OBJECTIVES

- Explain the terms of biology, cytology and cell biology. Then give good idea about types of cells and the big difference between them in addition to understanding and exploration the content of each of them and the importance and action of each part as alone.

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Biology is a science that studies living things & provides an understanding of life.

Cell biology is a specialized branch of biology which deals with the study of structure and function of cell organelles.

Cytology is the science that deals with studies of the cell.

The cell is the lowest level of structure capable of performing all the activities of life. The first cells were observed and named by Robert Hooke in 1665 from slice of cork.

Cell Theory
• Cells are the fundamental unit of life – nothing less than a cell is alive.
• All organisms are constructed of and by cells.
• All cells arise from preexisting cells. Cells contain the information necessary for their own reproduction. No new cells are originating spontaneously on earth today.
• Cells are the functional units of life. All biochemical processes are carried out by cells.
• Groups of cells can be organized and function as multicellular organisms
• Cells of multicellular organisms can become specialized in form and function to carry out sub processes of the multicellular

Some organisms consist of a single cells = unicellular organism, others are multicellular aggregates of specialized cells.

Whether multicellular or unicellular, all organisms must accomplish the same functions:
• Uptake and processing of nutrients
• Excretion of wastes
• Response to environmental stimuli
• And reproduction among other
How We Study Cells?
- microscope
- cell fractionation

Most cells are between 1–100 μm in diameter which can be visualized by light microscope.

Cells are divided to 2 types:

1. **The prokaryotic cell.** e.g. bacteria.
   Characterized by:
   - Small (1–10 μm) long.
   - Have cell wall outside the cell membrane.
   - Lack a nuclear envelope separating the genetic material (DNA) from other cellular constituents.
   - Have no histones (specific basic proteins) bound to their DNA.
   - Have no membranous organelles.
   - Prokaryotic cells divide by **binary fission**.

2. **The eukaryotic cells.** e.g. amoeba.
   Characterized by:
   - Larger than prokaryotic cells.
   - Have distinct nucleus surrounded by nuclear envelope.
   - Histones are associated with the genetic material.
   - Numerous membrane-limited organelles are found in the cytoplasm.
- Eukaryotic cells divided by mitosis & meiosis

**So Basic features of cells.**
- All cells are bounded by a plasma membrane.
- The semifluid substance within the membrane is the cytosol, containing the organelles.
- All cells contain chromosomes which carry genes in the form of DNA.
- All cells also have ribosomes, tiny organelles that make proteins using the instructions contained in genes.

**And main difference are.**
- Eukaryotic cell, chromosomes are contained in a membrane-enclosed organelle, the nucleus.
- Prokaryotic cell, the DNA is concentrated in the nucleoid without a membrane separating it from the rest of the cell.

**In general**
Eukaryotic cells are much bigger than prokaryotic cells.
Most bacteria are 1–10 microns in diameter.
Eukaryotic cells are typically 10–100 microns in diameter.
- A large cell requires "much more" in terms of the cellular components.
- There is less surface area compared to the volume in terms of uptake from the environment
- Distribution of nutrients from one portion of a large cell to another simply required a distance to travel.
The Cytoplasm

Basically, all human cells can be divided into two major compartments, the nucleus and the cytoplasm. The term protoplasm refers to the entire contents of the cell. The nucleus resides within the interior of the cell, is surrounded by a nuclear envelope, and contains nucleoplasm. It is from the nucleus that genetic instructions are conveyed to the rest of the cell.

The cytoplasm of eukaryotic cells is divided into several distinct compartments by membranes that regulate the intracellular traffic of ions and molecules.

Functions of the cytoplasm

• Regulates exchange of material outside the cell
• Biosynthesis of macromolecules
• Generation of energy
• Cell movement

Components of the cytoplasm

• Cytoplasmic organelles
• Cytoplasmic inclusions
• Cytoplasmic matrix or cytosol

Cytoplasmic Organelles

As the name implies, cytoplasmic organelles are small structures within the cytoplasm that carry out specific functions. They are classified as either membranous or non-membranous organelles, depending on whether a membrane surrounds them.

• Membranous Organelles

The Cell Membrane

The first membranous organelle we will consider is the cell membrane, also called the plasma membrane or plasmalemma. The cell membrane is important not only because it delimits the interior of the cell from the external environment, but also because it serves the essential functions of regulating the passage of material to and from the cell, and communicating with other cells through various surface receptors.
The structure & function of cell plasma membrane are critically depend on:

a) Universally, a plasma membrane protects a cell by acting as a barrier between its living contents and surrounding environment.
b) It regulates what goes into & out of the cell & marks the cell as being unique to the organism.
c) In multi cellular organisms, cell junctions requiring specialized features of the plasma membranes connect cells together in specific ways and pass on information to neighboring cells so that the activities of tissues and organs are coordinated.
d) Investigators noted that lipid- soluble molecules entered cells more rapidly than water- soluble molecules.
e) This promoted them to suggest that lipids are a component of the plasma membrane.
f) The formation of biological membranes is based on the properties of lipids, and all cell membranes share a common structural organization, bilayers of phospholipids with associated proteins.
g) The fluid- mosaic model of membrane structure is widely accepted at this time which proposed that the membrane is a fluid phospholipid bilayer in which protein molecules are either partially or wholly embedded and so the mosaic pattern of membrane is dependent on proteins which vary in structure and function.

**Membrane lipids.**

Lipid constitutes 50% of the mass of most cell membranes, although this proportion varies depending on the type of membrane.

1. **phospholipids.**
   - The fundamental building blocks of all cell membranes, which are amphipathic molecules, consisting of two hydrophobic fatty acid chains linked to a phosphate- containing hydrophilic head group.
The hydrophilic (polar) heads of the phospholipids molecules face the intercellular and extracellular fluids.

- The hydrophobic (non polar) tail face each other in the membrane interior.
- At body temperature, the phospholipid bilayer of the plasma membrane has the consistancy of olive oil. The entire phospholipid molecule can move side away, all these means that the cell is pliable (مرنة).

2. **glycolipids**
   - Have a structure similar to phospholipids except that the hydrophilic head is a variety of sugars joined to form a straight or branching carbohydrate chain.
   - Glycolipids have a protective function.

3. **cholesterol**
   - Is a lipid that is found in animal plasma membranes.
   - Cholesterol reduces the permeability of the membrane to the most biological molecules.

The Lipid Bilayer is a Two-dimensional Fluid. The aqueous environment inside and outside a cell prevents membrane lipids from escaping from the bilayer, but nothing stops these molecules from moving about and changing places with one
another within the plane of the bilayer. The membrane therefore behaves as a two-dimensional fluid, which is crucial for membrane function.

**Membrane proteins:**

- Proteins constituting 25–75% of the mass of various membranes of the cells.
- Membrane proteins carry out the specific functions of the different membranes of the cell.
- These proteins are divided into 2 general classes, based on the nature of their association with the membrane.

1. **Integral membrane proteins.** are embedded directly within the lipid bilayer, many integral membrane proteins called *transmembrane proteins* span the lipid bilayer with proteins exposed on both sides of the membrane.

2. **Peripheral membrane proteins.** are not inserted into the lipid bilayer but are associated with the membrane indirectly, generally by interactions with integral membrane proteins.

   - The carbohydrate chains of glycolipids and glycoproteins serves as the *fingerprints* of the cell.
   - The carbohydrate chains of the glycolipids & glycoproteins form a carbohydrate coat that envelops the outer surface of the plasma membrane.
   - On the inside, proteins serve as links to the cytoskeletal filaments and on the outside some serve as links to extracellular matrix.
Membrane protein diversity.

These are some of functions performed by proteins found in the plasma membrane:

1. **Channel protein**: allows a particular molecule or ion to cross the plasma membrane freely.
2. **Carrier protein**: selectively interacts with a specific molecule or ion so that it can cross the plasma membrane.
3. **Cell recognition protein**: a type of glycoproteins; which are involved in marking of the cell and are different for each person. e.g. major histocompatibility complex (MHC).
4. **Receptor protein**: is shaped in such a way that a specific molecule can bind to it.
5. **Enzymatic protein**: catalyzes a specific reaction.
Functions of the cell membrane
As you have probably already gathered from the foregoing, the cell membrane is much more than just a static barrier between the inside and the outside of the cell. It is also a dynamic structure that performs a variety of energy-requiring functions needed to maintain optimum cellular activity. Some of the more important functions include:

- Maintain the ionic content of the cell for proper osmotic balance and membrane potential
- Regulate the entry of nutrients and the exit of wastes
- Participate in the uptake of macromolecules from the environment (endocytosis) and the discharge of macromolecules from the cell (exocytosis)
- Receive chemical messages from other cells (receptor–ligand interactions) and initiate a response leading to specific cellular reactions

Cell membrane specialization
The lateral parts of the cell membrane can show several specialization that form "intercellular junctions", functions of these junctions.

1. They are the sites of adhesion between adjacent cells.
2. They prevent the flow of materials through the intercellular compartment.
3. They help in the intercellular communication.

There are three types of junctions,

1. **adhesion junctions (desmosomes).**
   - In this type, the internal cytoplasmic plaques firmly attached to the cytoskeleton within each cell, are joined by intercellular filaments.
- In some organs like the heart, stomach and bladder, where tissues get stretched, adhesion junctions hold the cell together.

2. **Tight junctions.**
   - Adjacent cells are even more closely joined by tight junctions in which plasma membrane proteins actually attach to each other producing a zipper like fastening.
   - These junctions between cells form an impermeable barrier and prevent the flow of materials in intercellular spaces. e.g. in the kidneys the urine stays within kidney tubules because the cells are joined by tight junction.

3. **Gap junctions.**
   - It allows cells to communicate, and is formed when two identical plasma membrane channels join.
   - The channel of each cell is lined by six plasma membrane proteins.
   - **Functions** of gap junctions are,
     1. It lends strength to the cells.
     2. It allows small molecules and ions to pass between them.

   Gap junctions are important in heart muscle and smooth muscle because they permit a flow of ions that is required for the cells to contract.
Endoplasmic reticulum (ER)

The endoplasmic reticulum (ER) is a network of membrane-enclosed tubules and sacs (cisternae) that extends from the nuclear membrane throughout the cytoplasm. The entire ER is enclosed by a continuous membrane and is the largest organelle of most eukaryotic cells. Its membrane may account for about half of all cell membrane and is enclosed a space (the cisternal space) (or lumen) from the cytosol.

There are 2 types of ER that perform different functions within the cell:

1. The rough ER, which is covered by ribosomes on its outer surface giving it a rough appearance (hence its name). Functions in protein processing.
2. The smooth ER is not associated with ribosomes and involved in lipid metabolism.

The ER is part of the endomembrane system.

Rough endoplasmic reticulum (RER).

Is found in all cells except erythrocytes and is especially abundant in glandular cells such as salivary gland cells.

Function of RER.

1. Has role in the synthesis of protein to be exported outside the cell.
2. Modification of newly formed polypeptides.
3. Assembly of multichain protein.
4. Initial glycosylation of the glycoprotein which means addition of glucose to the protein.

**Smooth endoplasmic reticulum (SER).**

SER is found in a variety of cell types (both animal and plant) and it serves different functions in each.

**Function of SER.**

1. It is abundant in the liver and intestinal epithelium and seems to be involved in detoxification of certain substances like alcohol and toxins.
2. Glycogen break down in the liver cells.
3. Lipid and cholesterol metabolism.
4. Biosynthesis of steroid hormones (adrenal gland).
5. Participates in the contraction process in muscle cells, here SER is called **sarcoplasmic reticulum**.

**Golgi apparatus**

Golgi apparatus (Golgi complex) is an organelle found in typical **eukaryotic cells**. It forms a part of the **endomembrane system** present in eukaryotic cells. Its primary **function** is to **process and package macromolecules** synthesized by the cell, primarily proteins and lipids.
Structure.

The Golgi is composed of membrane-bound sacs known as **cisternae**. Between (5–8) are usually present, however, as many as (60) have been observed. Surrounding the main cisternae are a no. of spherical vesicles which have budded off from the cisternae. The simplest model view the Golgi complex as consisting of 5 functional regions: **cis–Golgi network, cis–Golgi, medial Golgi, Trans–Golgi, and Trans–Golgi network**.

Protein &/or lipid vesicles from the endoplasmic reticulum fuse with the **cis–Golgi network** and subsequently progress through the stack to the **trans–Golgi network**, where they are packaged and sent to different locations in the cell.

**Functions of Golgi apparatus.**

1. Participate in protein synthesis.
2. Initial proteolysis (cutting of protein).
3. Terminating glycolysis and glycosylation.
4. Phosphorylation (addition of phosphate group).
5. Sulfation (addition of sulfa group).
6. Processing and sorting glycoprotein.
7. Lipid metabolism.

**Ribosomes.**

Ribosomes are small particles about 20*30 nm in size. They are not membrane-bound and occur in all cells. They are composed of 4 types of ribosomal RNA (rRNA) and almost 80 different proteins.
Ribosome is composed of 2 different sized subunits. Ribosomes are basophilic because of the presence of numerous phosphate groups in rRNA. Ribosomes are held together by a strand of messenger RNA (mRNA) to form polyribosomes (polysomes) and often are cluster on the endoplasmic reticulum.

Ribosomes are located in 4 places within the cytoplasm:

1. Free ribosomes are found suspended in cytosol and synthesize proteins that will be used in the cell (except for membrane proteins).
2. Bound ribosomes are found attached to the outer surface of the membranous endoplasmic reticulum. The areas of the ER that have attached ribosomes are called rough ER.
3. Nuclear envelope, which is an extension of the ER.
4. Inside mitochondria and chloroplasts.

The function of a ribosome is to convert the genetic code into a sequence of amino acids that form a specific protein. Ribosomes are involved in protein synthesis. It creates protein for the cell.
Part 2 biology of cell

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MEMBRANOUS ORGANELLES

The Mitochondrion
The next membranous organelle we will consider is the mitochondrion. The principal means by which the cell obtains energy for its metabolic processes is through the oxidation of nutrients to form energy-rich molecules of adenosine triphosphate (ATP). This process is called oxidative phosphorylation and it occurs in the mitochondria as in figure beside.

Mitochondria are 5–10 μm long and 0.5–1 μm in diameter. They are found in almost all cells, though the number of mitochondria per cell, as well as their individual size and shape, are characteristic of each cell type. In general, the number of mitochondria reflects the energy requirements of a given cell. For example, heart muscle contains many mitochondria, whereas lymphocytes contain few.

Ultrastructurally, the mitochondrion is surrounded by two unit membranes separated by an intermembranous space. The outer mitochondrial membrane is fairly permeable, but the inner mitochondrial membrane is more selective.

The inner membrane is convoluted into a series of self-like cristae that project into the mitochondrial matrix. On the surface of the cristae are numerous spherical projections, about 9 nm in diameter, supported on short stalks. These are called elementary particles and are thought to contain the enzyme complex.
The ultrastructural appearance of mitochondria is indicative of their functional state. For example, the **orthodox form** (prominent cristae and large matrix) is seen during low oxidative phosphorylation, and the **condensed form** (non-distinct cristae and large intermembranous space) is seen during high oxidative phosphorylation. Mitochondrial morphology is also a very sensitive indicator of cell injury. During cell stress, **cytochrome C** is released from the intermembranous space into the cytoplasm, initiating a cascade of events leading to cell death via **apoptosis**.

**Contents of the mitochondrial matrix**

- **Matrix granules**, which are thought to represent accumulations of divalent cations, mostly **calcium**. This suggests that the mitochondria help regulate calcium levels in the cytoplasm.
- **Various enzymes**, including those of the **citric acid cycle**
- The DNA isolated from the mitochondrial matrix is double stranded and has a circular structure, very similar to that of bacterial chromosomes. These strands are synthesized within the mitochondria, their duplication is independent of nuclear DNA replication.
- Mitochondria contain the 3 types of RNA: rRNA, mRNA and transfer RNA.
- Mitochondrial ribosomes are smaller than cytosolic ribosomes. Protein synthesis occur in mitochondria, but because of the reduced amount of mitochondrial DNA, only small proportion of the mitochondrial proteins is produced locally.

As mentioned above Metabolites are degraded within mitochondria by the catalytic activity of the enzymes of the citric acid cycle, and the energy librated in this process is partially captured through oxidative phosphorylation. The end result of these reactions is the production of **CO₂**, water, and heat, as well as the accumulation of energy in the high-energy compound ATP.
Several mitochondrial deficiency diseases have been described. Mitochondrial diseases take on unique characteristics both because of the way the diseases are often inherited and because mitochondria are so critical to cell function. The subclass of these diseases that have neuromuscular disease symptoms are often called a mitochondrial myopathy. In which skeletal muscle fiber are very sensitive to mitochondrial defects, these diseases usually begin with drooping of the upper eyelid and progress to difficulties in swallowing and limb weakness. They are caused by DNA mutation or defects that can occur in the mitochondria or the cell nucleus. Also Diabetes mellitus and deafness (DAD).

**Mitochondrial functions.**

1. Convert organic materials into cellular energy in the form of ATP.
2. Apoptosis (programmed cell death).
3. Cellular proliferation.

Some mitochondrial functions are performed only in specific types of cells, e.g. mitochondria in liver cells contain enzymes that allow them to detoxify ammonia, a waste product of protein metabolism.

**Recent Mitochondria Research.**

1. Scientists have been using DNA in mitochondria to track genetic diseases. In mammals, the mitochondrial DNA (mtDNA) is 99.99% inherited from the mother. This research has also show that through mitochondrial mutations, many diseases can occur, some of these diseases are Alzheimer’s, Parkinson’s, and complete or partial blindness.
2. Mitochondrial research has also taken samples of different genetic samples from people of different races to compare them and try to construct a family tree that shows when each group probably began evolving away from one another.

3. Scientists are using mitochondrial DNA analysis in forensic science. Scientists can use this DNA to find a criminal by matching the DNA at the scene of the crime with DNA from the suspect.

**Replication of Mitochondria.**

Mitochondria replicate similarly to bacterial cells, when they get large, they undergo fission. This involves furrowing of the inner and then the outer membrane as if someone was pinching the mitochondrion. The two daughter cells of the mitochondria must first replicate the DNA.

**The Lysosome**

Lysosomes are spherical, membrane-bound organelles, 0.2–0.4 μm in diameter, that contain a variety of acid hydrolases. Of these, acid phosphatase is the most readily detected histochemically and is considered the “marker” enzyme for lysosomes. Lysosomes have two primary functions:

- Degradation of **extracellular material** ingested from the environment.
- Degradation of **intracellular material** no longer useful to the cell.

However, leakage of hydrolytic enzymes can also result in undesirable destruction of cell components. This is called **autolysis**. Lysosomes are classified into two types:

- **Primary lysosomes** are those that are newly formed.
• **Secondary lysosomes** or **heterolysosomes** are those resulting from the fusion of a primary lysosome with a vesicle containing either extracellular or intracellular material.

Extracellular material can be brought into the cell by the process of **endocytosis**, of which there are three forms.

• In **phagocytosis** (heterophagy), particulate matter like bacteria is engulfed by the cell membrane to form a phagocytic vesicle, which then pinches off from the cell membrane to become a **phagosome**. After combining with a primary lysosome, the phagosome is then referred to as a **secondary lysosome**. A secondary lysosome containing undigested material is called a **residual body**, which may eventually be extruded from the cell by **exocytosis**.

• In **pinocytosis**, fluid and soluble material are taken into the cell by invaginations of the cell membrane and the formation of **pinocytotic vesicles**, which can fuse with primary lysosomes.

• A third form of endocytosis is called **receptor-mediated endocytosis**. This mechanism involves the selective uptake of certain macromolecular substances at regions along the cell surface called **coated pits**. These shallow indentations of the cell membrane are coated with the fibrous protein **clathrin** on the cytoplasmic side, and contain surface receptors on the exterior side. After a ligand attaches to its receptor, the membrane invaginates to form a **coated vesicle**. However, the “coat” is soon lost.

The vesicle containing the receptor–ligand complex has three possible fates:

• It can simply be transported across the cell and the contents released by exocytosis from some other part of the cell surface. This called **transcytosis** (e.g., maternal antibodies).
It can fuse with a primary lysosome and the contents degraded (e.g., epidermal growth factor).

It can fuse with an **early endosome**, a membranous compartment where the receptor–ligand complex is dissociated in a low pH environment and the receptor recycled to the cell membrane.

*Multivesicular bodies* then transport the ligand from the early endosome to the late endosome, where lysosomal enzymes degrade the ligand (e.g., low-density lipoprotein receptors).

In **autophagy**, intracellular organelles that are of no further use to the cell are sequestered within a membrane-bound structure thought to be derived from the **smooth endoplasmic reticulum**. After fusing with a primary lysosome, the resulting structure is called an **autophagic vacuole** or **autophagosome**. Undigested material may remain as a residual body or be extruded by exocytosis.

When excess secretory granules are eliminated, the autophagic process is more specifically called **crinophagy**.

A variant of autophagy is called **microautophagy**, which is a slow, non-specific process to dispose of cytosolic proteins, rather than entire organelles. In this process, cytoplasmic proteins are continuously internalized into primary lysosomes. A more specific process is called **chaperone-mediated microautophagy**, in which chaperone proteins recognize and facilitate the transport of targeted proteins into primary lysosomes.

**The Peroxisome**

Distinct from the lysosomes are the peroxisomes, which are a heterogeneous group of membranous vesicles, generally less than 1 μm in diameter, that contain enzymes for the formation (**various oxidases**) and breakdown (**catalase**) of hydrogen peroxide, as well as other enzymes. Peroxisomes are particularly common in liver and kidney cells. Although uncertain, it is thought that
peroxisomes bud directly from the smooth endoplasmic reticulum. Peroxisomes have been implicated in at least three major activities:

- Hydrogen peroxide is utilized in certain reactions by phagocytic cells to kill ingested microorganisms.
- Peroxisomes in liver cells are known to metabolize lipids and alcohol.
- Beta-oxidation of fatty acids

As an aside, peroxisomes are also called microbodies, a term which should not be confused with microsomes. Microsomes refer to a particular cell fraction obtained by differential centrifugation of homogenized cells. The microsomal fraction contains membrane fragments of the rough endoplasmic reticulum.

The two nonmembranous organelles we will consider are those that constitute the cytoskeleton, which refers to the structural and contractile elements of the cell. These are the microtubules and the filaments.

**Microtubules**

Microtubules are rigid, hollow tubes, 25 nm in diameter, and of variable length. Each microtubule is made up of 13 longitudinal protofilaments situated around the perimeter. Each protofilament, in turn, is made up of polymerized protein subunits. The protein is called tubulin. The polymerization of tubulin starts in the microtubule-organizing center.
(MTOC), which act as nucleating sites for polymerization. The dominant MTOC in most cells is the centrosome located near the cell nucleus. The rate of tubulin polymerization and depolymerization, as well as the stability of microtubules, are influenced by the presence of various microtubule-associated proteins (MAPs).

The microtubules provide several important functions, such as:

- Support cell structure
- Direct transport of organelles and vesicles within cell; that is, act as "railroad tracks". This requires the participation of molecular motor proteins that attach to the cytoplasmic structure and pull it along the microtubule.

- **Dyneins**, which move toward the cell center
- **Kinesins**, which move toward the cell periphery
  - Segregate chromosomes during cell division
  - Provide motive force for flagella and cilia movement

**Cilia**

Cilia are hair-like projections, 10 μm by 0.2 μm, extending from the luminal surface of certain epithelial cells (e.g., respiratory epithelium). They are derived from centrioles, which are nonmembranous organelles assembled from microtubules.

**Centrioles**

These small, cylindrical objects are 0.5 μm by 0.2 μm. Each cell contains a pair of centrioles, termed a diplosome, which is located near the center of the cell in a region of cytoplasm called the centrosome, i.e., the MTOC. The wall of the centriole is composed of 9
longitudinally oriented bundles of microtubules surrounding a central hub. Each bundle consists of 3 microtubules associated in a triplet. This structure gives the centriole its characteristic "cartwheel" appearance when viewed in crosssection with the EM.

**Axoneme structure**

In ciliated cells, numerous immature centrioles, termed procentrioles, arise de novo near the original centriole pair. After maturing, the new centrioles move to the underside of the cell membrane where they function as basal bodies and generate cilia.

**Microtubules** grow out of the distal end of the basal body, and anchoring rootlets form at its proximal end. The shaft or axoneme of the cilia is covered by cell membrane and displays a characteristic appearance in cross-section, 9 peripheral doublet microtubules surrounding 2 singlet microtubules (9 + 2 configuration). On each doublet is a pair of hook–like structures called dynein arms. They have ATPase activity and are involved in generating sliding movement between adjacent doublets to produce ciliary motion.

**Flagella**

These structures arise in the same fashion as cilia and have a similar axonemal structure. However, surrounding the axoneme are longitudinally oriented coarse fibers and circumferentially oriented fibrous ribs. These proteins provide extra structural support. Flagella are generally much longer than cilia and only one or two are present on an individual cell (e.g., spermatozoa).

**Filaments**
The last nonmembranous organelles we will consider are the filaments, of which there are three basic types.

- **Microfilaments (also called thin filaments)**
- **Thick filaments**
- **Intermediate filaments**

**Microfilaments** or thin filaments are slender rods, 6–7 nm in diameter, composed of the protein **actin**. **Thick filaments** are larger, 12–16 nm, and are composed of the protein **myosin**. In skeletal and cardiac muscle cells, actin and myosin are organized into distinct **contractile myofibrils** visible in the light microscope.

A variety of **actin-binding proteins** regulate the rate of microfilament assembly, as well as determine the specific organizational and structural properties of microfilaments. Microfilaments are found in all cell types, usually at the periphery of the cell just beneath the cell membrane. They are sometimes attached to the underside of the cell membrane and organized into large bundles called **stress fibers**.

In absorptive cells like those of the intestinal epithelia, the luminal surface is covered with numerous fingerlike projections of the cell membrane called **microvilli**. Collectively, these microvilli form what is referred to as a **brush border** or a **striated border**. The core of each microvillus contains a bundle of microfilaments, contraction of which is thought to affect the surface area of the microvilli.
There are two major forms of myosin:
- **Myosin I**, found in non-muscle cells
- **Myosin II**, found in muscle cells

Interactions between actin and myosin form the basis of cell movement:
- Changes in cell shape
- Cell migration
- Membrane movement such as phagocytosis
- Intracellular transport
- Cell constriction during division
- Muscle contraction

**Intermediate filaments** are 7–11 nm in diameter and represent a heterogeneous group of filaments composed of different proteins. They are generally thought to have a supporting or structural role. There are several major classes of intermediated filaments, each characteristic of a certain cell type. Some important examples include:
- **Keratins**, found in epithelia cells
- **Desmin**, found in muscle cells
- **Vimentin**, found in cells derived from mesenchyme
- **Glial fibrillary acid protein**, found in astrocytes
- **Neurofilaments**, found in neurons
- **Lamins**, found in the nuclear envelope

**Cytoplasmic Inclusions**
- **Stored Foods**
- **Carbohydrates**
Carbohydrates are stored in the form of glycogen deposits in the cytoplasm. These deposits are stored chiefly in liver cells and to a lesser extent in other cells as well.

- **Lipids**
  Lipids are stored as free droplets in the cytoplasm of fat cells and certain other cells.

- **Pigments**
  Pigments are naturally colored substances present in the cytoplasm. They are classified as being either exogenous or endogenous.

- **Exogenous pigments**
  Exogenous pigments are those that are formed outside the cell and subsequently internalized. These include:
  - **Carotene**, a fat-soluble, yellow orange pigment found in vegetables like carrots and tomatoes
  - **Inhaled dust**, such as tobacco smoke
  - **Certain minerals**, such as lead

- **Endogenous pigments**
  Endogenous pigments are those that are formed within the cell from nonpigmented precursors. These include:
  - **Hemoglobin** and its degradation products, **hemosiderin** and **bilirubin**
  - **Melanin**, the pigment found in hair, eyes, and skin
  - **Lipofuscin**, a pigment that accumulates in long-lived cells from the undigested remnants of residual bodies

**Cytoplasmic Matrix**

In finishing, let me briefly mention the cytoplasmic matrix. This is the portion of the cytoplasm between the various organelles and inclusions we have been discussing. Not only does it contain all of the soluble material of the cell, such as electrolytes and soluble enzymes, but it also contains a three-dimensional protein
network called the **microtrabecular lattice**. It is presumed that this lattice serves as scaffolding for the organelles and holds them in position. By interacting with components of the cytoskeleton, the lattice could also help to redistribute the organelles within the cytoplasm. Even the various soluble enzymes within the cytoplasm might bind to the lattice in such a way as to order the sequence of reactions for the most efficient processing of substrate.