Inquire: Prokaryotic vs. Eukaryotic Cells

Overview

Unlike prokaryotic cells, **eukaryotic cells** have: 1) a membrane-bound nucleus; 2) numerous membrane-bound **organelles** such as the endoplasmic reticulum, Golgi apparatus, chloroplasts, mitochondria, and others; and 3) several, rod-shaped chromosomes. Because a membrane surrounds a eukaryotic cell’s nucleus, it has a “true nucleus.” The word “organelle” means “little organ,” and as we already mentioned, organelles have specialized cellular functions, just as your body's organs have specialized functions.

![Diagram of Prokaryotic and Eukaryotic Cells]

At this point, it should be clear that eukaryotic cells have a more complex structure than prokaryotic cells. Organelles allow different functions to be compartmentalized in different areas of the cell.

**Big Question:** What are the functions of the major cell structures?

**Watch: Comparing Prokaryotic and Eukaryotic Cells**

Have you ever heard the phrase “form follows function?” It’s a philosophy that many industries follow. In architecture, this means that buildings should be constructed to support the activities that will be carried out inside them. For example, a skyscraper should include several elevator banks. A hospital should have its emergency room easily accessible.

Our natural world also uses the principle of form following function, especially in cell biology. This use will become clear as we explore prokaryotic and eukaryotic cells.

All cells share four common components: 1) a plasma membrane, an outer covering that separates the cell’s interior from its surrounding environment; 2) cytoplasm, consisting of a jelly-like cytosol within the
cell in which there are other cellular components; 3) DNA, the cell's genetic material; and 4) ribosomes, which synthesize proteins.

One type of cell is a prokaryote, a simple, mostly single-celled (unicellular) organism that lacks a nucleus or any other membrane-bound organelle. Prokaryotic DNA is in the cell's central part: the nucleoid.

Another type of cell is the eukaryotic cell. Unlike prokaryotic cells, eukaryotic cells have: 1) a membrane-bound nucleus; 2) numerous membrane-bound organelles such as the endoplasmic reticulum, Golgi apparatus, chloroplasts, mitochondria, and others; and 3) several, rod-shaped chromosomes. Because a membrane surrounds a eukaryotic cell's nucleus, it has a “true nucleus.”

Within the cytoplasm there are also differences between the eukaryotic and prokaryotic cell. Within the cytoplasm there is a network of protein fibers that collectively maintain the shape of the cell, secure some organelles in specific positions, allow cytoplasm and vesicles to move within the cell, and enable unicellular organisms to move independently called the cytoskeleton.

The eukaryotic and prokaryotic cells are composed of different types of microtubules. Microtubules are the structural elements of flagella, cilia, and centrioles. The flagella (singular = flagellum) are long, hair-like structures that extend from the plasma membrane and enable an entire cell to move (for example, sperm, Euglena, and some prokaryotes).

In animal cells, the centrosome is the microtubule-organizing center. In eukaryotic cells, flagella and cilia are quite different structurally from their counterparts in prokaryotes, as we discuss below.

It is clear that eukaryotic cells have a more complex structure than prokaryotic cells. Organelles allow different functions to be compartmentalized in different areas of the cell. Before turning to organelles, let's first examine two important components of the cell: the plasma membrane and the cytoplasm.

Read: Prokaryotic and Eukaryotic Cells

Overview

Cells fall into one of two broad categories: prokaryotic and eukaryotic. We classify only the predominantly single-celled organisms, Bacteria and Archaea, as prokaryotes (pro- = “before”; -kary- = “nucleus”). Animal cells, plants, fungi, and protists are all eukaryotes (eu- = “true”).

Components of Prokaryotic Cells

All cells share four common components: 1) a plasma membrane, an outer covering that separates the cell's interior from its surrounding environment; 2) cytoplasm, consisting of a jelly-like cytosol within the cell in which there are other cellular components; 3) DNA, the cell's genetic material; and 4) ribosomes, which synthesize proteins. Prokaryotes, however, differ from eukaryotic cells in several ways.

A prokaryote is a simple, mostly single-celled (unicellular) organism that lacks a nucleus or any other membrane-bound organelle. We will shortly come to
see that this is significantly different in eukaryotes. Prokaryotic DNA is in the cell's central part: the nucleoid.

Most prokaryotes have a cell wall. The cell wall acts as an extra layer of protection, helps the cell maintain its shape, and prevents dehydration. The capsule enables the cell to attach to surfaces in its environment. Some prokaryotes have flagella, pili, or fimbriae. Flagella are used for locomotion. Pili exchange genetic material during conjugation, the process by which one bacterium transfers genetic material to another through direct contact. Bacteria use fimbriae to attach to a host cell.

The Plasma Membrane
Like prokaryotes, eukaryotic cells have a plasma membrane, a phospholipid bilayer with embedded proteins that separates the internal contents of the cell from its surrounding environment. A phospholipid is a lipid molecule with two fatty acid chains and a phosphate-containing group. The plasma membrane controls the passage of organic molecules, ions, water, and oxygen into and out of the cell. Wastes (such as carbon dioxide and ammonia) also leave the cell by passing through the plasma membrane.

The Cytoplasm
The cytoplasm is the cell's entire region between the plasma membrane and the nuclear envelope (a structure we will discuss shortly). It is comprised of organelles suspended in the gel-like cytosol, the cytoskeleton, and various chemicals. Even though the cytoplasm consists of 70 to 80 percent water, it has a semi-solid consistency which comes from the proteins within it. However, proteins are not the only organic molecules in the cytoplasm. Glucose and other simple sugars such as polysaccharides, amino acids, nucleic acids, fatty acids, and derivatives of glycerol are also there. Ions of sodium, potassium, calcium, and many other elements also dissolve in the cytoplasm. Many metabolic reactions, including protein synthesis, take place in the cytoplasm.

The Nucleus
Typically, the nucleus is the most prominent organelle in a cell. The nucleus (plural = nuclei) houses the cell’s DNA and directs the synthesis of ribosomes and proteins. Let’s look at it in more detail.

The Nuclear Envelope
The nuclear envelope is a double-membrane structure that constitutes the nucleus’ outermost portion. Both the nuclear envelope's inner and outer membranes are phospholipid bilayers. The nuclear envelope is punctuated with pores that control the passage of ions, molecules, and RNA between the nucleoplasm and cytoplasm. The nucleoplasm is the semi-solid fluid inside the nucleus where we find the chromatin and the nucleolus.

Chromosomes
To understand chromatin, it is helpful to first explore chromosomes, structures within the nucleus that are made up of the hereditary material DNA. You may remember that in prokaryotes, DNA is organized into a single, circular chromosome. In eukaryotes, DNA is linear. Every eukaryotic species has a specific number of chromosomes in the nucleus of each cell. For example, in humans, the chromosome number is 46, while in fruit flies, it is eight. Chromosomes are only visible and distinguishable from one another when the cell is getting ready to divide.
The Nucleolus

We already know that the nucleus directs the synthesis of ribosomes, but how does it do this? Some chromosomes have sections of DNA that encode ribosomal RNA. The nucleolus (plural = nucleoli), a darkly staining area within the nucleus, aggregates the ribosomal RNA with associated proteins to assemble the ribosomal subunits that are then transported out through the pores in the nuclear envelope to the cytoplasm.

Mitochondria

Scientists often call mitochondria (singular = mitochondrion) the cell's "powerhouses" or "energy factories" because they are responsible for making adenosine triphosphate (ATP), the cell's main energy-carrying molecule. ATP represents the cell's short-term stored energy. Cellular respiration is the process of making ATP using the chemical energy in glucose and other nutrients. In mitochondria, this process uses oxygen and produces carbon dioxide as a waste product. In fact, the carbon dioxide that you exhale with every breath comes from the cellular reactions that produce carbon dioxide as a byproduct.

In keeping with our theme of form following function, it is important to point out that muscle cells have a very high concentration of mitochondria that produce ATP. Your muscle cells need considerable energy to keep your body moving. When your cells don't get enough oxygen, they do not make much ATP. Instead, your cells produce lactic acid that accompanies the small amount of ATP they make in the absence of oxygen.

Mitochondria are oval-shaped, double membrane organelles that have their own ribosomes and DNA. Each membrane is a phospholipid bilayer embedded with proteins. The inner layer has folds called cristae. We call the area surrounded by the folds the mitochondrial matrix. The cristae and the matrix have different roles in cellular respiration.

Ribosomes

Ribosomes are the cellular structures responsible for protein synthesis. When we view them through an electron microscope, ribosomes appear either as clusters (polyribosomes) or single, tiny dots that float freely in the cytoplasm. They may be attached to the plasma membrane's cytoplasmic side or the endoplasmic reticulum's cytoplasmic side and the nuclear envelope's outer membrane.

Because protein synthesis is an essential function of all cells, there are ribosomes in practically every cell. Ribosomes are particularly abundant in cells that synthesize large amounts of protein. For example, the pancreas is responsible for creating several digestive enzymes, and the cells that produce these enzymes contain many ribosomes. Thus, we see another example of form following function.

Peroxisomes

Peroxisomes are small, round organelles enclosed by single membranes. They carry out oxidation reactions that break down fatty acids and amino acids. They also detoxify many poisons that may enter the body. For example, peroxisomes in liver cells detoxify alcohol. Glyoxysomes, which are specialized peroxisomes in plants, are responsible for converting stored fats into sugars. Plant cells contain many different types of peroxisomes that play a role in metabolism, pathogene defense, and stress response.
Reflect: Cytology

Poll: Cytology is the study of cells. If you had to choose which type of cell you prefer to study, which would you choose?

- Prokaryotes
- Eukaryotes

Expand: Cytoskeleton

Discover

If you were to remove all the organelles from a cell, would the plasma membrane and the cytoplasm be the only components left? No. Within the cytoplasm, there would still be ions, organic molecules, and a network of protein fibers. These fibers help maintain the cell's shape, secure some organelles in specific positions, allow cytoplasm and vesicles to move within the cell, and enable cells within multicellular organisms to move. Collectively, scientists call this network of protein fibers the **cytoskeleton**. There are three types of fibers within the cytoskeleton: microfilaments, intermediate filaments, and microtubules.

Microfilaments

Of the three types of protein fibers in the cytoskeleton, **microfilaments** are the narrowest. They function in cellular movement, have a diameter of about seven nm, and are comprised of two globular protein intertwined strands which we call actin. For this reason, we also call microfilaments actin filaments.

ATP powers actin to assemble its filamentous form which serves as a track for the movement of a motor protein we call myosin. This enables actin to engage in cellular events requiring motion such as cell division in eukaryotic cells and cytoplasmic streaming (the cell cytoplasm's circular movement in plant cells). Actin and myosin are plentiful in muscle cells. When your actin and myosin filaments slide past each other, your muscles contract.

Microfilaments also provide some rigidity and shape to the cell. They can depolymerize (disassemble) and reform quickly, enabling a cell to change its shape and move. White blood cells (your body's infection-fighting cells) make good use of this ability. They can move to an infection site and phagocytize the pathogen.

Intermediate Filaments

Intermediate filaments are comprised of several strands of fibrous proteins that are wound together. Cytoskeleton elements get their name from the fact that their diameter, eight to 10 nm, is between those of microfilaments and microtubules.

Intermediate filaments have no role in cell movement. Their function is purely structural. They bear tension, thus maintaining the cell's shape and anchoring the nucleus and other organelles in place.

Intermediate filaments are the most diverse group of cytoskeletal elements. Several fibrous protein types are in the intermediate filaments. You are probably most familiar with keratin, the fibrous protein that strengthens your hair, nails, and the skin's epidermis.
**Microtubules**

As their name implies, microtubules are small hollow tubes. Polymerized dimers of α-tubulin and β-tubulin, two globular proteins, comprise the microtubule’s walls. With a diameter of about 25 nm, microtubules are cytoskeletons’ widest components. They help the cell resist compression, provide a track along which vesicles move through the cell, and pull replicated chromosomes to opposite ends of a dividing cell. Like microfilaments, microtubules can disassemble and reform quickly.

Microtubules are also the structural elements of flagella, cilia, and centrioles (the latter two elements are the centrosome’s two perpendicular bodies). In animal cells, the centrosome is the microtubule-organizing center. In eukaryotic cells, flagella and cilia are quite different structurally from their counterparts in prokaryotes, as we discuss below.

**Flagella and Cilia**

The flagella (singular = flagellum) are long, hair-like structures that extend from the plasma membrane and enable an entire cell to move (for example, sperm, Euglena, and some prokaryotes). The cell has just one flagellum or a few flagella, when present at all. However, when cilia (singular = cilium) are present, many of them extend along the plasma membrane’s entire surface. They are short, hair-like structures that move entire cells (such as paramecia) or substances along the cell’s outer surface. For example, the cilia of cells lining the fallopian tubes move the ovum toward the uterus. And, cilia lining the cells of the respiratory tract trap particulate matter and move it toward your nostrils.

Despite their differences in length and number, flagella and cilia share a common structural arrangement of microtubules called a “9 + 2 array.” This is an appropriate name because a single flagellum or cilium is made of a ring of nine microtubule doublets, surrounding a single microtubule doublet in the center.

**Lesson Toolbox**

**Additional Resources and Readings**

**White Blood Cell Chases Bacteria**
- An example of a white blood cell in action and a short time-lapse video of the cell capturing two bacteria. It engulfs one and then moves on to the other.
- [https://www.youtube.com/embed/AUih856vaQY](https://www.youtube.com/embed/AUih856vaQY)

**Prokaryotic and Eukaryotic Cells**
- A video illustrating the differences between prokaryotic and eukaryotic cells

**Cyanobacteria: Photosynthetic Prokaryotes**
- A video about cyanobacteria, a prokaryote
- [https://www.youtube.com/watch?v=uU00tg98Jjw](https://www.youtube.com/watch?v=uU00tg98Jjw)
Lesson Glossary

**chromosome**: structure within the nucleus that is made up of chromatin that contains DNA, the hereditary material

**cilia**: (singular = cilium) many short, hair-like structures that extend along the plasma membrane’s surface and move entire cells or substances along the cell’s outer surface

**cytoplasm**: entire region between the plasma membrane and the nuclear envelope, consisting of organelles suspended in the gel-like cytosol, the cytoskeleton, and various chemicals

**cytoskeleton**: network of protein fibers that collectively maintain the shape of the cell, secure some organelles in specific positions, allow cytoplasm and vesicles to move within the cell, and enable unicellular organisms to move independently

**eukaryotic cells**: cells that have a membrane-bound nucleus and several other membrane-bound compartments or sacs

**flagella**: (singular = flagellum) long, hair-like structures that extend from the plasma membrane and are used to move the cell

**microfilaments**: narrowest elements of the cytoskeleton system; provide rigidity and shape to the cell and enable cellular movements

**microtubules**: widest elements of the cytoskeleton system; help the cell resist compression, provide a track along which vesicles move through the cell, pull replicated chromosomes to opposite ends of a dividing cell, and are the structural elements of centrioles, flagella, and cilia

**mitochondria**: (singular = mitochondrion) cellular organelles responsible for carrying out cellular respiration, resulting in the production of ATP, the cell’s main energy-carrying molecule

**nuclear envelope**: double-membrane structure that constitutes the outermost portion of the nucleus

**nucleoid**: central part of a prokaryotic cell in which the chromosome is found

**nucleolus**: darkly staining body within the nucleus that is responsible for assembling the subunits of the ribosomes

**nucleoplasm**: semi-solid fluid inside the nucleus that contains the chromatin and nucleolus

**nucleus**: cell organelle that houses the cell’s DNA and directs the synthesis of ribosomes and proteins

**organelles**: compartments or sacs within a cell

**peroxisomes**: small, round organelles that contain hydrogen peroxide, oxidize fatty acids and amino acids, and detoxify many poisons

**plasma membrane**: phospholipid bilayer with embedded (integral) or attached (peripheral) proteins, that separates the internal content of the cell from its surrounding environment

**prokaryote**: unicellular organism that lacks a nucleus or any other membrane-bound organelle

**ribosomes**: cellular structures that carry out protein synthesis

Check Your Knowledge

1. Bacteria that lack fimbriae are less likely to __________.
   A. adhere to cell surfaces
   B. swim through bodily fluids
   C. synthesize proteins
   D. retain the ability to divide
2. Because protein synthesis is an essential function of all cells, there are _________ in practically every cell.
   A. ribosomes  
   B. mitochondrion  
   C. amoeba  
   D. flagella

3. _________ is the green pigment that captures the light energy that drives the light reactions of photosynthesis.
   A. E. Coli  
   B. Cytoplasm  
   C. Cytoskeleton  
   D. Chlorophyll

Answer Key:

Citations

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