Inquire: The Endomembrane System

Overview

The endomembrane system includes the nuclear envelope, lysosomes, vesicles, the ER, Golgi apparatus, and the plasma membrane. These cellular components work together to modify, package, tag, and transport proteins and lipids that form the membranes.

The RER modifies proteins and synthesizes phospholipids in cell membranes. The SER synthesizes carbohydrates, lipids, and steroid hormones; engages in the detoxification of medications and poisons; and stores calcium ions. The sorting, tagging, packaging, and distributing of lipids and proteins takes place in the Golgi apparatus. Budding RER and Golgi membranes create lysosomes. Lysosomes digest macromolecules, recycle worn-out organelles, and destroy pathogens.

Big Question: What is the relationship between the structure and function of the endomembrane system components?

Watch: Transportation Inside a Cell

The endomembrane system includes the nuclear envelope, lysosomes, vesicles, the endoplasmic reticulum, the Golgi apparatus, and the plasma membrane. These cellular components work together to modify, package, tag, and transport proteins and lipids that form the membranes.

The endoplasmic reticulum (ER) is a series of interconnected membranous sacs and tubules that collectively modify proteins and synthesize lipids. However, these two functions take place in separate areas of the ER: the rough ER and the smooth ER, respectively.

The rough ER is studded with ribosomes, the site of protein synthesis. Ribosomes transfer their newly synthesized proteins into the rough ER where they undergo structural modifications. If the modified proteins are not destined to stay in the rough ER, they will reach their destinations via transport vesicles that bud from the rough ER’s membrane.
The smooth endoplasmic reticulum is continuous with the rough ER but has few or no ribosomes on its surface. Smooth ER functions include synthesis of carbohydrates, lipids, and steroid hormones; detoxification of medications and poisons; and storing calcium ions.

Before reaching their final destination, the lipids or proteins within the transport vesicles still need sorting, packaging, and tagging so that they end up in the right place. Sorting, tagging, packaging, and distributing lipids and proteins takes place in the Golgi apparatus, a series of flattened membranes.

The transport vesicles that formed from the ER travel to the Golgi apparatus and empty their contents. As the proteins and lipids travel through the Golgi, they undergo further modifications that allow them to be sorted. These newly modified proteins and lipids then tag with phosphate groups or other small molecules in order to travel to their proper destinations.

Finally, the modified and tagged proteins are packaged into secretory vesicles that bud from the Golgi. While some of these vesicles deposit their contents into other cell parts where they will be used, other secretory vesicles fuse with the plasma membrane and release their contents outside the cell.

Read: The Endomembrane System and Proteins

Overview

The endomembrane system (endo = “within”) is a group of membranes and organelles in eukaryotic cells that work together to modify, package, and transport lipids and proteins. It includes the nuclear envelope, lysosomes, vesicles, endoplasmic reticulum, and Golgi apparatus. Although not technically within the cell, the plasma membrane is included in the endomembrane system because, as you will see, it interacts with the other organelles that make up the endomembrane. The endomembrane system does not include either mitochondria or chloroplast membranes.

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.

Endoplasmic Reticulum

The endoplasmic reticulum (ER) is a series of interconnected membranous sacs and tubules that collectively modify proteins and synthesize lipids. However, these two functions take place in separate areas of the ER: the rough ER and the smooth ER, respectively.
We call the ER tubules' hollow portion the lumen or cisternal space. The ER's membrane, which is a phospholipid bilayer embedded with proteins, is continuous with the nuclear envelope.

Rough ER

Scientists have named the rough endoplasmic reticulum (RER) as such because the ribosomes attached to its cytoplasmic surface give it a studded appearance when viewed through an electron microscope.

Ribosomes transfer their newly synthesized proteins into the RER's lumen, where they undergo structural modifications, such as folding or acquiring side chains. These modified proteins incorporate into cellular membranes — the ER or the ERs of other organelles' membranes. The proteins can also secrete from the cell (such as protein hormones, enzymes). The RER also makes phospholipids for cellular membranes.

If the phospholipids or modified proteins are not destined to stay in the RER, they will reach their destinations via transport vesicles that bud from the RER's membrane. Since the RER is engaged in modifying proteins (such as enzymes, for example) that secrete from the cell, you would be correct in assuming that the RER is abundant in cells that secrete proteins. This is the case with liver cells, for example.

Smooth ER

The smooth endoplasmic reticulum (SER) is continuous with the RER but has few or no ribosomes on its cytoplasmic surface. SER functions include synthesis of carbohydrates, lipids, and steroid hormones; detoxification of medications and poisons; and storing calcium ions. In muscle cells, a specialized SER, the sarcoplasmic reticulum, is responsible for storing calcium ions that are needed to trigger the muscle cells' coordinated contractions.

The Golgi Apparatus

We have already mentioned that vesicles can bud from the ER and transport their contents elsewhere, but where do the vesicles go? Before reaching their final destination, the lipids or proteins within the transport vesicles still need sorting, packaging, and tagging so that they end up in the right place. Sorting, tagging, packaging, and distributing lipids and proteins takes place in the Golgi apparatus (also called the Golgi body), a series of flattened membranes.

We call the Golgi apparatus the \textit{cis} face. The opposite side is the \textit{trans} face. The transport vesicles that formed from the ER travel to the \textit{cis} face, fuse with it, and empty their contents into the Golgi apparatus' lumen. As the proteins and lipids travel through the Golgi, they undergo further modifications that allow
them to be sorted. The most frequent modification is adding short sugar molecule chains. These newly modified proteins and lipids then tag with phosphate groups or other small molecules in order to travel to their proper destinations.

Finally, the modified and tagged proteins are packaged into secretory vesicles that bud from the Golgi’s trans face. While some of these vesicles deposit their contents into other cell parts where they will be used, other secretory vesicles fuse with the plasma membrane and release their contents outside the cell.

In another example of form following function, cells that engage in a great deal of secretory activity (such as salivary gland cells that secrete digestive enzymes or immune system cells that secrete antibodies) have an abundance of Golgi.

In plant cells, the Golgi apparatus has the additional role of synthesizing polysaccharides, some of which are incorporated into the cell wall and some of which other cell parts use.

Vesicles and Vacuoles

Vesicles and vacuoles are membrane-bound sacs that function in storage and transport. Other than the fact that vacuoles are somewhat larger than vesicles, there is a very subtle distinction between them. Vesicle membranes can fuse with either the plasma membrane or other membrane systems within the cell. Additionally, some agents, such as enzymes within plant vacuoles, break down macromolecules. The vacuole’s membrane does not fuse with the membranes of other cellular components.

Lysosomes

In addition to their role as the digestive component and organelle-recycling facility of animal cells, lysosomes are part of the endomembrane system. Lysosomes also use their hydrolytic enzymes to destroy pathogens (disease-causing organisms) that might enter the cell. A good example of this occurs in macrophages, a group of white blood cells which are part of your body’s immune system. In a process that scientists call phagocytosis or endocytosis, a section of the macrophage’s plasma membrane invaginates (folds in) and engulfs a pathogen. The invaginated section, with the pathogen inside, then pinches itself off from the plasma membrane and becomes a vesicle. The vesicle fuses with a lysosome. The lysosome’s hydrolytic enzymes then destroy the pathogen.

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.
Reflect: Lysosomes and Human Disease

Poll
There is a human disease that causes the lysosomes to work incorrectly. Can you identify the disease, and using your knowledge of lysosomes, do you think this disease could be fatal?

Tay-Sachs
- Yes
- No

Achondrogenesis
- Yes
- No

Expand: Career Connection

Cardiologist
Heart disease is the leading cause of death in the United States. This is primarily due to our sedentary lifestyle and our high trans-fat diets.

Heart failure is just one of many disabling heart conditions. Heart failure does not mean that the heart has stopped working. Rather, it means that the heart can't pump with sufficient force to transport oxygenated blood to all the vital organs. Left untreated, heart failure can lead to kidney failure and other organ failure.

Cardiac muscle tissue comprises the heart's wall. Heart failure occurs when cardiac muscle cells' endoplasmic reticula do not function properly. As a result, an insufficient number of calcium ions are available to trigger a sufficient contractile force.

Cardiologists (cardi- = "heart"; -ologist = "one who studies") are doctors who specialize in treating heart diseases, including heart failure. Cardiologists can diagnose heart failure through a physical examination, results from an electrocardiogram (ECG, a test that measures the heart's electrical activity), a chest X-ray to see whether the heart is enlarged, and other tests. If the cardiologist diagnoses heart failure, he or she will typically prescribe appropriate medications and recommend a reduced table salt intake and a supervised exercise program.

Geneticist
Many diseases arise from genetic mutations that prevent synthesizing critical proteins. One such disease is Lowe disease (or oculocerebrorenal syndrome, because it affects the eyes, brain, and kidneys). With Lowe disease, there is a deficiency in an enzyme localized to the Golgi apparatus. Children with Lowe disease are born with cataracts, typically develop kidney disease after their first year of life, and may have impaired mental abilities.

A mutation on the X chromosome causes Lowe disease. The X chromosome is one of the two human sex chromosomes, or chromosomes that determine a person's sex. Females possess two X chromosomes, while males possess one X and one Y chromosome. In females, only one of the two X chromosomes' genes are expressed. Females who carry the Lowe disease gene on one of their X chromosomes are
carriers and do not show symptoms of the disease. However, males only have one X chromosome and the genes on this chromosome are always expressed. Therefore, males will always show symptoms of Lowe disease if their X chromosome carries the Lowe disease gene. Geneticists have identified the mutated gene's location, as well as many other mutation locations that cause genetic diseases. Through prenatal testing, a woman can find out if the fetus she is carrying may be afflicted with one of several genetic diseases.

Geneticists analyze prenatal genetic test results and may counsel pregnant women on available options. They may also conduct genetic research that leads to new drugs or foods, or perform DNA analyses for forensic investigations.

Lesson Toolbox

Additional Resources and Readings
In Da Club - Membranes & Transport: Crash Course Biology #5
- A Crash Course video covering the endomembrane system
  https://www.youtube.com/watch?v=dPKvHrD1eS4

Endomembrane System
- An animation of the endomembrane system
  https://www.youtube.com/watch?v=uHV65INNLp

Endomembrane System
- An exciting video showing the entire endomembrane system
  https://www.youtube.com/watch?v=tOQvxFb5chI

Lesson Glossary

endomembrane system: group of organelles and membranes in eukaryotic cells that work together modifying, packaging, and transporting lipids and proteins
endoplasmic reticulum (ER): series of interconnected membranous structures within eukaryotic cells that collectively modify proteins and synthesize lipids
Golgi apparatus: eukaryotic organelle made up of a series of stacked membranes that sorts, tags, and packages lipids and proteins for distribution
lysosomes: organelle in an animal cell that functions as the cell’s digestive component; it breaks down proteins, polysaccharides, lipids, nucleic acids, and even worn-out organelles
nuclear envelope: double-membrane structure that constitutes the outermost portion of the nucleus
nucleoplasm: semi-solid fluid inside the nucleus that contains the chromatin and nucleolus
plasma membrane: phospholipid bilayer with embedded (integral) or attached (peripheral) proteins, that separates the internal content of the cell from its surrounding environment
rough endoplasmic reticulum (RER): region of the endoplasmic reticulum that is studded with ribosomes and engages in protein modification and phospholipid synthesis
smooth endoplasmic reticulum (SER): region of the endoplasmic reticulum that has few or no ribosomes on its cytoplasmic surface and synthesizes carbohydrates, lipids, and steroid hormones; detoxifies certain chemicals (like pesticides, preservatives, medications, and environmental pollutants), and stores calcium ions
vesicles: membrane-bound sacs that function in storage and transport
vacuoles: membrane-bound sacs that function in storage and transport
Check Your Knowledge

1. The endomembrane system is a group of organelles and membranes in eukaryotic cells that work together modifying, packaging, and transporting lipids and proteins.
   A. True
   B. False

2. In blood cells, a specialized smooth ER, the sarcoplasmic reticulum, is responsible for storing calcium ions that are needed to trigger the muscle cells' coordinated contractions.
   A. True
   B. False

3. The rough ER modifies proteins and synthesizes phospholipids in cell membranes.
   A. True
   B. False

Answer Key:
1. A  2. B  3. A

Citations

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