net movement of water (solvent) molecules across a semipermeable membrane from an area of high concentration to one of low concentration of water.
- Osmotic Pressure: Pressure required to prevent the movement of pure water into a solution.

Passive Transport Processes:
3. Osmosis (Continued):
- Bacterial cells can be subjected to three different types of osmotic solutions:
  1. Isotonic: Concentration of solutes (and water) are equal on both sides of a cell membrane (e.g.: 0.9% NaCl, 5% glucose).
     Result: No net movement of water into or out of the cell.
  2. Hypotonic: Solute concentration is lower outside the cell (e.g.: pure water).
     Result: Net movement of water into the cell. Most bacteria live in hypotonic environments. Cell wall protects them from lysis.
  3. Hypertonic: Solute concentration is higher outside the cell.
     Result: Net movement of water out of the cell.

Movement of Materials Across Membranes:
Active Processes:
- Substances are concentrated, i.e.: moved from an area of low concentration to one of high concentration.
- Require energy expenditure (ATP) by the cell.
- Include the following:
  1. Active transport
  2. Group translocation

1. Active Transport
- Requires carrier proteins or pumps in plasma membrane.
Active Transport Requires Energy

**Movement of Materials Across Membranes:**

**Active Transport Processes:**

2. **Group Translocation**
   - Similar to active transport, but substance transported is chemically **altered** during process.
   - **After** modification, the substance **cannot leave** the cell.
   - **Glucose** is phosphorylated during group translocation in bacterial cells.
   - **Note:** Endocytosis (phagocytosis, pinocytosis, etc.) does not occur in procaryotic cells.

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**Procaryotic Cell Structure**

**III. Structures Internal to the Cell Wall**

**Cytoplasm**
- Substance inside the cell membrane.
- Contains:
  - 80% water
  - Proteins
  - Carbohydrates
  - Lipids
  - Inorganic ions
  - Low molecular weight compounds
- **Lacks a cytoskeleton and cytoplasmic streaming.**

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**Procaryotic Cell Structure**

**III. Structures Internal to the Cell Wall**

**Ribosomes**:
- The site of **protein** synthesis (**translation**).
- Found in all eucaryotic and procaryotic cells.
- Made up of **protein** and **ribosomal RNA** (**rRNA**).
- Procaryotic ribosomes (70S) are smaller and less dense than eucaryotic ribosomes (80S).
- Procaryotic ribosomes have **two subunits**:
  - Small subunit: 30S
  - Large subunit: 50S
- Several **antibiotics** work by inhibiting protein synthesis by procaryotic ribosomes, without affecting eucaryotic ribosomes.

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**Procaryotic Cell Structure**

**III. Structures Internal to the Cell Wall**

**Inclusions**:
- Reserve deposits in the cytoplasm of cells.
- Not found in all cell types:
  1. **Metachromatic Granules**:
     - Contain inorganic **phosphate** that can be used in the synthesis of **ATP**.
     - Stain red with blue dyes.
     - Found in bacteria, algae, protozoa, and fungi.
     - Characteristic of *Corynebacterium diphtheriae*, causative agent of diphtheria. Useful for identification purposes.
Procaryotic Cell Structure
III. Structures Internal to the Cell Wall
Inclusions:
2. Polysaccharide Granules:
   - Contain glycogen and starch.
   - Stain blue or reddish brown with iodine.
3. Lipid Inclusions:
   - Contain lipids, detected with fat soluble dyes.
4. Sulfur Granules:
   - Contain sulfur and sulfur containing compounds.
   - “Sulfur bacteria” (Thiobacillus) obtain energy by oxidizing sulfur and its compounds.

Procaryotic Cell Structure
III. Structures Internal to the Cell Wall
5. Carboxysomes:
   - Contain enzyme ribulose 1,5-diphosphate carboxylase, necessary for carbon fixation during photosynthesis.
   - Found in nitrifying bacteria, cyanobacteria, and thiobacilli.
6. Gas Vacuoles:
   - Hollow cavities found in many aquatic bacteria.
   - Contain individual gas vesicles, hollow cylinders covered by protein.
   - Used to regulate buoyancy so cells can remain at appropriate water depth.

Procaryotic Cell Structure
III. Structures Internal to the Cell Wall
7. Magnetosomes:
   - Contain iron oxide (Fe$_3$O$_4$), which acts like a magnet.
   - Formed by several aquatic gram-negative bacteria.
   - Enable bacteria to respond to magnetic fields (magnetotaxis).
   - In Northern hemisphere swim towards North Pole.
   - In Southern hemisphere swim towards South Pole.
   - Also swim downwards in water, towards sediments where their food is abundant.
   - May help decompose hydrogen peroxide.
   - Used industrially to make magnetic audio tapes.

Procaryotic Cell Structure
Process of Sporulation: One cell produces one spore.
1. Newly replicated DNA is isolated by an ingrowth of the plasma membrane called a spore septum.
2. Spore septum becomes a double-layered membrane that surrounds chromosome and cytoplasm (forespore).
3. Peptidoglycan layer forms between membranes of forespore.
4. Spore coat forms: Thick layer of protein around the outer membrane. Makes endospore resistant to many harsh chemicals.
5. Maturation: Cell wall ruptures, endospore is released.

Procaryotic Cell Structure
III. Structures Internal to the Cell Wall
Endospores:
- Specialized “resting” cells formed by certain Gram-positive bacteria.
  - Genus Bacillus
  - Genus Clostridium
- Highly durable dehydrated cells with thick cell walls and additional layers.
- Can survive extreme temperatures, disinfectants, acids, bases, lack of water, toxic chemicals, and radiation.
- Endospores of some thermophilic bacteria can survive 19 hours of boiling.
- Concern in food and health industries.
Procaryotic Cell Structure

Sporulation
- May be part of normal life cycle or triggered by adverse environmental conditions.
- Endospores do not carry out metabolic reactions, unlike normal vegetative cells.
- Endospores can remain dormant for thousands of years.
- Germination: Endospore returns to its vegetative state. Usually occurs when environmental conditions become more favorable. Triggered by physical or chemical damage to the spore coat.

Vegetative Cell --------> Endospore --------> Vegetative Cell
(Metabolically active) (Not metabolically active) (Metabolically active)

Eucaryotic Cell Structure

- Include: Protist, fungi, plant, and animal cells
- Larger than procaryotic cells.
- Diameter ranges from 10 to 100 um (versus 0.2 to 2.0 um)
- Nucleus: Protects and houses DNA.
- Membrane-bound Organelles: Internal structures with specific functions.
- Compartmentalization of Function: Organelles allow special locations for different chemical reactions and functions.
  - Separate and store compounds
  - Store energy
  - Work surfaces
  - Maintain concentration gradients

Membrane-Bound Organelles of Eucaryotic Cells

- Nucleus
- Rough Endoplasmic Reticulum (RER)
- Smooth Endoplasmic Reticulum (SER)
- Golgi Apparatus
- Lysosomes
- Vacuoles
- Chloroplasts
- Mitochondria

Eucaryotic Cell Structure

The Cell Wall and Glycocalyx

- Cell wall is not found in all eucaryotic cells:
  - Protists have a flexible outer layer called a pellicle, instead of a cell wall.
  - Animal cells have a sticky glycocalyx surrounding the cell membrane. Important for attachment, strength, and cell-cell recognition.
- When present, cell wall is chemically simpler than procaryotic cell wall and lacks peptidoglycan.
- Eucaryotic cell wall composition:
  - Algae and plants: Cellulose
  - Fungi: Chitin (polysaccharide)
  - Yeasts: Glucan and mannan (polysaccharides)
Eucaryotic Cell Structure
The Cell Membrane
- Similar to prokaryotic cell membranes, but:
  - Have different membrane proteins
  - Contain carbohydrates that are important for cell-cell recognition and serve as sites for bacterial attachment.
  - Contain sterols which increase resistance to osmotic lysis.
- Movement across eucaryotic cell membranes:
  - Simple diffusion, facilitated diffusion, osmosis, and active transport.
- Endocytosis: Process in which plasma membrane encircles particles outside of cell.
  - Phagocytosis: Pseudopods engulf particle. Used by WBCs.
  - Pinocytosis: Small drops of fluid are brought into the cell.
  - Group translocation does not occur.

The Eucaryotic Cytoplasm Has Three Cytoskeleton Components

Eucaryotic Cell Structure
The Cytoplasm:
- Many enzymes are sequestered in organelles.
- Contains the cytoskeleton: A complex network of thread and tube-like structures, which provides support, shape, and movement.
  1. Microfilaments: Smallest fibers
     - Actin & myosin fibers in muscle cells
     - "Amoeboid motion" of white blood cells
  2. Intermediate Filaments: Medium sized fibers
     - Anchor organelles (nuclei) and hold cytoskeleton in place.
     - Abundant in cells with high mechanical stress.
     - Work in cell division, moving chromosomes
     - Flagella and ciliary movement.

Eucaryotic Cell Structure
Flagella and Cilia
- Projections used for locomotion or to move substances along cell surface.
- Enclosed by plasma membrane and contain cytoplasm.
- Consist of 9 pairs of microtubules in a ring, with 2 single microtubules in center of ring (9 + 2).
- Flagella: Long whip-like projections.
  - Eucaryotic flagella move in wavelike manner, unlike procaryotic flagella.
- Cilia: Short hair-like projections.
  - Human respiratory system uses cilia to remove harmful objects from bronchial tubes and trachea.

Eucaryotic Cell Structure: Organelles
The Nucleus
- Structure:
  - Envelope: Double nuclear membrane.
  - Large nuclear pores
  - DNA (genetic material) is combined with histones and exists in two forms:
    - Chromatin (Loose, threadlike DNA. Most of cell life)
    - Chromosomes (Tightly packaged DNA. Found only during cell division)
  - Nucleolus: Dense region where ribosomes are made
- Functions:
  - House and protect cell’s genetic information (DNA).
  - Ribosome synthesis
**Structure of Cell Nucleus**

- Chromatin
- Nucleolus
- Nuclear envelope
- Pore

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**Eucaryotic Cell Structure: Organelles**

**The Endoplasmic Reticulum (ER)**
- “Network within the cell”
- Extensive maze of membranes that branches throughout cytoplasm.
- ER is continuous with plasma membrane and outer nucleus membrane.
- Two types of ER:
  - Rough Endoplasmic Reticulum (RER)
  - Smooth Endoplasmic Reticulum (SER)

**Rough Endoplasmic Reticulum (RER)**
- Flat, interconnected, rough membrane sacs
- “Rough”: Outer walls are covered with ribosomes.
- Ribosomes: Protein making “machines”.
- May exist free in cytoplasm or attached to ER.
- **RER Functions:**
  - Synthesis and modification of proteins.
  - Synthesis of cell and organelle membranes.
  - Packaging, and transport of proteins that are secreted from the cell.
  - Example: Antibodies

**Smooth Endoplasmic Reticulum (SER)**
- Network of interconnected tubular smooth membranes.
- “Smooth”: No ribosomes
- **SER Functions:**
  - Lipid Synthesis: Phospholipids, fatty acids, and steroids (sex hormones).
  - Breakdown of toxic compounds (drugs, alcohol, amphetamines, sedatives, antibiotics, etc.).
  - Helps develop tolerance to drugs and alcohol.
  - Regulates sugar release from liver into the blood.
  - Calcium storage for cell and muscle contraction.

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**Eucaryotic Cell Structure: Organelles**

**Ribosomes**
- The site of protein synthesis (translation).
- Found in all eucaryotic and procaryotic cells.
- Made up of protein and ribosomal RNA (rRNA).
- May be found free in the cytoplasm or associated with the rough endoplasmic reticulum (RER).
- Eucaryotic ribosomes (80S) are larger and more dense than procaryotic ribosomes (70S).
- Eucaryotic ribosomes have two subunits:
  - Small subunit: 40S
  - Large subunit: 60S
- Mitochondria and chloroplasts have 70S ribosomes that are similar to procaryotic ribosomes.

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**Smooth and Rough Endoplasmic Reticulum**

[Diagram of Endoplasmic Reticulum]
**Eucaryotic Cell Structure: Organelles**

**Golgi Apparatus**
- Stacks of flattened membrane sacs that may be distended in certain regions. Sacs are not interconnected.
- First described in 1898 by Camillo Golgi (Italy).
- Works closely with the ER to secrete proteins.
- **Golgi Functions:**
  - *Receiving side* receives proteins in transport vesicles from ER.
  - *Modifies* proteins into final shape, sorts, and labels them for proper transport.
  - *Shipping side* packages and sends proteins to cell membrane for export or to other parts of the cell.
  - Packages digestive enzymes in lysosomes.

**Eucaryotic Cell Structure: Organelles**

**Lysosomes**
- Small vesicles released from Golgi containing at least 40 different digestive enzymes, which can break down carbohydrates, proteins, lipids, and nucleic acids.
- Optimal pH for lysosomal enzymes is about 5.
- Found mainly in animal cells.
- **Lysosome Functions:**
  - Molecular garbage dump and recycler of macromolecules (e.g.: proteins).
  - Destruction of foreign material, bacteria, viruses, and old or damaged cell components. Important in immunity.
  - Digestion of food particles taken in by cell.
  - After cell dies, lysosomal membrane breaks down, causing rapid self-destruction.

**Eucaryotic Cell Structure: Organelles**

**Vacuoles**
- Membrane bound sac.
- Different types, sizes, shapes, and functions:
  - **Central vacuole**: In plant cells. Store starch, water, pigments, poisons, and wastes. May occupy up to 90% of plant cell volume.
  - **Contractile vacuole**: Regulate water balance, by removing excess water from cell. Found in many aquatic protists.
  - **Food or Digestion Vacuole**: Engulf nutrients in many protozoa (protists). Fuse with lysosomes to digest food particles.
Central Vacuole in a Plant Cell

Eucaryotic Cell Structure: Organelles

Chloroplasts
- Site of photosynthesis in plants and algae.
  \[ \text{CO}_2 + \text{H}_2\text{O} + \text{Sun Light} \rightarrow \text{Sugar} + \text{O}_2 \]
- Number in cell may range from 1 to over 100.
- Disc shaped, with three membrane systems:
  - **Outer membrane:** Covers chloroplast surface.
  - **Inner membrane:** Contains enzymes needed to make glucose during photosynthesis. Enclloses stroma (liquid) and thylakoid membranes.
  - **Thylakoid membranes:** Contain chlorophyll, green pigment that traps solar energy. Organized in stacks called grana.

Eucaryotic Cell Structure: Mitochondria (Sing. Mitochondrion)
- Site of cellular respiration:
  \[ \text{Food (sugar)} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{ATP} \]
- Change chemical energy of molecules into the useable energy of the ATP molecule.
- Oval or sausage shaped.
- Contain their own DNA, 70S ribosomes, and make some proteins. Can divide to form daughter mitochondria.
- **Structure:**
  - Inner/outer membrane
  - Intermembrane space
  - Cristae (inner membrane extensions)
  - Matrix (inner liquid)
**Evolution of Eucaryotes**
**Endosymbiotic Theory**
- **Ancestors of eucaryotic cells** were large procaryotic cells with smaller procaryotic cells living inside of them.
- **Chloroplasts** and **mitochondria** originated from independent cells that entered and stayed inside a larger cell.
- Both organelles contain their own DNA.
- Have 70S ribosomes and make their own proteins.
- Replicate independently from the cell, by binary fission.
- **Symbiotic relationship**
  - Larger cell obtains energy or nutrients.
  - Smaller cell is protected by larger cell.

**Eucaryotic Cell Structure: Organelles**
**Centrioles**
- Found in animal cells, not plant cells.
- Pair of cylindrical structures located near the nucleus.
- Made up of microtubules (9 + 2 pattern).
- **Important functions:**
  - Movement of chromosomes during cell division.
  - Formation of cilia and flagella (as basal bodies).

**Important Differences Between Plant and Animal Cells**

<table>
<thead>
<tr>
<th>Plant cells</th>
<th>Animal cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell wall</td>
<td>No cell wall</td>
</tr>
<tr>
<td>Chloroplasts</td>
<td>No chloroplasts</td>
</tr>
<tr>
<td>Large central vacuole</td>
<td>No central vacuole</td>
</tr>
<tr>
<td>Flagella rare</td>
<td>Flagella more usual</td>
</tr>
<tr>
<td>No Centrioles</td>
<td>Centrioles present</td>
</tr>
<tr>
<td>No Lysosome</td>
<td>Lysosomes present</td>
</tr>
</tbody>
</table>

**Important Differences Between Eucaryotic and Procaryotic Cells**

<table>
<thead>
<tr>
<th></th>
<th>Procaryotes</th>
<th>Eucaryotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell size</td>
<td>0.2-2 um in diameter</td>
<td>10-100 um in diameter</td>
</tr>
<tr>
<td>Nucleus</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Membranous Organelles</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Cell Wall</td>
<td>Chemically complex</td>
<td>When present, simple</td>
</tr>
<tr>
<td>Ribosomes</td>
<td>Smaller (70S)</td>
<td>Larger (80S) in cell</td>
</tr>
<tr>
<td>DNA</td>
<td>Single circular chromosome</td>
<td>Multiple linear chromosomes (histones)</td>
</tr>
<tr>
<td>Cell Division</td>
<td>Binary fission</td>
<td>Mitosis</td>
</tr>
<tr>
<td>Cytoskeleton</td>
<td>Absent</td>
<td>Present</td>
</tr>
</tbody>
</table>