Cytology: Definition and Basics

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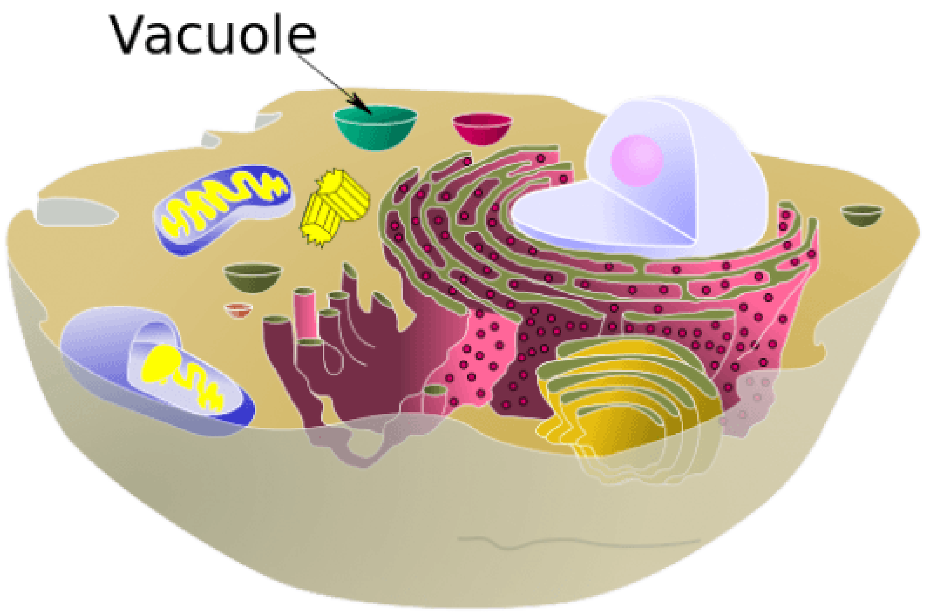
The understanding of eukaryotic and prokaryotic cells is one of the foundations of medicine. Each cell carries out specific functions depending on its field of application. During the foundation of new lives, two cells are left on their own because cells function in large groups in an organism. If the structure of the cells is similar in principle, important differences arise from the tiniest of changes, enabling the whole organism to function.



Eukaryotes and Prokaryotes: Similarities and Differences

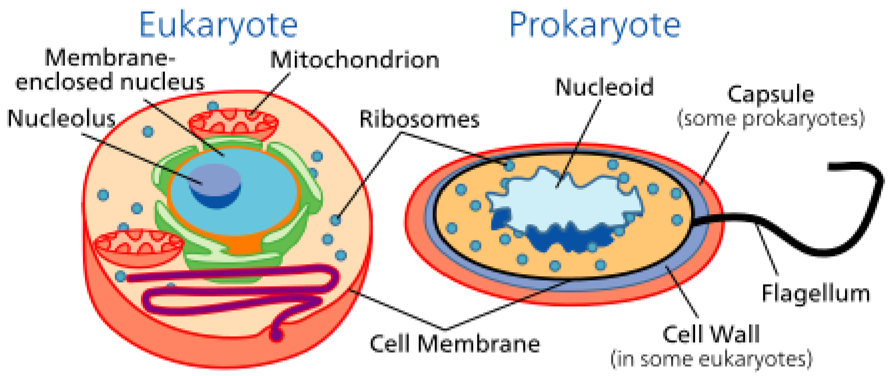


Image: "Cells of eukaryotes and prokaryotes". License: Public Domain

A cell is a tiny unit of an organism. Fundamentally, two types can be distinguished: the prokaryotic and the eukaryotic cells. Only **bacteria**, **archaea** and **cyanobacteria** are among the so-called **prokaryotes**, whereby, out of these, bacteria are the most important for medics, since they often need to be controlled using antibiotics. There may be some similarities, but many differences can also be identified after studying the structure of these two cell types.

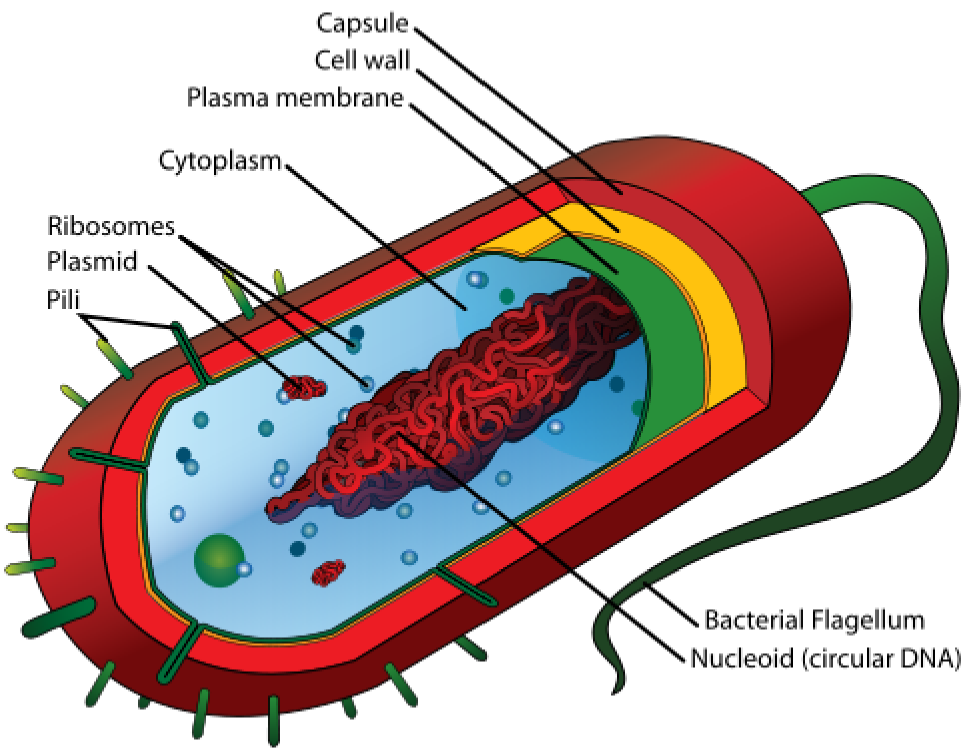
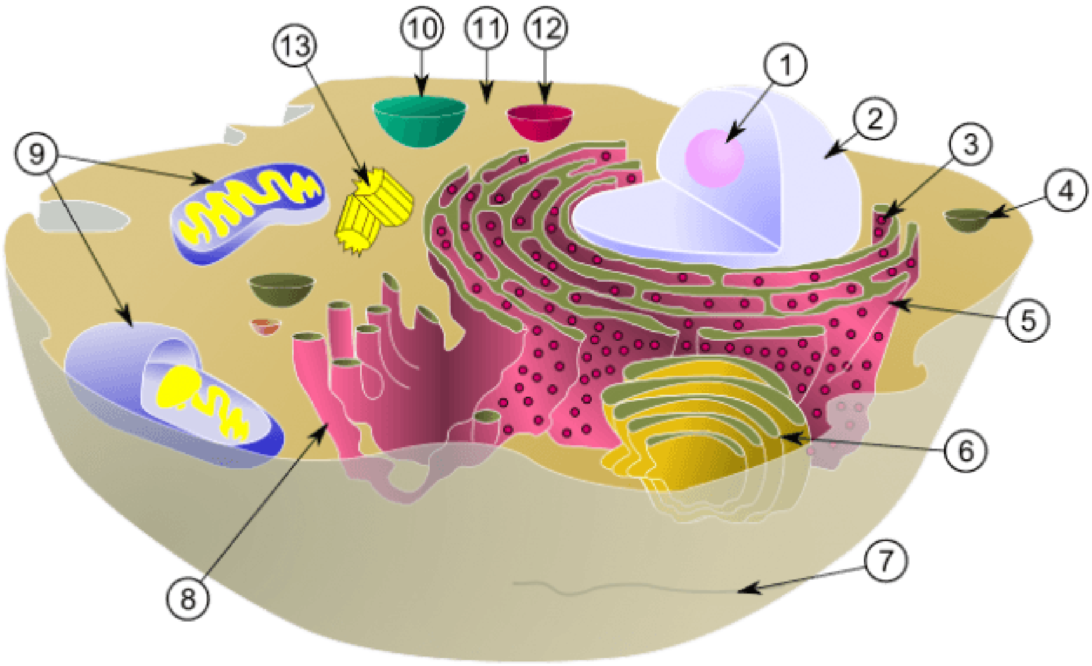


Image: "Average prokaryote cell". License: Public Domain

Common to both cells, is that they are surrounded by a **plasma membrane** and their **genetic information** is contained in the cells. Similar metabolic pathways and principles of the ATP-formation can also be observed. Prokaryotic cells are significantly smaller, do not contain any **cell organelles** and, in contrast to the eukaryotic cells, do not have a nucleus. Thus, their genetic material floats freely in the cytoplasm. Eukaryotic cells also contain a **cytoskeleton** and an **inner membrane system** in addition to the cell organelles. They have a complex **flagella**, a **spindle apparatus** and are capable of endo-cytosis or rather phagocytosis, meiosis and fertilization. Moreover, they have complex **chromosomes** and, in most cases, a diploid set of chromosomes.



[Image](): “Cells of eukaryotes and prokaryotes”. License: [CC BY-SA 3.0]()

Inscription: 1) Nucleolus 2) Cell nucleus (Nucleus) 3) Ribosomes 4) Vesicle 5) Rough endoplasmic reticulum 6) Golgi apparatus 7) Microtubules 8) Smooth endoplasmic reticulum 9) Mitochondria 10) Lysosome 11) Cytosol 12) Peroxisome 13) Centrioles

In simple terms, eukaryotes consist of a **nucleus and cytoplasm** that contains various cell organelles that are surrounded by a **plasma membrane**. The appearance of the cells, both in terms of surface structure and in terms of their internal structure varies greatly depending on their respective functional tasks. The human body consists of about 6×10^{13} cells.

The Nucleus

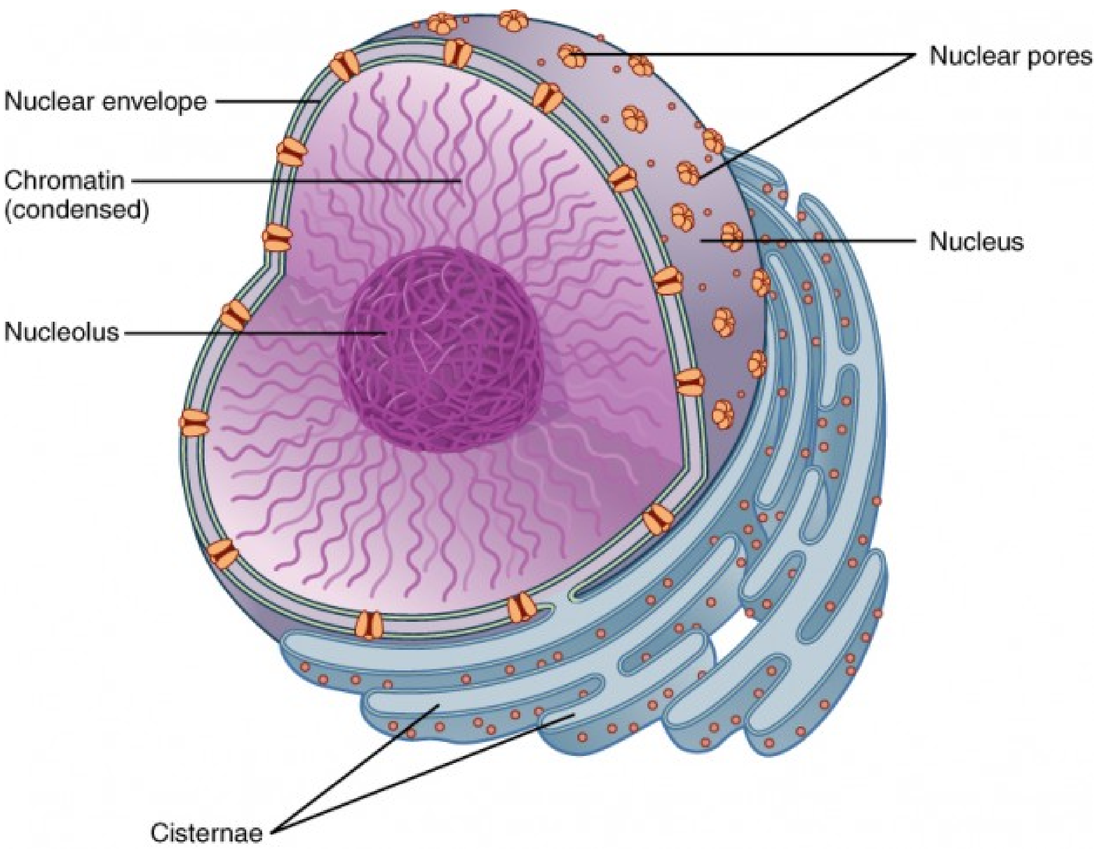


Image: “The Nucleus” by Phil Schatz. License: CC BY 4.0

An important component of almost every cell is the **cell nucleus** or **nucleus**. It contains DNA and thus provides the genetic information. Only **erythrocytes do not contain nuclei**. Other cells, for example nerve or liver cells can be polynuclear. The shape of the cell nucleus is dependent on the cell. For example, even elongated nuclei can be observed in elongated muscle cells.

Constituents of the cell nucleus are:

- Chromatin
- Nucleolus
- Nuclear envelope
- Nucleoplasm

Chromatin

The complex of DNA and some structural proteins in the cell nucleus, which can be dyed with basic dyes, is referred to as **chromatin**. It can be compressed into chromosomes in certain phases of the cell cycle. A distinction should be made between the so-called **euchromatin**, which is genetically active and is predominantly uncoiled, and the inactive **heterochromatin**.

The heterochromatin can be divided further into **constitutive heterochromatin**, which basically exists in condensed form, and **facultative heterochromatin**, which can exist in both condensed and non-condensed forms. Constitutive heterochromatin forms the **centromere region**. For example, a protein will never be seen in this material. Another example is the female sex gene, wherein one of the X-chromosomes is immobilized.

In mitosis, there are usually fully condensed **chromosomes**. For the organized flow of the non-condensed state, 2 m long DNA strands provide positively charged structural proteins, which are referred to as **histones**. The histones H2A, H2B, H3 and H4 are wound by the DNA, whereas the H1 complex is positioned outside and the so-called **linker DNA** interconnects multiple **nucleosomes**.

Nucleolus

A structure from which ribosomes arise is referred to as the nucleole or nucleolus in the cell nucleus. It consists of a fibrillar centre, the **pars fibrosa**, which contains DNA loops that encode ribosomal RNA, i.e. **rRNA**. Therefore, a high number of **RNA polymerases** can be found here. In the second part, **pars granulosa**, the synthesis of pre ribosomal particles occurs: Small and large sub-units of the ribosomes and proteins are associated with each other.

In humans, the nucleolus forms around the chromosomes 13, 14, 15, 21 and 22, which is referred to as the **Nucleolus Organizer Region** (NOR). Numerous rRNA genes are available here. Through the nuclear pores, ribosomal proteins are transported to the nucleus from the cytosol, the rRNAs attach themselves and are processed. The large 60S and the small 40S subunits once again leave the nucleus later and are assembled to form an 80S ribosome in the rough endoplasmic reticulum.

Nuclear envelope

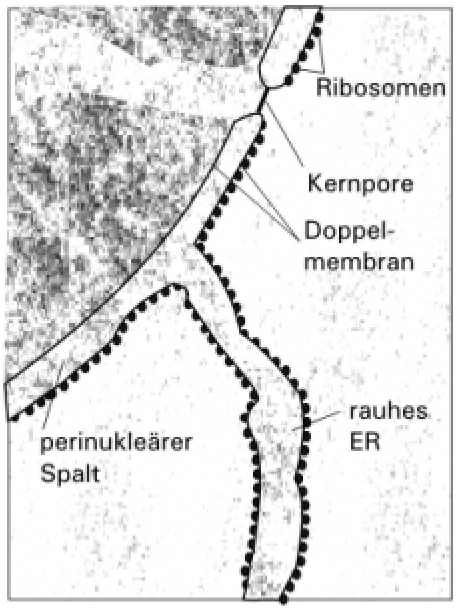


Image: "Kernmembran" by Opossum58. License: CC BY-SA 3.0

The **nuclear envelope**, also referred to as **karyolemma,** is a double membrane and demarcates the nucleoplasm from the cytoplasm. A **perinuclear gap** which is 10-15 nm wide is located between the two membranes. The inner membrane, which faces the nucleus, has superposed **lamin filaments**, to which the chromatin strands are attached. The outer membrane facing the cytoplasm can be occupied by ribosomes and directly passes into the **endoplasmic reticulum**.

There are numerous **pores** (up to 1 million) **for the exchange of substances** in the surface of the nuclear envelope. Their diameter is about 10-26 nm. Transport of substances is actively done through the pores **over ATP**. Various proteins, such as importin, help in the selection of materials which are to be transported through the pores, such as ribosomes, transcription factors or polymerase.

Nucleoplasm

The **nucleoplasm** is also called **karyoplasm** or **karyolymph**. It contains about 10,000 times more sodium and chloride ions as the cytoplasm. Its mass balance serves the purpose of **DNA replication and transcription,** which occurs in the core area. All proteins that are required in the karyoplasm must be imported from the cytoplasm, because the **protein biosynthesis** takes place there.

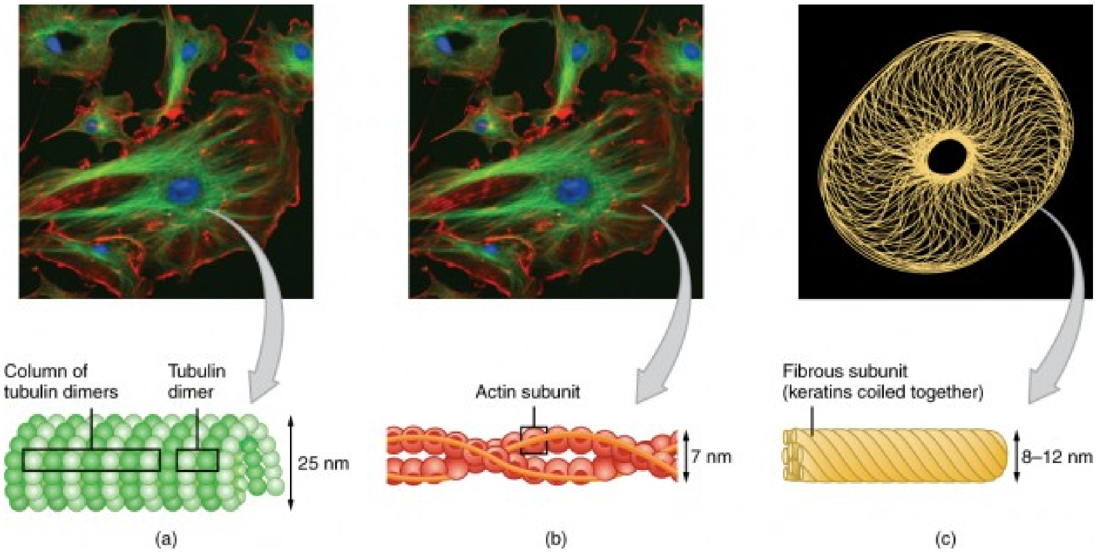
The Cytoplasm

Each cell contains a **cytoplasm**. It consists of the **cytosol**, the **cytoskeleton** and various **cell organelles** in eukaryotic cells. A proportion in the range of 80-85 % of the cytoplasm consists of water, whereas 10-15 % consists of proteins. Only a small mass thus consists of DNA, RNA, lipids and other components.

Cytosol

Almost 55 % of the cytoplasm is present in the cytosol. This is a **gel-like mass** which contains many proteins and enzymes. Hence, the cell is capable of synthesizing sugars, fatty acids and nucleotides for example, operating **glycolysis** and **protein biosynthesis** as well as decomposition of the proteins again. The cytosol also serves as a storage for glycogen and triglycerides.

Cytoskeleton



These are structured **protein filaments** inside the cells which handle the complex organization and processing that take place within the cell. The **actin filaments** and **microtubules**, as well as the intermediate filaments are of particular importance. These are protein structures which, in addition to various other proteins in the cell, are responsible for tasks such as, **cilia activity** or **muscle contraction**, among other things.

Microtubules

Microtubules are **tubes made up of proteins**, which enable transportation of substances within the cell. They consist of **α– and β-tubulin dimers**. Whereby, the α-tubulin is located in the negative pole and the β-tubulin is situated in the positive pole towards the **protofilaments** chain-like connected dimers. 9 triplets of microtubules respectively form the wall of a **centriole**, a hollow tube in the cell, which is important for enabling the **polarity** of a cell during mitosis.

In doing so, the mitotic spindle, a network of approximately 3,000 microtubules, also plays a role. The microtubules attach themselves to the chromosomes and pull them apart during anaphase, whereas other microtubules separate the cell's poles from each other. Consequently, the division of mitosis begins.

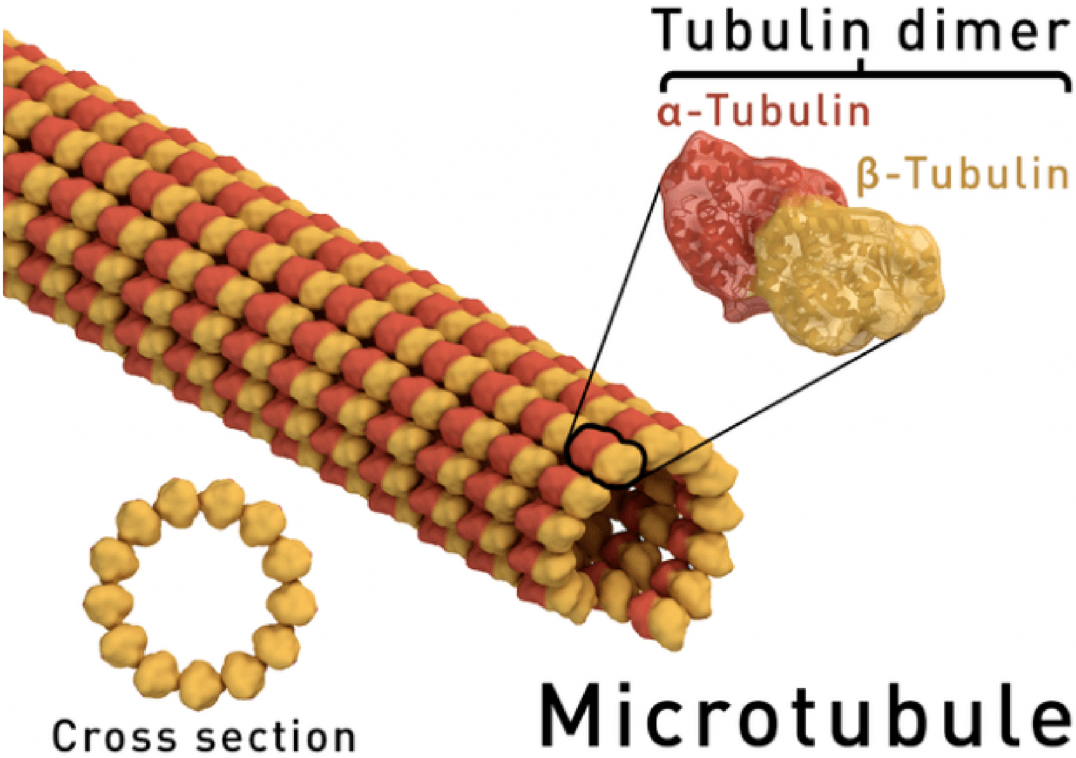


Image: "Microtubule structure" by Thomas Splettstoesser. License: CC BY 4.0

Actin filaments

Actin filaments are **capable of interacting with other proteins** and are therefore responsible for different tasks, especially movement. Actin filaments have two chains each with a positive and negative pole. Other than that, they are permanently linked to one another via interactions and are reciprocally twisted. Together with the molecule **myosin**, they are responsible for **muscle contraction**.

Myosin chains also have two chains, whereby at end there is a head. These heads can bind to the actin filaments. The filaments steadily slide past each other causing the contraction of muscles, such that the ATP-operated myosin heads always adhere elsewhere on the actin filaments. The principle of **ciliary movement** functions similarly: ATP-operated microtubules slide past each other and cause movement.

The cell organelles

Ribosomes

Ribosomes are RNAs which are linked to proteins. Ribosomes can be found in the **rough endoplasmic reticulum**, but are also **freely present in the cytosol**. Each ribosome consists of two subunits.

Their size can be determined through the respective rate of sedimentation in an ultracentrifuge, wherein the values of the large and small subunit cannot be added in order to determine the rate of sedimentation of the entire ribosome.

In this case, there is an significant **difference between prokaryotic and eukaryotic cells**: Prokaryotic cells consist of 50S and 30S subunits, which together produce a ribosome with a sedimentation constant of 70S. In the case of eukaryotes, it is about a 60S and 40S subunits, which together result in an 80S ribosomes. The aim of some of the antibiotic therapies is to intervene in the protein biosynthesis of prokaryotes.

Ribosomes are necessary for **protein biosynthesis**. When they are freely present in the cytoplasm and do not have a function, their subunits are separated. They are assembled only when a protein is to be synthesized. Free ribosomes produce proteins that are required by the cell. Ribosomes at the endoplasmic reticulum produce proteins, which are incorporated into the membrane wall or exit the cell.

Endoplasmic reticulum

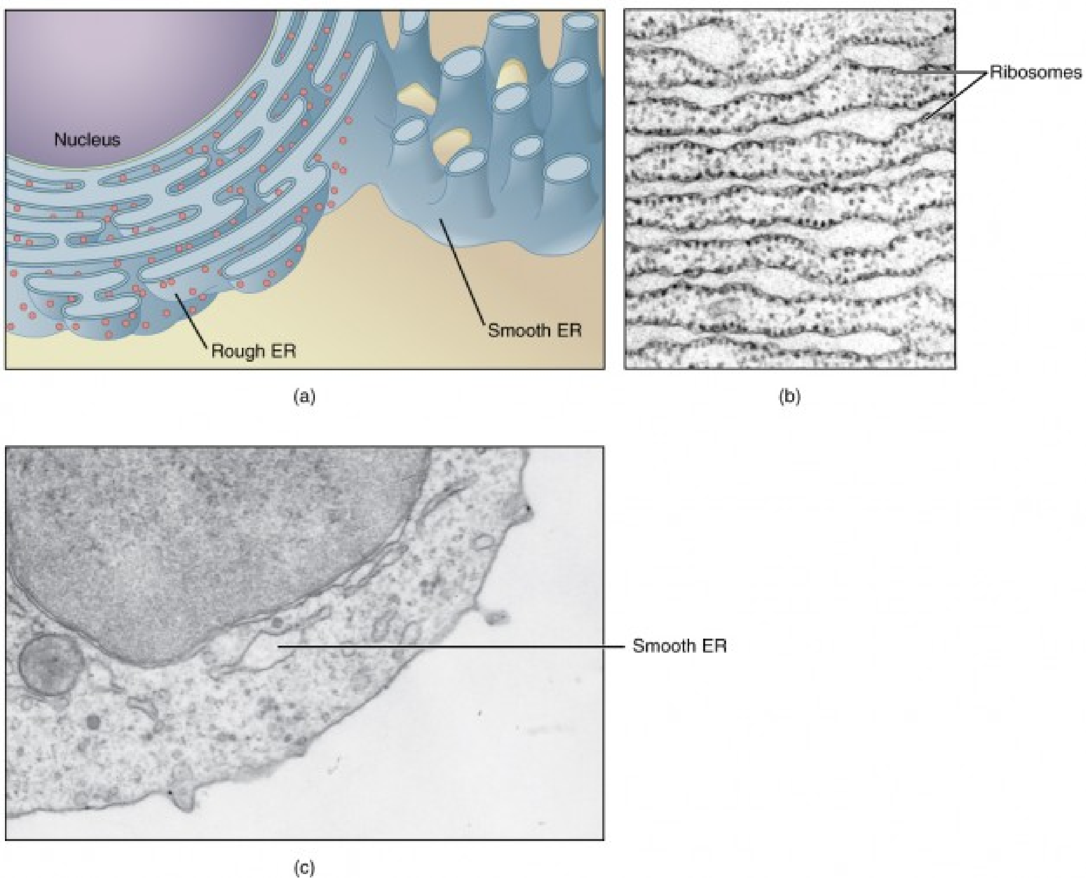


Image: "Endoplasmic Reticulum" by Phil Schatz. License: CC BY 4.0

The endoplasmic reticulum, often abbreviated as ER, can be differentiated into a rough endoplasmic reticulums (rER) and smooth endoplasmic reticulums (sER). Both are a **system of elementary membranes**, which consists of membrane tubules. Differences can be observed functionally, although both parts form a system together.

1. Smooth endoplasmic reticulum

In contrast to the rER, the sER does not carry any **ribosomes outside its membranes**. It serves as an **ion storage**, handles **hormone synthesis**, allows **carbohydrate metabolism** and also allows detoxification of medicines and other toxins. The sER transmits the **glucose 6-phosphatase** enzyme itself, which is required for gluconeogenesis. Among other things, the metabolism of carbohydrates is regulated through this mechanism.

Because of the role it plays in the synthesis of hormones, plenty of sER can be found in the adrenal cortex for the production of **corticosteroids** and **aldosterone**. The sER is also required in the **testes** and **ovaries**, to produce sex hormones, testosterone and estrogen. Similarly, the corpus luteum needs the sER in order to produce progesterone.

Liver cells carry a lot of sER whose purpose is to carry out detoxification. This applies, among other things, to barbiturates and alcohol. Through excessive consumption of these substances, the sER multiply strongly, enhancing the detoxification function. This mechanism can explain the development of tolerance to these substances, among other things.

The function of the sER as an ion storage is particularly of importance in the muscle cells: The sER, described here as the sarcoplasmic reticulum, stores extremely high amounts of Ca2 + ions, which are released during incoming nerve stimulus into the cytoplasm of the cell. Thus, the muscle cell is able to contract.

2. Rough endoplasmic reticulum

Ribosomes can be found in the rough endoplasmic reticulum on the side that faces the cytosol of the cell. The rER is thus a location of the **protein biosynthesis**. The following also applies to the rER: Cells that must produce a lot of proteins, show a particularly high number of rER. Examples of such cells include those of the **pancreas,** whose purpose is to produce insulin, a proteo-hormone.

In order for a protein to be produced in the rER and not in the free ribosomes, it carries a **specific signal sequence**. This distinction is important, as only proteins produced through the rER are suitable for export from the cell. A **signal recognition particle** (SRP) of the cytosol detects the signal sequence of the protein and binds the ribosome to the rER.

Golgi apparatus

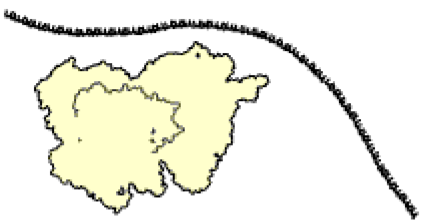


Image: “The elongation and membrane targeting stages of eukaryotic translation. The ribosome is green and yellow, the tRNAs are dark blue, and the other proteins involved are light blue." by Bensaccount. License: CC BY 3.0

Proteins wander through the Golgi apparatus and are provided with post-translational modifications in this region. The Golgi apparatus can be identified by the fact that it looks like a stack of several membranes. These are the so-called **Golgi cisternae**. Distinctions can be made between a **convex cis-side**, which faces the direction of the ER, and a **concave trans-side**, which faces the plasma membrane.

The proteins are placed over the transport vesicles on the cis-side of the Golgi apparatus and begin their way through the system from this point. When they reach the trans-side, they can either be transported to the membrane surface or are returned to the ER.

The Golgi apparatus therefore also follows a **sorting function** in addition to the **post-translational modifications**.

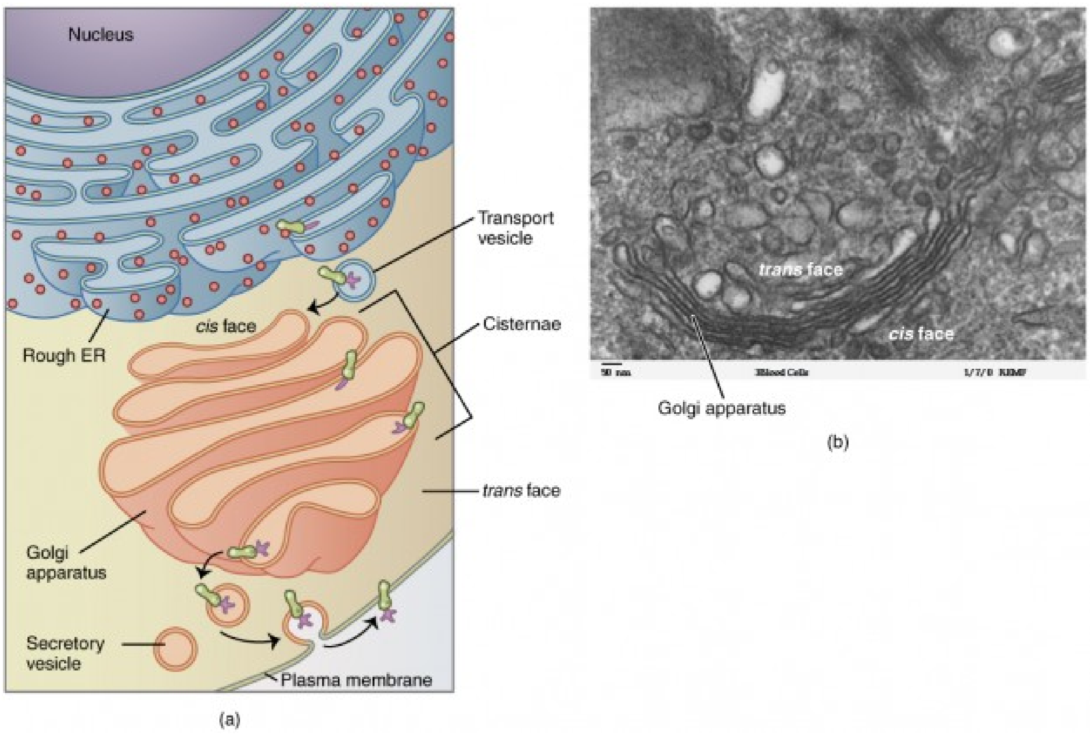
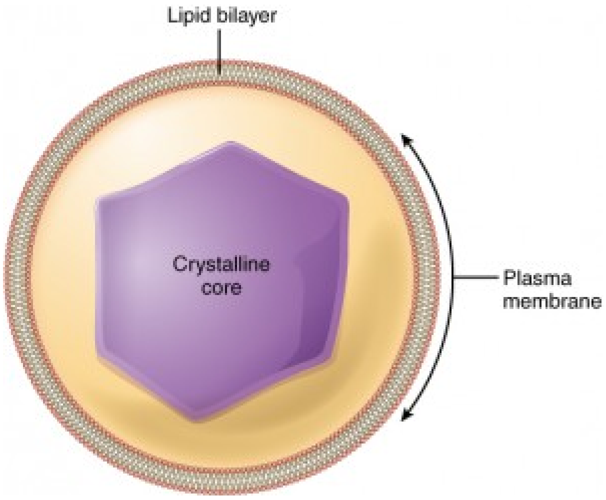


Image: "Golgi Apparatus" by Phil Schatz. License: CC BY 4.0

Lysosomes

A lysosome serves as the cell for **digestion**. An **acidic pH value** is found within the lysosomes, so that specific enzymes can work within them, which are only active in an acidic pH value. These hydrolytic enzymes are formed in the rER and pass through the Golgi apparatus at its trans-side, where they are cut off in vesicles. Lysosomes originate in this way. During digestion by the enzymes, degradation products such as carbohydrates are produced, which are released into the cytosol of the cell.

Peroxisomes



Peroxisomes can be **broken down resulting to a build up of hydrogen peroxide,** with the help of special enzymes, from which they have earned their name. Moreover, they are capable of **β-oxidation** of long chain fatty acids and **steroid synthesis**. They are often present in the myelin sheaths of axons in the brain, whereby pathological neurological changes during outages of peroxisomes are difficult to explain.

Mitochondria

Mitochondria are referred to in many textbooks as the **powerhouses of the cell**, since they **produce ATP** which is used for all energy-intensive processes. The biochemical process in which ATP is produced is based on a respiratory chain. The inner matrix space of the mitochondria is surrounded by two membranes: first by an **inner**, then by an **outer membrane**.

The inner membrane bulges outward mostly in the form of christae in the matrix space of the mitochondrion. A tubular type of surface enlargement is rare. The **inner membrane** is **impermeable** for most molecules, such that transporters are required in order to overcome this barrier. The **outer membrane** towards the cytosol is, on the other hand, **permeable** to ATP, NAD and CoA through protein channels.

In addition to the **respiratory chain,** which is linked to the inner mitochondrial membrane, more enzyme-linked metabolic pathways occur in the matrix space. These are the citric acid cycle, which makes acetyl-CoA, oxaloacetate and α-ketoglutarate available for the oxidation process, as well as the β-oxidation which provides, among other things, the hydrogen atoms for the respiratory chain.

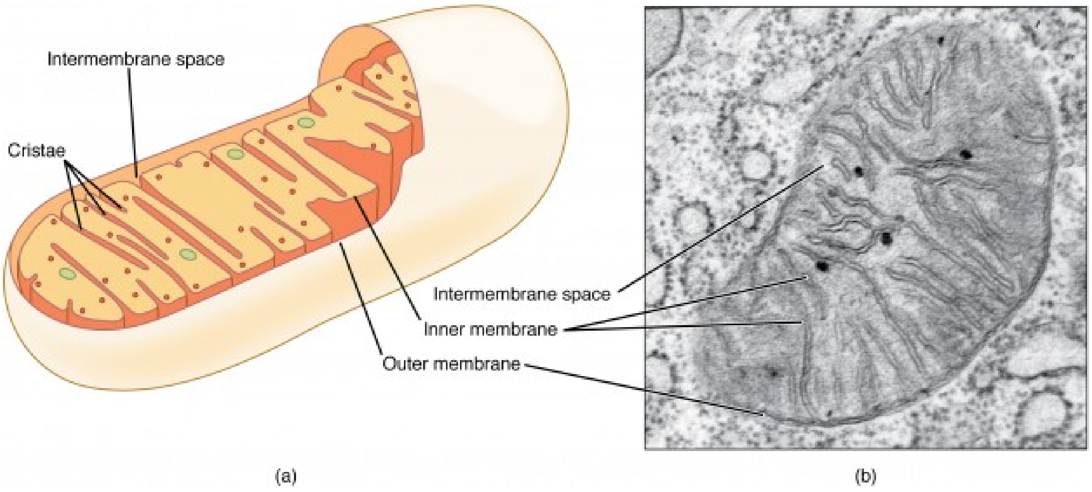


Image: “Mitochondrion” by Phil Schatz. License: CC BY 4.0

Review Questions

The answers can be found below the references.

1. What distinguishes the smooth from the rough endoplasmic reticulum?

A. The sER has more ribosomes than the rER.
B. Gluconeogenesis occurs in the rER.
C. Proteins are produced in the rER.
D. Protein biosynthesis occurs in the sER.
E. There is no functional difference, they just look different.

2. Between prokaryotes and eukaryotes…

A. … there are no differences.
B. One of the differences lies in the fact that eukaryotes have no nucleus.
C. One of the differences is that only prokaryotes have a plasma membrane.
D. …there is a difference: in prokaryotes, the genetic information is freely present in the cytoplasm.
E. …strong differences appear with regards to the formation of ATP.

3. Which cell organelles are called powerhouses of the cell?

A. Mitochondria
B. Ribosomes
C. Lysosomes
D. Peroxisomes
E. Golgi apparatus

References

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Correct answers: 1C, 2D, 3A

Notes