Cell: The Unit of Life - Part 4

Objectives

After going through this lesson, the learners will be able to

- enumerate the different cell organelles and their specific functions.

Content Outline

- Introduction
- Lysosomes
- Vacuoles
- Mitochondria
- Plastids
- Ribosomes
- Cytoskeleton
- Cilia & Flagella
- Centrosome & Centrioles
- Nucleus
- Microbodies
- Summary

Introduction

Golgi Apparatus

Camillo Golgi (1898) first observed densely stained reticular structures near the nucleus. These were later named Golgi bodies after him.

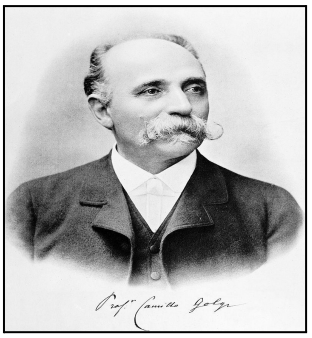

Figure 1: Camillo Golgi (7 July 1843 – 21 January 1926)

They consist of many flat, disc-shaped sacs or cisternae of 0.5µm to 1.0µm diameter. These are stacked parallel to each other. Varied number of cisternae are present in a Golgi complex. The Golgi cisternae are concentrically arranged near the nucleus with distinct convex *cis* or the forming face and concave *trans* or the maturing face.

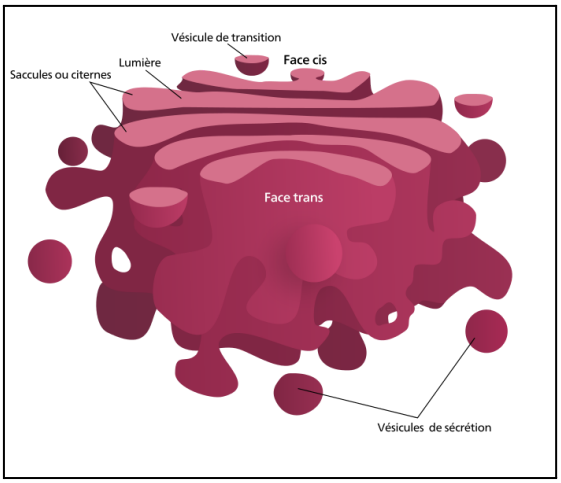

Figure 2: Golgi Apparatus

The *cis* and the *trans* faces of the organelle are entirely different, but interconnected. The golgi apparatus principally performs the function of packaging materials, to be delivered either to the intra-cellular targets or secreted outside the cell. Materials to be packaged in the form of vesicles from the ER fuse with the *cis* face of the golgi apparatus and move towards the maturing face. This explains why the golgi apparatus remains in close association with the endoplasmic reticulum. A number of proteins synthesised by ribosomes on the endoplasmic reticulum are modified in the cisternae of the golgi apparatus before they are released from its *trans* face. Golgi apparatus is the important site of formation of glycoproteins and glycolipids.

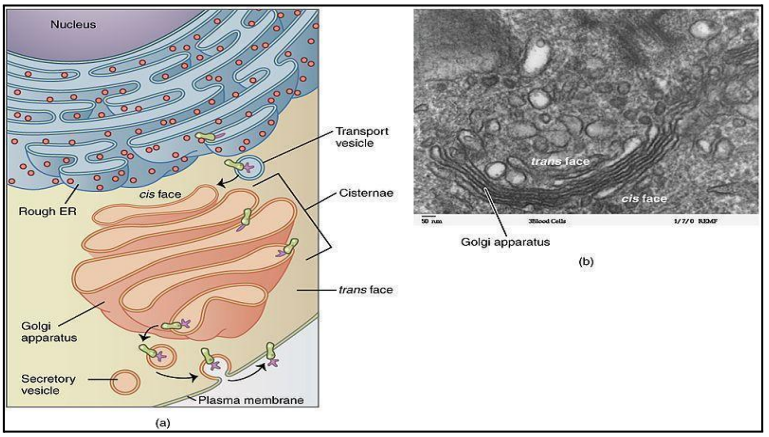

Figure 3: Transport through Golgi Apparatus

In non-biological terms the Golgi apparatus can be divided into three main sections:

1) Goods inwards
2) Main processing area
3) Goods outwards

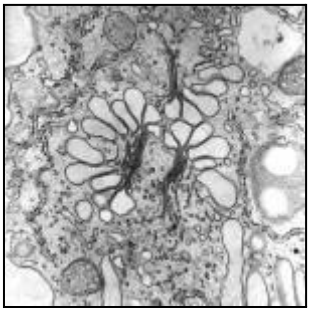

Figure 4

In the center of this image from a maize root cap slime-secreting cell there are two Golgi stacks. The large white sacs near them contain mucilage produced by the Golgi apparatus. (courtesy of Chris Hawes, The Research School of Biology & Molecular Sciences, Oxford Brookes University, Oxford, UK)

In terms of cell biology these sections, working from the rough endoplasmic reticulum (RER) outwards, are as follows:

1) **Cis Golgi network (Goods inwards)**

   Also called the cis Golgi reticulum it is the entry area to the Golgi apparatus. It follows the 'transitional elements' which are smooth areas of the RER that are also known as the 'endoplasmic reticulum Golgi intermediate compartments' (ERGIC).

2) **Golgi stack (Main processing area)**

   This section is composed of a variable number, typically 3-6, of flattened sacs called cisternae (sing. cisterna). The cisternae of the Golgi stack are divided into three working areas: cis cisternae, medial cisternae and trans cisternae.

3) **Trans Golgi network (Goods outwards)**

   This section is directly connected to the trans cisternae and it is here that final reactions and sorting takes place. The concentrated biochemicals are packed into sealed droplets or vesicles that form by budding off from the trans Golgi surface. The vesicles are then transported away for use in the cell and beyond.

Thus, the Golgi apparatus is rather like a food supermarket with an in store bakery. It takes in products from the Rough Endoplasmic Reticulum (RER) in what is called 'bulk flow' (the equivalent of a bulk delivery to the supermarket). These chemical products are transported to the Golgi apparatus in sealed droplets or sacs called vesicles and move to a 'deliveries only' part of the Golgi apparatus. In the Golgi apparatus the vesicles are delivered into the 'unloading bay' of the cis Golgi network. Here the 'goods received' are checked over. Any goods that have been wrongly delivered, including chemicals that should have stayed in the RER, are sent back, packed in vesicles to the rough endoplasmic reticulum.

Destination for Golgi Biochemicals

There are three main destinations for biochemicals released from the trans Golgi network: (1) inside the cell to the lysosomes; (2) the plasma membrane and (3) outside of the cell. In each case the destination is clearly linked to function.

Using the food supermarket analogy, all the biochemicals transported away from the trans Golgi network have labels and barcodes built into them. They are all packed in vesicles and the construction of the vesicle or vessel is largely related to the vesicle contents, its destination and end use.

Destination 1: inside the cell, 'the lysosome line'

About 40-50 different biochemicals dispatched from the Golgi apparatus in vesicles are destined for delivery to the lysosomes. Animal cells contain many lysosomes and it is in these structures that some life expired organelles and other materials are digested (see item CU9 about lysosomes).

Destination 2: the plasma membrane, 'the continuous secretion line'.

Vesicles containing biochemicals for continuous secretion flow to and fuse with the plasma membrane. This group of secretions will contribute to the biochemicals of the extracellular matrix, act as chemical signals to other cells, and provide proteins for the repair and replacement of the plasma membrane. This constitutive (or continuous) secretory pathway is also the default pathway. Products from the Golgi apparatus not labelled for other routes use this line.

Destination 3: outside the cell, 'the regulated secretion line'.

Vesicles and chemicals of this group are produced in specialist secretory cells. They move from the trans Golgi network (TGN) towards the plasma membrane but accumulate in number before reaching the membrane.

Certain triggers will make the vesicles fuse with the plasma membrane and release their contents in regulated bursts from the cell surface. Insulin release is an example of this when it is triggered by a rise in blood glucose level. Food intake is similar in that it triggers the release of mucus and digestive enzymes into the alimentary canal.

Lysosomes

These are membrane bound vesicular structures formed by the process of packaging in the golgi apparatus. The isolated lysosomal vesicles have been found to be very rich in almost all types of hydrolytic enzymes (hydrolases – lipases, proteases, carbohydrases) optimally active at the acidic pH. These enzymes are capable of digesting carbohydrates, proteins, lipids and nucleic acids.

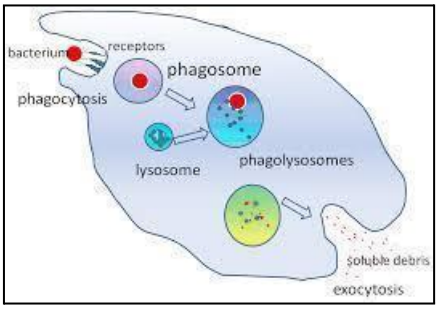

Figure 5: Action of Lysosome on Food Particles

Vacuoles

The vacuole is the membrane-bound space found in the cytoplasm. It contains water, sap, excretory products and other materials not useful for the cell. The vacuole is bound by a single membrane called tonoplast. In plant cells the vacuoles can occupy up to 90 per cent of the volume of the cell. In plants, the tonoplast facilitates the transport of a number of ions and other materials against concentration gradients into the vacuole, hence their concentration is significantly higher in the vacuole than in the cytoplasm.

In *Amoeba* the **contractile vacuole** is important for excretion. In many cells, as in protists, **food vacuoles** are formed by engulfing the food particles.

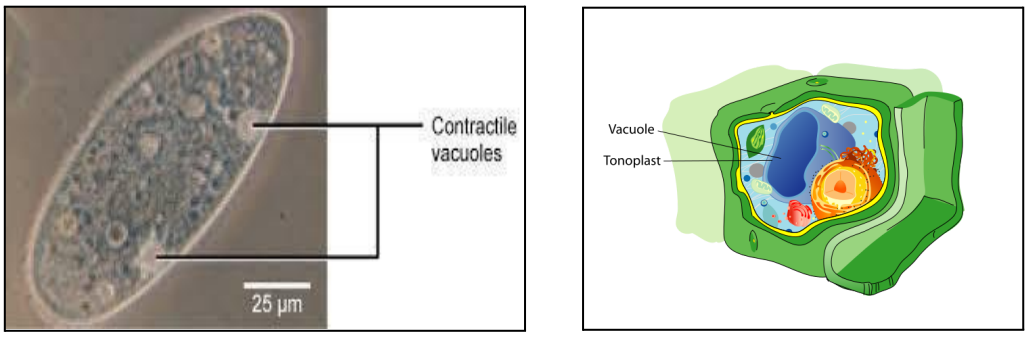

Figure 6: Vacuole in a Plant Cell

Mitochondria

Mitochondria are generally not easily visible under the microscope. The number of mitochondria per cell is variable depending on the physiological activity of the cells. In terms of shape and size also, a considerable degree of variability is observed. Typically it is sausage-shaped or cylindrical having a diameter of 0.2-1.0µm (average 0.5µm) and length 1.0-4.1µm. Each mitochondrion is a double membrane-bound structure with the outer membrane and the inner membrane dividing its lumen distinctly into two aqueous compartments, i.e., the outer compartment and the inner compartment. The inner compartment is called the **matrix**. The outer membrane forms the continuous limiting boundary of the organelle. The inner membrane forms a number of infoldings called the cristae (sing.: crista) towards the matrix (Figure 7). The cristae increases the surface area. The two membranes have their own specific enzymes associated with the mitochondrial function. Mitochondria are the sites of aerobic respiration. They produce cellular energy in the form of ATP, hence they are called 'power houses' of the cell. The matrix also possesses a single circular DNA molecule, a few RNA molecules, ribosomes (70S) and the components required for the synthesis of proteins. The mitochondria divide by fission.

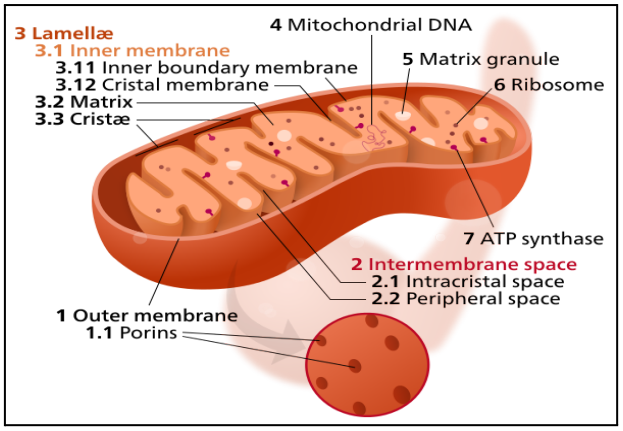

Figure 7: Detailed structure of a Mitochondrion

The mitochondrion is different from most other organelles because it has its own circular DNA (similar to the DNA of prokaryotes) and reproduces independently of the cell in which it is found; an apparent case of **endosymbiosis**. Scientists hypothesize that millions of years ago small, free-living prokaryotes were engulfed, but not consumed, by larger prokaryotes, perhaps because they were able to resist the digestive enzymes of the host organism. The two organisms developed a symbiotic relationship over time, the larger organism providing the smaller with ample nutrients and the smaller organism providing ATP molecules to the larger one. Eventually, according to this view, the larger organism developed into the eukaryotic cell and the smaller organism into the mitochondrion.

Mitochondrial DNA is localized to the matrix, which also contains a host of enzymes, as well as ribosomes for protein synthesis. Many of the critical metabolic steps of cellular respiration are catalyzed by enzymes that are able to diffuse through the mitochondrial matrix. The other proteins involved in respiration, including the enzyme that generates ATP, are embedded within the mitochondrial inner membrane. Infolding of the cristae dramatically increases the surface area available for hosting the enzymes responsible for cellular respiration.

Mitochondria are similar to plant chloroplasts in that both organelles are able to produce energy and metabolites that are required by the host cell. As discussed above, mitochondria are the sites of respiration, and generate chemical energy in the form of ATP by metabolizing sugars, fats, and other chemical fuels with the assistance of molecular oxygen. Chloroplasts, in contrast, are found only in plants and algae, and are the primary sites of photosynthesis. These organelles work in a different manner to convert energy from the sun into the

biosynthesis of required organic nutrients using carbon dioxide and water. Like mitochondria, chloroplasts also contain their own DNA and are able to grow and reproduce independently within the cell.

In most animal species, mitochondria appear to be primarily inherited through the maternal lineage, though some recent evidence suggests that in rare instances mitochondria may also be inherited via a paternal route. Typically, a sperm carries mitochondria in its tail as an energy source for its long journey to the egg. When the sperm attaches to the egg during fertilization, the tail falls off. Consequently, the only mitochondria the new organism usually gets are from the egg its mother provided. Therefore, unlike nuclear DNA, mitochondrial DNA doesn't get shuffled every generation, so it is presumed to change at a slower rate, which is useful for the study of human evolution. Mitochondrial DNA is also used in forensic science as a tool for identifying corpses or body parts, and has been implicated in a number of genetic diseases, such as Alzheimer's disease and diabetes.

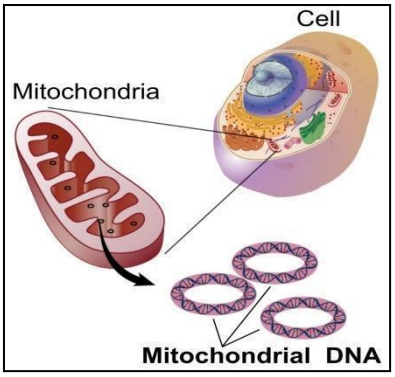

Figure 8: Mitochondrial DNA is the small circular chromosome found inside mitochondria.

These organelles found in cells have often been called the powerhouse of the cell. The mitochondria, and thus mitochondrial DNA, are passed only from mother to offspring through egg cell.

Uses of Mitochondrial DNA

Unlike nuclear DNA, which is prone to recombination, mitochondrial DNA can be put to many biochemical uses and procedures, as follows:

- Because the mutation rate of animal mtDNA is higher than that of nuclear DNA, mtDNA is a powerful tool for tracking ancestry through females (matrilineage) and

has been used in this role to track the ancestry of many species back hundreds of generations.

- Recently a mutation in mtDNA has been used to help diagnose prostate cancer in patients with negative prostate biopsy
- An IVF technique known as mitochondrial donation or mitochondrial replacement therapy (MRT) results in offspring containing mtDNA from a donor female, and nuclear DNA from the mother and father.

Plastids

Plastids are found in all plant cells and in euglenoides. These are easily observed under the microscope as they are large. They bear some specific pigments, thus imparting specific colours to the plants. Based on the type of pigments plastids can be classified into **chloroplasts, chromoplasts** and **leucoplasts.** The chloroplasts contain **chlorophyll** and carotenoid pigments which are responsible for trapping light energy essential for photosynthesis.

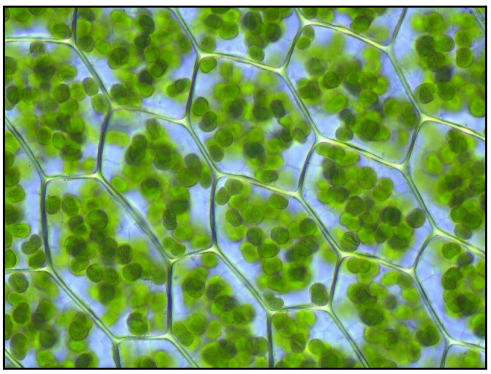

Figure 9: Plant cells with visible chloroplasts.

In the chromoplasts fat soluble **carotenoid** pigments like carotene, xanthophylls and others are present. This gives the part of the plant a yellow, orange or red colour.

Did you know?

Autumn leaf color is a phenomenon that affects the normally green leaves of many deciduous trees and shrubs by which they take on, during a few weeks in the autumn season, various shades of red, yellow, purple, black, orange, pink, magenta, blue and brown. The phenomenon is commonly called **autumn colours** or **autumn foliage**[3] in British English and **fall colors**,[4] **fall foliage** or simply **foliage**[5] in American English.

In some areas of Canada and the United States, "leaf peeping" tourism is a major contribution to economic activity. This tourist activity occurs between the beginning of color changes and the onset of leaf fall, usually around September and October in the Northern Hemisphere and April to May in the Southern Hemisphere.

Figure 10 : Autumn leaves in October (Europe)

Figure 11 : Japanese maple autumn leaves

Carotenoids are present in leaves the whole year round, but their orange-yellow colors are usually masked by green chlorophyll.[6] As autumn approaches, certain influences both inside and outside the plant cause the chlorophylls to be replaced at a slower rate than they are being used up. During this period, with the total supply of chlorophylls gradually dwindling, the "masking" effect slowly fades away. Then other pigments that have been present (along with the chlorophylls) in the cells all during the leaf's life begin to show through.[6] These are carotenoids and they provide colorations of yellow, brown, orange, and the many hues in between.

The leucoplasts are the colourless plastids of varied shapes and sizes with stored nutrients: **Amyloplasts** store carbohydrates (starch), e.g., potato; **elaioplasts** store oils and fats whereas the **aleuroplasts** store proteins. Majority of the chloroplasts of the green plants are found in the mesophyll cells of the leaves. These are lens-shaped, oval, spherical, discoid or even ribbon-like organelles having variable length (5-10ìm) and width (2-4ìm). Their number varies from 1 per cell of the Chlamydomonas, a green alga to 20-40 per cell in the mesophyll.

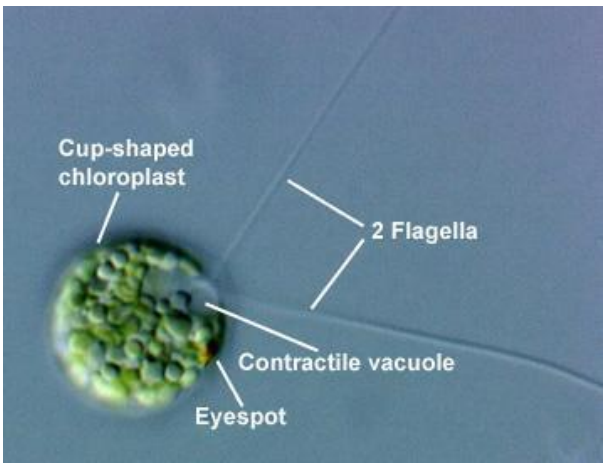

Figure 12: Chlamydomonas with cup-shaped Chloroplast

Like mitochondria, the chloroplasts are also double membrane bound. Of the two, the inner chloroplast membrane is relatively less permeable. The space limited by the inner membrane of the chloroplast is called the stroma. A number of organised flattened membranous sacs called the thylakoids, are present in the stroma. Thylakoids are arranged in stacks like the piles of coins called grana (singular: granum) or the intergranal thylakoids. In addition, there are flat membranous tubules called the stroma lamellae connecting the thylakoids of the different grana. The membrane of the thylakoids enclose a space called a lumen. The stroma of the chloroplast contains enzymes required for the synthesis of carbohydrates and proteins. It also contains small, double-stranded circular DNA molecules and ribosomes. Chlorophyll pigments are present in the thylakoids. The ribosomes of the chloroplasts are smaller (70S) than the cytoplasmic ribosomes (80S).

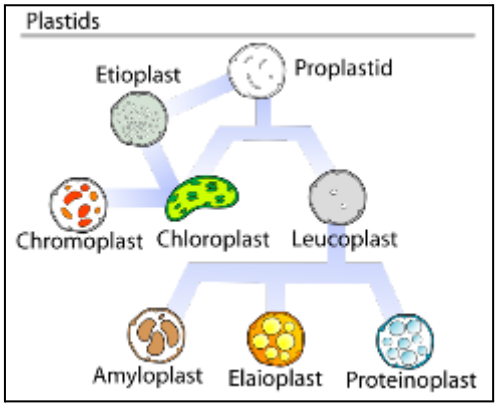

Figure 13: Different Types of Plastids in Plants for performing Photosynthesis, storage of fatty acids, and as cellular building blocks

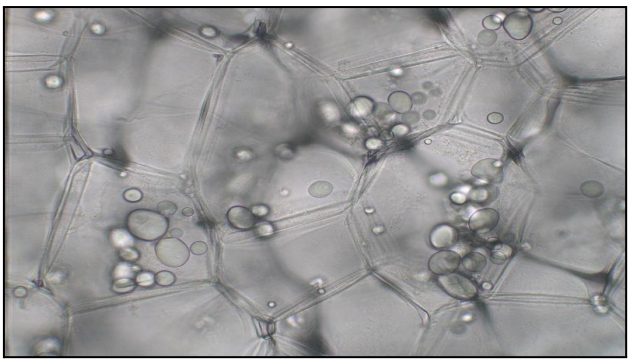

Figure 14: Leucoplasts in Plant Cell

Ribosomes

Ribosomes are the granular structures first observed under the electron microscope as dense particles by George Palade (1953). They are composed of ribonucleic acid (RNA) and proteins and are not surrounded by any membrane. The eukaryotic ribosomes are 80S while the prokaryotic ribosomes are 70S. Here 'S' (Svedberg's Unit) stands for the sedimentation coefficient; it indirectly is a measure of density and size. Both 70S and 80S ribosomes are composed of two subunits.

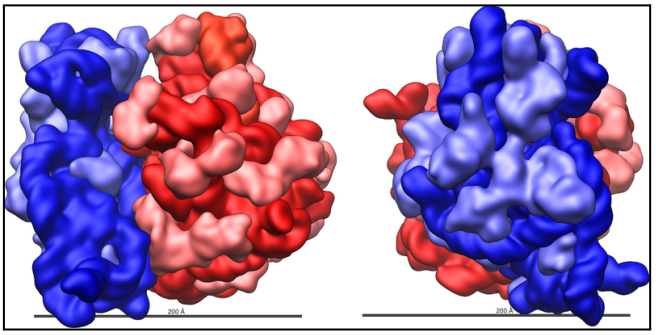

Figure 15: The two Ribosomal sub-units of the E.coli 70S Ribosome

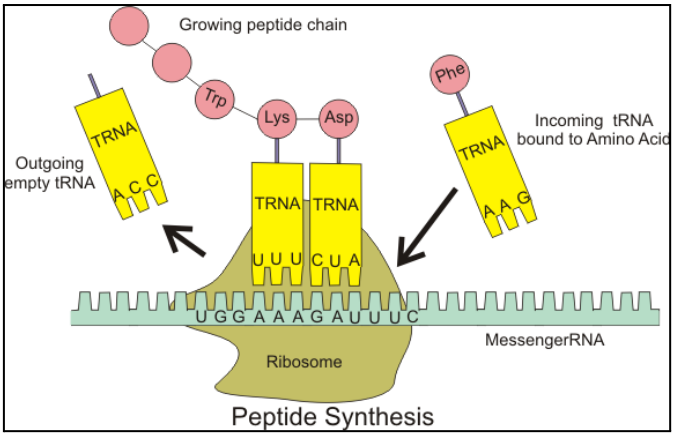

Figure 16: Protein Synthesis carried out in a cell with the help of Ribosome

Cytoskeleton

An elaborate network of filamentous proteinaceous structures present in the cytoplasm is collectively referred to as the **cytoskeleton**. The cytoskeleton in a cell are involved in many functions such as mechanical support, motility, maintenance of the shape of the cell.

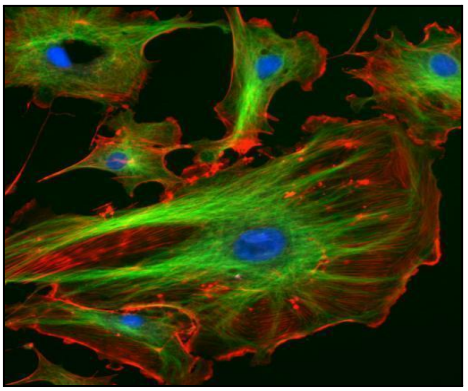

Figure 17: Cytoskeleton stained inside the cell

Cilia & Flagella

Cilia (sing.: cilium) and flagella (sing.: flagellum) are hair-like outgrowths of the cell membrane. Cilia are small structures that work like oars, causing the movement of either the cell or the surrounding fluid. Flagella are comparatively longer and responsible for cell movement. The prokaryotic bacteria also possess flagella but these are structurally different from that of the eukaryotic flagella. The electron microscopic study of a cilium or the flagellum shows that they are covered with plasma membrane. Their core, called the **axoneme,** possesses a number of microtubules running parallel to the long axis. The axoneme usually has nine pairs of doublets of radially arranged peripheral microtubules, and a pair of centrally located microtubules. Such an arrangement of axonemal microtubules is referred to as the 9+2 array. The central tubules are connected by bridges and are also enclosed by a central sheath, which is connected to one of the tubules of each peripheral doublets by a radial spoke. Thus, there are nine radial spokes. The peripheral doublets are also interconnected by linkers. Both the cilium and flagellum emerge from centriole-like structures called the basal bodies.

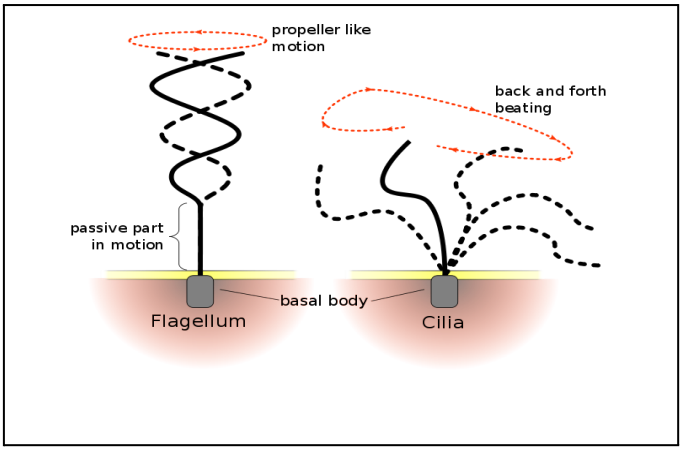

Figure 18: Beating Pattern of Flagellum & Cilia

Centrosome & Centrioles

Centrosome is an organelle usually containing two cylindrical structures called centrioles. They are surrounded by amorphous pericentriolar materials. Both the centrioles in a centrosome lie perpendicular to each other in which each has an organisation like the cartwheel. They are made up of nine evenly spaced peripheral fibrils of tubulin protein. Each of the peripheral fibril is a triplet. The adjacent triplets are also linked. The central part of the proximal region of the centriole is also proteinaceous and called the **hub**, which is connected with tubules of the peripheral triplets by radial **spokes** made of protein. The centrioles form the basal body of cilia or flagella, and spindle fibres that give rise to spindle apparatus during cell division in animal cells.

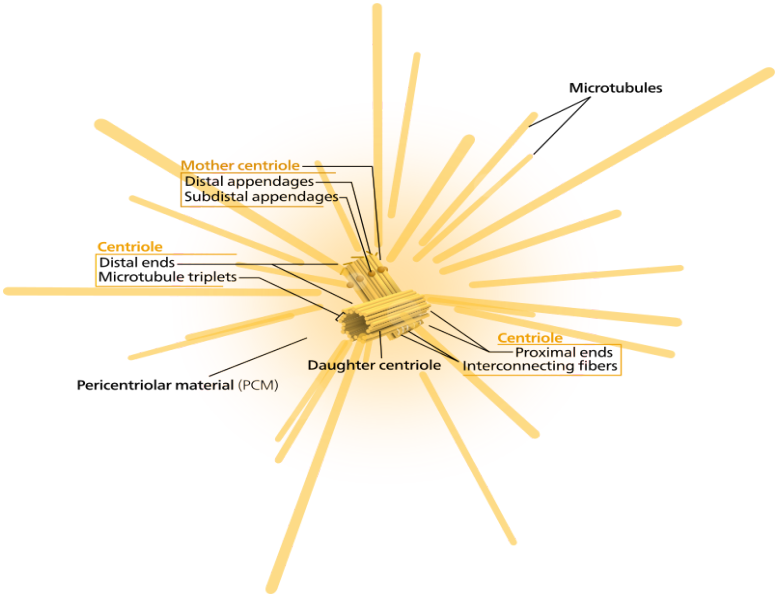

Figure 19: The structure of the centrosome

Nucleus

Nucleus as a cell organelle was first described by Robert Brown as early as 1831. Later the material of the nucleus stained by the basic dyes was given the name **chromatin** by Flemming. The interphase nucleus (nucleus of a cell when it is not dividing) has highly extended and elaborate nucleoprotein fibres called chromatin, nuclear matrix and one or more spherical bodies called **nucleoli** (sing.: nucleolus) (Figure 20). Electron microscopy has revealed that the nuclear envelope, which consists of two parallel membranes with a space between (10 to 50 nm) called the **perinuclear space**, forms a barrier between the materials present inside the nucleus and that of the cytoplasm. The outer membrane usually remains continuous with the endoplasmic reticulum and also bears ribosomes on it. At a number of places the nuclear envelope is interrupted by minute pores, which are formed by the fusion of its two membranes. These nuclear pores are the passages through which movement of RNA and protein molecules takes place in both directions between the nucleus and the cytoplasm. Normally, there is only one nucleus per cell, variations in the number of nuclei are also frequently observed. *Can you recollect names of organisms that have more than one nucleus per cell?* Some mature cells even lack nucleus, e.g., erythrocytes of many mammals and sieve tube cells of vascular plants. *Would you consider these cells as 'living'?* The nuclear matrix or the **nucleoplasm** contains nucleolus and chromatin. The nucleoli are spherical structures present in the nucleoplasm. The content of the nucleolus is continuous with the rest of the nucleoplasm as it is not a membrane bound structure. It is a site for active ribosomal RNA synthesis. Larger and more numerous nucleoli are present in cells actively carrying out protein synthesis.

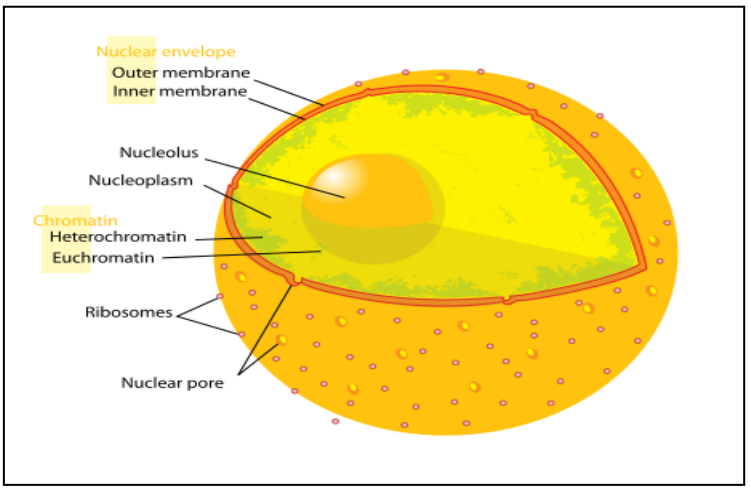

Figure 20: Eukaryotic Cell Nucleus

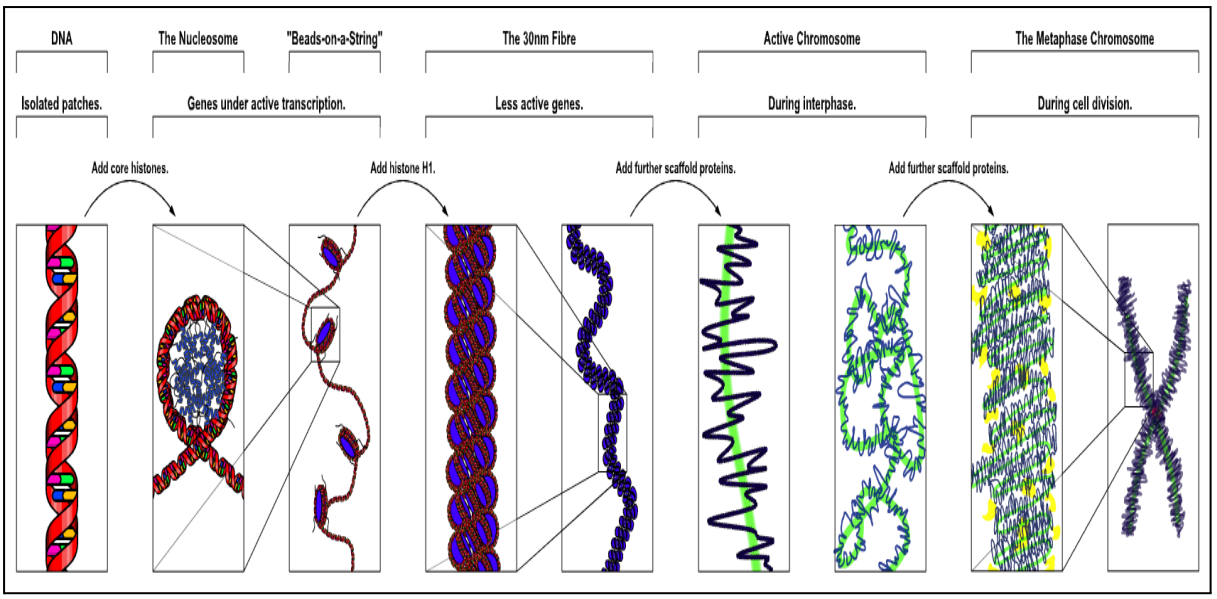

Figure 21: The major structures in DNA compaction

Microbodies

Many membrane bound minute vesicles called microbodies that contain various enzymes, are present in both plant and animal cells. A microbody is a type of organelle that is found in the cells of plants, protozoa, and animals. Organelles in the microbody family include peroxisomes, glyoxysomes, glycosomes and hydrogenosomes. In vertebrates, microbodies are especially prevalent in the liver and kidney organs. A **microbody** is usually a vesicle with a spherical shape, ranging from 0.2-1.5 micrometers in diameter.[1] Microbodies are found in the cytoplasm of a cell, but they are only visible with the use of an electron microscope. They are surrounded by a single phospholipid bilayer membrane and they contain a matrix of intracellular material including enzymes and other proteins, but they do not seem to contain any genetic material to allow them to self-replicate.

Microbodies contain enzymes that participate in the preparatory or intermediate stages of biochemical reactions within the cell. This facilitates the breakdown of fats, alcohols and amino acids. Generally microbodies are involved in detoxification of peroxides and in photo respiration in plants. Different types of microbodies have different functions.

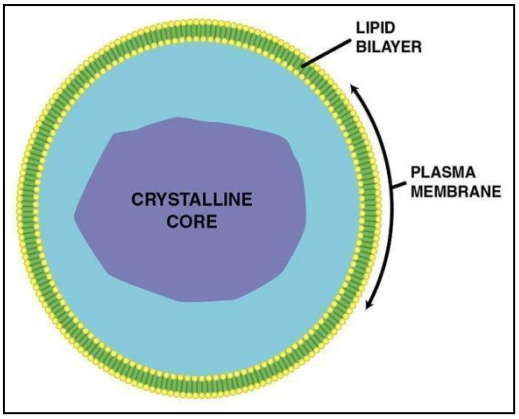

Figure 22: Microbody Structure- A Peroxisome

Summary

The present module discussed the internal structural components and their functions in a cell. The importance of each of the structural components referred to as 'organelle' has been highlighted along with their diagrammatic representation and electron microscopic view to enable a better understanding of their functions.