Chapter 4: The Organization of Cells

I The Cell: The Basic Unit of Life

- Which came first, the chicken or the egg?
  - It takes the instructions found in DNA to make protein, and it takes protein to make DNA.
  - It takes a series of protein-enzyme catalyzed reactions to make lipid but without lipid membrane, the compartmentalization necessary for the synthesis of the lipid would not exist. Moreover, without an existing membrane, new lipid and membrane-associated protein can not organize itself as it is found in living cells.
- The cell theory states that all organisms are composed of cells; and all cells come from preexisting cells.

A. Cell size is limited by the surface area-to-volume ratio

What limits the size of a cell?

- Diffusion is the random movement of molecules.
- Molecules like oxygen diffuse through a solution and then through the membrane of a cell.
- Diffusion is effective only over very small distances, just a few micrometers.
- Cells must diffuse substances in and out. They must be small or otherwise have a high surface to volume ratio to do this.

Surface-to-Volume

- The surface of an object is the area that interfaces with what is not the object.
- Both shape and volume influence the amount of surface area.
  - Two halves of an orange together has no less volume than the whole orange. The volume is unchanged, but two new surfaces have been exposed. The surface area has increased.
  - The change in the surface area from the uncut to the cut orange can be determined. It is the area of the newly exposed surfaces. It is a *positive* change or *increase* in surface area.
  - The volume of the orange can be determined. Volume is a measure of displacement. One way would be to drop the orange into a container filled with water. (Make sure the orange submerges.) The volume of the water that spills out is the volume of the orange.
- Surface to volume ratio is the surface area divided by the volume.
  - The *change* in surface to volume ratio for the cutting of the orange could be easily calculated: ((the original surface area + the surface area of the two newly exposed surfaces) / volume) - (original surface area / volume).
- Shape strongly influences surface-to-volume ratios.
  - A sphere has the least surface-to-volume ratio of any *shape*. When comparing spheres of different sizes, the smallest sphere will have the greatest surface-to-volume ratio.
  - Imagine you have a lump of clay. Fashioned into a sphere, the surface area is the least.
  - Flatten the ball of clay to make a pancake shape, and the surface area increases, while the volume remains the same.
    - If an infinitely thin pancake could be made of the clay, its volume would stay the same but its surface area would be infinite.
    - Cells like red blood cells flatten into pancake-shape to increase surface area.
  - Fashioned into a thin string shape, the surface area and surface-to-volume ratio increases. Nerve cells have this shape, which allows some to be a meter long or more.
  - If the clay is spherical but the surface is irregular with many fine projections coming off the surface, surface area is greatly increased. Some cells make such projections, which are called microvilli.

- See *Figure 4.2* for an example of how size affects the surface-to-volume ratio.
- Whereas cells use different means to increase surface area, they are usually small and the smaller the object the greater the surface-to-volume ratio. Cells tend to be small both in size and volume.

B. Microscopes are needed to visualize cells

The small size of cells makes the use of microscopes necessary. (Review *Figure 4.1* for the relative sizes of biological objects ranging from atoms to trees.)

- The normal human vision can resolve about 200 μm (0.2 millimeters). To resolve means to distinguish as two separate things. If two objects are closer than this, they start to look like one object, not two.
- Light microscopes also have resolution limits. The physical distances of the actual object where no distinctions could be made between two points using a light microscope depends on the wavelength of the illuminating light, but would typically be 0.2 μm (0.2×10^{-6} meter). This is about 1000 times better than an unaided human eye.
- Electron microscopes use magnets to focus an electron beam.
    - The wavelength of the electron beam is far less than light and the resulting image resolution is far greater.
    - The image is not visible without the use of either film or a fluorescent screen.
    - Resolution is about 0.5 nm (0.5×10^{-9} of a meter).
    - Subcellular features can be seen but the cells must be killed and fixed with special fixatives and stains.
- See *Figure 4.3* for examples of microscopy images.
- Cells are also studied using many other technologies: molecular separation techniques, cell culture, fluorescence, radioisotope labeling and more.

C. All cells are surrounded by a plasma membrane

The plasma membrane is a continuous membrane that surrounds the fluids and other structures of a cell.

- Every cell has a plasma membrane.
- The membrane is composed of a lipid bilayer with proteins floating within and upon it.
    - Some proteins associate with the membrane.
    - Some transverse the membrane with one part exposed on the cytoplasmic side, and the other on the outer face of the cell.
- The plasma membrane acts as a selectively permeable barrier. Some substances can diffuse in and out; others are restricted.
- The plasma membrane is an interface for cells where information is received from adjacent cells and certain extracellular signals.
- The membranes allow the cell to maintain separate and distinct chemical and structural environments.

D. Cells show two organizational patterns

Living organisms can be classified into one of two major categories based on where, within the cell, the major amount of genetic material is stored. *(See Figure 4.4)*

- Organisms called eukaryotes have a nucleus.
- Organisms called prokaryotes have no nucleus.
- Eukaryotic cells usually have other organelles as well.

- Prokaryotes lack distinct organelles, although some do have invaginous membrane structures.

II Prokaryotes

Prokaryotes inhabit the widest range of environmental extremes.

- They can be found living at temperatures above boiling at thermal vents deep in the ocean.
- Prokaryotes live in extremely salty environments, and at temperatures barely above freezing.
- Some have been found deep in the earth's crust, away from the sun, photosynthesizing organisms, and oxygen. These prokaryotes use inorganic (reduced) chemicals for an energy source.

A. All prokaryotic cells share certain features

- All have a plasma membrane.
- They have a region called the nucleoid where the DNA is concentrated.
- The cytoplasm, the plasma enclosed region of prokaryotes, consists of the nucleoid; ribosomes, which are the molecular protein synthesis machines, and a liquid phase called the cytosol.

B. Some prokaryotic cells have specialized components.

- Some have a cell wall just outside the plasma membrane.
  - The cell wall functions to prevent plasma membrane lysis (bursting) when cells are exposed to solutions with lower than the osmolarity of the cell. It also protects the membrane.
  - In bacteria (prokaryotes' common name) except archaea, the wall is made of a polymer of an amino sugar called peptidoglycan, which is covalently cross-linked to form one giant molecule.
- Some bacteria have another outer membrane outside the cell wall, a polysaccharide-rich, phospholipid membrane. This membrane has proteins imbedded that make it more permeable than the interior-most membrane.
- Some bacteria have even another coat. In addition to a plasma membrane, then a cell wall, then an outer membrane, the last, outermost coat is a polysaccharide, slimy capsule.
  - For some bacteria, this capsule provides a means to escape the immune system detection.
  - The capsule sometimes prevents the drying out of the cell. For some, it helps trap other cells for food.
  - If the cell loses the capsule, it survives. Therefore, it is not essential to the immediate survival of the bacteria.
- Some bacteria can photosynthesize, which is being able to collect solar energy.

    - Cyanobacterium has folded plasma membrane in the cytoplasmic compartment. *(See Figure 4.5)*
        - Photosynthesis requires the use of membrane. In eukaryotes, separate organelles have specialized membranes for this process.
        - The bacteria chlorophyll molecules are imbedded in internal folded extensions of the plasma membrane.
- Some bacteria have mesosomes, which are involved in certain energy releasing reactions.
    - Eukaryotes have mitochondria, separate organelles, for this purpose.
    - Like the photosynthetic membrane system, they are formed from plasma membrane folding.
- Some bacteria have flagella, a propeller-like structure that is shaped like a corkscrew. These structures spin and propel these bacteria. They bear no structural commonality to the flagella found in eukaryotic cells like sperm cells. *(See Figure 4.6)*
- Some bacteria have pili. This is a threadlike structure that helps bacteria during mating.

III Eukaryotic Cells

Animals, plants, fungi and protists have a nucleus in each of their cells and are classified as eukaryotes.

- Eukaryotic cells tend to be larger than prokaryotic cells.
- Eukaryotic cells have a variety of different membrane bound compartments called organelles.
- Eukaryotes have a cytoskeleton. This is protein scaffolding that provides structure to cells, as well as other functions.
- Study *Figure 4.7* and refer back to it when the different structures and organelles are covered.

A. Compartmentalization is the key to eukaryotic cell function

- The nucleus contains most of the cell's genetic material (DNA).
- The mitochondrion is a power plant and industrial park.
- The endoplasmic reticulum and Golgi apparatus make up a compartment where proteins are packaged and sent to appropriate locations in the cell.
- The lysosome and vacuole are cellular digestive systems, where large molecules are hydrolyzed into usable monomers.
- The chloroplast performs photosynthesis.

IV Organelles that Process Information

- Information is stored in DNA, most which is found in the nucleus.

- Information is translated from the language of DNA into the language of proteins at the ribosomes.

A. The nucleus stores most of the cell's DNA

The nucleus is where most of the cell's DNA is stored.

- It is the site of DNA synthesis.
- The nucleus also has a role in DNA regulation.
- Within the nucleus is a specialized, non-membrane bound region called the nucleolus where ribosomes, the molecular protein synthesis machinery, are assembled.
- Two lipid bilayers form the nuclear envelope.
- The nuclear envelope is perforated with nuclear pores. *(See Figure 4.8)*
    - Each is about 9nm in diameter. These connect the interior of the nucleus with the rest of the cytoplasm.
    - Outer and inner membranes are continuous at these pores. *(See Figure 4.8)*.
    - A protein complex consisting of eight very large protein granules arranged in an octagon surrounds the pore.
    - RNA and proteins must pass through these pores to enter or leave the nucleus.
    - The DNA of the nucleus is the information molecule that provides the instructions needed for cellular and organismal life.
        - It is the RNA, which is generated by using DNA as a template, which actually determines the construction of proteins.
        - The nucleus is where the RNA is made, but all proteins are made outside the nucleus. Therefore, the nucleus isolates these two processes.
- At certain sites the nuclear envelope is continuous with another organelle, the endoplasmic reticulum.
- Molecules that are small can enter and leave the nucleus by simple diffusion, but large molecules' traffic is regulated.

The Chromatin:

- The DNA is organized into very long thin fibers called chromatin.
- In humans, there are 46 separate strands of chromatin in each nucleus.
- Prior to cell division these condense into structures recognized as chromosomes.
- Surrounding the chromatin is the nucleoplasm.
- A network of proteins, the nuclear matrix organizes the chromatin.
- The nuclear lamina is a meshwork of proteins generated by (reversible) *(See Figure 4.10)* polymerization that maintains the shape of the nuclear envelope and the nucleus.

- When the cell is about to divide, the nuclear envelope fragments into pieces of membrane with pore complexes because the nuclear lamina depolymerizes.
- A nucleus reforms in each of the daughter cells.
- See *Figure 4.9* for images of chromotin and a chromosome.

B. Ribosomes are the site of protein synthesis.

- Ribosomes are tiny compared to organelles but huge as proteins go.
- In eukaryotes functional ribosomes are found free in the cytoplasm, in chloroplast, in mitochondria and bound to the endoplasmic reticulum.
- Ribosomes are the sites of protein synthesis.
- They consist of a certain type of RNA, called ribosomal RNA, and more than 50 other proteins.

V The Endomembrane System

- The membrane of eukaryotic cells is synthesized by the endoplasmic reticulum (ER).
- There is a direct flow of this membrane to the nuclear envelope, and via small vesicles, to the Golgi, lysosomes and plasma membrane.
- These structures are all called the endomembrane system.
- *Figure 4.11* is a print of an electonmicrograph of the ER and a cartoon of that micrograph.

A. ER is a complex factory.

- The ER is a network of interconnecting membranes distributed throughout the cytoplasm.
- The internal compartment, called the lumen, is a separate compartment of the cell with a distinct protein and ion composition.
- The ER is where most of the membrane of the cell is found.
- Approximately 15% of the entire fluid volume of the cell is inside the ER.
- The ER's folding generates a surface area much greater than that of the plasma membrane.
- At certain sites, the ER membrane is continuous with the outer nuclear envelope membrane.
- The rough ER (RER) has ribosomes attached, which are actively synthesizing proteins that are destined for the ER interior or incorporation into the membrane of the ER.
    - Some of these membrane and lumen proteins will stay with the ER, some will be transported to other points of the endomembrane system, and others will escape the ER only to be returned.
    - Some of the proteins that enter the lumen or face the lumen interior get folded, shaped by disulfide bridges, and/or get carbohydrate groups added.

- Some of the proteins that enter the ER have address information that instructs their final destination. By default, those with no address information are transported out of the cell.

- There is a ribosome-free region of the ER called the smooth endoplasmic reticulum (SER).
    - The SER of liver cells is the site of cholesterol synthesis.
    - SER of the liver is also the site for drug detoxification including alcohol.
    - This is the site for glycogen and steroid synthesis.
- Cells that are specialized for producing proteins for extracellular export have extensive ER membrane systems. Examples are the cells of glands.

B. The Golgi apparatus stores, modifies, and packages proteins

- The Golgi apparatus is difficult to see using standard light microscopy.
- The Golgi receives its lipid membrane from vesicles that bud off the ER. Proteins are imbedded in these vesicles and carried within them.

The organization of the golgi differs in different organisms.

- In organisms other than vertebrates, compartments are separate and scattered.
- In vertebrates, the Golgi is stacked like pancakes.
    - The compartment closest to the nucleus is called the cis face.
    - The middle compartment is the medial region.
    - The face that faces the plasma membrane is the trans face.
- These three parts are the sites of different functions and have different associated enzymes.
    - Vesicles from the ER fuse to the cis face. Vesicles from the cis compartment move to the next compartment, the median region and then to the trans compartment.
    - Modifications and sorting occur during this process. Chemical signals inform the system about the appropriate destinations for the products.
    - Some vesicles fuse with the cytoplasmic face of the plasma membrane. (This is where the plasma membrane originates.) The contents of the vesicles are released to the outside of the cell.
- This whole process of shipping in and on vesicles is called vesicular trafficking.
- See *Figure 4.12*, an electronmicrograph and a schematic of the relationship of the ER, golgi and the plasma membrane.

C. Lysosomes contain digestive enzymes

- Lysosomes are organelles that come indirectly from the Golgi.
    - They contain digestive enzymes, and are the sites of hydrolysis of macromolecules such as nucleic acids, proteins, lipids and polysaccharides.
    - Their size is approximately 1 μm.
    - They have a single lipid bilayer

- Cells take up large molecules; some take up whole cells in a process called endocytosis. *(See Figure 4.13)*
  - Three different types of endocytosis occur.
    - One is phagocytosis. The cell envelops another cell with its own membrane as it invaginates around it. Not all cells can do this, but is very common for protist.
    - Another is pinocytosis. These vesicles are much smaller.
    - The last is receptor-mediated endocytosis. The vesicles are small, like in pinocytosis, but cell surface receptors are involved.
  - When a phagosized particle enters the cell, the membrane encasing it pinches off. This vesicle is a phagosome.
  - The phagosome fuses with an organelle called a primary lysosome. Consequently, this is now a secondary lysosome and is where digestion occurs.
- The enzymes of the lysosome digest the molecules by hydrolyzing them.
- The undigested material is expelled from the cell when the "used" secondary lysosome fuses with the plasma membrane.
- Lysosomes are also the sites where digestion of spent cellular components occurs, a process called autophagy.

VI Organelles that Process Energy

This section discusses briefly mitochondria and chloroplast. Later chapters cover these in detail.

A. Mitochondria are energy transformers

- Mitochondria are small organelles (0.1-0.5 μm X 1-2 μm). *(See Figure 4.14)*
  - Mitochondria have an outer lipid bilayer and a highly folded inner membrane.
  - There is space between the outer and inner membrane and it is called the inner membrane space.
  - Within the inner membrane is the mitochondrial matrix.
  - A mitochondria has its own DNA molecule located within the matrix.
  - The inner membrane has imbedded proteins, which are important to the functioning of the organelle.
  - Mitochondria use simple energy molecules and oxygen to generate ATP from ADP. Most of the oxygen used by eukaryotic organisms is used directly by mitochondria.

B. Plastids photosynthesize or store material

- Chloroplasts are organelles of eukaryotic plants.
  - Chloroplasts are one of the types of plastids.
  - They are typically 0.5 - 2 um thick and the length vary. *(See Figure 4.15)*

- Chloroplasts are the sites where photosynthesis in plants occurs.
- Chloroplasts have special pigments imbedded in the membranes of the thylakoid vesicles. *(See Figure 4.16)*
- The chloroplast has an outer lipid bilayer; next is an inner membrane. As with mitochondria, the space between these is the inner membrane space. Next is the stroma, which is the fluid filled area of the inner membrane. In addition, inside the stroma are the membrane bound thylakoid vesicles. This is where chlorophyll and other pigments for photosynthesis are imbedded.
- Chloroplasts have their own DNA molecule in the stroma.
- Other plastids found in plants include chromoplasts, such as those that cause the red color of tomatoes. Leucoplasts are plastids specialized for storage of starch and fats.

C. Mitochondria and chloroplasts may have an endosymbiotic origin

Organelles with their own DNA?

Where did chloroplast and mitochondria come from?

- One proposal is the endosymbiosis theory.
  - The idea is that both were prokaryotic organisms that got incorporated into a larger cell.
  - This was such an advantage that it succeeded and the system evolved.
- Chloroplast and mitochondrial DNA, ribosomes and gene regulation, do seem to resemble that of prokaryotes.
- See *Figure 4.18* for a simple visual explanation of the endosymbiosis theory.

VII Other Organelles

A. Peroxisomes house specialized chemical reactions

- Peroxisomes, also called microbodies, are small organelles (0.2 to 1.0 μm in diameter). These are organelles specialized to compartmentalize toxic peroxides and break them down. *(See Figure 4.19)*
- Glyxysomes are structurally similar organelles, which are found in plants.

B. Vacuoles are filled with water and soluble substances

- Vacuoles are found in plants and protists. They are filled with an aqueous solution. Plants store wastes in these and use them to create turgor, which can be thought of as the opposite of wilting. *(See Figure 4.20)*
  - Water enters these and pressure builds up as they press against the cell membrane and wall.
  - Some of the bright rich colors of flowers are from pigments sequestered in the vacuole.

- Food vacuoles are formed in single-celled protists. They are like the phagosome mentioned previously.
- Freshwater protists have a contractile vacuole, which help eliminate water that rushes in through the membrane.

VIII The Cytoskeleton

- The cytoskeleton maintains cell shape and support, provides the mechanisms for cell and organismally controlled movement, and act as tracks for motor proteins that move materials in cells.
- There are three major types of cytoskeletal components. They are the microfilaments, microtubules and intermediate filaments. *(See Figure 4.21)*

A. Microfilaments function in support and movement

- Microfilaments are 7nm in diameter and several microns long.
- Each single strand of actin polymer interacts with another to create a helix dimer called the microfilament.
- Microfilaments are needed for cell contraction, such as in muscle cells.
- Microfilaments add structure to the plasma membrane and shape to cells. *(See Figure 4.23b)*
- They are involved in the movement of specific organelles and proteins; a process called cytoplasmic streaming.
- Microfilaments are involved in the formation of pseudopodia; the overt appearance is amebic motion.
- Microvilli are very fine plasma membrane covered projections that some cells have to increase surface area. Their core is protein cross-linked actin bundles. *(See Figure 4.23a)*

B. Intermediate Filaments are tough supporting elements

- They are 8 to 12 nm in diameter.
- These fibrous proteins can associate with each other.
- They can also interact with other cellular components, particularly those of cell adhesion molecules.
- They are important to the tensile strength of cells, especially for tissues that must stretch.
- Intermediate filaments are found at focal points around the cortex of the cell and especially at the basal side of cells that connect to the extracellular matrix.
- See *Figure 4.21*

C. Microtubules are long and hollow

- Microtubules are hollow cylinders 25nm thick. Microtubules can be micrometers in length.

- Two roles are to provide a rigid intracellular skeleton and as tracks that motor proteins can move along in the cell.
- They are made of tubulin protein subunits.
- Tubulin is a dimer made of α - and β - tubulin.

- Thirteen rows of tubulin dimers surround and define the central cavity.
  - There is a + end and a - end to the microtubules.
  - Tubulin dimers can be added or subtracted at either end, but the + end is more dynamic.

D. Microtubules power cilia and flagella

- Microtubules are structurally essential parts of cilia and flagella.
- Cilia and flagella are plasmic membrane covered projections that move cells.
- Flagella are usually longer than cilia and exist one or two per cell.
- Cilia are usually present in great numbers. *(See Figure 4.24)*
- Both are membrane bound.
- The microtubules in cilia and flagellum are arranged in a 9+2 array
  - The nine are fused pairs of microtubules arranged to form an outer cylinder.
  - A pair (the 2 mentioned of the 9+2) are singles in the center of the cylinder.
  - At the base of each flagellum or cilium is a basal body. The nine pairs extend into the basal body.
  - In the basal body, each of the nine pairs has an additional microtubule associated with it, 3 instead of just the 2.
- The microtubules are cross-linked by protein in the cilia and flagellum.
  - Dynein is a motor protein that uses ATP to move along a microtubule pair. Many dynein molecules associate along the length of the microtubule pair.
  - Both the plasma membrane and other protein components limit the amount the dynein can move along the microtubule and so dynein causes the cilium to bend instead. *(See Figure 4.26)*
- Kinesin is another motor protein that moves along microtubules. Kinesin associates with vesicles and motors them in the + direction along microtubule tracks.
- Dynein moves vesicles also but in the – direction.
- Centrioles are like basal bodies but are located toward the center of the cell.
- Most eukaryotic cells have them, except higher plants, pine trees and some protists.
- Centrioles, like basal bodies, are made from 9 sets of three fused microtubules. *(See Figure 4.26)*
- Centrioles and the microtubules that radiate from them provide tracks for intracellular molecular trafficking, help maintain the positions of certain organelles within the cell and help in the movement of chromosomes during cell division.

IX Extracellular Structures

- Extracellular structures are those made by cells of multicellular organisms but that are outside of cells.
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A. The plant cell wall consists largely of cellulose

- In plants, cell walls exist which are made primarily of cellulose. *(See Figure 4.27)*
- It provides a rigid structure for the plasma membrane to press against.
- It is a barrier to many fungi, bacteria and other organisms.

B. Multicellular animals have elaborate extracellular matrices

- Multicellular animals have an extracellular matrix. It is composed of fibrous proteins and glycoproteins. *(See Figure 4.28)*
  - An example is the cartilage of kneecaps and the nose.
  - Epithelial cells have a basement membrane of extracellular material called the basal lamina.
  - This is an extracellular matrix that cells connect to and that provides strength and tensile.
  - One component called proteoglycan is huge; it can be as large as 100 million daltons.