Anatomy and Physiology

The Cytoplasm and Cellular Organelles

For the 3rd Medical Physics Students

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3.1 The Cytoplasm and Cellular Organelles

The internal environmental of a living cell is made up of a fluid, jelly-like substance called cytosol, which consists mainly of water, but also contains various dissolved nutrients and other molecules. The cell contains an array of cellular organelles, each one performing a unique function and helping to maintain the health and activity of the cell. The cytosol and organelles together compose the cell's cytoplasm. Most organelles are surrounded by a lipid membrane similar to the cell membrane of the cell.
The **nucleus** is a cell's central organelle, which contains the cell's DNA (Figure 3.1).

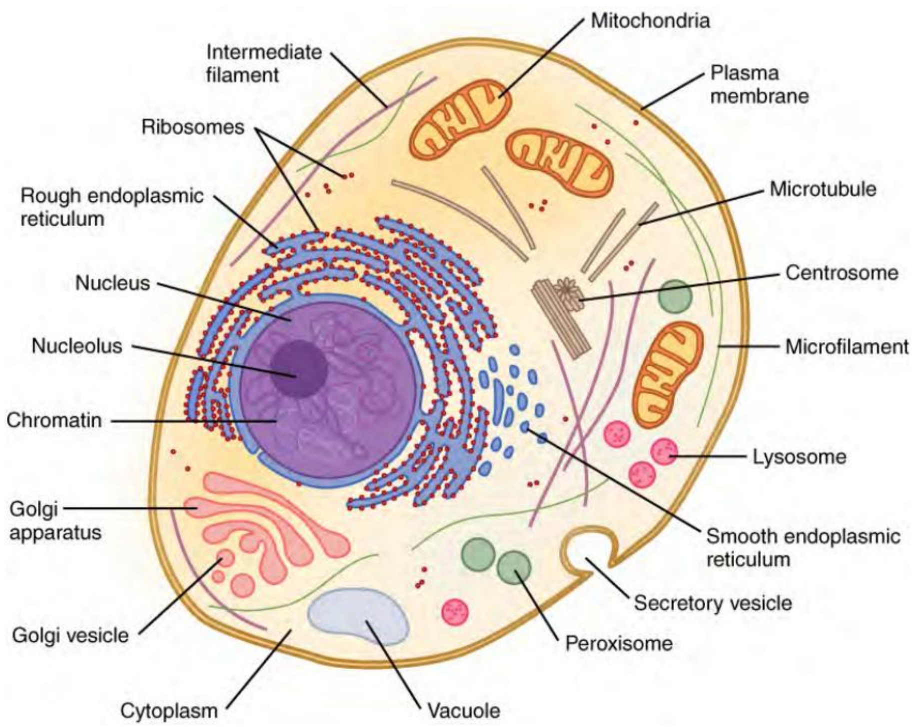

Fig 3-1: Prototypical Human Cell

3.2 Organelles of the Endomembrane System

A set of three major organelles together form a system within the cell called the endomembrane system. These organelles work together to perform various cellular jobs, including the task of producing, packaging, and exporting certain cellular products. The organelles of the endomembrane system include the endoplasmic reticulum, Golgi apparatus, and vesicles.

1- Endoplasmic Reticulum

The endoplasmic reticulum (ER) is a system of channels that is continuous with the nuclear membrane (or "envelope"). Covering the nucleus and composed of the same lipid bilayer material. (Figure 3.2).

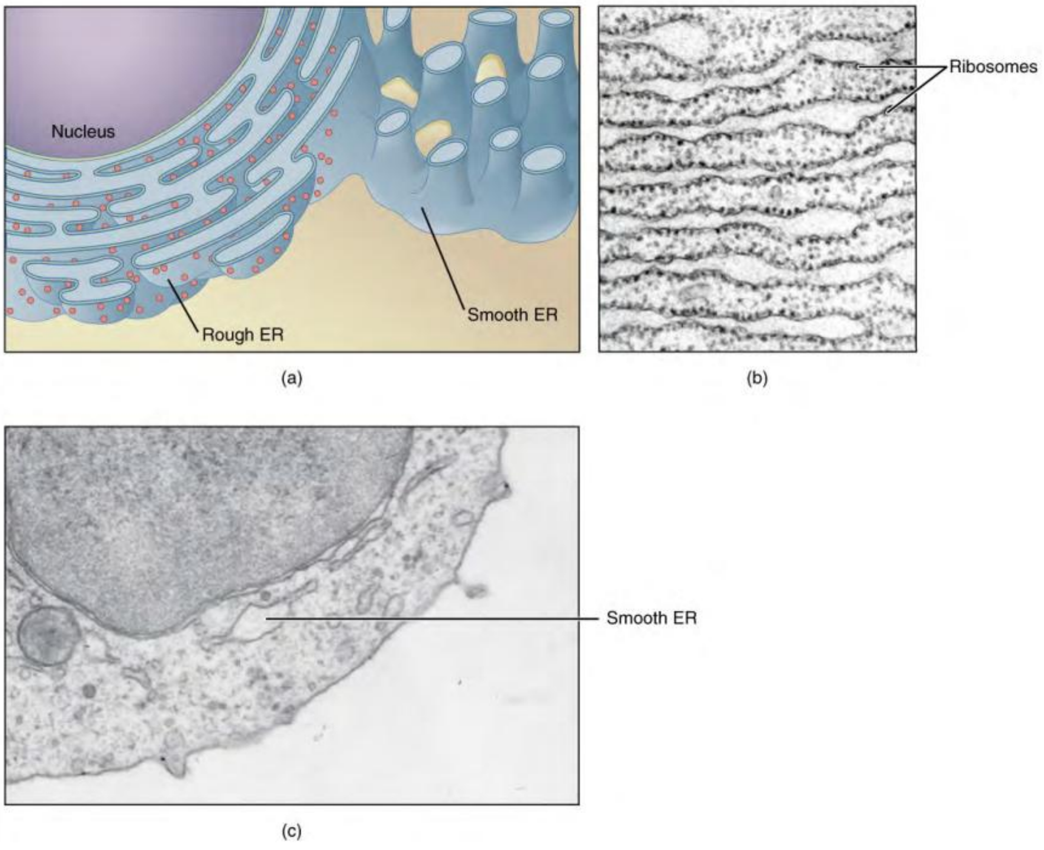

Fig3-2: Endoplasmic Reticulum (ER)

Endoplasmic reticulum can exist in two forms:

Endoplasmic reticulum can exist in two forms: rough ER and smooth ER. These two types of ER perform some very different functions and can be found in very different amounts depending on the type of cell. Rough ER (RER) is called because its membrane is dotted with embedded granules organelles called ribosomes. A ribosome is an organelle that serves as the site of protein synthesis.

Smooth ER (SER) lacks these ribosomes. One of the main functions of the smooth ER is in the synthesis of lipids. The smooth ER synthesizes phospholipids, the main component of biological membranes, as well as steroid hormones. For this reason, cells that produce large quantities of such hormones, such as those of the female ovaries and male testes. In addition to lipid synthesis, the smooth ER also sequesters (i.e., stores) and regulates the concentration of cellular Ca++, a function extremely important in cells of the nervous system.

2- The Golgi Apparatus: The Golgi apparatus is responsible for sorting, modifying, and shipping off the products that come from the rough ER, much like a post-office. The Golgi apparatus looks like stacked flattened discs. The Golgi apparatus has two distinct sides, each with a different role. One side of the apparatus receives products in vesicles. These products are sorted through the apparatus, and then they are released from the opposite side after being repackaged into new vesicles. If the product is to be exported from the cell, the vesicle migrates to the cell surface and fuses to the cell membrane, and the cargo is secreted (Figure 3.3).

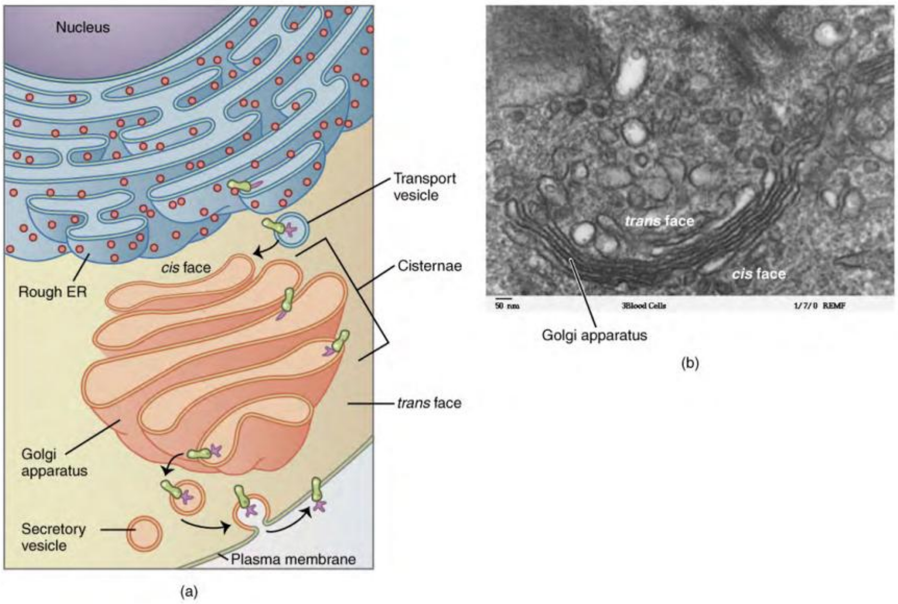

Fig 3-3: Golgi Apparatus Golgi Apparatus

3- Lysosomes: A lysosome is an organelle that contains enzymes that break down and digest unneeded cellular components, such as a damaged organelle. Autophagy ("self-eating") is the process of a cell digesting its own structures. Lysosomes are also important for breaking down foreign material. For example, when certain immune defines cells (white blood cells) phagocytize bacteria, the bacterial cell is transported into a lysosome and digested by the enzymes inside. As one might imagine, such phagocytic defence cells contain large numbers of lysosomes. In the case of damaged or unhealthy cells, lysosomes can be triggered to open up and release their digestive enzymes into the cytoplasm of the cell, killing the cell. This "self-destruct" mechanism is called autolysis, and makes the process of cell death controlled (a mechanism called "apoptosis").

3.3 Organelles for Energy Production and Detoxification

In addition to the jobs performed by the endomembrane system, the cell has many other important functions. Just as you must consume nutrients to provide yourself with energy, so must each of your cells take in nutrients, some of which convert to chemical energy that can be used to power biochemical reactions. Another important function of the cell is detoxification. Humans take in all sorts of toxins from the environment and also produce harmful chemicals as by-products of cellular processes. Cells called hepatocytes in the liver detoxify many of these toxins.

1- Mitochondria:

A mitochondrion (plural = mitochondria) is a membranous, bean-shaped organelle that is the "energy transformer" of the cell. Mitochondria consist of an outer lipid bilayer membrane as well as an additional inner lipid bilayer membrane (Figure 3.4).

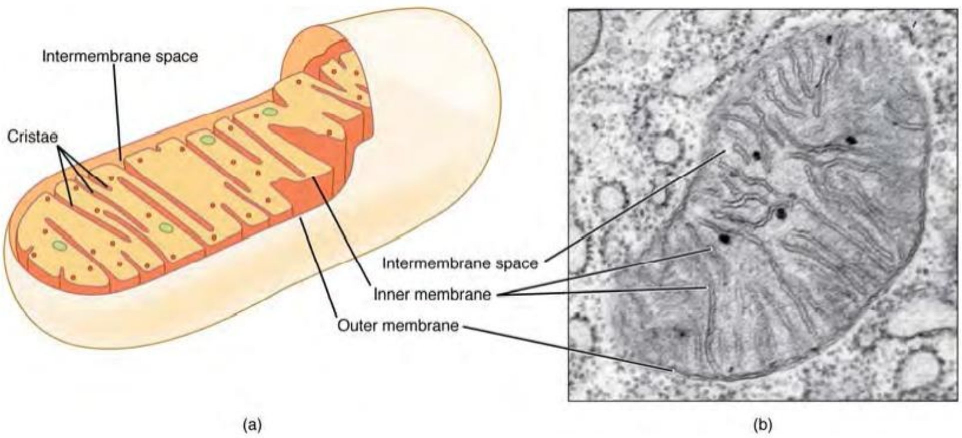

Fig 3-4: The mitochondria are the energy-conversion factories of the cell. (a) A mitochondrion is composed of two separate lipid bilayer membranes. Along the inner membrane are various molecules that work together to produce ATP. (b) An electron micrograph of mitochondria. EM × 236,000.

It is along this inner membrane that a series of proteins, enzymes, and other molecules perform the biochemical reactions of cellular respiration. These reactions convert energy stored in nutrient molecules (such as glucose) into adenosine triphosphate (ATP), which provides usable cellular energy to the cell. Cells use ATP constantly, and so the mitochondria are constantly at work.

2- Peroxisomes:

A peroxisome is a membrane-bound cellular organelle that contains mostly enzymes (Figure 3.5). Peroxisomes perform a couple of different functions, including lipid metabolism and detoxifying harmful substances.

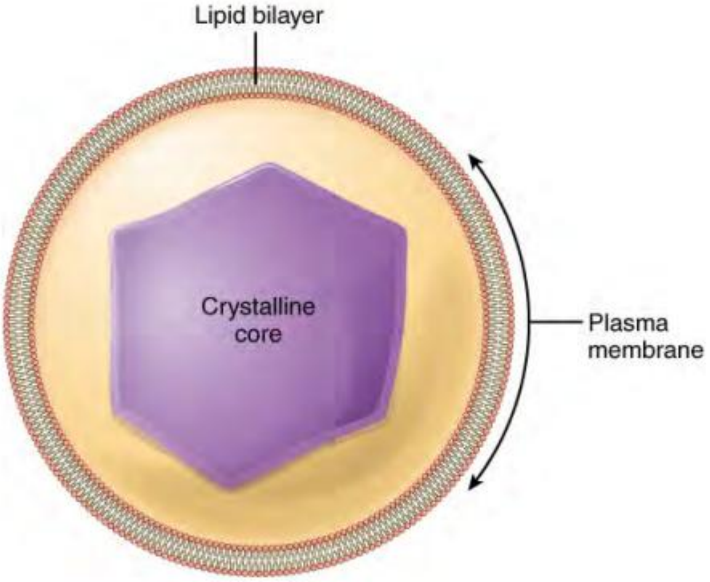

Fig 3-5: Peroxisomes are membrane-bound organelles that contain an abundance of enzymes for detoxifying harmful substances and lipid metabolism.

3.4 The Cytoskeleton

Much like the bony skeleton structurally supports the human body, the cytoskeleton helps the cells to maintain their structural integrity. The cytoskeleton is a group of fibrous proteins that provide structural support for cells. The cytoskeleton forms a complex thread-like network throughout the cell consisting of three different kinds of protein based filaments: microfilaments, intermediate filaments, and microtubules (Figure 3.6).

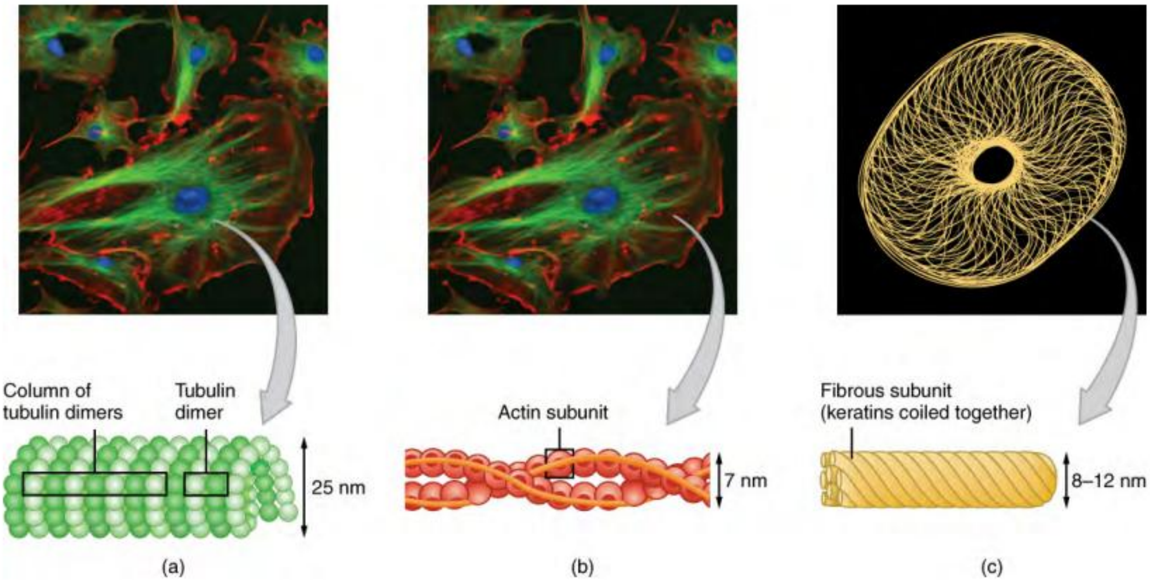

Fig 3-6: The Three Components of the Cytoskeleton The cytoskeleton consists of (a) microtubules, (b) microfilaments, and (c) intermediate filaments. The cytoskeleton plays an important role in maintaining cell shape and structure, promoting cellular movement, and aiding cell division.

3.5 The Nucleus and DNA Replication

The nucleus is the largest and most prominent of a cell's organelles (Figure 3.7). The nucleus is generally considered the control centre of the cell because it stores all of the genetic instructions for manufacturing proteins.

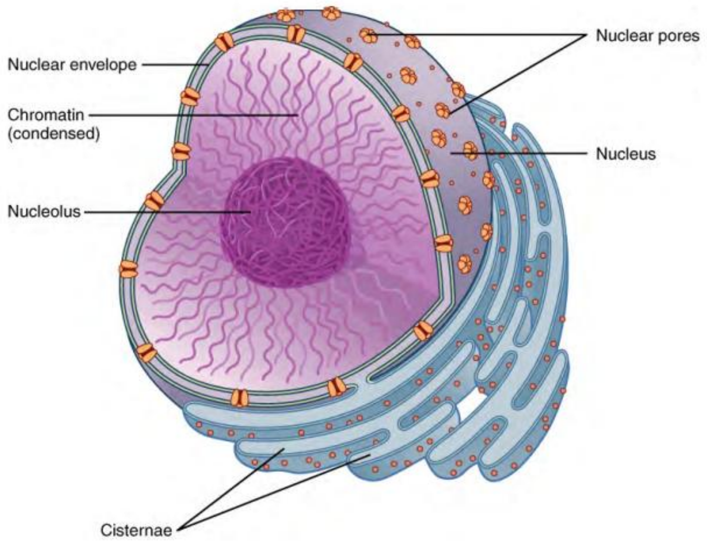

Fig 3-7: The nucleus is the control center of the cell. The nucleus of living cells contains the genetic material that determines the entire structure and function of that cell.

1- Organization of the Nucleus and Its DNA

Like most other cellular organelles, the nucleus is surrounded by a membrane called the nuclear envelope. This membranous covering consists of two adjacent lipid bilayers with a thin fluid space in between them. Spanning these two bilayers are nuclear pores. A nuclear pore is a tiny passageway for the passage of proteins, RNA, and solutes between the nucleus and the cytoplasm. Proteins called pore complexes lining the nuclear pores regulate the passage of materials into and out of the nucleus. There also can be a dark-staining mass often visible under a simple light microscope, called a nucleolus. The nucleolus is a region of the nucleus that is responsible for manufacturing the RNA necessary for construction of ribosomes. Within the nucleus are threads of chromatin composed of DNA and associated proteins (Figure 3.8).

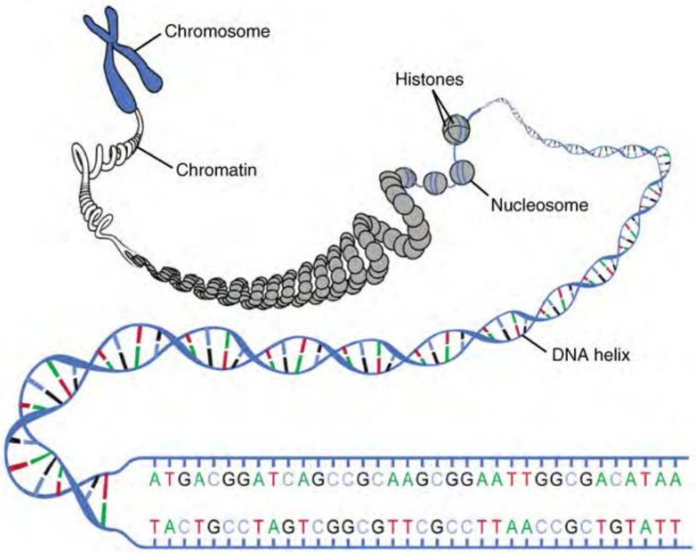

Fig 3-8: DNA Macrostructure Strands of DNA are wrapped around supporting histones. These proteins are increasingly bundled and condensed into chromatin, which is packed tightly into chromosomes when the cell is ready to divide.

2- DNA Replication

In order for an organism to grow, develop, and maintain its health, cells must reproduce themselves by dividing to produce two new daughter cells, each with the full complement of DNA as found in the original cell. Billions of new cells are produced in an adult human every day. Only very few cell types in the body do not divide, including nerve cells, skeletal muscle fibers, and cardiac muscle cells. The division time of different cell types varies. Epithelial cells of the skin and gastrointestinal lining, for instance, divide very frequently to replace those that are constantly being rubbed off of the surface by friction.

A DNA molecule is made of two strands that “complement” each other in the sense that the molecules that compose the strands fit together and bind to each other, creating a double-stranded molecule that looks much like a long, twisted ladder. The two sides of the ladder are not identical, but are complementary. The four DNA bases are adenine (A), thymine (T), cytosine (C), and guanine (G). Because of their shape and charge, the two bases that compose a pair always bond together. Adenine always binds with thymine, and cytosine always binds with guanine. The particular sequence of bases along the DNA molecule determines the genetic code. For example, if one strand has a region with the sequence AGTGCCT, then the sequence of the complementary strand would be TCACGGA (figure 3.9).

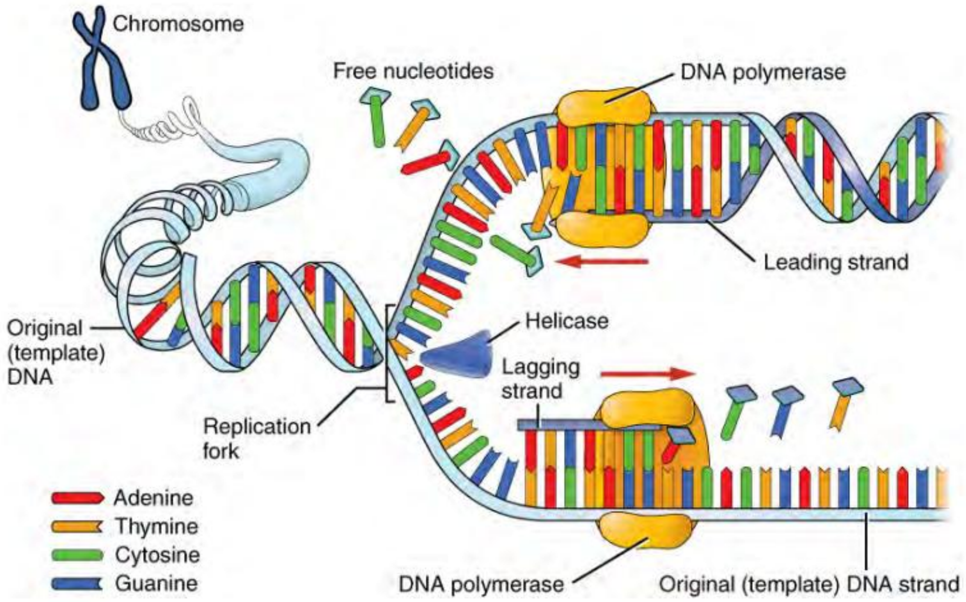

Fig 3-9: DNA Replication DNA replication faithfully duplicates the entire genome of the cell. During DNA replication, a number of different enzymes work together to pull apart the two strands so each strand can be used as a template to synthesize new complementary strands

DNA replication is the copying of DNA that occurs before cell division can take place. This method is illustrated in Figure 3.9.

3.6 Cell Growth and Division

The cell cycle consists of two general phases: interphase, followed by mitosis and cytokinesis.

Interphase: is the period of the cell cycle during which the cell is not dividing. The majority of cells are in interphase most of the time.

Mitosis: is the division of genetic material, during which the cell nucleus breaks down and two new, fully functional, nuclei are formed.

Cytokinesis: divides the cytoplasm into two distinctive cells. Figure 3.10.

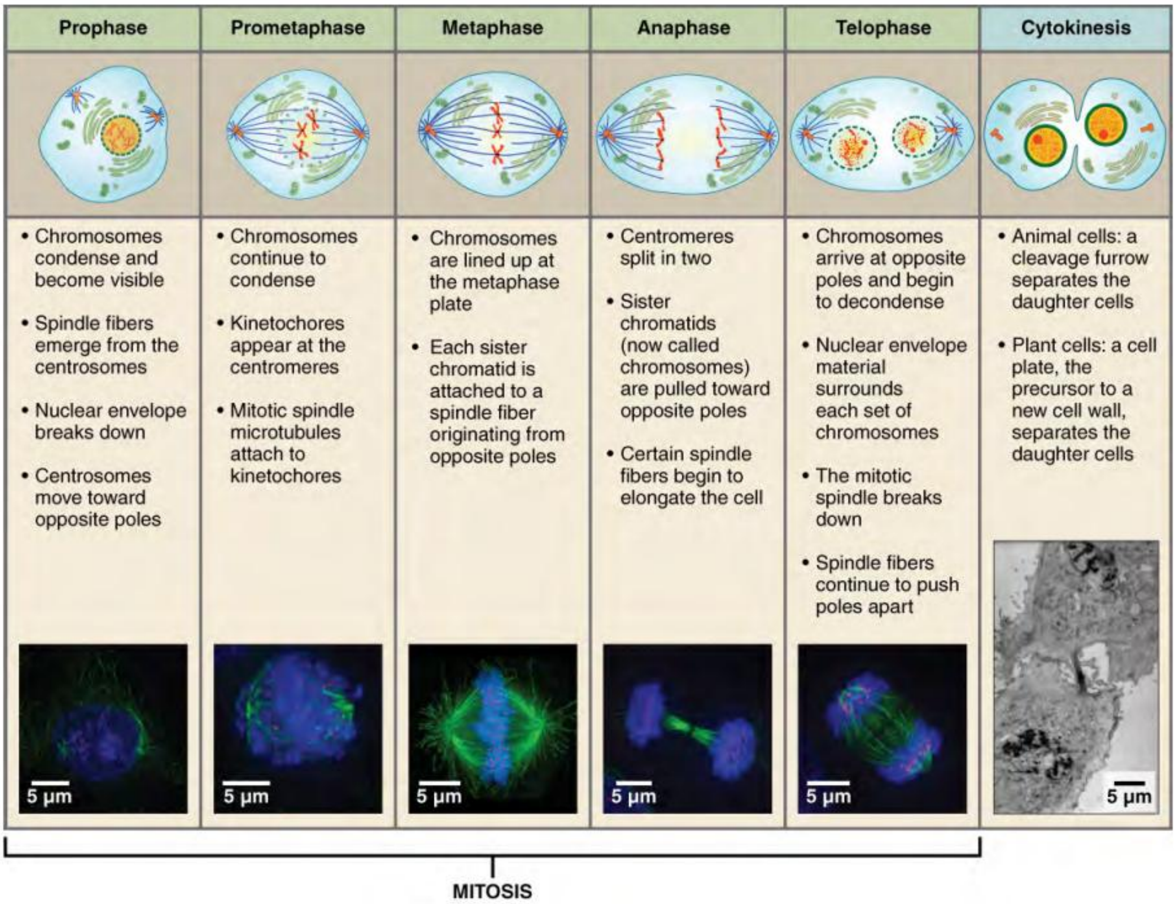

Fig3-10: Cell Division: Mitosis Followed by Cytokinesis The stages of cell division oversee the separation of identical genetic material into two new nuclei, followed by the division of the cytoplasm.