...going one step further

R05

Model of a Plant Cell

English

(Magnification approx. 500,000-1,000,000)

The history of cytology

Cytology is an independent science in botany and deals with the structure and function of plant cells. The term cell (Latin: cellula = chamber, compartment, cell) was coined in 1665 by Robert Hooke, after he had discovered and recorded the cells within the tissue of a bottle cork with the help of one of the earliest light microscopes. At the beginning of the 19th Century, Franz Meyen (1804-1840) recognised cells as the elementary units of plant organs. In 1838/1839, Matthias Jacob Schleiden and Theodor Schwann establish **cell theory**: "Cells are the basis for all plants and animals." In 1845, Karl Theodor Ernst von Siebold, based on his observations on protozoa (unicellular organisms), wrote that cells can exist independently and represent the smallest unit of life. At the same time, Louis Pasteur and other scientists refuted the prevailing theory of the time which stated that cells can originate spontaneously out of dead organic matter (generatio spontanea). In 1855, Rudolf Virchow confirmed Meyen's theory which stated that every cell originates from another cell ("omnis cellula ex cellula"). In 1879, Eduard Strasburger discovered the division of the nucleus in plants. An important breakthrough in understanding the structure and function of cells was achieved by E. Ruska and H. Mahl in 1940, thanks to the development of the transmission electron microscope.
As in the animal world, plant cells, too, are characterised by the following:

- They have a more complex structure than their environment
- They react to inner and outer stimuli
- They have the ability to reproduce

Differences between animal and plant cells

In spite of the consistency regarding the cellular structure of animal and plant cells – which had been detected by Schleiden and Schwann in 1838 – there still are important differences in their basic structural plan. The following three features characterise the differences between most plant cells and animal cells:

1. Plant cells are enclosed by a **cell wall** which is responsible for resisting the inner osmotic pressure of the cell (turgor pressure), thereby giving it rigidity and increased stability.
2. As organelles, only plant cells possess **plastids**. These include, for example, the green chloroplasts, the scene of photosynthesis.
3. They possess the **sap vacuoles** characteristic of plants, in which dissolved substances are stored and macromolecules broken down.

Plant cells have an average size of 10-100 µm and can be observed by using a simple light microscope. A tree is made up of 10^{13} (= 10 trillion) cells! In multicellular organisms, they form groups of homogenous, in part strongly differentiated and specialised cells (= tissues).

Structure and function of a plant cell

(For numbering see diagram)

Note: Unlike the model presented, all components of a living cell are in a state of constant motion!!!

The individual cell components have differences in their composition, e.g. proteins/enzymes, ionic milieu, etc., and can best be classified according to their functions. An important term in plant cytology is **protoplast**, which refers to a cell surrounded by a plasma membrane in which the **cell wall has been removed**.

Cytoplasm with cytoskeleton (1)

In the course of evolution, a kind of division of work originated in a cell. This division of work is called **compartmentation**. It is achieved when special reaction complexes, the organelles (Greek: organon = tool), are surrounded and defined by membranes. These organelles can be detected, with the help of a light microscope, in the fluid and colourless cytoplasm of protoplasts (60 to 90% water, proteins, lipids, nucleic acids). The cell membrane (2) forms the boundary of the cell, marking it off from its exterior surroundings. The cell membrane consists of monomolecular layers of phospholipids and proteins which can move in the lipid matrix ("fluid mosaic" – model). Incidentally, all plant and animal membranes are based on the same elementary principle (unit membrane).

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This membrane is responsible for controlling the selective transport into and out of the cell. It has the same function with regard to the organelles, too. The cytoskeleton in the cytoplasm, which is made up of proteins, guarantees not just the stability of the cell but also the most diverse intracellular movements (e.g. visible plasma streams).

Nucleus (3a) with nucleolus (3b)
The nucleus (approx. 5-25 µm) is the information centre of the cell. It is enclosed within a double membrane lining with defined channels (= nuclear pores for controlling the metabolic flow between the nucleus and the cytoplasm) and contains the main part of the cell's genetic information, present in the form of chromatin. Only during cell division is the chromatin (normally not visible under a light microscope) transformed into its more compact form, viz. **chromosomes**. In the process, the DNA, which is bound by proteins, is strongly reduced by condensation and spiralisation. The nucleoli occur exclusively in the interior of the nucleus and are the site for the synthesis of preliminary stages of cytoplasmic ribosomes (5).

Endoplasmic Reticulum (smooth ER (4a) and rough ER (4b)) Ribosomes (5)
All proteins of the cell are built at the "sewing machine" of proteins, the ribosomes. These extremely small organelles (approx. 20-30 nm) can float freely in the cytoplasm or get attached to the sacciform or tubular membrane system of the endoplasmic reticulum (rough ER). Inside the ER´s compartment, proteins are in part transformed into helper proteins, commonly known as molecular chaperones, and are transported to their biophase. The smooth ER, without ribosomes attached, is mainly responsible for the synthesis of lipids. The structure of the ER is extremely dynamic and always subject to constant reorganisation. The ER is also connected to the membrane coating of the nucleus. That is to say, the membrane and the lumens of both of the organelles blend directly with one another.

Plasmodesmata (6)
Plasmodesmata constitute contact structures between neighbouring plant cells. In the process they form connections, in the form of fine channels, between the living protoplasts through the cell wall and the middle lamella. The coupling is built through tubular ER cisternae of both of the cells and its function is to transfer low-molecular substances between cells.

Plastids
Plastids are compartments typical to plant cells. They are always surrounded by a double membrane. The inner membrane is formed for the purpose of enlarging the reactive surface into the interior of the plastids. Plastids emerge on their own from the division of young proplastids and spread themselves during mitosis into daughter cells. Chloroplasts possess their own genetic information (ring-shaped, extrachromosomal genome; plastids DNA).
The green **chloroplasts** (7) are the site of photosynthesis and the synthesis of numerous plant constituents (e.g. fatty acids). The colourless and fluid matrix is denoted as stroma; the enlarged lamellar/sacciform inner membranes are called thylakoids. The stacked membrane areas are called grana thylakoids. The protein-bound pigments responsible for photosynthesis are found in these membranes (chiefly chlorophyll and carotenoids). These photosynthesis pigments are also responsible for the Hill reaction. The Calvin-Benson cycle or the photosynthetic carbon reduction cycle (PCR) CO_2 fixation as well as the formation of carbohydrates and starch take place in the stroma region.
Other plastids:
Chromoplasts: are inactive photosynthesis plastids responsible for the colouration of plant organs
Leucoplasts: are responsible for storing starch (amyloplasts), proteins (proteinoplasts), oils (elaioplasts)
Etioplasts: are the preliminary stage of chloroplasts and originate in the dark
Gerontoplasts: are all plastids at a very mature age

Mitochondria (8)
Mitochondria are the organelles responsible for cell respiration and energy conversion. They are therefore the "power plant" of every cell. Only mitochondria can give rise to mitochondria. Just like plastids,

mitochondria, too, are enclosed in a double membrane coating and possess their own genetic information. The components/proteins responsible for the respiratory chain (ATP synthesis) are located on the inner side of the membrane. The citrate cycle and the fatty acid oxidation cycle take place inside the mitochondrial matrix.

Endosymbiont theory

The endosymbiont theory attempts to explain the origin of mitochondria and plastids. According to this theory, mitochondria and plastids go back to intercellular protozoan (bacterial) symbiosis. In other words: plastids have developed from cyanobacteria, and mitochondria have developed from purple bacteria. At some point in the course of evolution, a “prototype“ cell with a nucleus (urocyte) incorporated prokaryotes and integrated them into its cellular functions. A strong indication of this is the fact that mitochondria and plastids have the following in common:

- A double membrane coating (inner and outer membranes are quite different in their chemical composition; the inner membrane resembles bacterial membranes)
- Inherent ring-shaped genome
- Inherent ribosomes (correspond to bacterial ribosomes, differ from cytoplasmic ribosomes)

Dictyosomes/Golgi apparatus (9)

Dictyosomes are disc-shaped, membranous hollow cavities (cisternae). The sum of all dictyosomes in a cell are termed the Golgi apparatus. They are closely connected to the ER and are responsible for the conversion, storage and transfer of the products of the ER. Consequently, a distinction can be drawn between a generation side (facing the ER, regeneration from the ER) and a secretion side (facing away from the ER) which forms a significant cellular transport system responsible for exocytosis (elimination of substances from the cell), the construction of biomembranes and is also involved in cell-wall formation.

Vacuole (10)

The vacuole is an organelle only to be found in plant cells. It is a space filled with fluid and is surrounded by a simple membrane (= tonoplast). In mature plant cells, the volume of the central vacuole can constitute up to 80% of the total volume of the cell. In the cell, vacuoles serve as reaction, storage (e.g. of ions, organic acids, saccharides, proteins, pigments), transport and deposit compartments (for substances that can be harmful to the cell, e.g. toxins, tanning agents). The breakdown of macromolecules (lytic compartment) is also carried out in the vacuoles.

Microsomes/Microbodies (11)

Microsomes are organelles with a homogenous structure (simple membrane, spherical, size: 1 µm, granular matrix) on the one hand, and strong biochemical and functional differences on the other.
Different functions:

- **Lysosomes:** are responsible for the break-up of proteins, polysaccharides and nucleic acids
- **Glyoxysomes:** play an important part in converting depot fats to carbohydrates
- **Oleosomes** (oil globules): are responsible for the break-up of fats and oils
- **Peroxisomes:** play an important part in photorespiration. Peroxisomes also break up the glycollate which is inevitably created during CO_2 fixation. Carbon is fed back into the photosynthesis cycle, and two amino acids are produced for protein synthesis.

Cell wall (12)

Possessing a rigid cell wall is an additional feature which distinguishes plant cells from animal cells. The cell wall gives the plant cell rigidity and form (exoskeleton) by resisting the interior osmotic pressure (= turgor pressure) of the cell. It is a product secreted by the protoplasts (apoplast). From a chemical point of view, the cell wall is made up of polysaccharides and proteins.
The cell wall is made up of up to three layers.
Middle lamella: a gelatinous layer, only a few nm in thickness, made up of pectin compounds with a low quantity of proteins. It has no fibril structure and is therefore elastic.

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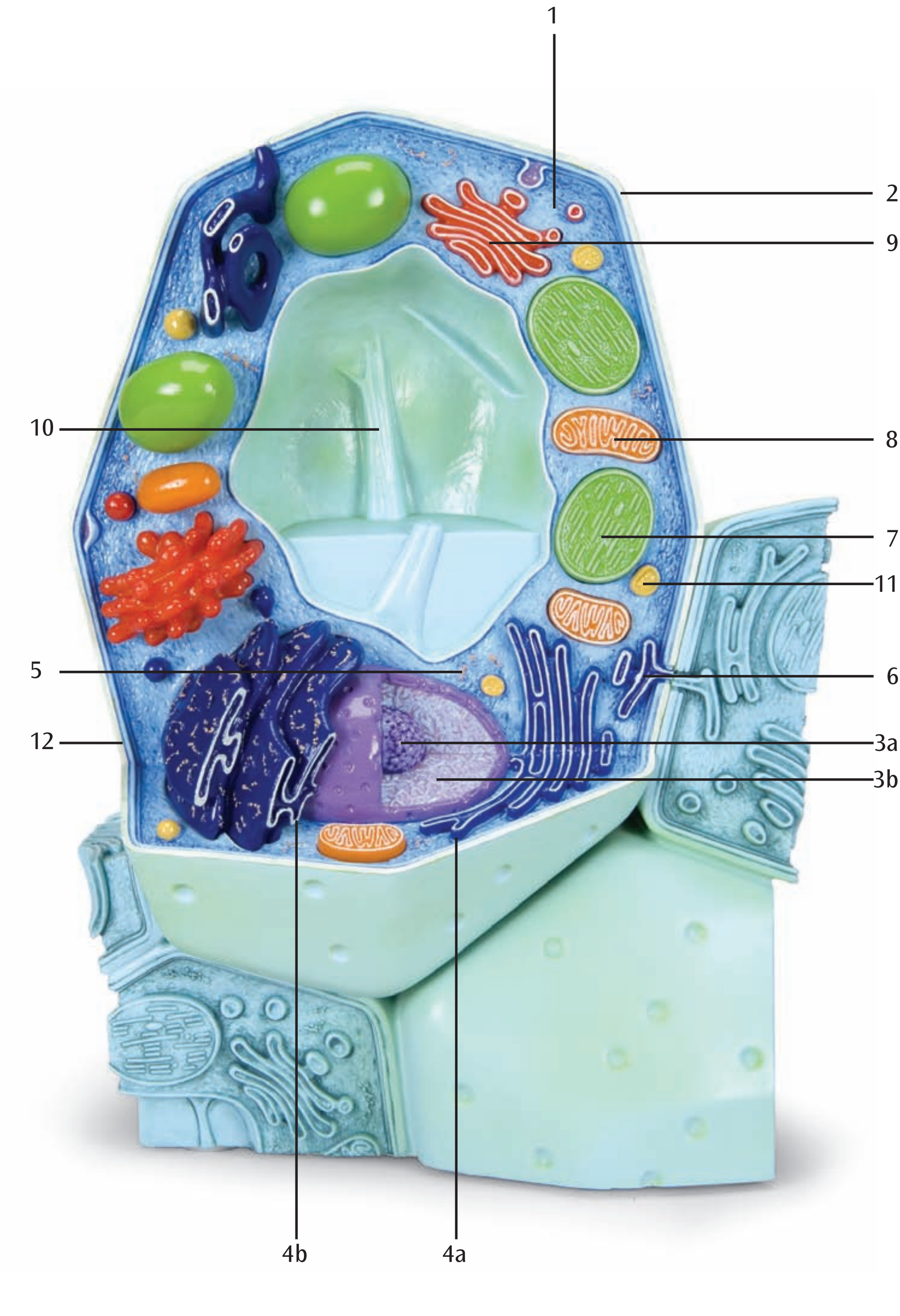
Primary cell wall: a gelatinous base substance (matrix) made up of pectin compounds, hemicellulose components and proteins. In the matrix, fibril structures can be detected (10-25%) which are arranged in an irregular, scattered texture (elasticity still present).

Secondary wall: is chiefly composed of 90% cellulose fibrils. The arrangement of the fibrils is primarily in a parallel texture. There are often deposits of lignin, tanning agents, $CaCO_3$, SiO_2 or colouring agents. Cells having a marked secondary wall are no longer capable of growth.

Author: Dr. Gerd Vogg, University of Würzburg, Germany

Numbering:

1 Cytoplasm with cytoskeleton
2 Cell membrane
3a Nucleus
3b Nucleolus
4a Smooth Endoplasmic Reticulum (smooth ER)
4b Rough Endoplasmic Reticulum (rough ER)
5 Ribosomes
6 Plasmodesmata
7 Chloroplasts
8 Mitochondria
9 Dictyosomes/Golgi apparatus
10 Vacuole
11 Microsomes/Microbodies
12 Cell wall (layered structure)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