The Organization of Cells

Biochemistry/Biology Teaching Unit

Preface: Cells are the structural and functional units of all living organisms. The smallest organisms consist of single cells and are microscopic, whereas larger organisms are multicellular. The human body, for example, contains at least 10^{14} cells. Unicellular organisms are found in great variety throughout virtually every environment from Antarctica to Hot Springs to the inner recesses of larger organisms. Multicellular organisms contain many different types of cells, which vary in size, shape, and specialized function. Yet, no matter how large and complex the organism, each of its cells retains some individuality and independence.

Despite their many differences, cells of all kinds share certain structural features. The **plasma membrane** defines the periphery of the cell, separating its contents from the surroundings. It is composed of enormous numbers of lipids and protein molecules, held together primarily by noncovalent hydrophobic interactions, forming a thin, tough, pliable, hydrophobic bilayer around the cell. The membrane is a barrier to the free passage of inorganic ions and most other charged or polar compounds; the transport proteins in the plasma membrane allow the passage of certain ions and molecules. Other membrane proteins are receptors that transmit signals from the outside to the inside of the cell, or are enzymes that participate in membrane-associated reaction pathways.

The plasma membrane is remarkably flexible because its individual lipid and protein subunits are not covalently linked. This flexibility allows changes in the shape and size of the cell. As a cell grows, newly made lipid and protein molecules are inserted into its plasma membrane; cell division produces two cells, each with its own membrane. Growth and fission occur without loss of membrane integrity.

The internal volume bounded by the plasma membrane, the **cytoplasm**, is composed of an aqueous solution, the **cytosol**, and a variety of insoluble, suspended particles. The cytosol is not simply a dilute aqueous solution; it has a complex composition and gel-like consistency. Dissolved in the cytosol are many enzymes and the RNA molecules that encode them; the monomeric subunits (amino acids and nucleotides) from which these macromolecules are assembled; hundreds of small organic molecules call **metabolites**, intermediates in biosynthetic and degradative pathways; **coenzymes**, compounds of intermediate molecular weight (M_r200 to 1,000) that are essential participants in many enzyme-catalyzed reactions; and inorganic ions.

Among the particles suspended in the cytosol are supramolecular complexes and, in higher organisms but not in bacteria, a variety of membrane-bounded organelles in which specialized metabolic machinery are localized. **Ribosomes**, complexes of over 50 different protein and RNA molecules, are small particles, 18 to 22 nm in diameter.

Ribosomes are the enzymatic machines on which protein synthesis occurs; they often occur in clusters call **polysomes** (polyribosomes) held together by a strand of messenger RNA. Also present in the cytoplasm of many cells are granules containing stored nutrients such as starch and fat. Nearly all-living cells have either a **nucleus** or a **nucleoid,** in which the **genome** (the complete set of genes, composed of DNA) is stored and replicated. The DNA molecules are always very much longer then the cells themselves, and are tightly folded and packed within the nucleus or nucleoid as supramolecular complexes of DNA with specific proteins. The bacterial nucleoid is not separated from the cytoplasm by a membrane, but in higher organisms, the nuclear material is enclosed within a double membrane, the nuclear envelope. Cells with nuclear envelopes are called **eukaryotes** (Greek eu, "true", and karyon, "nucleus"); those without nuclear envelopes – bacterial cells – are **prokaryotes** (Greek pro, "before"). Unlike bacteria, eukaryotes have a variety of other membrane-bounded organelles in their cytoplasm, including mitochondria, lysosomes, endoplasmic reticulum, Golgi complexes, and in photosynthetic cells, chloroplasts.

Goals: The student will:

1. Know the characteristics, which define a "prokaryotic cell" and a "eukaryotic cell".
2. Define what constitutes an organelle and specify the functions of the organelles found in a human cell.
3. Indicate the difference(s) between a cell membrane and a cell wall.
4. Characterize the structural components and the function of mitochondria.
5. Describe the two forms of the endoplasmic reticulum and their location within the cell.
6. Name the five classes of biological organisms and give an example of each.
7. Discuss and define "mutualism" and "parasitic symbiosis" and present an example of each.

DAY 1: <u>Introduction</u>

A. Most biochemical reactions take place within membrane-bounded compartments called "cells".

- <u>Cells</u> – The smallest functional and structural component of living system.
- Every organism is either a single cell or is composed of many cells.
- The realization that cells are the basic unit of life had to await the invention of the microscope.
  a. Almost 300 years ago, Robert Hooke used the microscope he had built to examine a thin slice of cork.
  b. He saw that the plant tissue was divided into small compartments, which he named cells (Latin, "cella", small room).

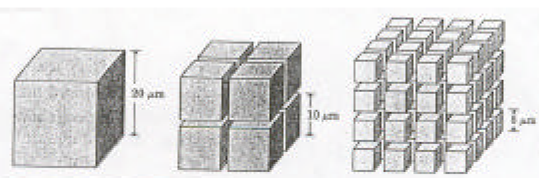
- Over 150 years elapsed between Hooke's observation and Mathias Schleiden's proposal that the structures of all plant tissues are based upon an organization of cells.

  a. At about the same time, bacteria and algae were recognized as unicellular organisms.

B. <u>Cellular Dimensions</u>
Most cells are microscopic in size. Animal and plant cells are typically 10 to 30 μm In diameter, and many bacteria are only 1 to 2 μm long.

- What limits the dimensions of a cell? The lower limit is probably set by the minimum number of each of the different biomolecules required by the cell. The smallest complete cells, certain bacteria known collectively as mycoplasm, are 300 nm in diameter and have a volume of about 10^{-14} mL.

- The upper limit of cell size is set by the rate of diffusion of solute molecules in aqueous systems. The availability of fuels and essential nutrients from the surrounding medium is sometimes limited by the rate of diffusion to all regions of the cell. A bacterial cell that depends upon oxygen-consuming reactions for energy production (an aerobic cell) must obtain molecular oxygen (O_2) from the surrounding medium by diffusion through its plasma membrane. The cell is so small, and the ratio of its surface area to its volume is so large, that every part of its cytoplasm is easily reached by O_2 diffusing into the cell. As the size of a cell increases, its surface-to-volume ratio decreases (Fig.2-2) until metabolism consumes O_2 faster than diffusion can supply it. Aerobic metabolism thus becomes impossible as cell size increases



Number of cubes, n	1	8	64
Length of a side, l (μm)	20	10	5
Total surface area, $l^2 \times 6n$ (μm^2)	2,400	4,800	9,600
Total volume, $l^3 \times n$ (μm^3)	8,000	8,000	8,000
Surface area: volume ratio, $\frac{6}{l}$	0.3	0.6	1.2

Figure 2–2 Smaller cells have larger ratios of surface area to volume, and their interiors are therefore more accessible to substances diffusing into the cell through the surface. When the large cube (representing a large cell) is subdivided into many smaller cubes (cells), the total surface area increases greatly without a change in the total volume, and the surface-to-volume ratio increases accordingly.

beyond a certain point, placing a theoretical upper limit on the size of the aerobic cell.

- There are interesting exceptions to this generalization that cells must be small. The giant alga Nitella has cells several centimeters long. To assure the delivery of nutrients, metabolites, and genetic information (RNA) to all of its parts, each cell is vigorously "stirred" by active cytoplasmic streaming. The shape of a cell can also help to compensate for its large size. A smooth sphere has the smallest surface-to-volume ratio possible for a given volume. Many large cells, although roughly spherical, have highly convoluted surfaces, creating larger surface areas for the same volume and thus facilitating the uptake of fuels and nutrients and release of waste products to the surrounding medium. Other large cells (neurons, for example) have large surface-to-volume ratios because they are long and thin, star-shaped, or highly branched, rather than spherical.

DAY 2: Evolution and Structure of Prokaryotic Cells

- Define the following terms: archaebacteria, eubacteria, cyanobacteria.
- Discuss the classification of organisms based upon their mode of obtaining fuel and energy (chemotrophs, phototrophs, autotrophs, and heterotrophs) [Figure 2-4]
- Discuss the evolution of life on earth (Figure 2-5)
- Define "prokaryotic" cell.
- List all of the characteristics of a prokaryotic cell (Figure 2-6)
- Discuss Echerichia coli as the best example of a prokaryotic cell (Figure 2-6)

DAY 3: Evolution of Eukaryotic Cells

- Discuss the evolution of eukaryotic cells from prokaryotes in several stages.
- Discuss the three (3) major changes that must have occurred as prokaryotes gave rise to eukaryotes (Figure 2-7)
- Discuss the rise of eukaryotic cells to diverse protists.
- Discuss the major structural features of eukaryotic cells (Figure 2-8)

1. Plasma membrane contains transporters and receptors (Figure 2-9)
2. Endocytosis and exocytosis carry traffic across the plasma membrane (Figure 2-10)
   a. Define "endocytosis", "phagocytosis" and "exocytosis".
3. The endoplasmic reticulum organizes the synthesis of proteins and lipids (Figure 7-11)
   a. Define "endoplasmic reticulum", "rough endoplasmic reticulum" and "smooth endoplasmic reticulum".
4. The Golgi Complex processes and sorts protein (Figure 7-12)

5. Lysosomes are packets of hydrolyzing enzymes (Figure 7-13) and (Figure 7-14)
6. Vacuoles of plant cells play several important roles (Figure 7-15)
7. Peroxisomes destroy hydrogen peroxide, and Glyoxysomes converts fats to carbohydrates (Figure 7-19)
   a. Some of the oxidative reactions in the breakdown of amino acids and fats produce free radicals and hydrogen peroxide (H_2O_2), a very reactive chemical species that could damage cellular machinery.
   b. To protect the cell from these destructive byproducts, such reactions are segregated within small membrane-bounded vesicles call peroxisomes.
   c. The hydrogen peroxide is degraded by catalase, an enzyme present in large quantities in peroxisomes and glyoxysomes; it catalyzes the reaction

$$2H_20_2 \xrightarrow{\text{catalase}} 2H_20 + 0_2$$

   d. Glyoxysomes are specialized peroxisomes found in certain plant cells. They contain high concentrations of the enzymes of the glyoxylate cycle, a metabolic pathway unique to plants that allow the conversion of stored fats into carbohydrates during seed germination.
   e. Lysosomes, peroxisomes, and glyoxysomes are sometimes referred to collectively as microbodies.

DAY 4: The Nucleus of Eukaryotes Contains the Genome

8. The eukaryotic nucleus is very complex in both its structure and its biological activity, compared with the relatively simple nucleoid of prokaryotes (Figure 7-19)
9. Mitochondria are the power plants of aerobic eukaryotic cells (Figure 7-17)
10. Chloroplasts converts solar energy into chemical energy (Figure 7-18)

DAY 5: Mitochondria and chloroplasts probably evolved from Endosymbiotic bacteria.

- Several independent lines of evidence suggest that the mitochondria and chloroplasts of modern eukaryotes were derived during evolution from aerobic bacteria and cyanobacteria that took up endosymbiotic residence in early eukaryotic cells.

1. The cytoskeleton stabilizes cell shape, organizes the cytoplasm, and produces motion.

   a. Define and discuss “cytoskeleton”.
   b. Define and discuss “actin” and “myosin”.
   c. Define and discuss “microtubules”, “cilia” and “flagella”.

DAY 6: Organelles can be isolated by centrifugation (Figure 7-3) A major advance in the biochemical study of cells was the development of methods for separating organelles from the cytosol and from each other.

DAY 7: "Hanging Out With Cell Models" Project – (handout)

a. This project requires several class periods to complete.

DAY 8: Examination