CHAPTER

1

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The Cellular Organization of a Living Organism

INTRODUCTION

Biology is a broad field of science focusing on the "study of life." It covers a wide-range of subjects from cell biology that explains the workings of the cells to the study of ecosystems that govern the survival of the living organisms. Technological advances have made it possible to examine the contents of the cells, the organelles, in minute details to unraveling the contents of these organelles especially, the deoxyribonucleic acid (DNA) inside the nucleus. As long as there is an urge to lead a life without diseases and live longer with better quality, it is important to study biology because it provides clues to solving many of these problems. Understanding the nature of the cellular organelles and its functions provides basic information about the cell that can help us to devise strategies to correct the problems seen in this cellular machinery in diseases.

Genetic information stored in the form of DNA in the chromosomes of the nucleus is not only important for propagation of species but also in the production of various proteins that is critical for the survival of an organism. Genes serve as blueprints for synthesis of proteins that have several functions in the body: provide structural support, regulate metabolism, and stimulate chemical reactions involved in anabolism and catabolism of biomolecules. Metabolism is a key process through which the living organism is able to generate energy for its sustenance. Plants get energy through photosynthesis using sunlight, water, and carbon dioxide while animals depend on external sources including plants. All the processes within the organism are carried out by maintaining equilibrium in order to adjust to the external environment. This process of homeostasis allows the organism to live under different climatic conditions and during healthy and diseased states. Reproduction is a key process for the propagation of living organisms and is done through both mitosis and meiosis involving cell division.

1.1 BIOLOGY AS ONE OF THE FIELDS OF SCIENCE

Science is an organized approach to a systematic study of the universe with the aim to increase our knowledge about the universe. Biology is one of the realms of science and its sole purpose is to understand the living organisms. A *living organism* is defined as a complex entity of physicochemical components that is capable of surviving through self-regulatory mechanisms such as metabolism, reproducing, and coping with the external environment. It also possesses the capabilities to move, respond to external and internal stimuli, grow and develop to adjust to the environment in which they live in.

Biologists believe in the concept of *evolution* which states that the present day living organisms have originated from ancestral forms of life which had undergone continuous modifications over a period of time. These concepts have been developed by Jean Baptiste Lamarck (1801) and later modified by Charles Darwin (1859). It also helped in the classification of living organisms into groups in such a manner that they are linked chronologically and morphologically. The branch of science dealing with classification organisms is called as *taxonomy*. A kingdom is the broadest classification in taxonomy and all living organisms belong to one of the 5 kingdoms (Table 1.1).

The five kingdoms are **Monera, Protista, Fungi, Plantae**, and **Animalia**. Living organisms are further classified into **prokaryote** and **eukaryote** based on the presence or absence of nucleus. **Monera** consists of unicellular organisms that lack a nucleus and many of the specialized cell parts, called organelles. Such organisms are said to be prokaryotic (pro "before"; karyotic "kernel," "nucleus") and consist of bacteria. All of the other kingdoms consist of eukaryotic (eu: "true") organisms, which have cells that contain a nucleus and a number of specialized organelles.

Table 1.1 *Classification of kingdoms with their characteristic features*

S. No.	*Kingdom*	*Characteristics*	*Examples*
1	Monera	Single-celled, prokaryotic, cells do not have nucleus and specialized organelles	Bacteria
2	Protista	Single-celled, eukaryotic, cells possess nucleus and specialized organelles	Protozoa
3	Plantae	Multicellular, eukaryotic, produce their own food for survival and reproduction	Trees
4	Fungi	Single or multicellular, eukaryotic, acquire food from their surroundings	Yeasts and molds
5	Animalia	Multicellular, eukaryotic, obtain food from the environment and process it through metabolic pathways for survival and reproduction	Fishes, Birds, Reptiles, Cows, Human beings

Biologists have been able to classify the living organisms by investigating their characteristic features. This was accomplished by adopting rigorous *scientific methods* as a model of research developed by Francis Bacon (1561–1626). It has the following sequences:

1. Recognizing the problem
2. Gathering data through experiments (measurement, observations, etc)
3. Analyzing the data for meaningful connections between various parameters chosen for study and any deviations
4. Formulating a *hypothesis* (a generalization), which is an educated guess that explains the existing data and suggests further avenues of investigation
5. Testing the hypothesis rigorously by gathering new data
6. Confirming, modifying, or rejecting the hypothesis in light of the new findings

Scientists have strict guidelines of doing research as postulated by Fracis Bacon. Any procedure or data that do not conform to the rigors of testing and go wrong are discarded and the whole process is repeated. However in some instances, errors have lead to new discoveries.

- Wilhelm Röntgen observed a faint shimmering in the corner of the laboratory where he had a kept a chemical that later led to the discovery of X-rays.
- Charles Goodyear accidently dropped a mixture of rubber and sulfur on a hot stove and found the mixture to be flexible and tough led to the discovery of vulcanization process
- Alexander Fleming found a contaminated mold growing in a bacterial culture on a petri dish. Any bacteriologist would have thrown away that petri dish because of contamination. But Fleming observed an area around the mold had no bacterial growth. He realized that this may have been due to the product produced by the mold. He isolated the chemical from the mold which happens to be penicillin, the first antibiotic that revolutionized the treatment options for various bacterial diseases.

1.2 CELL: BASIC UNIT OF LIFE

All living beings are made up of the basic unit of life- cells (Fig:1.1). It is the smallest unit of living matter and each cell is able to carry out the processes of life. Some structures transport materials, some make food and others release energy for the cell to use. All the cells are involved in metabolic processes through cellular respiration, reproduction (meiosis), and growth (mitosis). They are also capable of transforming into different types of cells, a specialization called as cell differentiation. The cells have a few things in common such as having cell membrane, deoxyribonucleic acid (DNA), cytoplasm, and ribosome but they are different with regard to structure, shape, and functions.

The cells were first described by Robert Hooke in 1665. He examined thin slices of cork and found pores. But his examination did not indicate any nucleus, and other organelles. Later in 1674, Antony van Leeuwenhoek found moving organisms by observing them under lenses and microscopes. The observation of Hooke and others led to the development of cell theory.

The cell theory states

- All living things and organisms are made up of cells and their products. Multicellular organisms (example: humans) are composed of many cells while unicellular organisms (example: bacteria) are composed of only one cell.
- Cells are the basic building units of life.
  They are the smallest structures capable of surviving on their own.
- New cells arise from the pre-existing cells by division.
  For example, new cells arise from cell division and a zygote (the very first cell formed when an organism is produced) arises from the fusion of an egg cell and a sperm cell.

Evidence for the cell theory

When scientists started to look at the structures of organisms under the microscope, they discovered that all living organisms where made up of these small units which they named them as cells. When these cells were taken from tissues they were able to survive for some period of time. Nothing smaller than the cell was able to live independently and so it was concluded that the cell was the smallest unit of life. For some time, scientists thought that cells must arise from non-living material but it was eventually proven that this was not the case, and instead proved to arise from pre-existing cells.

A simple experiment to prove this can be done as follows:

- Take two containers and put food in both of these
- Sterilize both of the containers so that all living organisms are killed
- Leave one of the containers open and seal the other closed

One will be able to observe that there will be growth of mold in the open container whereas there will be no such growth in the sealed container. The reason for this is because in the open container, cells are able to enter the container from the external environment and start to divide and grow. However, due to the sealing on the other container no cells could enter and hence, no mold growth was observed proving that cells cannot arise from non-living material.

Multicellular organisms possess developing properties

Multicellular organisms are the product of development from simpler to complex structures. For example: cells form tissues, tissues form organs, organs form organ systems and organ systems form multicellular organisms. The idea is that the whole is greater than the composition of its parts. For example your lungs are made of many cells. However, the cells by themselves aren't much use. It is the many cells working as a unit that allow the lungs to perform their function.

Every cell in multicellular organisms contains all the genes of that organism. However, the genes that are activated vary from cell to cell. The reason we have different types of cells in our body (the cells in your eyes are not the same as the ones that make up your hair) is because different genes are activated in different cells. For example, the gene that produces keratin will be active in hair and nail cells. Keratin is the protein which makes up hair and nails. Genes encode for proteins and the proteins affect the cell's structure and function so that the cell can specialize. This means cells develop in different ways. This is called differentiation. Differentiation depends on gene expression which is regulated mostly during transcription. It is an advantage for multicellular organisms as cells can differentiate to be more efficient unlike unicellular organisms that have to carry out all of the functions within that one cell.

Prokaryotes

These kinds of organisms do not have a nucleus, mitochondria or any other membrane-bound organelles. In other words, neither their DNA nor any other of their metabolic functions is collected together in a discrete membrane enclosed area. Instead everything is openly accessible within the cell; though some bacteria have internal membranes as sites of metabolic activity, these membranes do not enclose a separate area of the cytoplasm.

The prokaryote cell is simpler and therefore smaller than a eukaryote cell. The prokaryotes do not have a nucleus and most other organelles of eukaryotes. There are two kinds of prokaryotes, bacteria and archaea. Nuclear material of prokaryotic cell consists of a single chromosome which is in direct contact with cytoplasm. Here the undefined nuclear region in the cytoplasm is called nucleiod. A prokaryotic cell has the following features:

- On the outside, flagella and pili project from the cell's surface. These are structures (not present in all prokaryotes) made of proteins that facilitate movement and communication between cells;
- Enclosing the cell is the cell envelope consisting of a cell wall covering a plasma membrane though some bacteria also have a further covering layer called a capsule. The envelope gives rigidity to the cell and separates the interior of the cell from its environment.
- Prokaryotes can carry extra chromosomal DNA elements called plasmids, which are usually circular. Plasmids enable additional functions, such as antibiotic resistance and therefore, survival.

Eukaryotes

Eukaryotic cells are about 15 times wider than a typical prokaryote and can be as much as 1000 times greater in volume. The major difference between prokaryotes and eukaryotes is that eukaryotic cells contain membrane-bound compartments in which specific metabolic activities take place. Most important among these is a cell nucleus, a membrane-delineated compartment that houses the eukaryotic cell's DNA. This nucleus gives the eukaryote its name, which means "true nucleus." Other differences include:

- The plasma membrane resembles that of prokaryotes in function, with minor differences in the setup. Cell wall may or may not be present.
- The eukaryotic DNA is organized in one or more linear molecules, called chromosomes, which are associated with histone proteins. All chromosomal DNA is stored in the cell nucleus, separated from the cytoplasm by a membrane. Some eukaryotic organelles such as mitochondria also contain some DNA.
- Many eukaryotic cells are ciliated with primary cilia. Primary cilia play important roles in chemo-sensation, mechano-sensation, and thermo-sensation.
- Eukaryotes can move using motile cilia. The flagella are more complex than those of prokaryotes.
- Plastids are a feature of most plant cells but are not found in the cells of animals. Vacuoles are quite prominent in plant cells, but are far less significant in or absent from animal cells.

1.3 CELL STRUCTURE AND FUNCTION

Earlier before the advent of electron microscope, cell was described as a unit possessing a limiting outer membrane and an inner central nucleus surrounded by large mass of cytoplasm (Fig. 1.1). Staining of cells facilitated to identification of subcellular features such as chromosome and nucleolus of the nucleus. Electron microscopic studies made it possible for the elucidation of the subcellular structures called as *organelles* that perform specialized functions. Most of the organelles are derived from membranes but some of them do not possess membrane structure such as ribosomes, microtubules, and microfilaments, flagella, cilia, and centrioles.

Cell/plasma membrane: The outermost layer of the living cell that gives structure and shape is the cell membrane. The chief function is to regulate the passage of materials into and out of the cell. Initial structural studies using electron microscope revealed that it consists of inner and outer dense protein layer enclosing a less dense phospholipid layer. Channels were also observed to traverse the through exterior surface of the membrane. Recent studies by Singer and Nicholson have demonstrated that the cell membrane has fluid

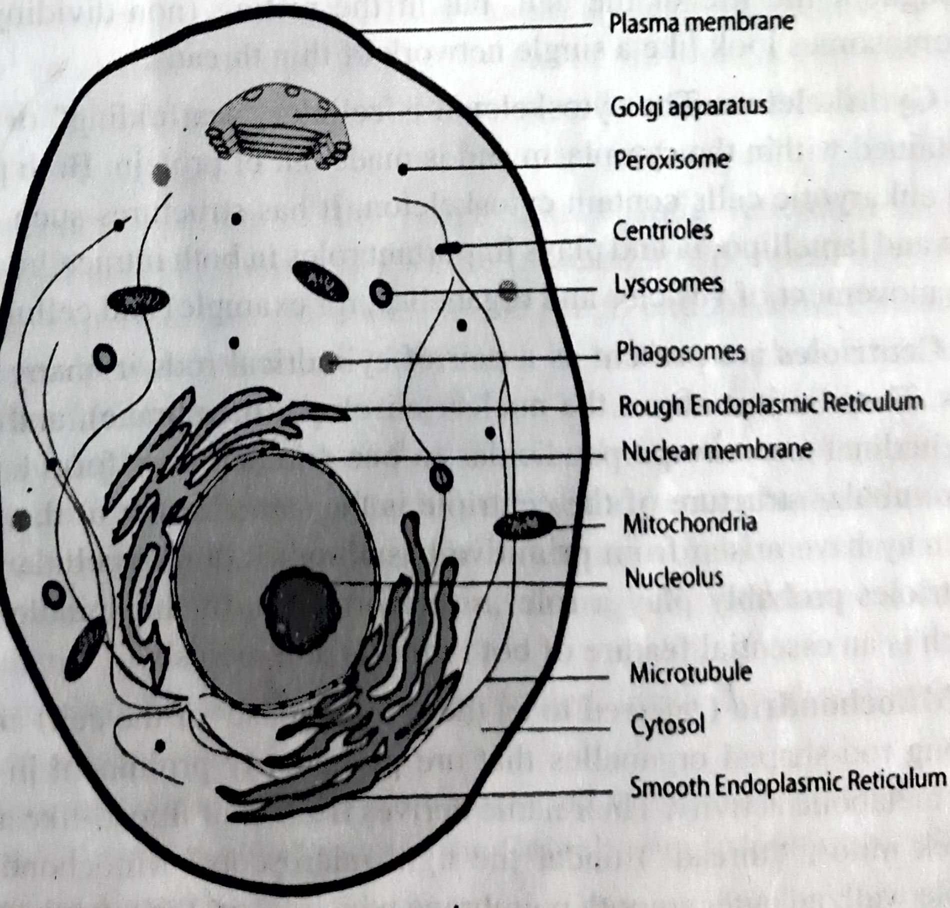

Fig. 1.1 *Cell structure with outer plasma membrane and inner cytoplasm, organelles, and nucleus*

mosaic model which better explains the dynamic nature of the proteins in the cell membrane. The only difference in the proposed model was the arrangement of phospholipids: their polar ends facing the inner and outer surfaces and the hydrophobic, non-polar ends opposed at the center of the bilayer.

Nucleus and Nucleolus: The nucleus is a round or oval body lying in the center of the cell enclosed by a double membrane that is called as nuclear membrane or envelope. In certain regions of the nuclear envelope, these membranes join together and there may be pores in these areas. The pores serve as a direct passage route for the substances to leave the nucleus. The outer membrane of the nuclear envelope is continuous with the endoplasmic reticulum and thus, may facilitate passage of materials from the nucleus directly into the channels of endoplasmic reticulum. Within the nucleus, one or more *nucleoli* may be seen. These are dense bodies containing the subunits for the ribosomes, the cytoplasmic organelles involved in the synthesis of protein. The nucleolus is involved in the assembly and synthesis of ribosomes.

The nucleus is the storehouse of the genetic material called as *chromosomes*. Each chromosome exists as a tiny individual rod or string throughout the life of the cell, but in the resting (non-dividing) cell, the chromosomes look like a single network of thin threads.

Cytoskeleton: The cytoskeleton is cellular "scaffolding" or "skeleton" contained within the cytoplasm and is made out of protein. Both prokaryotic and eukaryotic cells contain cytoskeleton. It has structures such as flagella, cilia and lamellipodia and plays important roles in both intracellular transport (the movement of vesicles and organelles, for example) and cellular division.

Centrioles are present as a pair of cylindrical rods in many eukaryotic cells. They lie just above the nuclear envelope (membrane), and since their longitudinal axes are perpendicular to one another, they form a cross. The microtubular structure of the centriole is the same as that of the basal body and may have arisen from primitive basal bodies during cellular evolution. Centrioles probably play a role in the formation of the spindle apparatus, which is an essential feature of both mitosis and meiosis.

Mitochondria (referred to as the 'Powerhouse' of the cell) are rounded or long rod-shaped organelles that are particularly prominent in cells with high metabolic activity. Their name derives from their thread-like appearance (Greek mitos, "thread") under the light microscope. Mitochondria have a double wall: an outer smooth membrane which forms the outer boundary and an inner membrane which is extensively folded. The folds, or cristae, project into the interior of the organelle and have a variety of enzymes embedded in them. These enzymes are involved in the systematic degradation of organic molecules to yield energy for the cell. They are responsible for the breakdown of sugar molecules to release ATP (adenosine triphosphate), which is used to transport energy within the cell for metabolism. (through citric acid cycle and electron transport chain as explained in chapter 3). Like the chloroplasts of plants, the mitochondria contain their own DNA and ribosomes; they replicate independently of the rest of the cell and appear to control the synthesis of their membranes.

Endoplasmic reticulum (ER) is a series of membranous channels that traverse the cytoplasm of most eukaryotic cells. It forms a continuous network extending from the cell membrane to the nuclear membrane. In some regions of the cell, it may appear as a series of flattened disks or sacs. The endoplasmic reticulum serves many general functions, including the facilitation of protein folding and the transport of synthesized proteins in sacs called cisternae. Only properly-folded proteins are transported from the rough ER to the Golgi complex.

In many parts of the cell, the endoplasmic reticulum is associated with small dense granules lying along the outer border of its membrane. These structures are known as *ribosomes*. They impart a rough appearance to the endoplasmic reticulum, so that the ER is called the *rough endoplasmic reticulum (RER)* in these regions, which are usually associated with active protein synthesis. Form. of prim. lysosome, cell plate

- The primary function of the rough endoplasmic reticulum is the production and processing of specific proteins at ribosomal sites that are later exported. The ribosomes in the rough endoplasmic reticulum synthesize proteins which are then sent in to the rough endoplasmic reticulum for advanced processing.
- Rough endoplasmic reticulum function involves creation of two types of proteins. One is the type which fortifies and gets embedded into the reticulum membrane. The other types are water-soluble proteins which after production at ribosomal sites, pass through the membrane and into the lumen.
- The proteins that enter are further folded inside by the chaperone proteins present in the lumen.
- Subsequently, these proteins are transported to the sites where they are required. They may also be sent to the Golgi bodies for further advanced processing, through vesicles.

The *smooth endoplasmic reticulum (SER)* does not contain any ribosomes and is associated with cellular regions which are involved in the synthesis and

It contains 30 types of enzymes helps in biosynthesis.

RER - Prot. synth. - forms SER, transport vesicles

SER lipid synth, steroid hormones - testosterone - estrogen
detoxify of harmful drugs,

transport of lipids or the detoxification of a variety of poisons. Smooth endoplasmic reticulum is found in a variety of cell types and it serves different functions in each. It consists of tubules and vesicles that branch forming a network. The network of smooth endoplasmic reticulum allows increased surface area for the action or storage of key enzymes and the products of these enzymes.

Ribosomes are the components of cells that make proteins from the amino acids. Ribosomes are the workhorses of protein biosynthesis, the process of translating messenger ribonucleic acid (mRNA) into protein. The "central dogma" of biology is that DNA is used to make RNA, which, in turn, is used to make protein (discussed in detail in Chapter 2). The DNA sequence in genes is copied (transcription) into an mRNA. Ribosomes then read the information in this RNA and use it to create proteins. This process is known as translation; i.e., the ribosome "translates" the genetic information from RNA into proteins. Ribosomes do this by binding to an mRNA and using it as a template for the correct sequence of amino acids in a particular protein. The amino acids are attached to transfer RNA (tRNA) molecules, which enter one part of the ribosome and bind to the messenger RNA sequence. The attached amino acids are then joined together by another part of the ribosome. The ribosome moves along the mRNA, "reading" its sequence and producing a chain of amino acids.

Ribosomes are made from complexes of RNAs and proteins. Ribosomes are divided into two subunits, one larger and another smaller subunit. The smaller subunit binds to the mRNA, while the larger subunit binds to the tRNA and the amino acids. When a ribosome finishes reading an mRNA, these two subunits split apart. Ribosomes have been classified as ribozymes, since the ribosomal RNA seems to be most important for the peptidyl transferase activity that links amino acids together.

Golgi apparatus/bodies: They exist as stacks of flattened sacs, or vesicles that are continuous with the channels of the smooth endoplasmic reticulum. Their major function is the storage, modification, and packing of materials for release outside the cell membrane. These organelles are particularly prominent in secretory cells such as those of the pancreas. The outer portion of the Golgi apparatus releases its secretory material within membrane-enclosed globules (secretory vesicles) that migrate to the surface of the cell. The Golgi apparatus may actually be part of a dynamic system of membranous channels within the cell in which all elements such as the nuclear envelope, the endoplasmic reticulum, the Golgi apparatus, and the cell membrane are connected to each other without sharp boundaries. This interconnected network facilitates transport of materials across the cell.

cell secretion, formation of hormones, cell plate for.
pdn; lysosome, takes part for vitellogenesis

Lysosomes are similar in shape to mitochondria but are smaller and consist of a single membrane covering the structure. They contain powerful enzymes that would digest the cellular contents if they were not contained within the impermeable lysosomal membrane. Rupture of this membrane releases these enzymes. The lysosome plays a role in intracellular digestion and may also be important in the destruction of certain structures during the process of development.

Vacuoles are discrete, clear regions within the cell that contain water and dissolved materials. The vacuole may act as a reservoir for fluids and salts that might otherwise interfere with metabolic processes occurring in the cytoplasm. The membrane enclosing the vacuole is called a tonoplast. Many protozoans have a contractile vacuole, which periodically contracts and forces fluid and salts out of the cell. The structure serves to prevent an accumulation of fluids in organisms that live in fresh water. Vacuoles containing digestive enzymes may also be formed around ingested food particles in a variety of cells. In the cells of many plants, a large central vacuole is a prominent feature; this vacuole may swell, press against the rigid cell wall, and give the cell a high degree of rigidity or turgor.

Organelles in plant cell

Plant and animal cells differ in the number and structure of the above organelles, but the most fundamental difference in plant cell organelles is the presence of the chloroplast and cell wall. Plants differ integrally from animals in their ability to prepare food within their cells by the process of photosynthesis.

Chloroplasts are organelles found in plant cells and other eukaryotic organisms that conduct photosynthesis. The material within the chloroplast is called the stroma containing the stacks of thylakoids, the sub-organelles, which are the site of photosynthesis (described in detail in chapter 3).

Cell Wall is a structure made out of polysaccharide, peptidoglycan or glycoprotein that provides structural support and protection to the cell. In combination with the vacuole, which is large in plant cells, the other cell wall function includes controlling the turgidity of the cell.

All cells, whether prokaryotic or eukaryotic, have a membrane that envelops the cell, separates its interior from its environment, regulates what moves in and out (selectively permeable), and maintains the electric potential of the cell. Inside the membrane, a salty cytoplasm takes up most of the cell volume. All cells possess DNA, the hereditary material of genes, and RNA, containing the information necessary to build various proteins such as enzymes, the cell's primary machinery. There are also other kinds of biomolecules in cells.

Electron microscope uses a beam of electrons to illuminate the specimen and produce a magnified image of the specimen under study. It can magnify an object million times whereas light microscopes can do it only thousand times the original image. It was invented by a Hungarian physicist, Leo Szilárd but was developed into a prototype in 1930s by German physicist Ernst Ruska and electrical engineer Max Knoll. Subsequently, several engineers worked on the prototype to increase its magnification power and practical utility that resulted in the development of two types of electron microscopes: scanning electron microscope and transmission electron microscope. These microscopes are not only of use in biology and life sciences field but also in other fields such as semiconductor and data storage, nanotechnology, mining, chemical and petrochemical, and high-resolution imaging.