THE CELL

Humans are made up of trillions of cells — the basic unit of life on earth. In this article, we explain some of the structures found in cells and describe a few of the many types of cell found in our bodies.

Cells can be thought of as tiny packages that contain minute factories, warehouses, transport systems, and power plants. They function on their own, creating their own energy and self-replicating — the cell is the smallest unit of life that can replicate.

However, cells also communicate with each other and connect to create a solid, well stuck-together animal. Cells build tissues, which form organs; and organs work together to keep the organism alive.

Robert Hook first discovered cells in 1665. He gave them their name because they resembled the cella (Latin for "small rooms") where monks lived in monasteries.

Life is both wonderful and majestic. Yet for all of its majesty, all organisms are composed of the fundamental unit of life, the cell. The cell is the simplest unit of matter that is alive. From the unicellular bacteria to multicellular animals, the cell is one of the basic organizational principles of biology. Let's look at some of the components of this basic organizer of living organisms.

Eukaryotic Cells and Prokaryotic Cells

There are two primary types of cells: eukaryotic cells and prokaryotic cells. Eukaryotic cells are called so because they have a true nucleus. The nucleus, which houses DNA, is contained within a membrane and separated from other cellular structures. Prokaryotic cells, however, have no true nucleus. DNA in a prokaryotic cell is not separated from the rest of the cell but coiled up in a region called the nucleoid.

Classification

As organized in the Three Domain System, prokaryotes include archaeans and bacteria. Eukaryotes include animals, plants, fungi and protists (ex. algae). Typically, eukaryotic cells are more complex and much larger than prokaryotic cells. On average, prokaryotic cells are about 10 times smaller in diameter than eukaryotic cells.

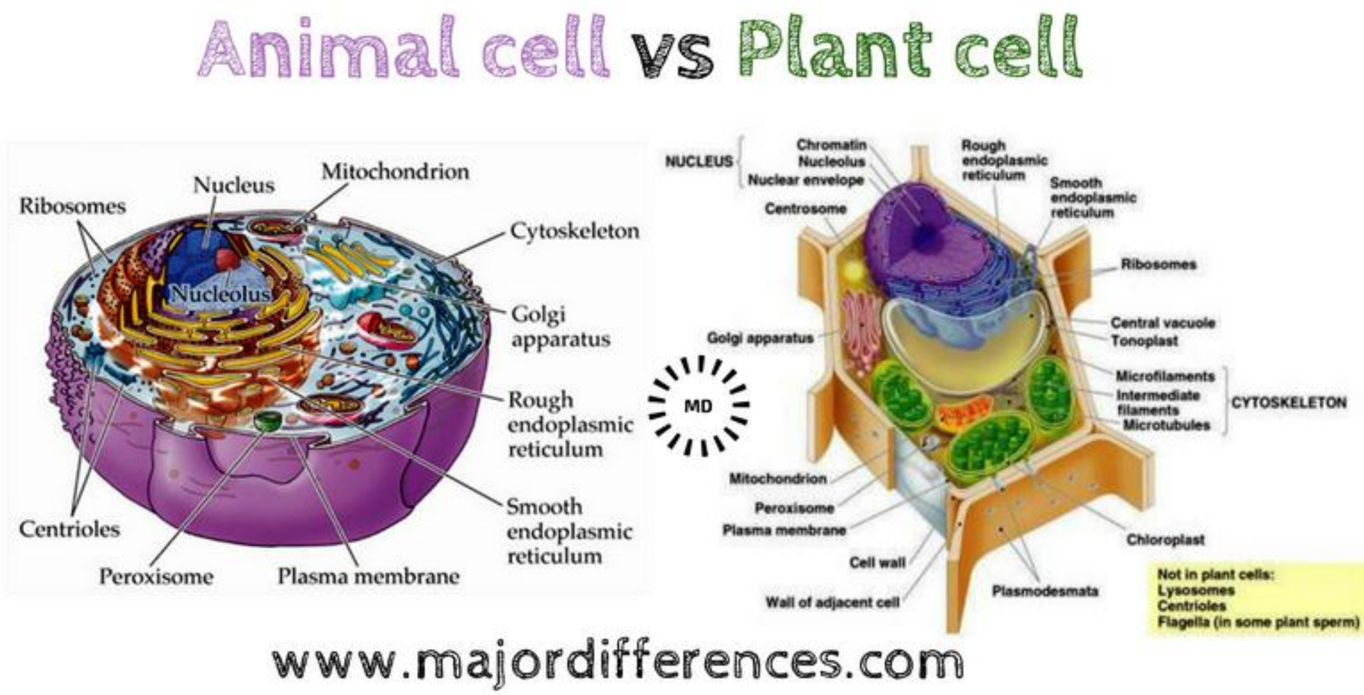
Cell Reproduction

Eukaryotes grow and reproduce through a process called mitosis. In organisms that also reproduce sexually, the reproductive cells are produced by a type of cell division called meiosis.

Most prokaryotes reproduce asexually and some through a process called binary fission. During binary fission, the single DNA molecule replicates and the original cell is divided into two identical daughter cells. Some eukaryotic organisms also reproduce asexually through processes such as budding, regeneration, and parthenogenesis.

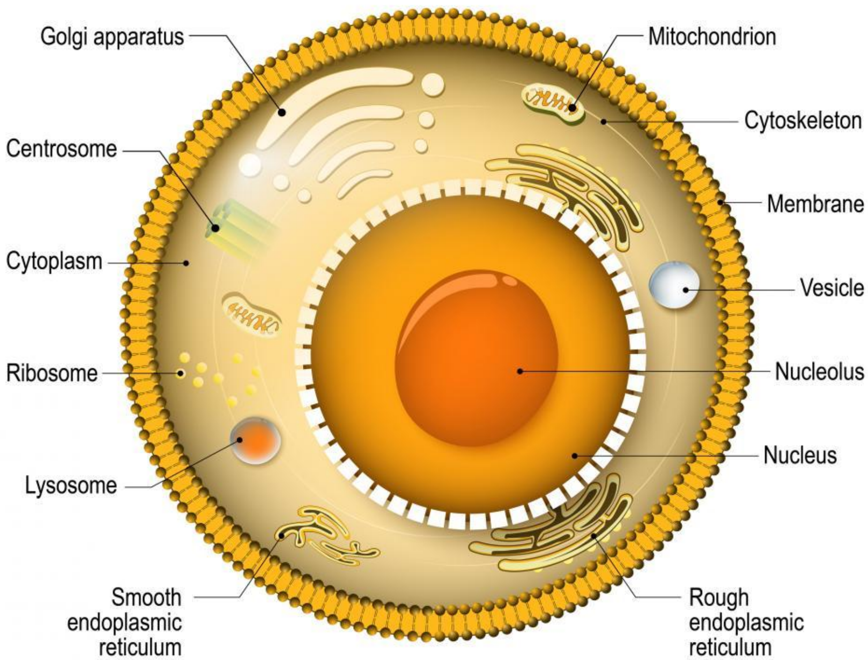
Cellular Respiration

Both eukaryotic and prokaryotic organisms get the energy they need to grow and maintain normal cellular function through cellular respiration. Cellular respiration has three main stages: glycolysis, the citric acid cycle, and electron transport. In eukaryotes, most cellular respiration reactions take place within the mitochondria. In prokaryotes, they occur in the cytoplasm and/or within the cell membrane.



INSIDE THE CELL

Different cell types can look wildly different, and carry out very different roles within the body.
For instance, a sperm cell resembles a tadpole, a female egg cell is spherical, and nerve cells are essentially thin tubes.
Despite their differences, they often share certain structures; these are referred to as organelles (mini-organs). Below are some of the most important:



A simplified diagram of a human cell.

Nucleus

The nucleus can be thought of as the cell's headquarters. There is normally one nucleus per cell, but this is not always the case, skeletal muscle cells, for instance, have two. The nucleus contains the majority of the cell's DNA (a small amount is housed in the mitochondria, see below). The nucleus sends out messages to tell the cell to grow, divide, or die.
The nucleus is separated from the rest of the cell by a membrane called the nuclear envelope; nuclear pores within the membrane allow through small molecules and ions, while larger molecules need transport proteins to help them through.

Plasma membrane

To ensure each cell remains separate from its neighbor, it is enveloped in a special membrane known as the plasma membrane. This membrane is predominantly made of phospholipids, which prevent water-based substances from entering the cell. The plasma membrane contains a range of receptors, which carry out a number of tasks, including being:

Gatekeepers: Some receptors allow certain molecules through and stop others.
Markers: These receptors act as name badges, informing the immune system that they are part of the organism and not a foreign invader.
Communicators: Some receptors help the cell communicate with other cells and the environment.
Fasteners: Some receptors help bind the cell to its neighbors.

Cytoplasm

Both lysosomes and peroxisomes are essentially bags of enzymes. Lysosomes contain enzymes that break down large molecules, including old parts of the cells and foreign material. Peroxisomes contain enzymes that destroy toxic materials, including peroxide.

Cytoskeleton

The cytoskeleton can be considered the scaffolding of the cell. It helps it maintain the correct shape. However, unlike regular scaffolding, the cytoskeleton is flexible; it plays a role in cell division and cell motility — the ability of some cells to move, such as sperm cells, for instance.
The cytoskeleton also helps in cell signaling through its involvement in the uptake of material from outside the cell (endocytosis) and is involved in moving materials around within the cell.

Endoplasmic reticulum

The endoplasmic reticulum (ER) processes molecules within the cell and helps transport them to their final destinations. In particular, it synthesizes, folds, modifies, and transports proteins.
The ER is made up of elongated sacs, called cisternae, held together by the cytoskeleton. There are two types: rough ER and smooth ER.

Golgi apparatus

Once molecules have been processed by the ER, they travel to the Golgi apparatus. The Golgi apparatus is sometimes considered the post office of the cell, where items are packaged and labeled. Once materials leave, they may be used within the cell or taken outside of the cell for use elsewhere.

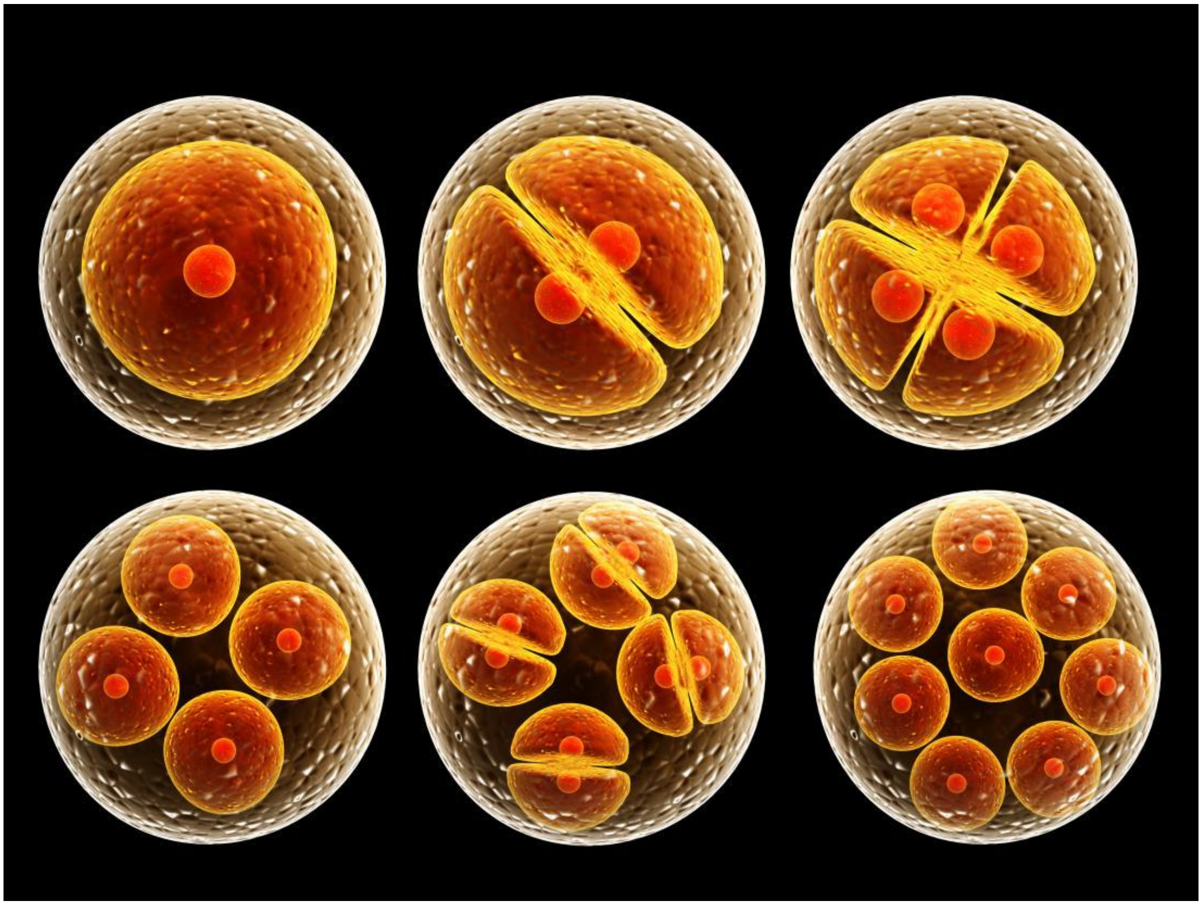
Mitochondria

Often referred to as the powerhouse of the cell, mitochondria help turn energy from the food that we eat into energy that the cell can use — adenosine triphosphate (ATP). However, mitochondria have a number of other jobs, including calcium storage and a role in cell death (apoptosis).

Ribosomes

In the nucleus, DNA is transcribed into RNA (ribonucleic acid), a molecule similar to DNA, which carries the same message. Ribosomes read the RNA and translate it into protein by sticking together amino acids in the order defined by the RNA.
Some ribosomes float freely in the cytoplasm; others are attached to the ER.

CELL DIVISION



Cell division is ongoing for our entire life.

Our body is constantly replacing cells. Cells need to divide for a number of reasons, including the growth of an organism and to fill gaps left by dead and destroyed cells after an injury, for instance.

There are two types of cell division: Mitosis and meiosis.

Mitosis

Mitosis is how most of the cells in the body divide. The "parent" cell splits into two "daughter" cells.
Both daughter cells have the same chromosomes as each other and the parent. They are referred to as diploid because they have two complete copies of the chromosomes.

Meiosis

Meiosis creates sex cells, such as the male sperm and female egg cells. In meiosis, a small portion of each chromosome breaks off and sticks to another chromosome; this is called genetic recombination.
This means that each of the new cells has a unique set of genetic information. It is this process that allows genetic diversity to occur.
So, in brief, mitosis helps us grow, and meiosis makes sure we are all unique.

CELL TYPES

When you consider the complexity of the human body, it is no surprise that there are hundreds of different types of cell. Below is a small selection of human cell types:

Stem cells

Stem cells are cells that are yet to choose what they are going to become. Some differentiate to become a certain cell type, and others divide to produce more stem cells. They are found in both the embryo and some adult tissues, such as bone marrow.

Bone cells

There are at least three primary types of bone cell:
Osteoclasts, which dissolve bone.
Osteoblasts, which form new bone.
Osteocytes, which are surrounded by bone and help communicate with other bone cells.

Blood cells

There are three major types of blood cell:
red blood cells, which carry oxygen around the body
white blood cells, which are part of the immune system
platelets, which help blood clot to prevent blood loss after injury

Muscle cells

Also called myocytes, muscle cells are long, tubular cells. Muscle cells are important for a huge range of functions, including movement, support, and internal functions, such as peristalsis — the movement of food along the gut.

Sperm cells

These tadpole-shaped cells are the smallest in the human body.
They are motile, meaning that they can move. They achieve this movement by using their tail (flagellum), which is packed with energy-giving mitochondria.
Sperm cells cannot divide; they only carry one copy of each chromosome (haploid), unlike the majority of cells, which carry two copies (diploid).

Female egg cell

Compared with the sperm cell, the female egg cell is a giant; it is the largest human cell. The egg cell is also haploid so that the DNA from the sperm and egg can combine to create a diploid cell.

Fat cells

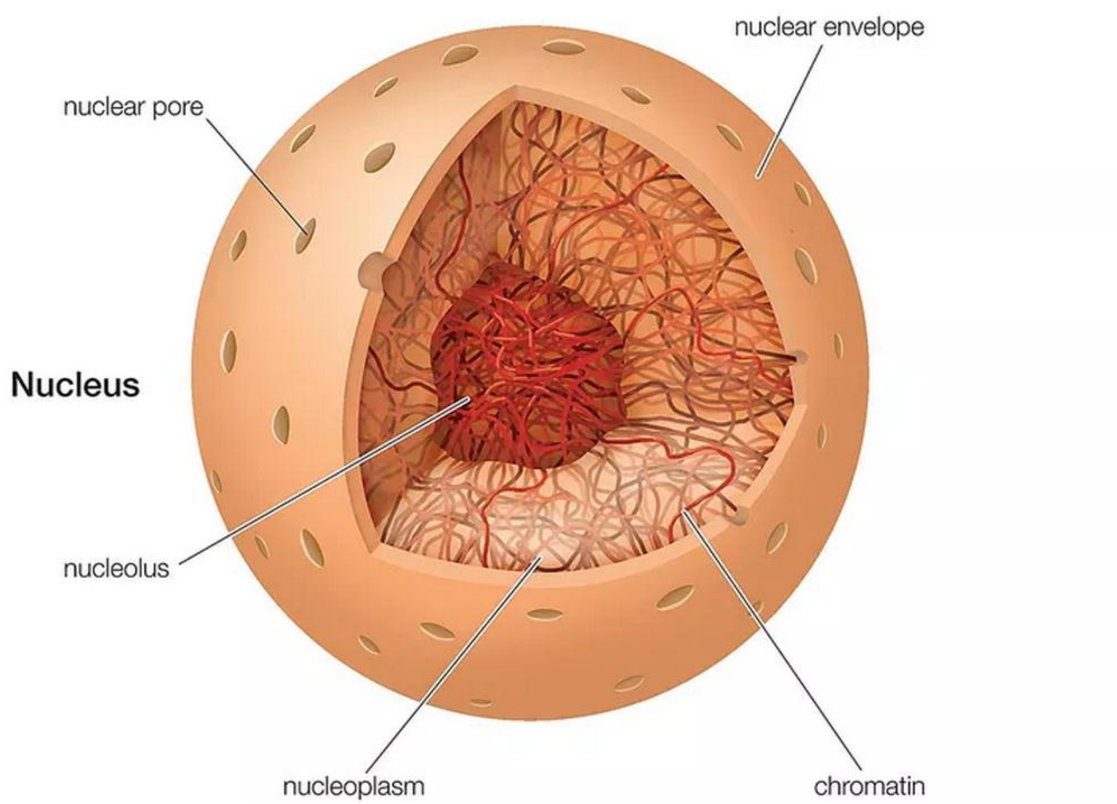
Fat cells are also called adipocytes and are the main constituent in adipose tissue. They contain stored fats called triglycerides that can be used as energy when needed. Once the triglycerides are used up, the fat cells shrink. Adipocytes also produce some hormones.

Nerve cells

Nerves cells are the communication system of the body. Also called neurons, they consist of two major parts — the cell body and nerve processes. The central body contains the nucleus and other organelles, and the nerve processes (axons or dendrites) run like long fingers, carrying messages far and wide. Some of these axons can be over 1 meter long.

Cell Organelles

Nucleus



The cell nucleus is a membrane bound structure that contains the cell's hereditary information and controls the cell's growth and reproduction. It is the command center of a eukaryotic cell and is commonly the most prominent organelle in a cell.

Distinguishing Characteristics

The cell nucleus is bound by a double membrane called the **nuclear envelope**. This membrane separates the contents of the nucleus from the cytoplasm. Like the cell membrane, the nuclear envelope consists of phospholipids that form a lipid bilayer. The envelope helps to maintain the shape of the nucleus and assists in regulating the flow of molecules into and out of the nucleus through **nuclear pores**. The nuclear envelope is connected with the **endoplasmic reticulum (ER)** in such a way that the internal compartment of the nuclear envelope is continuous with the lumen of the ER.
The nucleus is the organelle which houses chromosomes. Chromosomes consist of DNA, which contains heredity information and instructions for cell growth, development, and reproduction. When a cell is "resting" i.e. not dividing, the chromosomes are organized into long entangled structures called chromatin and not into individual chromosomes as we typically think of them.

Nucleoplasm

Nucleoplasm is the gelatinous substance within the nuclear envelope. Also called karyoplasm, this semi-aqueous material is similar to cytoplasm and is composed mainly of water with dissolved salts, enzymes, and organic molecules suspended within. The nucleolus and chromosomes are surrounded by nucleoplasm, which functions to cushion and protect the contents of the nucleus. Nucleoplasm also supports the nucleus by helping to maintain its shape. Additionally, nucleoplasm provides a medium by which materials, such as enzymes and nucleotides (DNA and RNA subunits), can be transported throughout the nucleus. Substances are exchanged between the cytoplasm and nucleoplasm through nuclear pores.

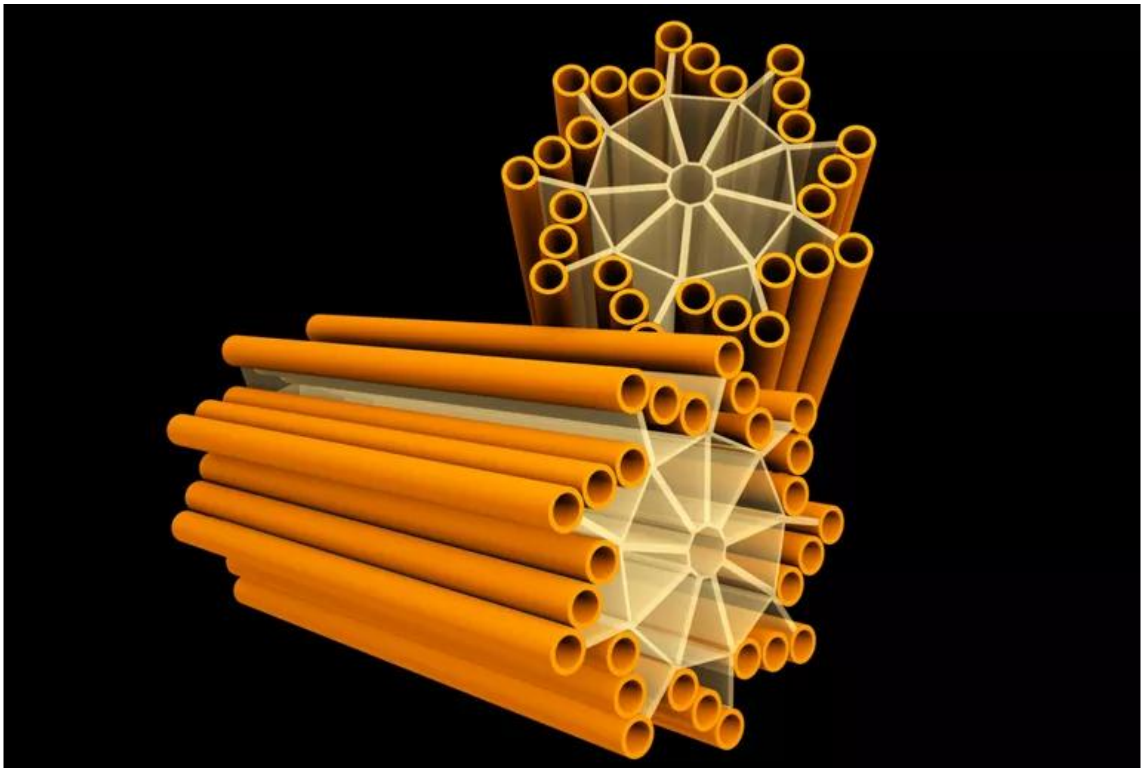
The Nucleolus

Contained within the nucleus is a dense, membrane-less structure composed of RNAand proteins called the nucleolus. The **nucleolus** contains nucleolar organizers, which are parts of chromosomes with the genes for ribosome synthesis on them. The nucleolus helps to synthesize ribosomes by transcribing and assembling ribosomal RNA subunits. These subunits join together to form a ribosome during protein synthesis.

Protein Synthesis

The nucleus regulates the synthesis of proteins in the cytoplasm through the use of messenger RNA (mRNA). Messenger RNA is a transcribed DNA segment that serves as a template for protein production. It is produced in the nucleus and travels to the cytoplasm through the nuclear pores of the nuclear envelope. Once in the cytoplasm, ribosomes and another RNA molecule called transfer RNA work together to translatemRNA to produce proteins.

Centrioles



Centriole's Two Main Functions

During mitosis or cell division, the centrosome and centrioles replicate and migrate to opposite ends of the cell. Centrioles help to arrange the microtubules that move chromosomes during cell division to ensure each daughter cell receives the appropriate number of chromosomes.

Centrioles are also important for the formation of cell structures known as cilia and flagella. Cilia and flagella, found on the outside surface of cells, aid in cellular movement. A centriole combined with several additional protein structures is modified to become a basal body. Basal bodies are the anchoring sites for moving cilia and flagella

In microbiology, centrioles are cylindrical cell structures that are composed of groupings of microtubules, which are tube-shaped molecules or strands of protein. Without centrioles, chromosomes would not be able to move during the formation of new cells.

Centrioles help to organize the assembly of microtubules during cell division. Simplified, chromosomes use the centriole's microtubules as a highway during the cell division process.

Chromosomes

Chromosome Structure

A **non-duplicated chromosome** is single-stranded and consists of a centromere region that connects two arm regions. The short arm region is called the **p arm** and the long arm region is called the **q arm**. The end region of a chromosome is called a telomere. Telomeres consist of repeating non-coding DNA sequences that get shorter as a cell divides.

Chromosome Duplication

Chromosome duplication occurs prior to the division processes of mitosis and meiosis. DNA replication processes allow correct chromosome numbers to be preserved after the original cell divides. A **duplicated chromosome** is comprised of two identical chromosomes called sister chromatids that are connected at the centromere region. Sister chromatids remain together until the end of the division process where they are separated by spindle fibers and enclosed within separate cells. Once the paired chromatids separate from one another, each is known as a daughter chromosome.

Chromosomes and Cell Division

One of the most important elements of successful cell division is the correct distribution of chromosomes. In mitosis, this means that chromosomes must be distributed between two daughter cells. In meiosis, chromosomes must be distributed among four daughter cells. The cell's spindle apparatus is responsible for moving chromosomes during cell division. This type of cell movement is due to interactions between spindle microtubules and motor proteins, which work together to manipulate and separate chromosomes. It is vitally important that a correct number of chromosomes be preserved in dividing cells. Errors that occur during cell division may result in individuals with unbalanced chromosome numbers. Their cells may have either too many or not enough chromosomes. This type of occurrence is known as **aneuploidy** and may happen in autosomal chromosomes during mitosis or in sex chromosomes during meiosis. Anomalies in chromosome numbers can result in birth defects, developmental disabilities, and death.

Chromosomes and Protein Production

Protein production is a vital cell process that is dependent upon chromosomes and DNA. DNA contains segments called genes that code for proteins. During protein production, the DNA unwinds and its coding segments are transcribed into an RNAtranscript. The RNA transcript is then translated to form a protein.

Chromosome Mutation

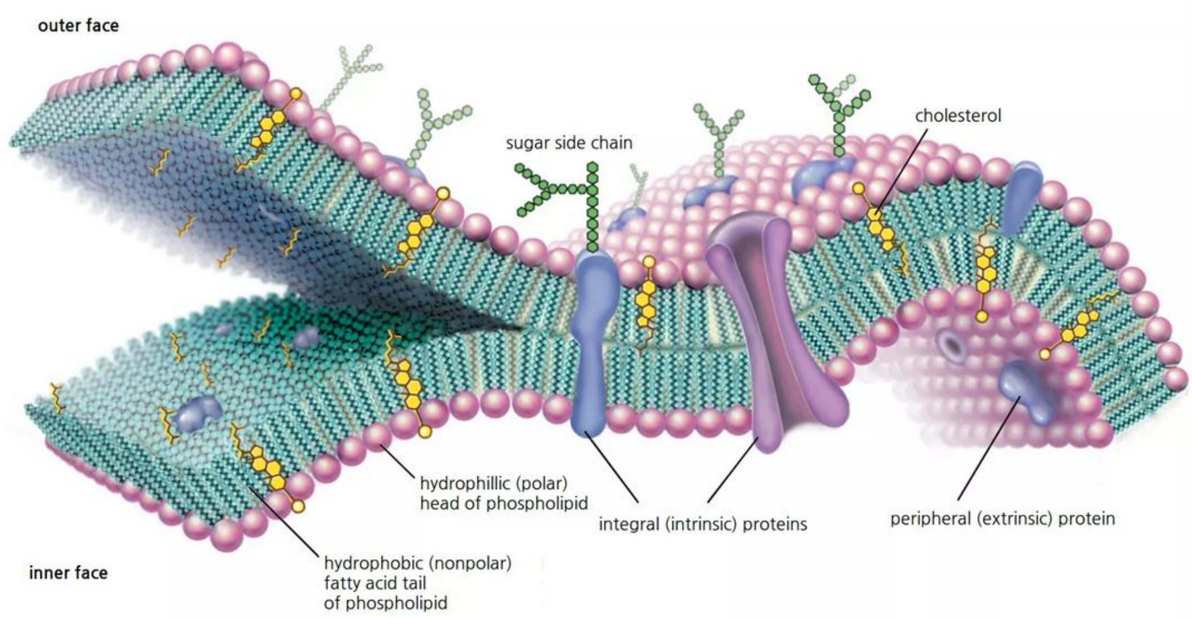
Chromosome mutations are changes that occur in chromosomes and are typically the result of either errors that happen during meiosis or by exposure to mutagens such as chemicals or radiation. Chromosome breakage and duplications can cause several types of chromosome structural changes that are typically harmful to the individual. These types of mutations result in chromosomes with extra genes, not enough genes, or genes that are in the wrong sequence. Mutations can also produce cells that have abnormal numbers of chromosomes. Abnormal chromosome numbers typically occur as a result of nondisjunction or the failure of homologous chromosomes to separate properly during meiosis.

Cell Membrane or Plasma Membrane

The cell membrane (plasma membrane) is a thin semi-permeable membrane that surrounds the cytoplasm of a cell. Its function is to protect the integrity of the interior of the cell by allowing certain substances into the cell while keeping other substances out. It also serves as a base of attachment for the cytoskeleton in some organisms and the cell wall in others. Thus the cell membrane also serves to help support the cell and help maintain its shape.

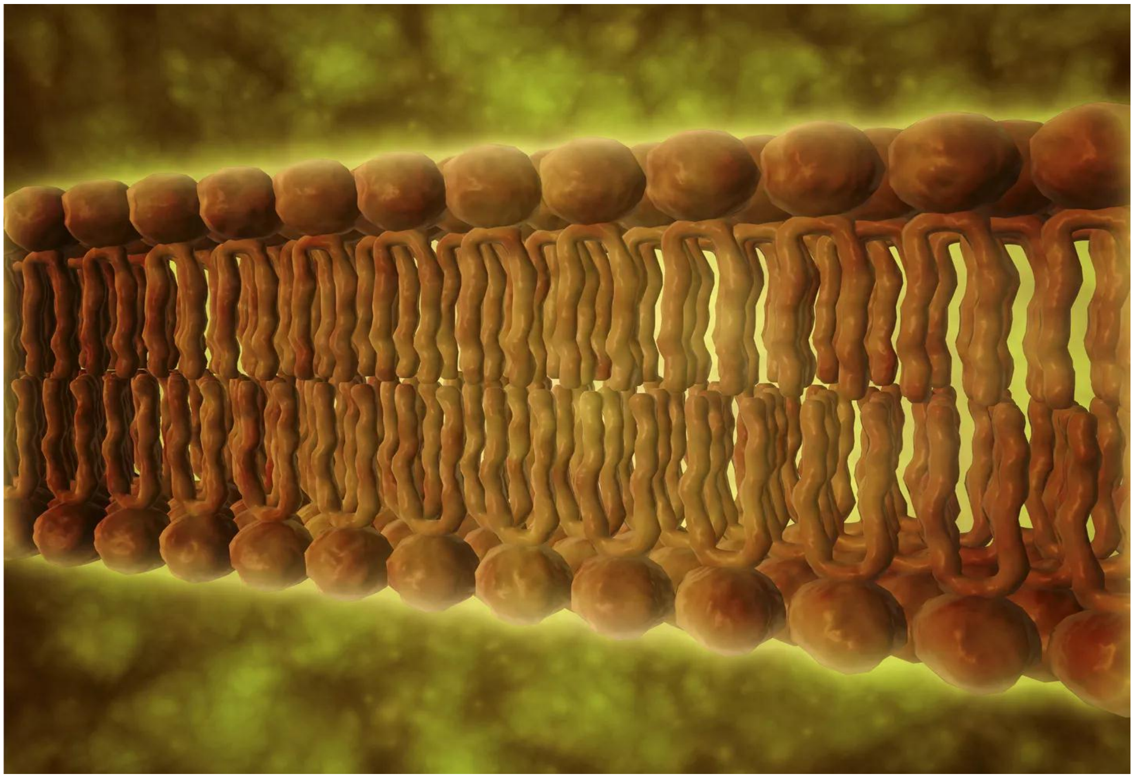
Another function of the membrane is to regulate cell growth through the balance of endocytosis and exocytosis. In endocytosis, lipids and proteins are removed from the cell membrane as substances are internalized. In exocytosis, vesicles containing lipids and proteins fuse with the cell membrane increasing cell size. Animal cells, plant cells, prokaryotic cells, and fungal cells have plasma membranes. Internal organelles are also encased by membranes.

Cell Membrane Structure



The cell membrane is primarily composed of a mix of proteins and lipids. Depending on the membrane's location and role in the body, lipids can make up anywhere from 20 to 80 percent of the membrane, with the remainder being proteins. While lipids help to give membranes their flexibility, proteins monitor and maintain the cell's chemical climate and assist in the transfer of molecules across the membrane.

Cell Membrane Lipids

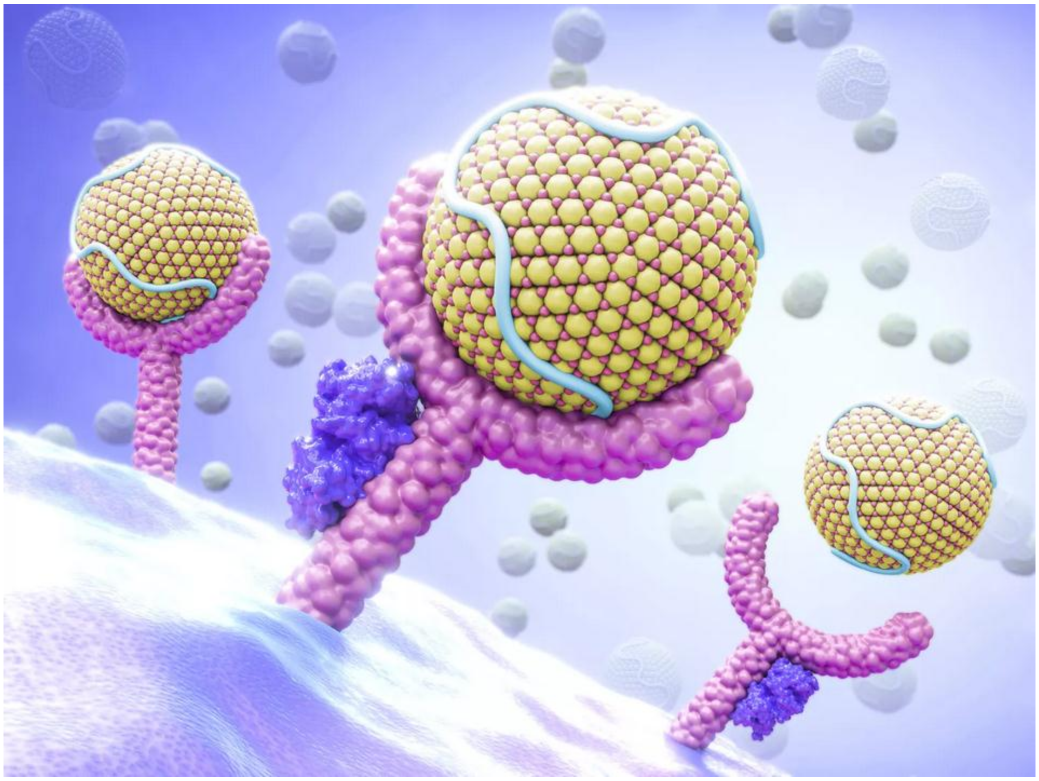


Phospholipids are a major component of cell membranes. Phospholipids form a lipid bilayer in which their hydrophilic (attracted to water) head areas spontaneously arrange to face the aqueous cytosol and the extracellular fluid, while their hydrophobic (repelled by water) tail areas face away from the cytosol and extracellular fluid. The lipid bilayer is semi-permeable, allowing only certain molecules to diffuse across the membrane.

Cholesterol is another lipid component of animal cell membranes. Cholesterol molecules are selectively dispersed between membrane phospholipids. This helps to keep cell membranes from becoming stiff by preventing phospholipids from being too closely packed together. Cholesterol is not found in the membranes of plant cells.

Glycolipids are located on cell membrane surfaces and have a carbohydrate sugar chain attached to them. They help the cell to recognize other cells of the body.

Cell Membrane Proteins



The cell membrane contains two types of associated proteins. **Peripheral membrane proteins** are exterior to and connected to the membrane by interactions with other proteins. **Integral membrane proteins** are inserted into the membrane and most pass through the membrane. Portions of these trans membrane proteins are exposed on both sides of the membrane. Cell membrane proteins have a number of different functions.

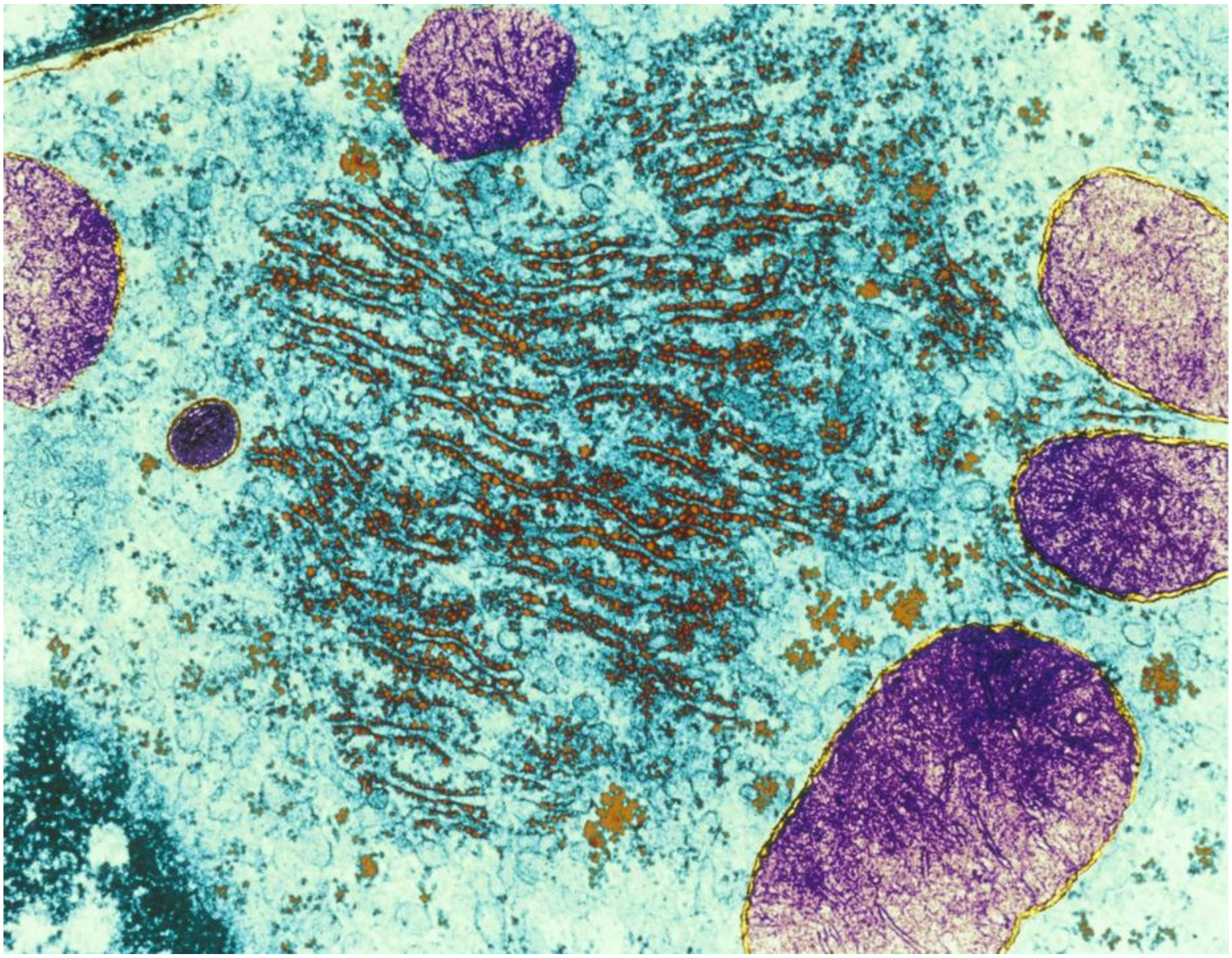
Structural proteins help to give the cell support and shape.

Cell membrane **receptor proteins** help cells communicate with their external environment through the use of hormones, neurotransmitters, and other signaling molecules.

Transport proteins, such as globular proteins, transport molecules across cell membranes through facilitated diffusion.

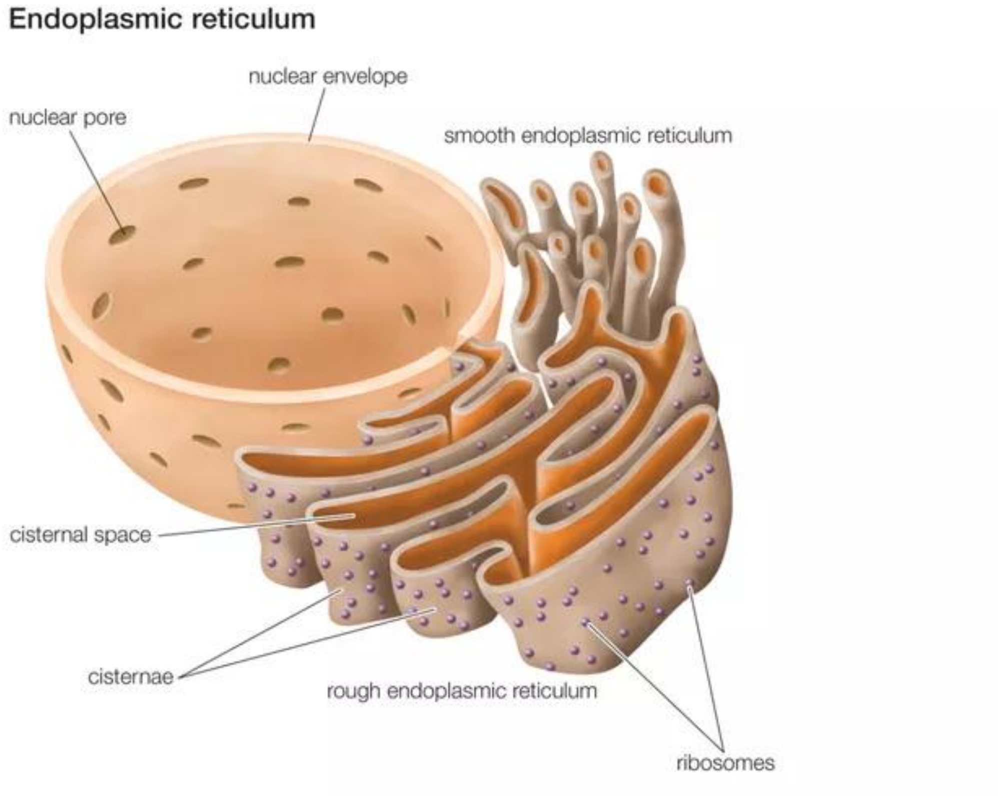
Glycoproteins have a carbohydrate chain attached to them. They are embedded in the cell membrane and help in cell to cell communications and molecule transport across the membrane.

Organelle Membranes



Some cell organelles are also surrounded by protective membranes. The nucleus, endoplasmic reticulum, vacuoles, lysosomes, and Golgi apparatus are examples of membrane-bound organelles. Mitochondria and chloroplasts are bound by a double membrane. The membranes of the different organelles vary in molecular composition and are well suited for the functions they perform. Organelle membranes are important to several vital cell functions including protein synthesis, lipid production, and cellular respiration.

Endoplasmic Reticulum



The endoplasmic reticulum (ER) is an important organelle in eukaryotic cells. It plays a major role in the production, processing, and transport of proteins and lipids. The ER produces transmembrane proteins and lipids for its membrane and for many other cell components including lysosomes, secretory vesicles, the Golgi apparatus, the cell membrane, and plant cell vacuoles.

The endoplasmic reticulum is a network of tubules and flattened sacs that serve a variety of functions in plant and animal cells. There are two regions of the ER that differ in both structure and function. One region is called rough ER because it has ribosomes attached to the cytoplasmic side of the membrane. The other region is called smooth ER because it lacks attached ribosomes. Typically, the smooth ER is a tubule network and the rough ER is a series of flattened sacs. The space inside of the ER is called the lumen. The ER is very extensive extending from the cell membrane through the cytoplasm and forming a continuous connection with the nuclear envelope. Since the ER is connected with the nuclear envelope, the lumen of the ER and the space inside the nuclear envelope are part of the same compartment.

Rough Endoplasmic Reticulum

The rough endoplasmic reticulum manufactures membranes and secretory proteins. The ribosomes attached to the rough ER synthesize proteins by the process of translation. In certain leukocytes (white blood cells), the rough ER produces antibodies. In pancreatic cells, the rough ER produces insulin. The rough and smooth ER are usually interconnected and the proteins and membranes made by the rough ER move into the smooth ER to be transferred to other locations. Some proteins are sent to the Golgi apparatus by special transport vesicles. After the proteins have been modified in the Golgi, they are transported to their proper destinations within the cell or exported from the cell by exocytosis.

Smooth Endoplasmic Reticulum

The smooth ER has a wide range of functions including carbohydrate and lipid synthesis. Lipids such as phospholipids and cholesterol are necessary for the construction of cell membranes. Smooth ER also serves as a transitional area for vesicles that transport ER products to various destinations. In liver cells the smooth ER produces enzymes that help to detoxify certain compounds. In muscles the smooth ER assists in the contraction of muscle cells, and in brain cells it synthesizes male and female hormones.

Ribosomes

Distinguishing Characteristics

Ribosomes are typically composed of two subunits: a large subunit and a small subunit. Ribosomal subunits are synthesized in the nucleolus and cross over the nuclear membrane to the cytoplasm through nuclear pores. These two subunits join together when the ribosome attaches to messenger RNA (mRNA) during protein synthesis. Ribosomes along with another RNA molecule, transfer RNA (tRNA), help to translate the protein-coding genes in mRNA into proteins. Ribosomes link amino acids together to form polypeptide chains, which are further modified before becoming functional proteins.

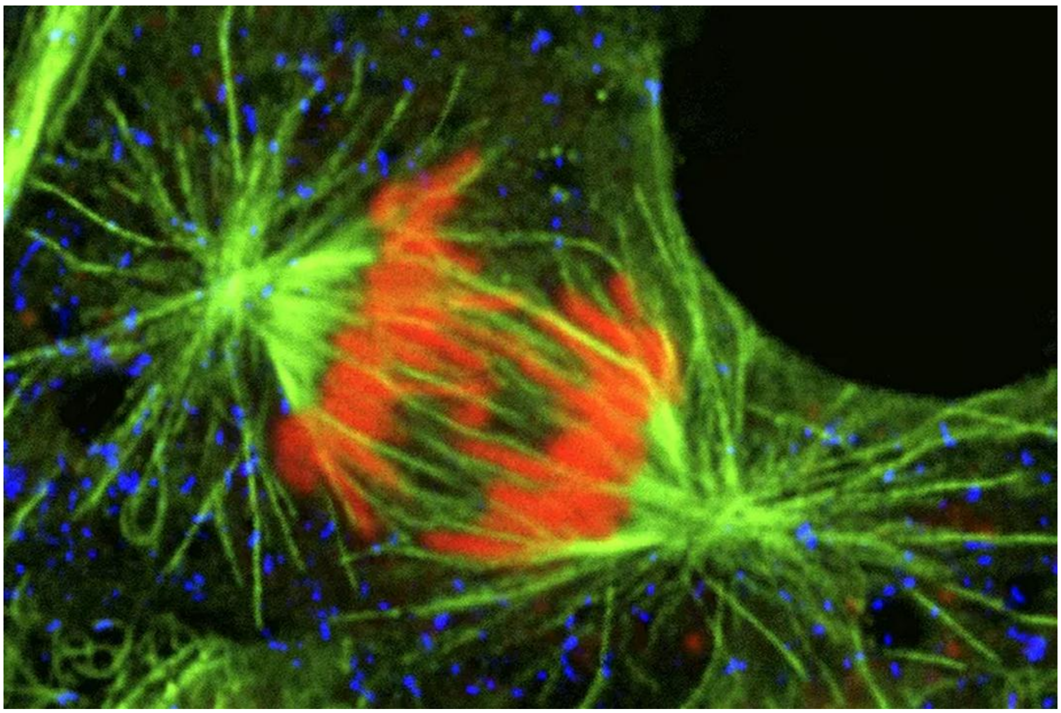
Location in the Cell

There are two places that ribosomes usually exist within a eukaryotic cell: suspended in the cytosol and bound to the endoplasmic reticulum. These ribosomes are called free ribosomes and bound ribosomes respectively. In both cases, the ribosomes usually form aggregates called polysomes or polyribosomes during protein synthesis. Polyribosomes are clusters of ribosomes that attach to a mRNA molecule during protein synthesis. This allows for multiple copies of a protein to be synthesized at once from a single mRNA molecule. Free ribosomes usually make proteins that will function in the cytosol (fluid component of the cytoplasm), while bound ribosomes usually make proteins that are exported from the cell or included in the cell's membranes. Interestingly enough, free ribosomes and bound ribosomes are interchangeable and the cell can change their numbers according to metabolic needs.

Ribosomes and Protein Assembly

Protein synthesis occurs by the processes of transcription and translation. In transcription, the genetic code contained within DNA is transcribed into an RNAversion of the code known as messenger RNA (mRNA). In translation, a growing amino acid chain, also called a polypeptide chain, is produced. Ribosomes help to translate mRNA and link amino acids together to produce a polypeptide chain. The polypeptide chain eventually becomes a fully functioning protein. Proteins are very important biological polymers in our cells as they are involved in virtually all cellfunctions.

Peroxisomes



Peroxisomes are small organelles found in eukaryotic plant and animal cells. Hundreds of these round organelles can be found within a cell. Also known as microbodies, peroxisomes are bound by a single membrane and contain enzymes that produce hydrogen peroxide as a by-product. The enzymes decompose organic molecules through oxidation reactions, producing hydrogen peroxide in the process. Hydrogen peroxide is toxic to the cell, but peroxisomes also contain an enzyme that is capable of converting hydrogen peroxide to water. Peroxisomes are involved in at least 50 different biochemical reactions in the body. Types of organic polymers that are broken down by peroxisomes include amino acids, uric acid, and fatty acids. Peroxisomes in liver cells help to detoxify alcohol and other harmful substances through oxidation.

Key points:

- Peroxisomes, also known as micro bodies, are organelles that are found in both eukaryotic animal and plant cells.
- A number of organic polymers are broken down by peroxisomes including amino acids, uric acid, and fatty acids. At least 50 different biochemical reactions in the body involve peroxisomes.

- Structurally, peroxisomes are surrounded by one membrane that encloses digestive enzymes. Hydrogen peroxide is produced as a by-product of peroxisome enzyme activity which decomposes organic molecules.
- Functionally, peroxisomes are involved in both the destruction of organic molecules and the synthesis of important molecules in the cell.
- Similar to mitochondria and chloroplast reproduction, peroxisomes have the ability to assemble themselves and reproduce by dividing in a process known as peroxisomal biogenesis.

Peroxisomes Function

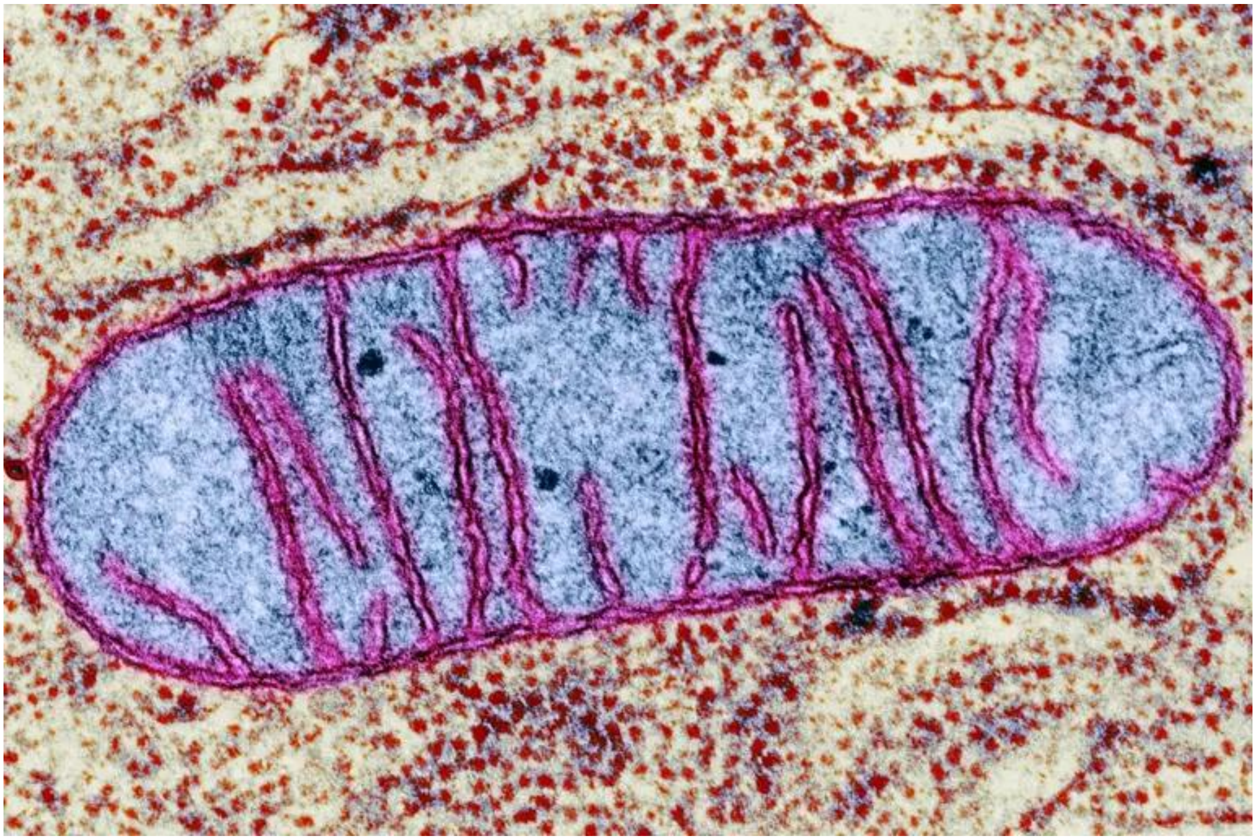
In addition to being involved in the oxidation and decomposition of organic molecules, peroxisomes are also involved in synthesizing important molecules. In animal cells, peroxisomes synthesize cholesterol and bile acids (produced in the liver). Certain enzymes in peroxisomes are necessary for the synthesis of a specific type of phospholipid that is necessary for the building of heart and brain white matter tissue. Peroxisome dysfunction can lead to the development of disorders that affect the central nervous system as perioxsomes are involved in producing the lipid covering (myelin sheath) of nerve fibers. The majority of peroxisome disorders are the result of gene mutations that are inherited as autosomal recessive disorders. This means that individuals with the disorder inherit two copies of the abnormal gene, one from each parent.

In plant cells, peroxisomes convert fatty acids to carbohydrates for metabolism in germinating seeds. They are also involved in photorespiration, which occurs when carbon dioxide levels become too low in plant leaves. Photorespiration conserves carbon dioxide by limiting the amount of CO_2 available to be used in photosynthesis.

Peroxisome Production

Peroxisomes reproduce similarly to mitochondria and chloroplasts in that they have the ability to assemble themselves and reproduce by dividing. This process is called peroxisomal biogenesis and involves the building of the peroxisomal membrane, intake of proteins and phospholipids for organelle growth, and new peroxisome formation by division. Unlike mitochondria and chloroplasts, peroxisomes have no DNA and must take in proteins produced by free ribosomes in the cytoplasm. The uptake of proteins and phospholipids increases growth and new peroxisomes are formed as the enlarged peroxisomes divide.

Mitochondria



Cells are the basic components of living organisms. The two major types of cells are prokaryotic and eukaryotic cells. Eukaryotic cells have membrane-bound organelles that perform essential cell functions. **Mitochondria** are considered the "power houses" of eukaryotic cells. What does it mean to say that mitochondria are the cell's power producers? These organelles generate power by converting energy into forms that are usable by the cell. Located in the cytoplasm, mitochondria are the sites of cellular respiration. Cellular respiration is a process that ultimately generates fuel for the cell's activities from the foods we eat. Mitochondria produce the energy required to perform processes such as cell division, growth, and cell death.

Mitochondria have a distinctive oblong or oval shape and are bounded by a double membrane. The inner membrane is folded creating structures known as **cristae**. Mitcohondria are found in both animal and plant cells. They are found in all body cell types, except for mature red blood cells. The number of mitochondria within a cell varies depending on the type and function of the cell. As mentioned, red blood cells do not contain mitochondria at all. The absence of mitochondria and other organelles in red blood cells leaves room for the millions of hemoglobin molecules needed in order to transport oxygen throughout the body. Muscle cells, on the other hand, may contain thousands of mitochondria needed to provide the energy required for muscle activity. Mitochondria are also abundant in fat cells and liver cells.

Mitochondrial DNA

Mitochondria have their own DNA, ribosomes and can make their own proteins. **Mitochondrial DNA (mtDNA)** encodes for proteins that are involved in electron transport and oxidative phosphorylation, which occur in cellular respiration. In oxidative phosphorylation, energy in the form of ATP is generated within the mitochondrial matrix. Proteins synthesized from mtDNA also encode for the production of the RNA molecules transfer RNA and ribosomal RNA.

Mitochondrial DNA differs from DNA found in the cell nucleus in that it does not possess the DNA repair mechanisms that help prevent mutations in nuclear DNA. As a result, mtDNA has a much higher mutation rate than nuclear DNA. Exposure to reactive oxygen produced during oxidative phosphorylation also damages mtDNA.

Mitochondrial Membranes

Mitochondria are bounded by a double membrane. Each of these membranes is a phospholipid bilayer with embedded proteins. The **outermost membrane** is smooth while the **inner membrane** has many folds. These folds are called **cristae**. The folds enhance the "productivity" of cellular respiration by increasing the available surface area. Within the inner mitochondrial membrane are series of protein complexes and electron carrier molecules, which form the **electron transport chain (ETC)**. The ETC represents the third stage of aerobic cellular respiration and the stage where the vast majority of ATP molecules are generated. **ATP** is the body's main source of energy and is used by cells to perform important functions, such as muscle contraction and cell division.

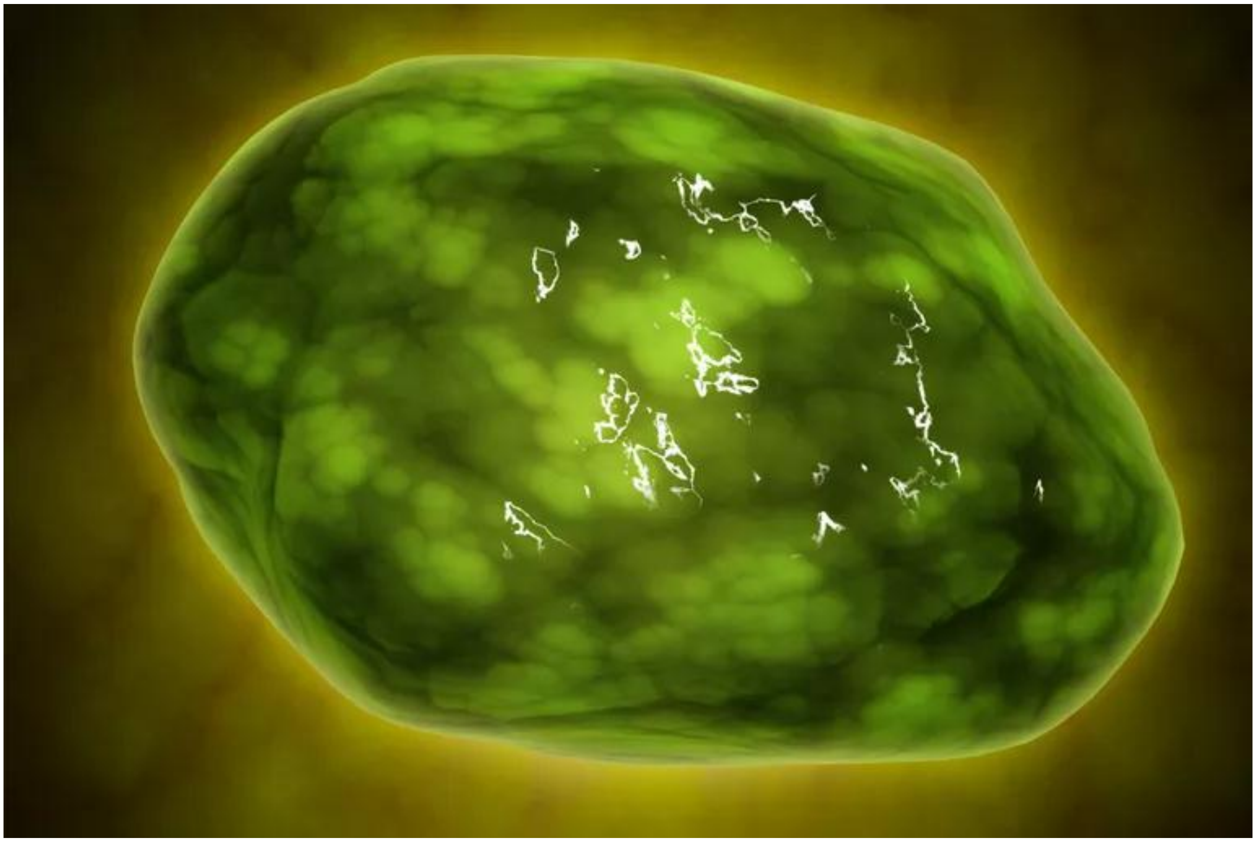
Mitochondrial Spaces

The double membranes divide the mitochondrion into two distinct parts: the **intermembrane space** and the **mitochondrial matrix**. The intermembrane space is the narrow space between the outer membrane and the inner membrane, while the mitochondrial matrix is the area that is completely enclosed by the innermost membrane. The **mitochondrial matrix** contains mitochondrial DNA(mtDNA), ribosomes, and enzymes. Several of the steps in cellular respiration, including the Citric Acid Cycle and oxidative phosphorylation occur in the matrix due to its high concentration of enzymes.

Mitochondrial Reproduction

Mitochondria are semi-autonomous in that they are only partially dependent on the cell to replicate and grow. They have their own DNA, ribosomes, make their own proteins, and have some control over their reproduction. Similar to bacteria, mitochondria have circular DNA and replicate by a reproductive process called binary fission. Prior to replication, mitochondria merge together in a process called fusion. Fusion is needed in order to maintain stability, as without it, mitochondria will get smaller as they divide. These smaller mitochondria are not able to produce sufficient amounts of energy needed for proper cell function.

Lysosomes



Lysosomes

Lysosomes are spherical membranous sacs of enzymes. These enzymes are acidic hydrolase enzymes that can digest cellular macromolecules. The lysosome membrane helps to keep its internal compartment acidic and separates the digestive enzymes from the rest of the cell. Lysosome enzymes are made by proteins from the endoplasmic reticulum and enclosed within vesicles by the Golgi apparatus. Lysosomes are formed by budding from the Golgi complex.

Lysosome Enzymes

Lysosomes contain various hydrolytic enzymes (around 50 different enzymes) that are capable of digesting nucleic acids, polysaccharides, lipids, and proteins. The inside of a lysosome is kept acidic as the enzymes within work best in an acidic environment. If a lysosome's integrity is compromised, the enzymes would not be very harmful in the cell's neutral cytosol.

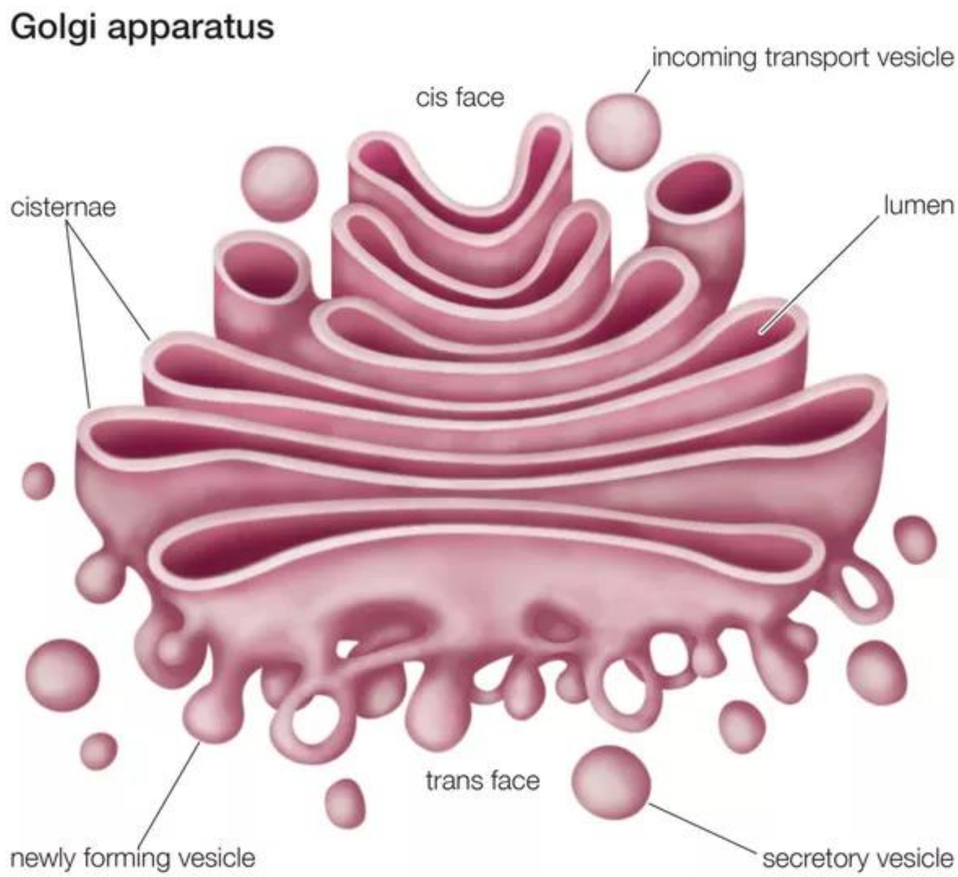
Lysosome Formation

Lysosomes are formed from the fusion of vesicles from the Golgi complex with endosomes. Endosomes are vesicles that are formed by endocytosis as a section of the plasma membrane pinches off and is internalized by the cell. In this process, extracellular material is taken up by the cell. As endosomes mature, they become known as late endosomes. Late endosomes fuse with transport vesicles from the Golgi that contain acid hydrolases. Once fused, these endosomes eventually develop into lysosomes.

Lysosome Function

Lysosomes act as the "garbage disposal" of a cell. They are active in recycling the cell's organic material and in the intracellular digestion of macromolecules. Some cells, such as white blood cells, have many more lysosomes than others. These cells destroy bacteria, dead cells, cancerous cells, and foreign matter through cell digestion. Macrophages engulf matter by phagocytosis and enclose it within a vesicle called a phagosome. Lysosomes within the macrophage fuse with the phagosome releasing their enzymes and forming what is known as a phagolysosome. The internalized material is digested within the phagolysosome. Lysosomes are also necessary for the degradation of internal cell components such as organelles. In many organisms, lysosomes are also involved in programmed cell death.

Golgi Apparatus



The Golgi apparatus is the "manufacturing and shipping center" of a eukaryotic cell.

The Golgi apparatus, sometimes called the Golgi complex or Golgi body, is responsible for manufacturing, warehousing, and shipping certain cellular products, particularly those from the endoplasmic reticulum (ER). Depending on the type of cell, there can be just a few complexes or there can be hundreds. Cells that specialize in secreting various substances typically have a high number of Golgi.

Distinguishing Characteristics

A Golgi apparatus is composed of flat sacs known as cisternae. The sacs are stacked in a bent, semicircular shape. Each stacked grouping has a membrane that separates its insides from the cell's cytoplasm. Golgi membrane protein interactions are responsible for its unique shape. These interactions generate the force that shapes this organelle. The Golgi apparatus is very polar. Membranes at one end of the stack differ in both composition and in thickness from those at the other end. One end (cis face) acts as the "receiving" department while the other (trans face) acts as the "shipping" department. The cis face is closely associated with the ER.

Molecule Transport and Modification

Molecules synthesized in the ER exit via special transport vehicles which carry their contents to the Golgi apparatus. The vesicles fuse with Golgi cisternae releasing their contents into the internal portion of the membrane. The molecules are modified as they are transported between cisternae layers. It is thought that individual sacs are not directly connected, thus the molecules move between cisternae through a sequence of budding, vesicle formation, and fusion with the next Golgi sac. Once the molecules reach the trans face of the Golgi, vesicles are formed to "ship" materials to other sites.

The Golgi apparatus modifies many products from the ER including proteins and phospholipids. The complex also manufactures certain biological polymers of its own. The Golgi apparatus contains processing enzymes, which alter molecules by adding or removing carbohydrate subunits. Once modifications have been made and molecules have been sorted, they are secreted from the Golgi via transport vesicles to their intended destinations. Substances within the vesicles are secreted by exocytosis. Some of the molecules are destined for the cell membrane where they aid in membrane repair and intercellular signaling. Other molecules are secreted to areas outside of the cell. Transport vesicles carrying these molecules fuse with the cell membrane releasing the molecules to the exterior of the cell. Still other vesicles contain enzymes that digest cellular components. These vesicle form cell structures called lysosomes. Molecules dispatched from the Golgi may also be reprocessed by the Golgi.

The Golgi apparatus or Golgi complex is capable of disassembly and reassembly. During the early stages of mitosis, the Golgi disassembles into fragments which further breakdown into vesicles. As the cell progresses through the division process, the Golgi vesicles are distributed between the two forming daughter cells by spindle microtubules. The Golgi apparatus reassembles in the telophase stage of mitosis. The mechanisms by which the Golgi apparatus assembles are not yet understood.

Cilia and Flagella

What Are Cilia and Flagella?

Both prokaryotic and eukaryotic cells contain structures known as **cilia and flagella**. These extensions from the cell surface aid in cell movement. They also help to move substances around cells and direct the flow of substances along tracts. Cilia and flagella are formed from specialized groupings of microtubules called basal bodies. If the protrusions are short and numerous they are termed cilia. If they are longer and less numerous (usually only one or two) they are termed flagella.

What Are Their Distinguishing Characteristics?

Cilia and flagella have a core composed of microtubules that are connected to the plasma membrane and arranged in what is known as a **9 + 2 pattern**. The pattern is so named because it consists of a ring of nine microtubule paired sets (doublets) that encircle two singular microtubules. This microtubule bundle in a 9 + 2 arrangement is called an **axoneme**. The base of cilia and flagella is connected to the cell by modified centriole structures called **basal bodies**. Movement is produced when the nine paired microtubule sets of the axoneme slide against one another causing cilia and flagella to bend. The motor protein dynein is responsible for generating the force required for movement. This type of organization is found in most eukaryotic cilia and flagella.

What Is Their Function?

The primary function of cilia and flagella is movement. They are the means by which many microscopic unicellular and multicellular organisms move from place to place. Many of these organisms are found in aqueous environments, where they are propelled along by the beating of cilia or the whip-like action of flagella. Protists and bacteria, for example, use these structures to move toward a stimulus (food, light), away from a stimulus (toxin), or to maintain their position in a general location. In higher organisms, cilia is often used to propel substances in a desired direction. Some cilia, however, do not function in movement but in sensing. **Primary cilia**, found in some organs and vessels, can sense changes in environmental conditions. Cells lining the walls of blood vessels exemplify this function. The primary cilia in blood vessel endothelial cells monitor the force of blood flow through the vessels.

Where Can Cilia and Flagella Be Found?

Both cilia and flagella are found in numerous types of cells. For instance, the sperm of many animals, algae, and even ferns have flagella. Prokaryotic organisms may also possess a single flagellum or more. A bacterium, for example, may have: one flagellum located at one end of the cell (montrichous), one or more flagella located at both ends of the cell (amphitrichous), several flagella at one end of the cell (lophotrichous), or flagella distributed all around the cell (peritrichous). Cilia can be found in areas such as the respiratory tract and female reproductive tract. In the respiratory tract, cilia helps to sweep mucus containing dust, germs, pollen, and other debris away from the lungs. In the female reproductive tract, cilia helps to sweep sperm in the direction of the uterus.