Eukaryotic Cell Structure and Function:
(Part 2)

11. **Microtubules** – Microtubules are microscopic tube-like structures (cylinders) made up of proteins called **tubulins** or **tubulin proteins**. Each tubulin unit is actually a **heterodimer** composed of one alpha (α) and one beta (β) tubulin (an **$\alpha\beta$-heterodimer**). The tubulin dimers polymerize (connect together in long chains) to form linear structures called **protofilaments**, each with an α-subunit at one end and a β-subunit at the other. This orientation is significant and consistent within each microtubule. The β-subunit end is called the positive end, while the α-subunit end is called the negative end. The wall of a typical microtubule is composed of thirteen protofilaments arranged as linear strands that spiral around the tubule forming imperfect helixes. In cross section these appear as thirteen globular protein dimers arranged in a circle. Microtubules can be lengthened or shortened by adding or removing tubulin dimers, and so exist as dynamic structures, changing as necessary for cellular function. Addition of tubulin dimers occurs most readily at the positive end while removal of dimers occurs most readily at the negative end.

    Microtubules function as support structures forming part of the **cytoskeleton**, and are also involved in intracellular motion. Proteins known as **microtubule-associated proteins** or **MAPs** interact with them in various ways. Two types of MAPs known as motor proteins are **Kinesin** and **Dynein**. Kinesin proteins (kine = movement) attach to and "walk" along protofilaments toward the positive end, and can carry cellular components such as small organelles, vesicles and other cytoskeletal elements along the microtubule. Dynein is also capable of moving along microtubules, but carries materials toward the negative end. Dynein is also involved in the movement of cilia and flagella. Both motor proteins **require ATP as an energy source** (have ATPase activity). Together they can allow materials to travel along microtubules in opposite directions at the same time, forming an intracellular highway.

12. **Cilia and flagella** – Cilia (singular = cilium) and flagella (singular = flagellum) are **locomotor structures** found on the surfaces of some eukaryotic cells. Cilia are typically short and hair-like while flagella are longer and whip-like. Both cilia and flagella are attached to **basal bodies**, surrounded by the cell membrane and supported by microtubules arranged in a specific pattern; typically nine groups of two around the periphery, and two at the center, i.e., 9x2 + 2 (although 9x2 + 1 and 9x2 + 0 variations can occur). The center two microtubules are attached to the outer nine pairs by "spokes" made of **dynein**, and this motor protein with its ATPase activity provides the motion required to bend the cilium or flagellum. The complex formed by microtubules and MAPs within a cilium or flagellum is called an **axoneme**, and is formed in coordination with a basal body (a centriole-like structure that has formed at or moved to the cell surface).

    Flagella are typically less numerous than cilia and most flagellated cells have only one or two. Cilia are usually quite numerous and often cover the entire cell surface. A single flagellum can pull a cell through its environment, or flagella in pairs can move together like the arms of a person swimming the breaststroke. Sometimes one flagellum in a pair pulls the cell forward while the other trails along at rest. Cilia move in a highly coordinated fashion, creating wave-like patterns that flow over the cell surface, or rotate around food-getting structures. Some cilia move single-celled organisms through their watery habitats while others move materials along the surfaces of stationary cells (as occurs within the human respiratory system). Many types of protozoa use cilia to sweep food materials toward and into a cellular "mouth" or **cytostome**.

13. **Centrioles** – Centrioles are cylindrical bodies made up of microtubules arranged in nine groups of three. They typically occur as a single pair oriented at right angles to one another within a region of the cell called the **centrosome**. In addition to forming the basal bodies producing cilia and flagella, centrioles coordinate the formation a structure known as the **spindle apparatus**, involved in chromosome separation during cell division (mitosis and meiosis).

    Some of the microtubules forming the spindle apparatus attach to chromosomes at their center (the kinetochore) and then pull the chromosomes apart by shortening (a process involving the removal of $\alpha\beta$-dimers as described above). Other microtubules move the centrosomes toward opposite sides of the cells, which also serves to pull the chromosomes apart.

14. **Actin microfilaments** – In addition to the tubulin protofilaments found in microtubules, eukaryotic cells produce **microfilaments** made up of **actin**, a protein usually thought of as being associated with muscle fibers (along with myosin). Actin monomers can be rapidly polymerized into filaments and taken apart as needed. Their microfilaments form a changable scaffolding just inside the cell membrane and are involved in a variety of cellular processes including **cytokinesis** (separation of the cytoplasm during cell division), **endocytosis, exocytosis** and the extension of the cytoplasm into finger-like locomotor structures called **pseudopodia**.

15. **Nucleus** – The nucleus is a relatively large, centrally located organelle surrounded by a double layer of membrane called the **nuclear envelope**, and containing the **nucleoplasm**. Though separated from the cytoplasm by two layers of membrane, the nucleus maintains contact by transporting materials through **nuclear pores** (regions with greater permeability). The nuclear envelope is also connected to the endoplasmic reticulum.

    Sometimes called the "brain of the cell", the nucleus is a control center involved in regulating physiological processes. Most of the DNA contained within eukaryotic cells is located here, and the associated genes determine which proteins the cell can make. The nucleoplasm includes a diffuse, thread-like material called chromatin and one or more dark-staining bodies called nucleoli.

    Chromatin is a thread-like material made up of DNA and proteins, some of which are **homogeneous** (all of the same type) and others **heterogeneous** (of different types). Groups of homogeneous proteins called **histones** help maintain the structural stability of DNA and influence gene expression by binding with DNA in structures called **nucleosomes.** Each nucleosome contains a histone octomer wrapped with DNA, and multiple nucleosomes are bound together by other histones to form bead-like chromatin strands. Heterogeneous proteins include **enzymes** of various types and are involved in processes such as DNA replication and transcription. During cell division, the chromatin threads are highly folded into discrete structures called **chromosomes**. These are clearly visible with a light microscope in some type of cells.

16. **Nucleoli** (singular **nucleolus**) – Nucleoli are dark-staining bodies sometimes visible within the nucleoplasm of certain cells. They are composed of **ribosomal-RNA** (r-RNA) and protein, and are sometimes referred to as the "pacemakers" of the cell because they influence protein synthesis. These bodies are the site of **r-RNA synthesis** and the **assembly of ribosomal subunits**. In essence, they make the ribosomes responsible for all protein synthesis.

17. **Spliceosomes** – Spliceosomes are small granular bodies made up of small or short-RNA (**s-RNA**) and protein. The s-RNA molecules present contain high levels of uracil (uridine nucleotides) and there are several different segments of s-RNA involved. The function of spliceosomes within the nucleus is to modify RNA molecules as they are transcribed from DNA. The process is called **post-transcriptional modification** and involves cutting out some regions of RNA and splicing the remaining pieces together (this will be explained in greater detail later).

18. **Inclusions** – Inclusions are bodies of material stored within the cytoplasm of eukaryotic cells and sometimes considered to be non-living. They frequently include such materials as crystals, fat droplets, pigment granules or glycogen. Some inclusions contain materials produced by the cell, while others contain materials taken from the outside environment.

19. **Cell Walls and Skeletons** – Cell walls and skeletons are rigid layers found outside the cell membranes of certain types of cells including algae, fungi and certain protozoa. Cell walls are generally associated with plant-like cells such as algae, while skeletons occur on animal-like protozoa. Fungi were originally classified with plants, so their rigid coverings are also called walls.

    Cell walls are typically made of **polysaccarides** such as cellulose, chitin, glucan, pectin or agar, but sometimes contain glass. They give cells a characteristic shape and provide protection against changes in osmotic pressure (e.g., in hypotonic environments) and potential predators.

    Skeletons occur on some animal-like, single celled organisms (protozoa), and are typically made of **glass** or **calcium carbonate**. They also give organisms a characteristic shape and provide protection against potential predators. Most skeletons do not provide protection against the osmotic pressure exerted by hypotonic environments because they are perforated by numerous holes.