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КАФЕДРА БИОЛОГИИ

**ВВЕДЕНИЕ**  
**В МЕДИЦИНСКУЮ БИОЛОГИЮ**  
для слушателей подготовительного отделения,  
обучающихся на английском языке

**INTRODUCTION**  
**TO MEDICAL BIOLOGY**  
for students of the pre-university department  
studying in English

Учебно-методическое пособие

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## INTRODUCTION

Biology is a system of sciences studying living matter. The problems it studies are the origin and the development of life on the Earth, the basic properties of living matter, the structure and vital processes of living organisms (bacteria, plants, fungi, animals), transmission of genetic information from generation to generation, structure and evolution of the biosphere, the problems of environmental protection.

At the Department of Pre-University Training of BSMU, foreign students study the structure of the human body (Anatomy) and vital processes proceeding there (Physiology); the structure and vital processes of bacteria (Microbiology), protists and animals (Zoology); chemical composition, structure, functions, substance and energy exchange of cells (Cytology); heredity and variation (Genetics).

Insight into these aspects of Biology is necessary for successful studying many disciplines of medical university. So, Cytology, Genetics, Ecology, Parasitology and Comparative Anatomy are considered in more details in the course of Biology delivered in medical universities.

The basic knowledge gained at the pre-university level is the basis for studying Anatomy, Physiology, Histology, Hygiene, Microbiology and other disciplines, which are indispensable for the comprehension of vital functions of healthy and sick people (preventive and clinical disciplines). Academician I. V. Davydovsky called Biology «the theoretical basis of Medicine». Consequently, the training of a student in Biology is necessary not only for admission to a medical university, but also to further successful training.

### **Requirements for applicants during the entry exam:**

- **to possess** the basic biological concepts, biological laws and theories;
- **know and understand** basic patterns that occur in the nature;
- **know the structure and vital processes** of bacteria, protists and animals including humans;
- **be able to** find out a causal connections between the structure and functions of cell organelles, structures and functions of tissues, organ and organ systems.
- **be able to** solve problems on subjects: Chargaff's rules, monohybrid, dihybrid crossing, genetic linkage and chromosomal crossing-over, sex linked inheritance, make and analyze pedigrees.

## SECTION 1 BIOLOGY OF THE CELL

### 1. BIOLOGY AS A SCIENCE. BASIC PROPERTIES OF LIVING MATTER

**The science of Biology.** The word «Biology» means science about life. It is derived from Greek words «bios» which means life and «logos» which means science. But what is life? There are many definitions. According to one of them, life is form of functioning of *proteins* and *nucleic acids* which maintains its orderliness at the expense of the environment. Biology studies all forms of life. The largest groups of living organisms are *bacteria*, *protists*, *plants*, *fungi* and *animals* (including human). Biology also studies *viruses* which are not considered as living organisms. Then what differentiates living things from non-living ones? Unlike inanimate (non-living) objects, living organisms have the following essential properties:

– Living organisms can create new individuals of their kind. This property is called self-reproduction.

– Living organisms can adjust themselves to changes of the environment. This property is called self-regulation.

– Living organisms can restore injured, lost or worn-out parts. This property is called self-renewal.

These properties are based on more fundamental characteristics of living matter:

1. Life that we know is based on functioning of *organic molecules* the most important of which are *nucleic acids* and *proteins*. They will be described in the next chapter. Though, same as inanimate objects, living organisms have not only organic, but also inorganic molecules. In addition, organic molecules can be produced in non-living nature.

2. Living organisms *consist of cells* — microscopic structures covered with semipermeable membrane.

3. Life is not possible without *exchange of substances and energy* between the environment and an organism. As noticed above, any living organism maintains its internal orderliness at the expense of the environment. In any chemical reaction occurring in the cell, a portion of released energy dissipates and is lost for the cell. That is why cell needs external source new energy. Living organisms receive food, water and other substances from the environment and release metabolic wastes they produce. Most of them can breathe: gain O<sub>2</sub> from the environment and release CO<sub>2</sub>.

4. Living organisms can multiply. The creation of new individuals of the same species by already existing organisms is called *reproduction*. Living organisms age and die. Young organisms replace them to continue the existence

of the species. «Multiplication» of living organisms is different from that one of the nonliving (e.g. fire) because of *heredity*.

5. *Heredity* is the transmission of characteristics from parents to progeny. Because of heredity, children are similar to their parents.

6. *Variation* is ability of organism to acquire new traits (ability to change). Due to this, children are never identical to their parents. Such changes have chance to make the new organism adapted to the environmental conditions better (or worse) than others.

7. Reproduction, heredity and variation cause *evolution*. The evolutionary history of species development is its *phylogenesis*.

8. Living organisms can *grow*. The individual development of an organism from the moment when its first cell is created to the death of the organism is called *ontogenesis*.

9. *Irritability* is the capability of living matter to respond to the environmental stimuli. For example, the nervous system causes pupil to become smaller when eye is exposed to bright light. Such response of organisms that have nervous system is called *reflex*. Another example of irritability is the movement of bacteria to/from a stimulus such as higher concentration of particular substance. Such response of *unicellular* (i.e. consisting of a single cell) organisms is called *taxis*.

10. *Homeostasis* is dynamic constancy of organism's internal environment (constant concentration of solutes in the blood, pH and etc.).

11. *Integrity* means that the organism is functionally indivisible and should be considered as a solid functioning unit. *Discretion* means that any organism is composed of various parts and can be considered as a group of structural and functional units.

#### ***Organization levels of living matter:***

1. Level of molecules. Processes occurring inside living organism are chemical reactions — interactions and changes of different *molecules*. Molecules form *cells*.

2. Level of cell. As mentioned above, all living organisms are composed of one or more cell. Cell is the smallest unit of life.

3. Level of tissue. The organisms consisting of more than one cell, have tissues — groups of cells and extracellular substance that are structurally and functionally related.

4. Level of organs. Tissues form organs — the body structures performing specific functions. Organs participating in performance of the same major function are united into organ systems.

5. Level of organism. All the organ systems form an organism. The organism is an elementary unit of life.

6. Level of population. A group of individuals of one species, occupying a definite territory for a long time, freely crossing and relatively isolated from

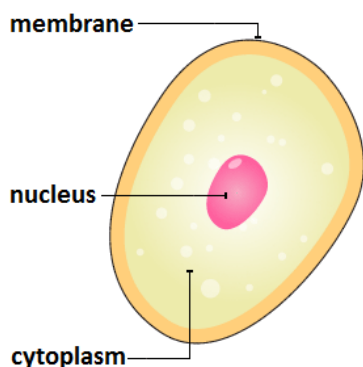
other groups of individuals of the same species, form a population. The population is an elementary unit of evolution.

7. Level of biogeocenosis (community) and biosphere. A biogeocenosis (or community) includes all populations of different species which live on definite residential territory and are historically related with each other. All the communities compose the biosphere — an area of the planet occupied by living organisms.

**Cytology** is defined as the science studying structure and functioning of cells.

Components of cells (fig. 1) are:

1. Plasma membrane is the covering of the cell consisting of lipids (they will be considered in the next chapter).



2. Nucleus is the cell's compartment which contains the information that helps to produce proteins — the molecules very necessary for life. Proteins will be considered in the next chapter. Nucleus is present in cells of animals, plants, fungi and protists (these organism are called *eukaryotes*), but not bacteria (they belong to *prokaryotes*).

3. Cytoplasm — all the contents of the cell between the membrane and the nucleus. Cytoplasm contains *organelles* — differentiated structures performing particular functions. The rest of the cytoplasm is cytosol — viscous water solution of organic and inorganic molecules.

All basic knowledge about cells was expressed in the Cell Theory in 1839:

1. Cell is the smallest living unit of all living organisms.
2. Cells of animals, plants and other organisms are similar in structure, chemical composition and functioning.
3. Growth and development of organisms occur due to multiplication and development of cells.
4. New cells appear only by means of division of already existing cells.

## 2. CHEMISTRY OF LIFE

**Organic and inorganic molecules.** All cells contain various organic and inorganic substances consisting of different chemical elements.

*Organic molecules* are carbon-containing molecules which, in most of cases, produced by living organisms. Examples: sugars, proteins, oils and many others.

All other substances are *inorganic* (and even some carbon containing molecules are not organic).

**Macro- and microelements.** Both organic and inorganic molecules are composed of atoms of different *chemical elements*. The elements that are contained in organisms in large amounts (more than 0.01 %) in the cell are called *macroelements*:

– *Oxygen (O)* — more than 65 % of organism’s mass. Oxygen is present in most of organic molecules and in water the amount of which in a cell is very high.

– *Carbon (C)* — present in organic molecules.

– *Hydrogen (H)* — present in organic molecules, in water.

– *Nitrogen (N)* — present in many organic molecules.

– *Phosphorus (P)* and *sulfur (S)* — present in many organic and inorganic molecules.

– *Sodium (Na)*, *potassium (K)*, *magnesium (Mg)*, *calcium (Ca)*, *chlorine (Cl)* — present in organism as ions dissolved in water.

The elements contained in the organism in small amounts (less than 0.01 %) are called *microelements* (*copper (Cu)*, *iodine (I)*, *zinc (Zn)*, *cobalt (Co)*, *fluorine (F)* and many others).

**Water and minerals.** The most of inorganic substances in the cell are water and minerals. Water ( $H_2O$ ) is vital for all living organisms, and life could not exist without it.

1. *All the content of the cell is water solution.* Water forms the medium inside the cell and is commonly on the outside of the cell.

2. All biochemical reactions of the cell take place in water solution. Water itself participates in many chemical reactions in the cell.

3. Water molecule is polar (i.e. it has regions with slight positive and negative charges) and can dissolve charged parts of molecules called ions (e.g.  $H^+$  or  $HCOO^-$ ) or other polar molecules (e.g. sugars). Large non-polar molecules (e.g. fats) do not interact with water and cannot be effectively dissolved in it (fig. 2).

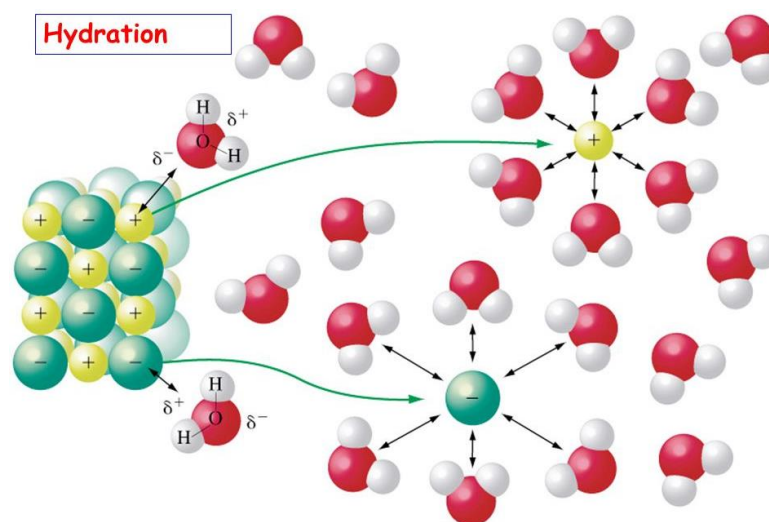


Fig. 2. Polar molecules of water interact with ions

Amount of water varies in living organisms from 60 to 95 % and depends on the type of the cell (10 % — teeth, 20 % — bone, 70 % — nerve tissue, 90 % — embryo).

Minerals in the cells are dissolved in water in the form of positive-charged ions called *cations* ( $K^+$ ,  $Na^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $NH_4^+$ ) and negative-charged ions called *anions* ( $Cl^-$ ,  $H_2PO_4^-$ ,  $HCO_3^-$ ,  $SO_4^{2-}$ ).

The content of cation  $H^+$  (which is in balance with the anion  $OH^-$ ) determines acidity of cell's media. The measure of cell's acidity is called *pH*. If the pH is 7 than the content of  $H^+$  and  $OH^-$  is in equilibrium. The pH less than 7 means that the solution is acidic: the concentration of  $H^+$  is more than that of  $OH^-$ . The pH more than 7 means that the solution is alkaline: the concentration of  $H^+$  is less than that of  $OH^-$ .

**Organic substances** of the cell are proteins, carbohydrates, lipids, nucleic acids, ATP, hormones, vitamins. Many organic substances of cells are made of many repeating structural units. Such molecules are called *polymers* while these repeating structural elements are their *monomers*.

**Proteins** are one of the main biomolecules of life as they are the molecules which can «work». Proteins are responsible for almost all functions of cells. The information about the structure of all proteins required by the cell is stored in the nucleus of eukaryotic cell in long molecules called *DNA*. All proteins are polymers as they are long chains of different *amino acids* connected to one another with *peptide bonds* so they are also called *polypeptides* (fig. 3).

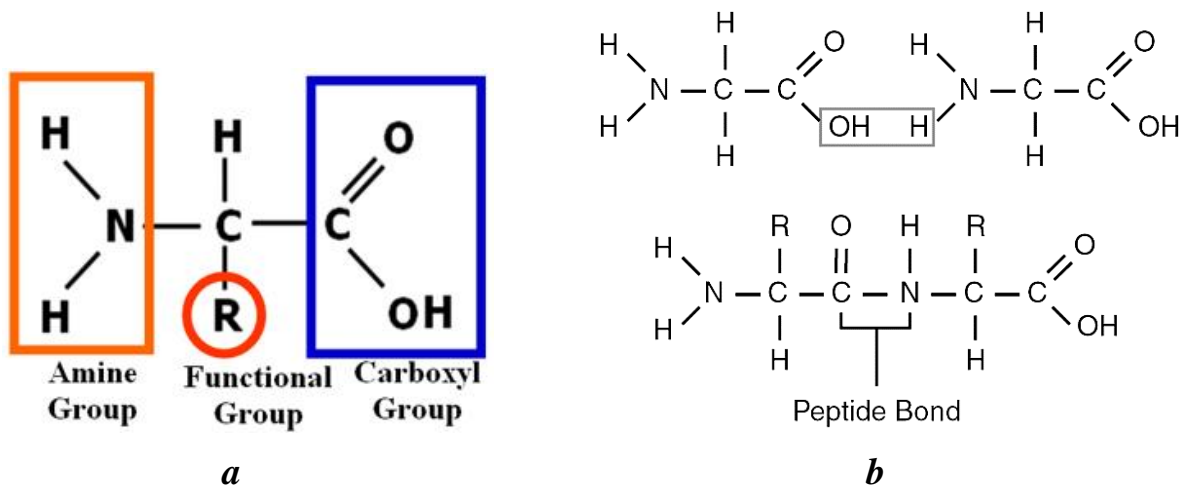


Fig. 3. The structure of amino acid (a) and formation of peptide bond (b)

The chain of amino acids itself is not a functional protein yet. Amino acid chains of proteins must acquire their specific tridimensional structures, so they become able to interact with their target molecules but not with others.

There are four levels of protein structure:

– Primary structure of protein is a linear chain of amino acids linked to one another with peptide bonds (fig. 4, a).

- Secondary structure forms due to hydrogen bonds between regions from amino groups and carboxyl groups of amino acids. The linear chain may coil into a spiral ( $\alpha$ -helix) or forms wrinkled loops ( $\beta$ -sheet) (fig. 4, *b*);
- Tertiary structure is the three-dimensional globe of a single polypeptide chain maintained by disulfide, ionic, hydrogen bonds between radicals of amino acids and by hydrophobic-hydrophilic interactions (fig. 4, *c*);
- Quaternary structure means that two or more polypeptides bind to each other due to ionic, hydrogen bonds and hydrophobic-hydrophilic interactions (fig. 4, *d*).

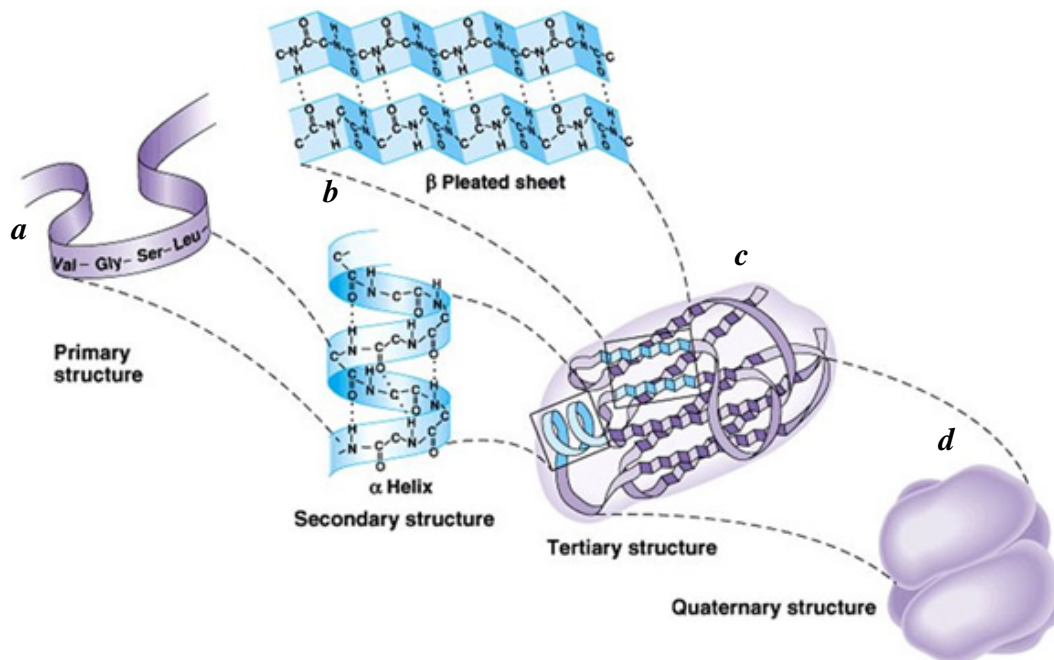


Fig. 4. The four levels of protein structure

### ***Functions of proteins:***

1. Catalytic function — the work of many proteins is acceleration of specific chemical reactions (*catalysis*) required by the cell. Such proteins-catalysts are called *enzymes*.

2. Structural function — proteins are structural parts of many cell's and body's structures. For example, cartilages, tendons, hairs, nails contain large amounts of proteins keratin and collagen.

3. Regulatory function — many *hormones* (chemical signals recognized by cells) are proteins.

4. Transport function — many proteins can hold and transport other substances. For example, *hemoglobin* of erythrocytes carries oxygen and carbon dioxide.

5. Motor, or contractile function — *myosin* and *actin* are the proteins involved in muscle contraction.

6. Energetic function — proteins can be broken down so the cell can release their chemical energy and use it.

**Carbohydrates** are also known as sugars. They consist of carbon, hydrogen, and oxygen. There are simple sugars and complex sugars-polymers.

– Simple non-polymer sugars are called *monosaccharides*. Different monosaccharides may have various number of carbon atoms. Sugars with five carbon atoms are called *pentoses*, those with six carbons are *hexoses*.

– Pentoses (*ribose* and *deoxyribose*) are parts of nucleic acids (DNA, RNA) and ATP (the molecule which carries energy in the cell).

– Hexoses (*glucose*, *fructose*, *galactose*) are contained in the cells of plants, blood of animals and other locations.

Monosaccharides are well soluble in water and have sweet taste.

– *Disaccharides* are sugars composed of two monosaccharides (fig. 5). Examples: *maltose* (malt sugar), *lactose* (milk sugar) and *sucrose* (cane sugar).

– *Polysaccharides* are long chains of simple sugars (polymers). They are not soluble in water. Examples of polysaccharides: starch, glycogen, cellulose and chitin. Starch and glycogen are energy storages of plants and animals respectively.

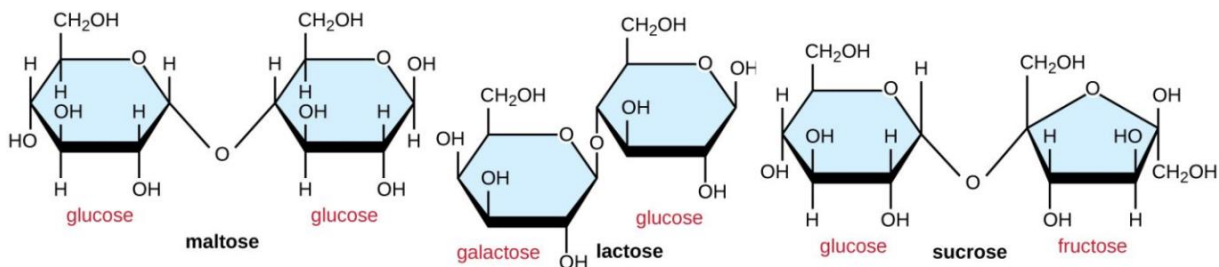


Fig. 5. Disaccharides — molecules consisting of two monosaccharides

Functions of carbohydrates:

1. Energetic function — carbohydrates are often the first energy source for cells.

2. Storage of energy — starch and glycogen are the polysaccharides consisting of glucoses, they are used by the cell as the storage of glucoses.

3. Structural function — carbohydrates are parts of cell membranes and other cell's structures.

**Lipids** are various water-insoluble organic compounds. Their most known groups of them are fats, steroids, phospholipids.

*Fats* consist of one molecule of an alcohol *glycerol* and 3 molecules of *fatty acids* (fig. 6).

Some fatty acids contain double bonds between carbons ( $-\text{CH}=\text{CH}-$ ). They are called *unsaturated* fatty acids. Fatty acids that have no double bonds ( $-\text{CH}_2-\text{CH}_2-$ ) are called *saturated*.

Fats of animal origin (e.g. butter) contain many residues of saturated fatty acids and due to this they are solid at room temperature. Lipids of vegetable oils (e.g. olive oil) contain many residues of unsaturated fatty acids and are liquid at room temperature.

Three fatty acid chains are bound to glycerol by dehydration synthesis.

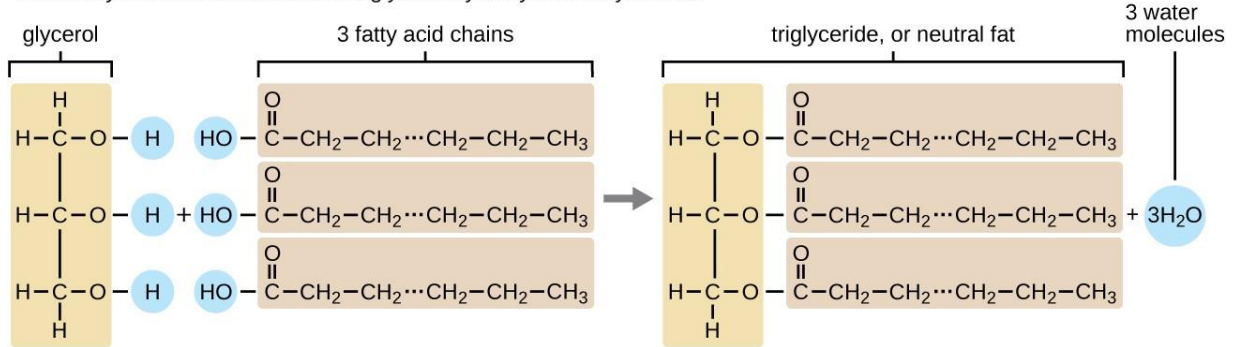


Fig. 6. Formation of a fat from glycerol and fatty acids: hydroxyl ( $-\text{OH}$ ) groups of glycerol interacts with carboxyl ( $-\text{COOH}$ ) groups of the fatty acids

Lipids may form complex chemical compounds with proteins (lipoproteins), carbohydrates (glycolipids) and residues of phosphoric acid (phospholipids).

Functions of lipids:

1. Structural function — lipids are basic elements of cell's membranes.
2. Energetic function — breakdown of lipids is a good source of energy for the cell.
3. Thermoregulatory function — fats may help to retain heat and prevent cooling of the body.
4. Storage function — breakdown of 1 gram of fats produces near two times more energy than the breakdown of the same mass of carbohydrates or proteins. That is why fat is the best molecule for energy storage.

### 3. THE STRUCTURE OF PLASMA MEMBRANE. TRANSPORT ACROSS THE PLASMA MEMBRANE

**Plasma membrane.** As noted in the chapter 1, the basic cell parts are nucleus, cytoplasm and plasma membrane. Cytoplasm consists of *organelles* and *cytosol* — colloidal solution of proteins and other substances.

All cells are covered with *plasma membrane*. The thickness of such membrane is near 7–10 nm. The basic components of the membrane are *phospholipids*, though other lipids such as *lecithin* and *cholesterol* are present there. Most common of them are *phospholipids*.

Each phospholipid has polar (or *hydrophilic*) head and two non-polar (*hydrophobic*) tails (fig. 7). When many phospholipids are mixed with water, they arrange themselves into a bilayer (double layer). This occurs because the heads interact with water and the tails do not. For this reason, the tails of phospholipids are turned to the inside of the membrane (where water is absent) and the heads to the outside. There are no bonds between lipids. Such bilayer of lipids is the basis of the membrane.

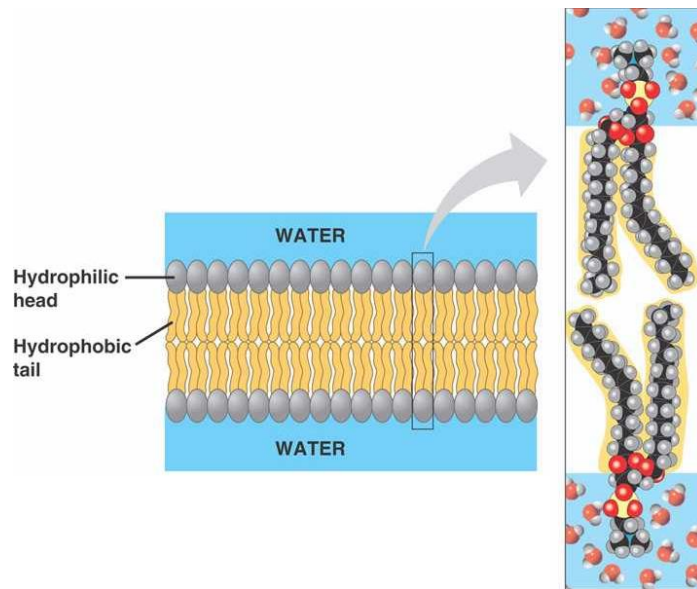


Fig. 7. Bilayer of phospholipids in water

Apart from lipids, membrane contains proteins (fig. 8). Such proteins can also have polar and nonpolar regions, so their nonpolar regions are immersed into the membrane.

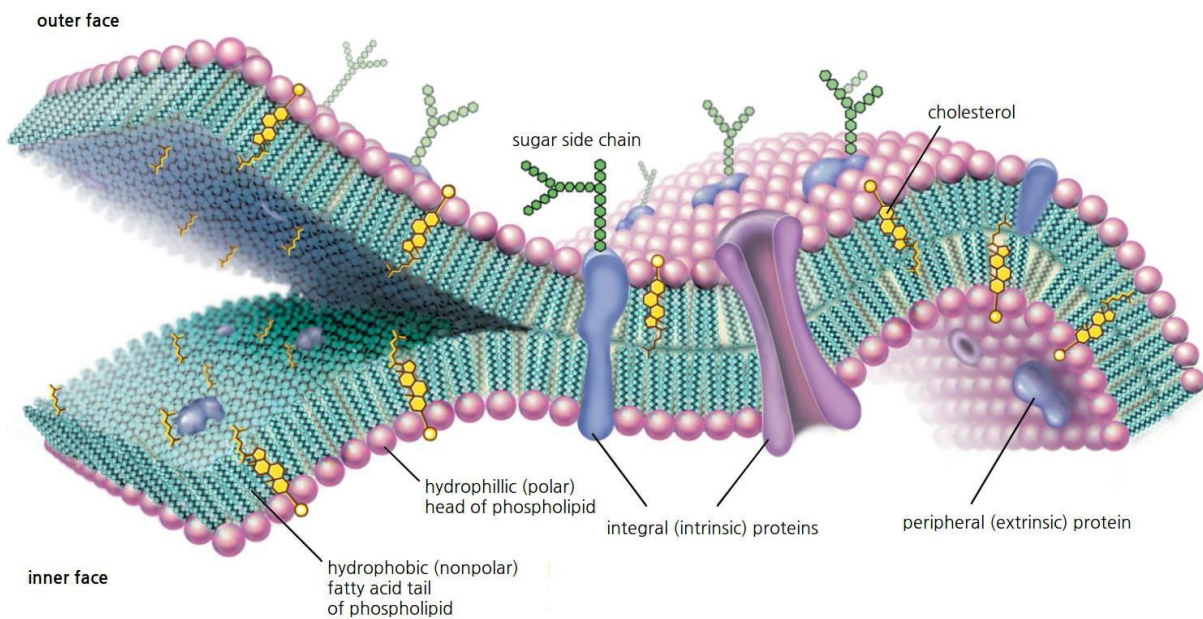


Fig. 8. The structure of plasma membrane

According to their position, proteins can be:

*Peripheral* — such proteins are attached to the surface of the membrane.

*Integral monotopic* — such proteins are immersed into the membrane and project above its surface on only one side.

*Integral bitopic* — such proteins are immersed into the membrane and project above its surface on two sides.

Other components of plasma membrane are carbohydrate chains. The carbohydrates attached to proteins are called *glycoproteins*, those attached to lipids are called *glycolipids*. Such carbohydrates take part in recognition of one cell by another one. Plant cells are covered with thick layers of polysaccharide fibers which are called *cell wall*.

Functions of the plasma membrane:

- barrier — separation the inside of the cell from environment and protection from external factors;
- structural — membranes are structural parts of most of cell organelles (except ribosomes and centrosomes considered in the next chapter);
- transport — cell receives essential substance through the membrane;
- receptor — some proteins and carbohydrates of the membrane participate in transmission of chemical signals from the environment;
- metabolic — many enzymes are attached to membranes;
- compartmentalization — the division of cell cytoplasm into compartments where different chemical reactions take place.

Properties of the plasma membrane:

- plasticity — the membrane stretches and constricts in cellular movements;
- self-locking — the membrane is able to restore immediately after impairment; this property is necessary to form vesicles and vacuoles;
- selective-permeability — the membrane selectively passes molecules.

**Active and passive transport across the membrane** (fig. 9). The plasma membrane is selectively permeable. The *selective permeability* is the property of biological membranes which allows some substances to cross more easily than others. This allows regulating the type and rate of molecular traffic into and out of the cell.

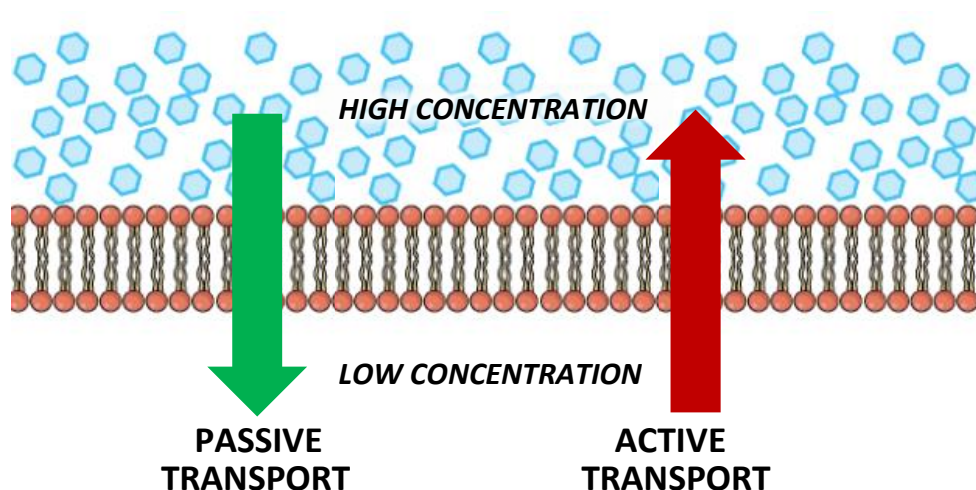


Fig. 9. Directions of the active and passive transports depending on concentration of a solute

Due to selective permeability the concentration of particular substance on the different sides of the membrane can be different. Such difference in substance concentration is called *concentration gradient*.

- If molecules of a substance move from the area of their high concentration to the area of their low concentration (i.e. they move *down the gradient*), the concentration gradient decreases. This occurs because molecules just move in random directions, collide and change their directions all the time (fig. 10). Ultimately, such random motions equalize the concentrations on different sides of the membrane.

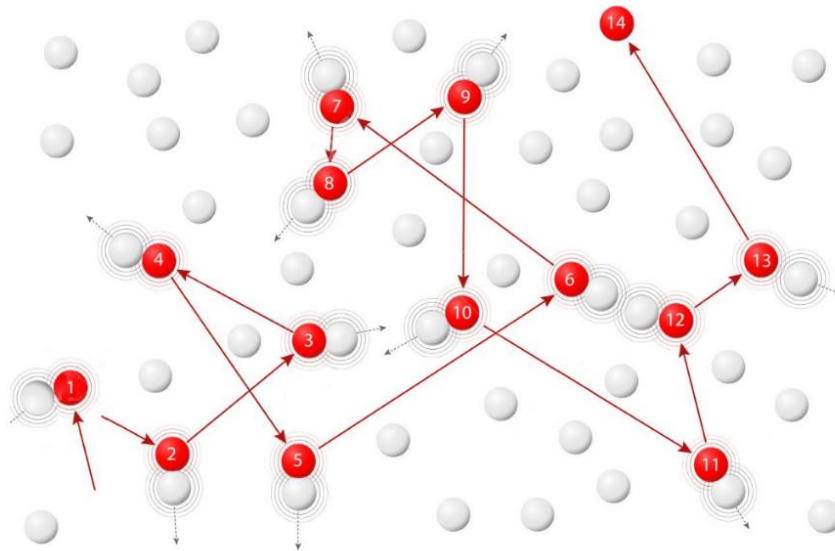


Fig. 10. Random motions and collisions of molecules

- If molecules of a substance move from the area of their low concentration to the area of their high concentration (i.e. they move *against the gradient*), the concentration gradient increases. This is possible only if cell's proteins actively pump these molecules.

Based on these mechanisms, the transport across the membrane can be *passive or active*.

An example of passive transport is diffusion. *Diffusion* is the passive transport of solutes across the membrane down their concentration gradient. Cell does not need to use its energy for such transport.

- *Simple diffusion* occurs when molecules pass directly through the lipid bilayer by themselves (between lipid molecules). This is possible for lipid-soluble and small nonpolar molecules such as hydrocarbons, O<sub>2</sub>, CO<sub>2</sub>. This is also possible for small, polar uncharged molecules such as H<sub>2</sub>O or ethanol.

- All ions (e.g., Na<sup>+</sup>, H<sup>+</sup>), larger, polar uncharged molecules (e.g., glucose) will not easily pass through membranes. The diffusion of such molecules across the membrane may occur through transport proteins. Such passive transport is called *facilitated diffusion*.

Another example of passive transport is osmosis. *Osmosis* is diffusion of water across a selectively permeable membrane. If two solutions of different concentrations are separated by a membrane that is permeable to water but not to solute, water will diffuse from the solution with the lower solute concentration to the solution with the higher solute concentration.

- If a solution has an equal solute concentration compared to that inside a cell, it is called *isotonic solution*.

- *Hypertonic solution* is the solution with greater solute concentration than that inside a cell. The cells placed in such solution passively lose their water.

- *Hypotonic solution* is a solution with a lower solute concentration compared to that inside a cell. Cells placed in such solution passively uptake water from the outside.

*Active transport* occurs when transport proteins in a membrane pump a solute through the membrane against its concentration gradient. This process requires source of energy (common energy source in the cell — molecules of ATP). Example of active transport is the work of the protein called *sodium-potassium pump*. This transport protein uses ATP to pump 3  $\text{Na}^+$  ions to the outside and take 2  $\text{K}^+$  ions into the cell. This is associated with normal physiology of many cells (e.g. human cells):  $\text{Na}^+$  on the outside must be much more concentrated than in the cytoplasm, while the  $\text{K}^+$  ions must be more concentrated inside the cell than on the outside.

**Endocytosis and exocytosis.** *Exocytosis* is the process of exporting macromolecules from a cell by fusion of vesicles with the plasma membrane. Vesicles usually bud from some organelles of the cell and merge with plasma membrane. By this mechanism many cell products can be secreted from the cell to the cell's environment.

*Endocytosis* is the process of importing macromolecules into a cell by forming vesicles derived from the plasma membrane (fig. 11). Vesicle forms from a localized region of plasma membrane that sinks inward and pinches off into the cytoplasm.

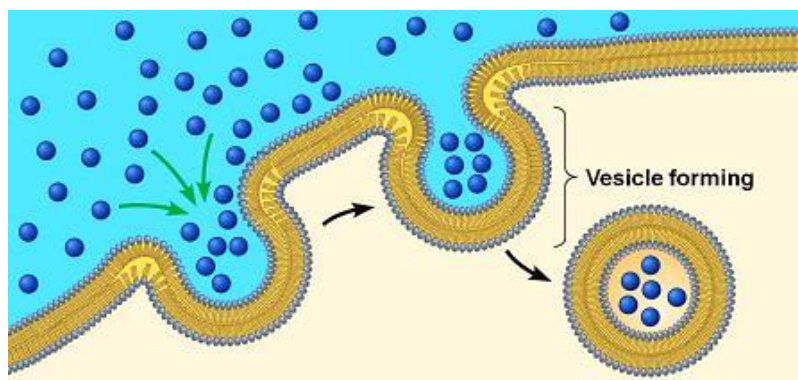


Fig. 11. Endocytosis

The endocytosis of solid particles or other cells is called *phagocytosis*; the endocytosis of liquids is called *pinocytosis*. The produced vesicle is called phagosome. Phagosomes may fuse with other vesicles in the cell which are called lysosomes (organelles containing enzymes for breakdown of various macromolecules, e.g. proteins). The vesicle formed from a phagosome and lysosome is called phagolysosome. The substances engulfed by endocytosis are digested there.

#### 4. ORGANELLES OF THE CELL AND THEIR ROLE IN METABOLISM

As you have learned from the previous chapters, the cell has plasma membrane and nucleus (except prokaryotic and some other cells). All other contents of the cell are called *cytoplasm*. Cytoplasm consists of viscous solution called cytosol and discrete macromolecular structures specialized for particular functions. Such structures are called organelles (fig. 12).

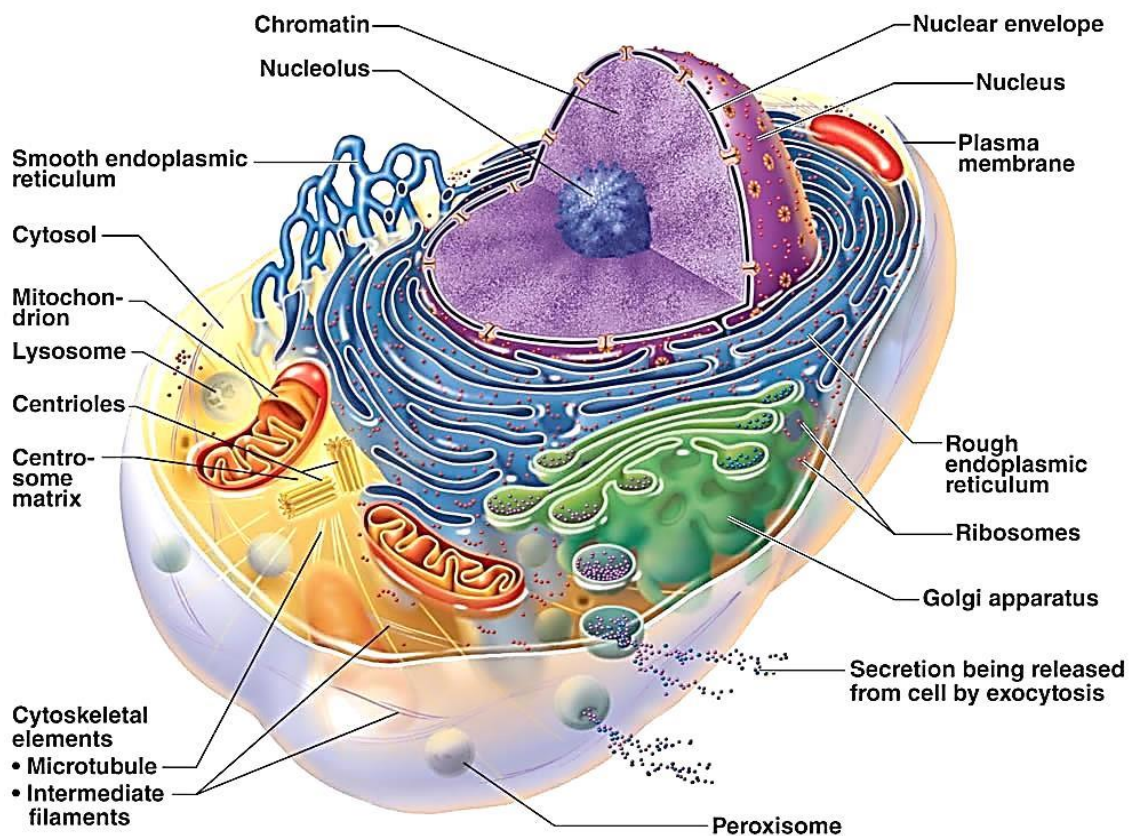


Fig. 12. Organelles of the cell

Organelles can be big or small, many organelles are covered with membranes (they are called *membrane-bound* organelles), some organelles are present in all cells, others — only in specific cells.

**Ribosomes.** Ribosomes are small membraneless organelles (20–30 nanometers in size) that synthesize cell's proteins (fig. 13). Proteins are «workers» of the cell (each protein does its specific works), and there is no life without them. Hence, all types of cells of all organisms have ribosomes.

A ribosome consists of two parts (large and small subunits) which, in turn, consist of many proteins and RNA (it is another important type of molecule which will be considered in next chapters).

Most ribosomes are bound with the membranes of *another* organelle — *rough endoplasmic reticulum* and outer membrane of the nucleus (*bound ribosomes*) when they work. Other ribosomes are not bound to that organelle (*free ribosomes*).

**Endoplasmic reticulum.** Endoplasmic reticulum (ER) is membranous network of tubules and sacs (cisternae) in the cytoplasm. These membranes separate internal lumen (cisternal space) from the rest of cytosol. ER is connected to the outer membrane of the nucleus.

There are two distinct regions of ER that differ in structure and function: smooth ER and rough ER (fig. 14).

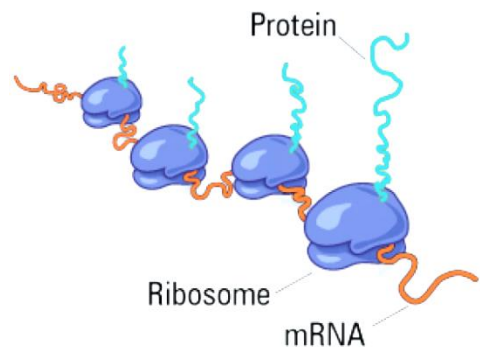


Fig. 13. Ribosomes in the process of their work. RNA is the molecule which contains the instruction for making particular protein

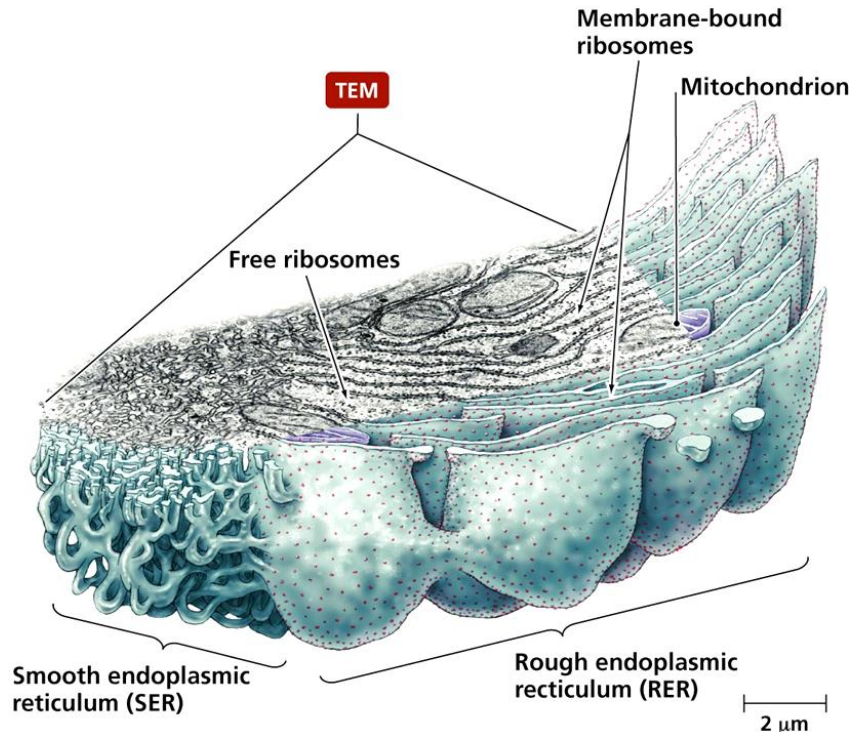
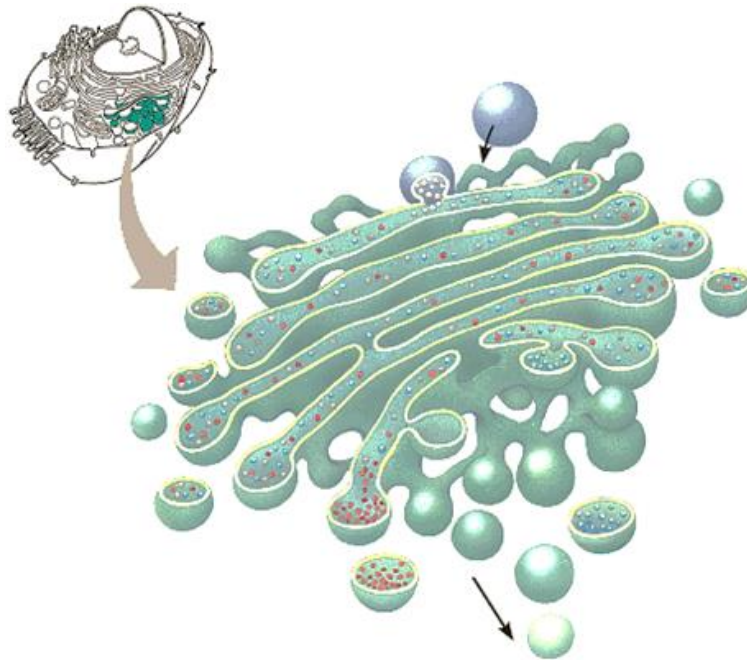


Fig. 14. A fragment of endoplasmic reticulum

Smooth ER has no ribosomes and participates in the synthesis of lipids including phospholipids for new membranes. It also participates in chemical changes of carbohydrates, detoxifies poisons and drugs (especially in the liver cells) by making them soluble in water. In muscle cells it stores calcium ions necessary for muscle contraction.

Rough ER looks rough under an electron microscope due to ribosomes on its surface. It is connected with the outer membrane of the nucleus. The rough ER's ribosomes immediately transport proteins they make to the inside of ER where proteins are processed. Then the proteins are delivered to another organelle — *Golgi apparatus* in a transport vesicles pinched off from ER.

**Golgi apparatus** (fig. 15). Golgi apparatus is an organelle consisting of stacked, flattened membranous sacs (cisternae). It modifies, stores and routes products delivered in vesicles from the endoplasmic reticulum. One side of Golgi apparatus receives vesicles with the products from the ER and the other one exports vesicles containing processed products.



*Fig. 15. Golgi body*

Each cisterna between the sides of the Golgi apparatus contains unique combinations of enzymes. Those enzymes modify products of the ER as they move through the stack of cisternae.

**Lysosomes** (fig. 16). Lysosomes are the vesicle-like organelles which contain hydrolytic enzymes that digest all major classes of macromolecules e.g. lipids, carbohydrates, proteins, nucleic acids. Lysosomes bud from the Golgi apparatus.

These organelles perform digestion of products contained in phagosomes when fuse with them as described in the previous chapter. This mechanism is

used for feeding of many single-cell organisms (e.g. amoeba) and for the destruction of pathogenic bacteria in specialized cells of the immune system. Lysosomes may also breakdown damaged or worn-out organelles or parts of the cytosol.

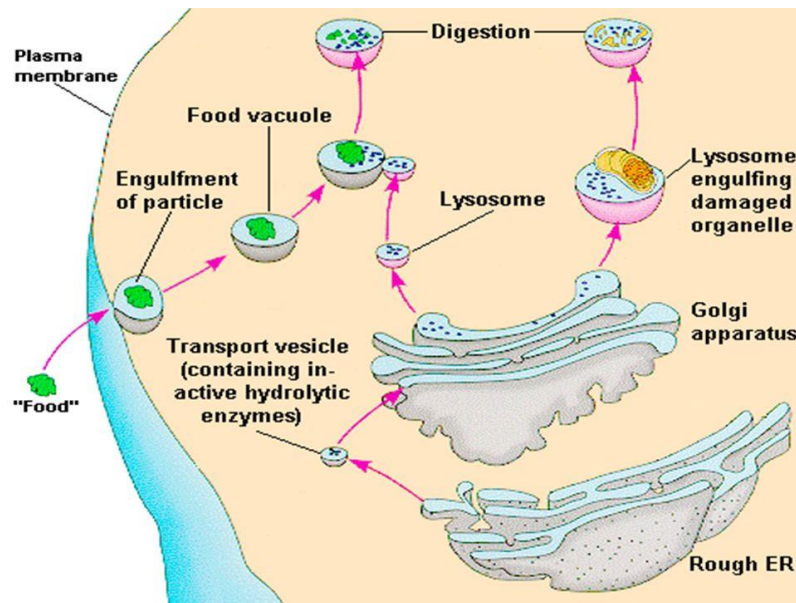


Fig. 16. Origination and functioning of lysosomes

**Mitochondria** (fig. 17). Mitochondria are the organelles which perform final steps in breakdown of organic macromolecules into  $\text{CO}_2$  and  $\text{H}_2\text{O}$  in order to produce ATP (ATP is a molecule in which cell can store energy required for other chemical reactions). Such conversion requires oxygen. Mitochondria are present in almost all eukaryotic cells.

Mitochondria are enclosed by two membranes (the inner and outer ones). The inner membrane has multiple folds called *cristae*. The space between the membranes is called *intermembrane space*. The compartment enclosed by the inner mitochondrial membrane is called *mitochondrial matrix*. In addition, mitochondria have own DNA and ribosomes. This is because of their origin — mitochondria were bacteria «domesticated» by the ancient eukaryotic cell.

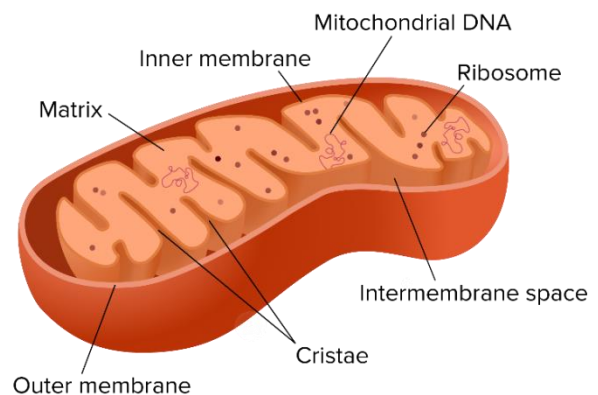
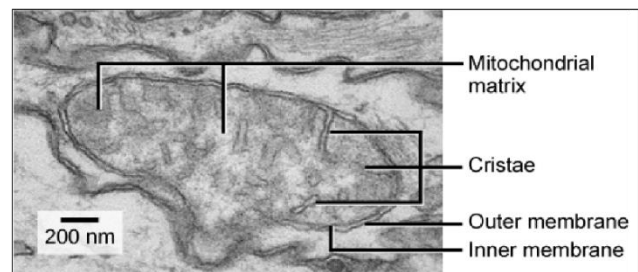


Fig. 17. The structure of a mitochondrion

**Plastids** are other organelles which originate from bacteria. They are present only in the cells of plants. The most important plastids are **chloroplasts** (fig. 18). A chloroplast is covered with outer and inner membranes and contains liquid material called *stroma*. There is a network of flattened membranes called *thylakoids* that stack on one another to form structures called *grana* in the chloroplasts.

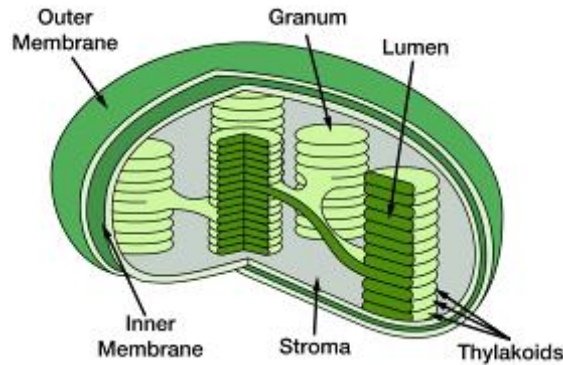


Fig. 18. The structure of chloroplast

Chloroplasts contain the green light-sensitive pigment *chlorophyll* to perform *photosynthesis*. Photosynthesis is usage of the sun's energy which ultimately helps to produce new organic molecules (e.g. sugars) from inorganic carbon dioxide and water.

**Cytoskeleton.** Cytoskeleton is the network of long protein chains in the cytoplasm that controls cell shape, maintains intracellular organization, and is involved in cell movement. One type of these protein chains, microtubules, participate in transport of different structures (e.g. vesicles) within the cell.

**Centrioles** (fig. 19) are organelles of animal cells which look like barrel-shaped rings consisting of nine microtubule triplets. The two centrioles together with the cytoplasm surrounding them are known as *centrosome* or cell center. Centrosome is the structure which helps to organize microtubules in animal cell.

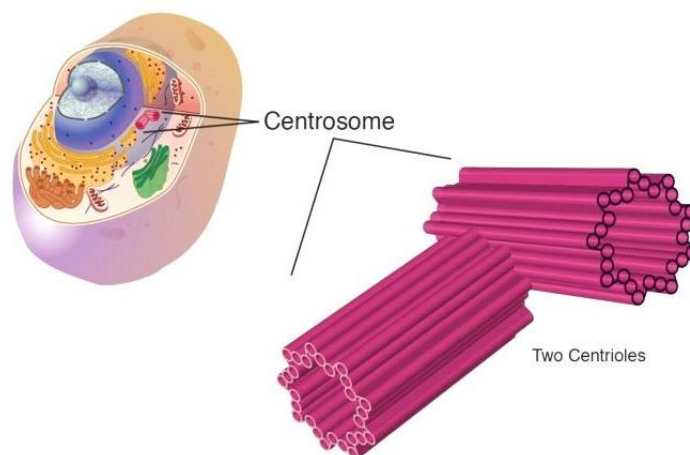


Fig. 19. Centrosome

**Metabolism.** All organelles have specific functions in the cell. However, all of them to some extent participate in numerous chains or cycles of chemical reactions occurring in the cell. All the chemical reactions of the cell are called *metabolism*. It consists of anabolism and catabolism.

*Anabolism* (or assimilation) is the constructive part of metabolism which includes synthesis of macromolecules from simpler molecules. For example: synthesis of glucose ( $C_6H_{12}O_6$ ) from  $H_2O$  and  $CO_2$  (photosynthesis) or synthesis of proteins from amino acids. Such reactions require energy.

*Catabolism* (or dissimilation) is the part of metabolism including breakdown of complex organic compounds into simpler substances, so energy is released. An example of catabolism is the set of reactions in which glucose is broken down into  $H_2O$  and  $CO_2$ .

According to the type of assimilation, organisms are *autotrophs* and *heterotrophs*. Autotrophic organisms can use inorganic carbon of  $CO_2$  to synthesize new organic compounds such as glucose. Plants, many protists and many bacteria are autotrophs.

Heterotrophic organisms use only ready-made organic compounds as a source of carbon. For example the material of fats can be used for synthesis of carbohydrates. Animals, including human, fungi, many protists and many bacteria are heterotrophs.

According to the type of dissimilation all organisms are *anaerobic* and *aerobic*. Cells of aerobic organisms require  $O_2$  for breakdown of organic substances. Anaerobic organisms break down organic compounds without oxygen.

Assimilation and dissimilation are closely related. Synthesis reaction usually require energy, and the energy is released when organic compounds are broken down. Cell uses energy not only for making new molecules, but also for active transport of substances across the membrane, movements and changes of cell's shape, division and other processes.

The energy received by the cell from available chemical and physical processes is stored in ATP molecules (fig. 20).

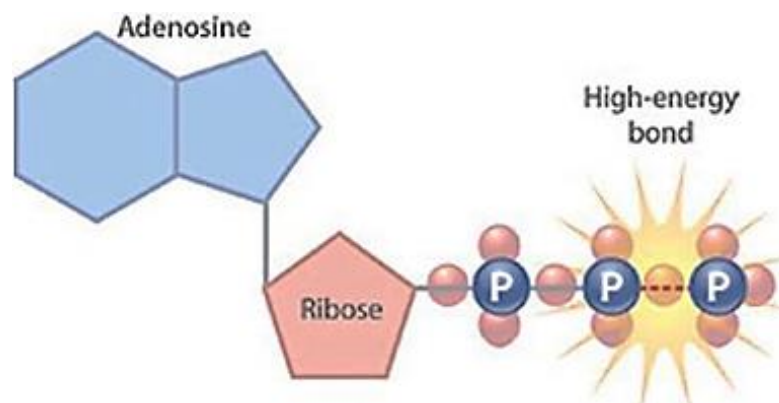


Fig. 20. ATP — the molecule which stores and releases energy when it is needed

ATP can easily break and release its energy when it is required. Such source of energy is used in many reactions occurring in the cell. They can be created during catabolic reactions when energy is released, and then their energy is used in other reactions in the cell.

## 5. THE STRUCTURE OF THE NUCLEUS AND CHROMOSOMES

**Nucleus.** The nucleus is a membrane-enclosed compartment of a eukaryotic cell where genetic information is stored. As you learned from the chapter 2, genetic information is mainly the instructions for synthesis of different proteins — the molecules responsible for almost all activities of the cell. Such instructions are called *genes*. The molecules where genes are «written» is called *DNA*.

Nucleus is enclosed by nuclear envelope which is composed of two membranes (fig. 21). Each membrane is a lipid bilayer which has its own specific proteins. The gap between the membranes is called *intermembrane* (or perinuclear) *space*. The outer membrane of the nucleus proceeds into the membranes of the rough endoplasmic reticulum. It also carries ribosomes on the outer surface. The exchange of materials between the nucleus and cytoplasm occurs through pores. Nuclear pores are a protein-lined channels in the nuclear envelope. The membranes fuse at each pore. The liquid contained in the nucleus is called nucleoplasm.

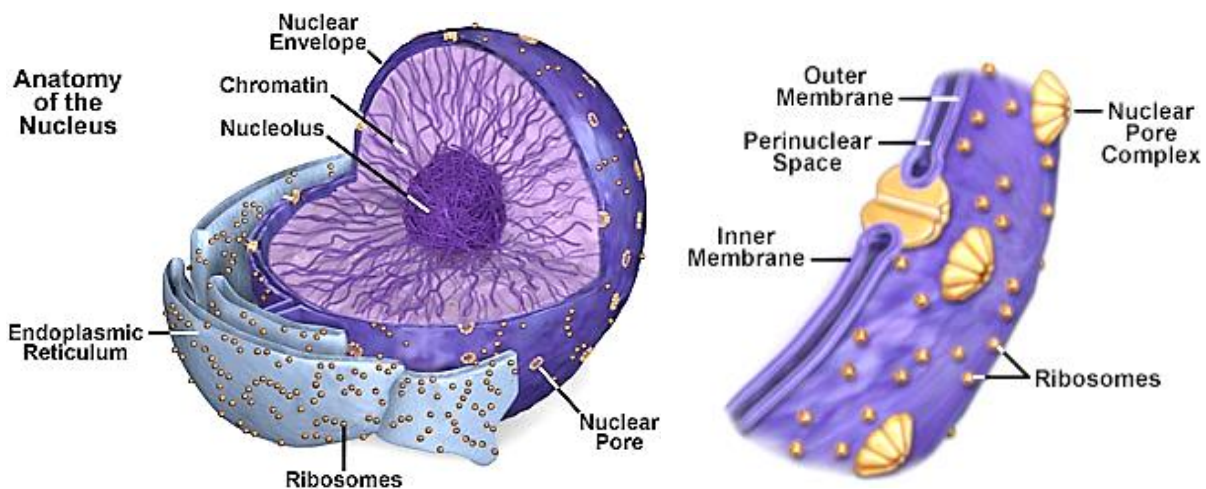


Fig. 21. Nucleus and the structure of the nuclear envelope

**Nucleolus** is a roughly spherical region in the nucleus of nondividing cells where ribosomal subunits are created. Ribosomal subunits then pass through nuclear pores to the cytoplasm, where their protein synthesis occurs.

**Chromatin and chromosomes.** Chromatin is a complex of DNA and proteins. Chromatin makes up most of the content inside the nucleus. Chromatin is also material of *chromosomes*. In nondividing cells chromatin appears as

a mass of loose material filling the nucleus. Separate chromosomes are undistinguishable under the microscope. Chromosomes, commonly familiar as X-shaped structures, appear only in dividing cell when chromatin condenses and becomes tightly packaged. After division, chromosomes lose their clear outlines as their chromatin becomes loose and less tightly packaged. Separate chromosomes become undistinguishable again. Hence, chromosomes can be observed only in dividing eukaryotic cell, and when the cell is not dividing, chromosomes exist as regions of nuclear chromatin the borders between which are not visually distinguishable.

In the beginning of cell division, each chromosome consists of two *sister chromatids* (fig. 22). Each sister chromatid contains one copy of the same DNA. In other words, they contain same genetic information. The sister chromatids will be separated and delivered to different daughter cells during division. Hence, both daughter cells have same DNA.

The sister chromatids are linked together in the region which is called *centromere* (or *primary constriction*). The centromere is the region where microtubules link to the chromosome and pull the chromatids apart during division.

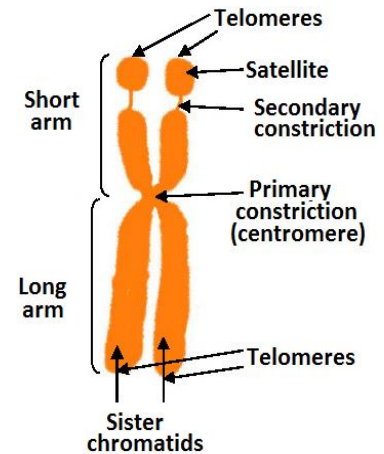


Fig. 22. Chromosome

The chromosome regions on the sides of centromere are called arms. Each sister chromatid has 2 arms, so in the beginning of division a chromosome has 4 arms. The arms of a chromosome may have different length. Hence the arms are called *short* (or *p arm*) and *long* (or *q arm*). Based on the length, chromosomes can be of 3 types (fig. 23):

- *Metacentric* chromosomes have q and p arms of almost same length.
- *Submetacentric* chromosomes are those in which the length of arms is unequal.
- *Acrocentric* chromosomes are those in which p arm is much shorter than the q arm.



Fig. 23. Classification of chromosomes with different centromere position

Terminal regions of arms are called *telomeres*. They do not let chromosomes stick to one another by their ends. Arms of some chromosomes may have narrow region which is called *secondary constriction*. Some parts of these constrictions indicate sites of nucleolus formation — nucleolar organizing regions.

The terminal region of such chromosome's arm is called a satellite. The chromosomes having secondary constrictions are called satellite chromosomes.

**Functions of chromosomes.** The main function of chromosomes is storage of genetic information and its equal distribution to daughter cells when cell divides.

All species have their unique *genetic information* (instructions for creation of their proteins). For example, all genes of human are contained in 23 chromosomes (in other species it is different: 39 in dogs, 4 in fruit fly). Each of those chromosomes is unique, has own length and information. Most of animals, including humans, have double set of all chromosomes. I.e. humans have 23 chromosomes + 23 same chromosomes. Cells with such double chromosome set are called *diploid* and denoted as  $2n$ . Hence, every chromosome has a pair — another chromosome with same genes. Such chromosomes are *homologs* (or *homologous chromosomes*). Every cell of the body has same set of 46 chromosomes.

All individuals of the same species have same chromosomes. The only exception is the last pair of chromosomes in many animals (including humans): women have two X chromosomes while men have one X and one Y chromosomes.

**There are 4 rules of chromosomes of all organisms:**

1. The rule of a constant number. All species have constant number of chromosomes in every cell (46 in human, 78 in dogs, 8 in fruit fly). The set of chromosomes characterizing the species is called *karyotype*.

2. The rule of pairing. Every chromosome in a diploid set has a pair — the other chromosome of identical shape and size. Such chromosomes are *homologous*.

3. The rule of individuality. Chromosomes of different pairs have different shape, structure and size.

4. The rule of continuity. New chromosomes are made as result of copying of other chromosomes.

## 6. CELL CYCLE AND MITOSIS

**Cell cycle.** Cell cycle (mitotic cell cycle) is the complete sequence of cellular events from one cell division to the next. Cell cycle consists of four successive phases:  $G_1$  phase  $\rightarrow$  S phase  $\rightarrow$   $G_2$  phase  $\rightarrow$  M phase (fig. 24).

The  $G_1$ , S, and  $G_2$  phases are together referred to as *interphase*. During interphase cell prepares itself for division. Division occurs at the M phase. The M phase in a cell is followed by  $G_1$  phase starting in two daughter cells. The «M» means *mitosis*. Mitosis is the division of the nucleus in eukaryotes. The division of cytoplasm also occurs during M phase and is called cytokinesis.

During all the cell cycle, diploid cells stay diploid ( $2n$ ). If the cell is going to divide, chromosomes double their DNA. That is why a chromosome of a dividing cell consists of two sister chromatids (2chr). The sister chromatids of

each chromosome separate and move to different daughter cells. That is why daughter cells have the same number of chromosomes as their mother cell had, but each their chromosome consists of only one chromatid (1chr).

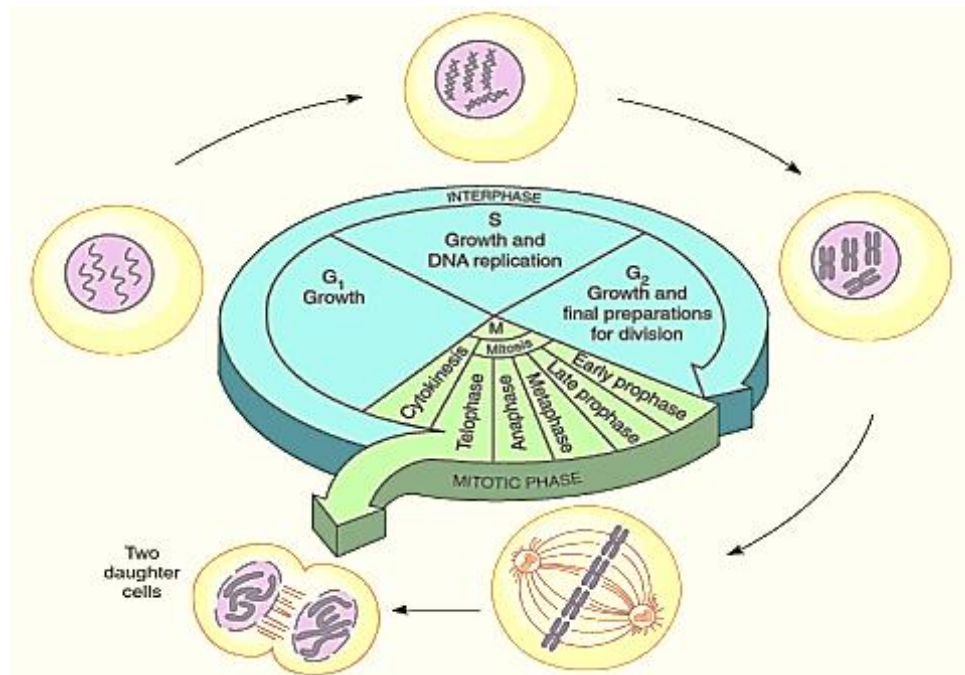


Fig. 24. Cell cycle

**Interphase.** Interphase starts from  $G_1$  phase. The « $G_1$ » means first gap or first growth phase. In this phase cell determines whether it will divide or not. During  $G_1$  phase, the cell grows and synthesizes different proteins, including those required for successful doubling the genetic information. At this stage, cell is diploid (and it will stay diploid during all the cycle) and each chromosome has only one copy of DNA:  $2n1chr$ .

The  $S$  phase (synthesis phase) follows the  $G_2$  phase. It is the phase of the cell cycle in which DNA is doubled. This process of DNA doubling is called replication. The set of genetic material changes from  $2n1chr$  to  $2n2chr$ . Cell continues to grow.

The  $S$  phase is followed by  $G_2$  phase. The « $G_2$ » means second gap or second growth phase. During this phase, cell grows more and completes preparations for cell division. The set of genetic material does not change.

**Mitosis.** Mitosis is common division of somatic cells (cells of the body, not sex cells). It is usually divided into four stages: prophase, metaphase, anaphase, and telophase (fig. 25). Cytokinesis usually occurs at approximately the same time with telophase.

Before mitosis starts, cell has nucleus with loose chromatin and nucleolus, and two centrosomes adjacent to the nucleus. The centrosomes were formed earlier by replication of a single centrosome.

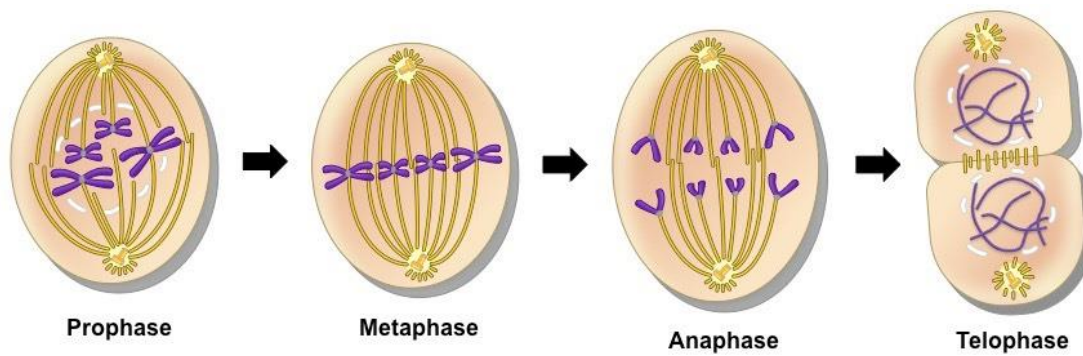


Fig. 25. Stages of mitosis

1. *Prophase*: Nucleoli disappear and the loose fibers of chromatin condense into observable chromosomes composed of two identical sister chromatids. *Mitotic spindle* forms. It is composed of microtubules which extend from two centrosomes. Centrosomes move apart, propelled by lengthening of the microtubule bundles between them. Nuclear envelope breaks into membrane vesicles. Spindle microtubules extend from each pole (because centrosomes ultimately reach opposite cell poles) toward the cell's equator. Some microtubules attach to kinetochores — protein structures bound with centromeres. By this such microtubules connect with chromosomes. As microtubules change their length, the chromosomes start to move.

2. *Metaphase*. During metaphase, chromosomes move to the *metaphase plate*, the plane at the equator of the cell between the poles where centrosomes are situated. The two kinetochores of the two chromatids of every chromosome are attached to microtubules growing from different poles of the cell.

3. *Anaphase*. It begins when centromeres of each chromosome move apart. Microtubules attached to kinetochore shorten and pull sister chromatids of each chromosome to different cell poles. Sister chromatids move towards opposite poles of the cell. Simultaneously, the poles of the cell move farther apart, elongating the cell. At the end of anaphase, the two poles have identical collections of chromosomes. The set of genetic material of dividing cell (it was  $2n2chr$  from the S phase) becomes  $2n1chr$  at each cellular pole.

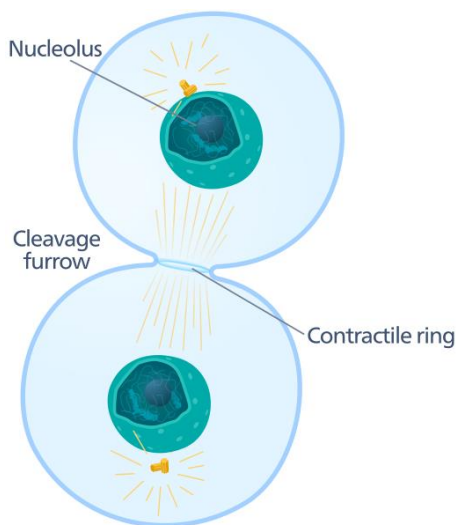


Fig. 26. Cytokinesis

4. *Telophase*. Daughter nuclei begin to form at the two poles. Nuclear envelopes form around the chromosomes from fragments of the parent cell's nuclear envelope and portions of the ER. Nucleoli reappear. Chromosomes become less condensed and form loose chromatin mass of the nucleus. This occurs at

every pole of the dividing cell. Cytokinesis occurs and the cytoplasm of the mother cell is divided (fig. 26). In animal cells it is done by a protein ring on cell's equator. Such ring contracts and cleaves the cytoplasm into two. Two new cells are formed.

## 7. MEIOSIS

**Meiosis.** Unlike mitosis, meiosis is not used for common reproduction of cells. Meiosis is the first step in *sexual reproduction*. Unlike mitosis, producing two diploid cells ( $2n$ ) from one diploid cell, meiosis produces 4 haploid ( $n$ ) cells from one diploid cell. Unlike *diploid cells* ( $2n$ ) having two same sets of chromosomes ( $23 + 23 = 46$  for human), *haploid cells* ( $n$ ) have only one set of unique chromosomes (23 for human). The second set of same chromosomes is absent in them. At the next step of sexual reproduction, two haploid cells (usually from different organisms) fuse together into a single diploid cell ( $n + n = 2n$ ). Such diploid cell is called *zygote*. Haploid cells that fuse into zygote are called *gametes* or *sex cells*.

Every human (or almost all other animals), develops from a zygote. Zygote forms when father's sperm cell ( $n$ ) fuses with mother's ovum ( $n$ ). Sperms and ova are formed by meiosis.

As you learned from previous chapters, homologous chromosomes have same genes (a gene is the instruction for making certain protein). Though even the same gene can be slightly different in different chromosomes. Because of difference in gene variants, one person is not same as another one. As different people or even homologous chromosomes of the same organism may have different variants of the same gene, sexual reproduction creates new individuals with new random combinations of gene variants. This is the main advantage of sexual reproduction. Hence, mitosis is a common division producing same cells. Meiosis is specialized division producing gametes for sexual reproduction, which, in turn produces cells with new combinations of genes.

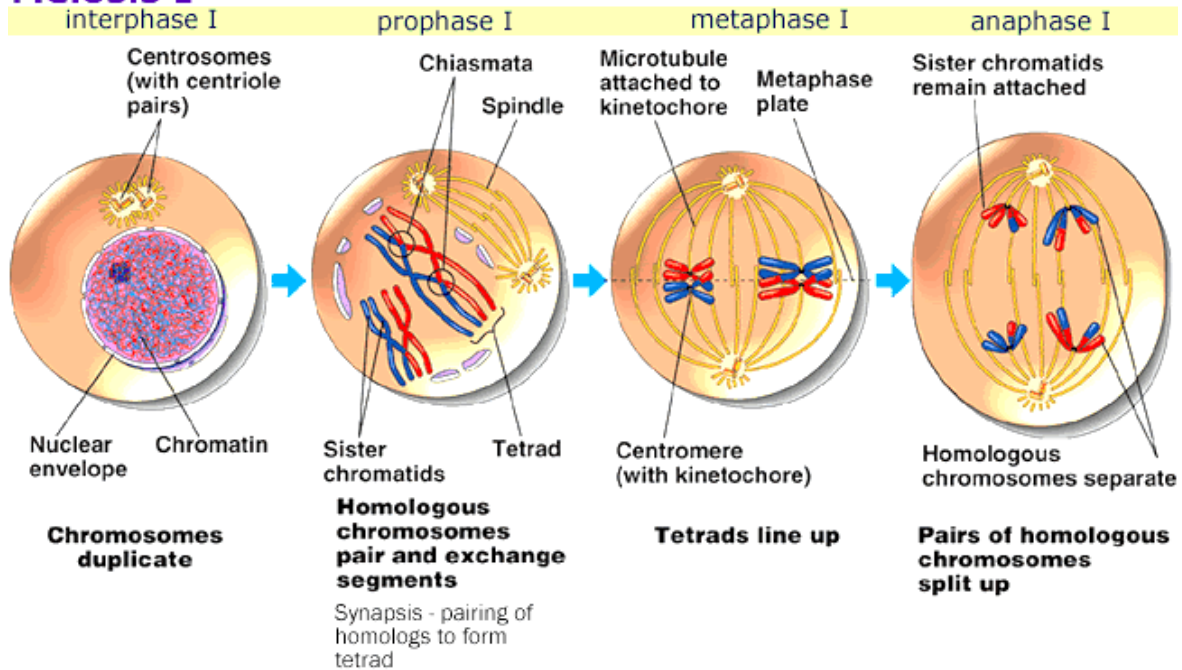
**The mechanism of meiosis.** Meiosis consists of two divisions called meiosis I and meiosis II (fig. 27). Both divisions have four phases: prophase I, metaphase I, anaphase I, telophase I and prophase II, metaphase II, anaphase II, telophase II. Before meiosis, cell prepares itself and has the set of chromosomes  $2n$ chr.

Meiosis I (reductional division):

1. *Prophase I* is complicated. Two important processes occur: *synapsis* and *crossing over*. Synapsis is a connection of homologous chromosomes: regions of one homologous chromosome connect to the same regions of the other homolog. Two connected homologs are called *bivalents* («bi» = 2) or *tetrads* of chromatids («tetra» = 4). Crossing over is exchange of the same segments of homologous chromosomes. The sites where it occurs are relatively random. This

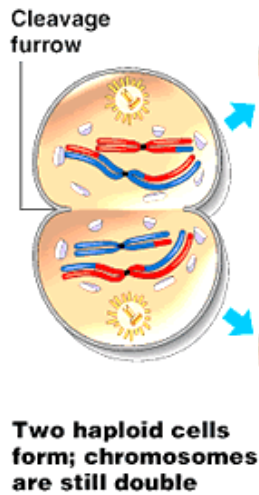
process increases the diversity of gene variants from one parent in a gamete. Centrosome movement, spindle formation, and nuclear envelope breakdown also occur as in mitosis.

## Meiosis I

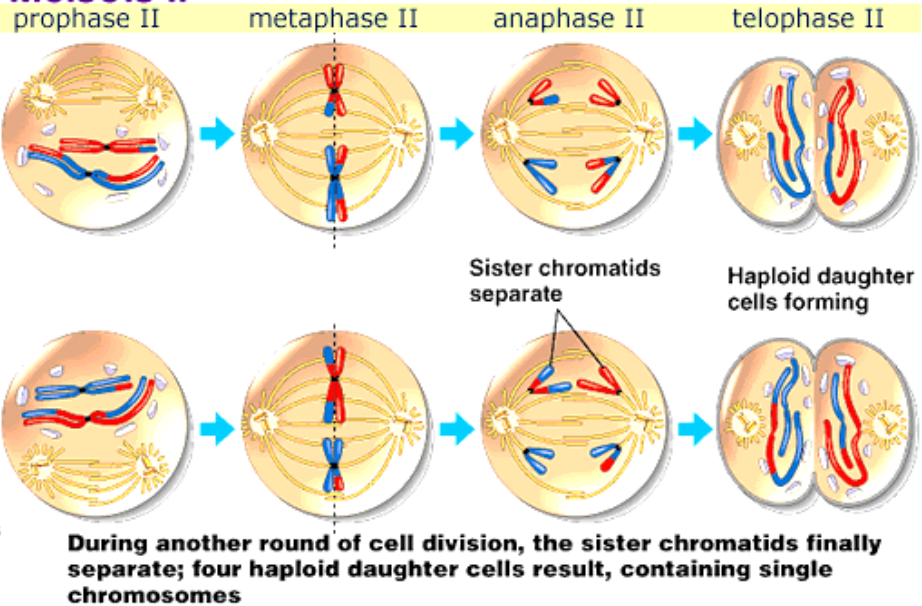


## Meiosis I

telophase & cytokinesis



## Meiosis II



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Fig. 27. Meiosis

2. In *metaphase I*, bivalents are located on the equator of the cell.

3. In *anaphase I*, the microtubules of the spindle apparatus pull homologous chromosomes (not sister chromatids as in mitosis!) from every bivalent to different sides of the cell. Each chromosome still contains 2 sister

chromatids. Each cell pole has the set of genetic material  $1n2chr$  instead  $2n2chr$  that was previously present in the mother cell.

4. In *telophase I*, new nuclei appear, cytokinesis occurs and two haploid daughter cells are formed.

The period between the two divisions of meiosis is interkinesis.

Meiosis II (equational division): is more similar to mitosis.

5. Prophase II: a spindle apparatus forms, chromosomes, each still composed of two chromatids associated at the centromere, are moved by microtubules toward the metaphase plate.

6. Metaphase II: chromosomes are on the equator of the cell.

7. Anaphase II: chromatids are pulled apart as in mitosis. Chromosome set at each cell pole becomes  $1n1chr$ .

8. Telophase II: nuclei form, the chromosomes begin decondensing, and cytokinesis occurs. Four daughter cells are formed.

## SECTION 2 GENETICS

### 1. GENETICS AS A SCIENCE. NUCLEIC ACIDS. SYNTHESIS OF PROTEINS

**Genetics** is the biological discipline studying heredity and variation.

Heredity is transmission of characteristics from ancestor to descendant (from parents to children). Variation is the changes which occur in descendants. It causes species to evolve.

The characteristics inherited from parents are encoded in their DNA. This information is genetic information. More exactly, DNA carries the information about the structure of various proteins. A DNA segment carrying the instructions for creation of a protein is called **gene**.

Genetics studies the molecular structure and functions of genes, gene behavior in context of a cell or organism, patterns of inheritance from parent to offspring.

**Nucleic acids** are DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). These acids were first described 1870 by Friderich Misher as macromolecules in the nucleus. He named them nucleic acids.

The structure of a DNA molecule was decoded in 1953 by James Watson, Francis Krik and Maurice Wilkinson.

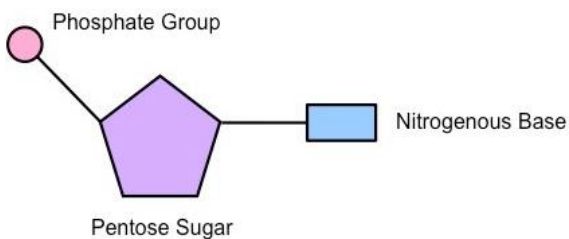


Fig. 28. Scheme of nucleotide

The nucleic acids are biopolymers. Their monomers are *nucleotides* (fig. 28). Nucleotide consists of 3 parts: nitrogenous base, 5-carbon sugar (i.e. pentose) and residue of the phosphoric acid (phosphate). Five-carbon sugars are deoxyribose (in DNA) and ribose (in RNA). Nucleotides may

have one of 5 nitrogenous bases: adenine (A), guanine (G), cytosine (C), thymine (T), uracil (U). They are of 2 types: *purines* (adenine and guanine) and *pyrimidines* (cytosine, thymine and uracil). Such nucleotides are connected into chains (strands).

**DNA** consists of two strands which are coiled into a double helix. A DNA nucleotide consists of four nitrogenous bases (adenine, guanine, cytosine or thymine, but not uracil), deoxyribose and a residue of phosphoric acid (fig. 29).

The nucleotides are linked by phosphodiester bonds between deoxyribose of one nucleotide and the phosphoric acid residue of the other one.

Opposite nitrogenous bases of two strands are bound according to the principle of *complementarity*:

- adenine is bound only with thymine (with two hydrogen bonds — A=T)
- guanine is bound only with cytosine (with 3 hydrogen bonds — G≡C).

The complementarity of nitrogenous bases was understood due to works of Ervin Chargaff.

**Chargaff's rules:**

1. The number of purine bases in DNA is always equal to the number of pyrimidine bases:  $A + G = C + T$ ;

2. The amount of adenine in DNA is equal to the amount of thymine ( $A = T$ ), the amount of guanine is equal to the amount of cytosine ( $G = C$ ).

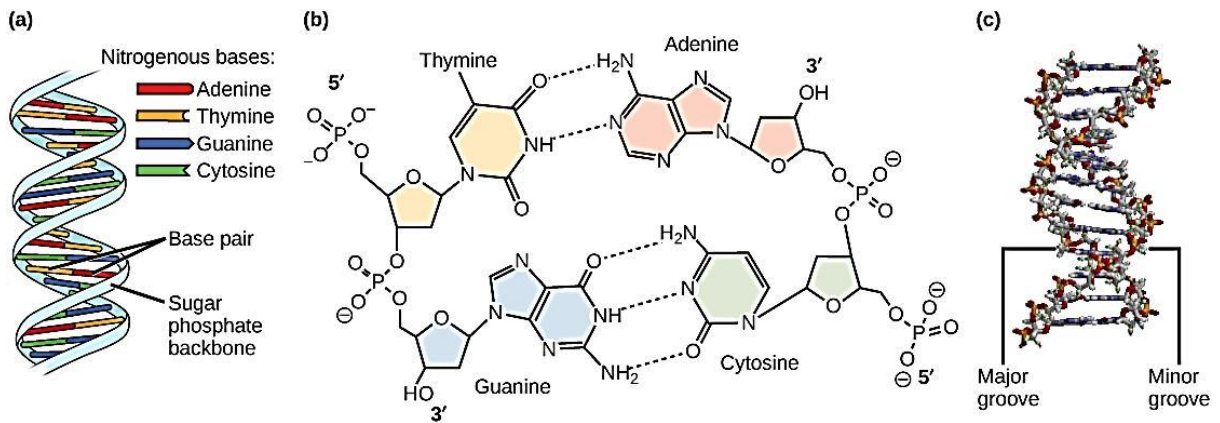


Fig. 29. Models of DNA

Apart from the nucleus, DNA is present in mitochondria and plastids. DNA is capable of replication (self-doubling) and repair (restoration of the structure after impairment of the molecule). This is done by many different proteins associated with DNA.

**Replication** occurs in the S-phase of the cell cycle. It is the process which copies genetic information for further cell division. *DNA polymerase* is the enzyme that play main role in this process. The segment of DNA where replication occurs is called *replication fork*. Enzymes break the hydrogen bonds between the nitrogenous bases of the two strands and separate them (fig. 30). DNA polymerases assemble chains of complementary nucleotides on each strand. That is how two new DNA molecules are formed.

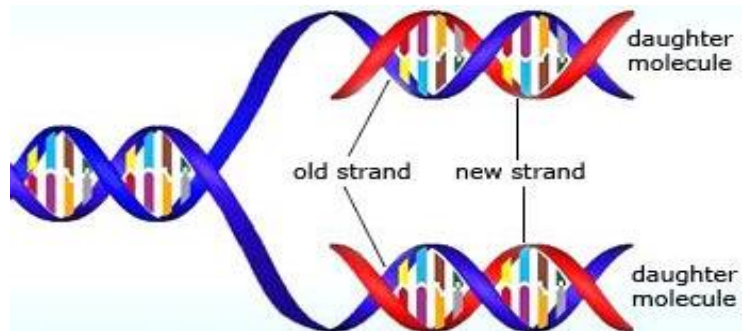


Fig. 30. Principle of replication

After replication, each DNA molecule contains one maternal chain and the second newly synthesized daughter chain. This mechanism of DNA doubling is called *semi-conservative* synthesis.

DNA functions are storing and transmitting genetic information during multiplication of cells and organisms.

**RNA** is a polynucleotide which is similar to DNA. Though it consists of only one strand, its nucleotides contain sugar ribose instead of deoxyribose and uracil instead of thymine. In some viruses, RNA can be double-stranded.

Cells have 3 main types of RNA. They are in the nucleus, cytoplasm, mitochondria and plastids. About 3–4 % of the whole RNA is the messenger RNA (*mRNA*). It «records» the genetic information from DNA and transmits it into ribosomes where protein molecules are assembled. The ribosomal RNA (*rRNA*) composes 80–85 % of the whole RNA. It is crucial functional part

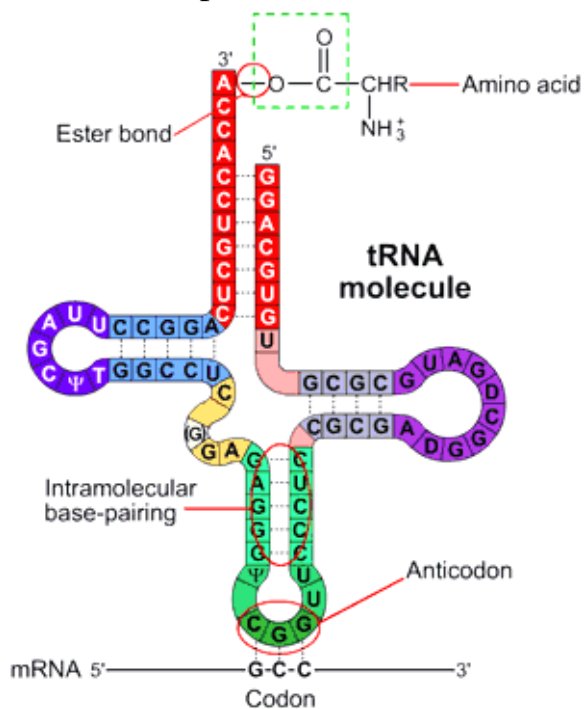


Fig. 31. Structure of tRNA

ribosomes and provides especial spatial relations between mRNA and rRNA. The transfer RNA (*tRNA*) comprises 10–20 % of the whole RNA (fig. 31). Such tRNAs deliver amino acids to ribosomes.

**Genetic code.** The unit of heredity and variation is gene. Gene is DNA segment that carries the information about the structure of a polypeptide (protein).

The recording of genetic information as a nucleotide sequence in DNA and mRNA is genetic code. Each nucleotide *triplet* (3 adjacent nucleotides) codes for a definite amino acid. Such coding triplet is called a *codon*.

**Properties of the genetic code:**

- tripletness — one amino-acid is encoded by three nucleotides — codon (e.g. AUG — methionine, CCG — proline);
- universality — a codon codes for the same amino acid in all species;
- no overlapping — one nucleotide cannot be read twice. I.e. it cannot be in two adjacent codons at the same time;
- degeneracy, or redundancy — some amino acids are encoded by several different codons (there are 20 amino acids, and 64 possible triplets);
- continuity — there are no disjunctive symbols between codons;
- single direction (ribosome moves in the direction from 5' to 3' end of mRNA);
- presence of codons-terminators (they don't specify any amino acids, but only determine the end of protein biosynthesis);
- co-linearity — nucleotide sequence in nucleic acids corresponds to amino acid sequence in proteins.

**Protein biosynthesis** begins from making complementary RNA copy of a gene (it is called mRNA). The enzyme doing this is called RNA-polymerase, and mRNA synthesis is called **transcription**. The nucleotide sequence of such RNA (or the sequence of its codons) defines the sequence of amino acids in a protein. Then the mRNA is transported from the nucleus to the cytoplasm, where ribosomes «read» the codons and synthesize proteins.

Synthesis of protein on the mRNA matrix is called **translation** (fig. 32).

The start of translation is *initiation* (small subunit connects to mRNA, first tRNA with amino acid attaches to the first codon and large subunit comes). The formation of peptide bonds between amino acids which are continuously brought to the ribosome by tRNAs is *elongation*. The end of translation when protein is assembled and ribosome dissociates is *termination*.

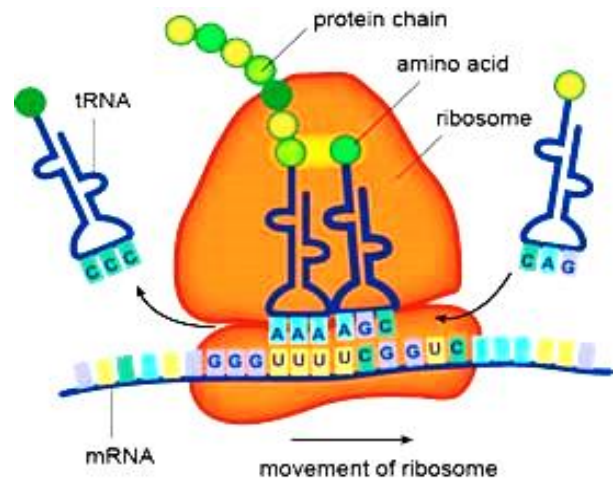


Fig. 32. Protein synthesis in the ribosome

**Ribosome** has two sites (aminoacyl and peptidyl or A and P) where two mRNA codons are placed simultaneously. The transport RNA (tRNA) has a specific structure: one end of the molecule contains a nucleotide triplet which is called an anti-codon. It defines the amino acid which can be carried by the tRNA. An amino acid joins the proper tRNA due to enzyme amino-acyl-tRNA-synthetase and ATP. The amino acid with its tRNA forms a complex: amino-acyl-tRNA. Recognition (recognizing of its own amino acid by tRNA) occurs in the cytoplasm.

Elongation begins after initiation. An amino-acyl-tRNA comes to the A-site and if its anticodon matches to the mRNA codon then amino-acyl-tRNA forms a temporary bond with the mRNA codon. A peptide bond sets between the first and second amino acids, the ribosome moves by one triplet, and the amino-acyl-tRNA passes into the P-site. The second tRNA with the amino acid can come to the A-site. The ribosome moves by one triplet, the released tRNA leaves the ribosome. The second tRNA passes into the peptidyl site. The process repeats many times.

Termination of polypeptide synthesis is determined by one of three stop-codons: UAA, UAG, UGA. When ribosome reaches them its subunits dissociate, mRNA and protein are released.

Several ribosomes may work on the same mRNA. Such complex of several ribosomes united by one mRNA, is called polyribosome.

## 2. MONOHYBRID CROSS. THE LAW OF HYBRID UNIFORMITY. THE LAW OF SEGREGATION

Basic regularities of heredity were discovered by Gregor Mendel in 1865 year. He carried out experiment on pea plants with different traits: red or white flowers, yellow or green seeds and etc.

Traits (characteristics) that exclude each other (cannot exist together in one individual) are called alternative traits (i.g. seeds cannot have two colors at the same time). They develop under the action of different variants of the same gene. Such gene variants responsible for different alternative characteristics are called *alleles* (allelic genes). Genes have constant location in chromosomes. Therefore, alleles are situated in the same loci of homologous chromosomes. The sum of all variants of alleles in an individual that were inherited from parents is *genotype*. The set of genes characterizing species is its *genome*.

Diploid organisms have two alleles of every gene because as they have pairs of chromosomes. Homologous chromosomes are inherited from different parents. The organism that inherited same alleles from both parents (and has the genotype AA or aa) is *homozygote*.

As soon as homozygous organisms have same alleles, all their gametes may contain only that allele. I.e. they form only one type of gametes. Consequently, all the children of homozygous parents have identical genotype.

*Heterozygous* organism has different alleles (Aa). Heterozygotes form two types of gametes. There is segregation of characteristics in their descendants.

The number of types of gametes is calculated by formula:  $N = 2^n$ . N — the number of types of gametes, n — the number of allele pairs that are in heterozygous state. For example, a homozygote AA form only one type of gametes — A ( $2^0 = 1$ ); a heterozygote Aa form two types of gametes — A and a ( $2^1 = 2$ ).

Alleles are situated in homologous chromosomes. Chromosomes diverge during meiosis and only one gene of a pair gets to the gamete. The sum of all traits and properties of an organism that are determined by the genotype and the environment is called *phenotype*.

Alleles of heterozygotes (Aa) may not cause development of both their traits. Only one trait develops and suppresses the effect of the other allele. Such allele is called *dominant* and denoted with capital letter (A). So, the trait of the dominant allele develops both in homozygous (AA) and heterozygous (Aa) organisms (for example, yellow seeds of pea).

The trait which develops only in homozygous state (aa) and is always suppressed by the dominant allele is called *recessive* (green seeds).

G. Mendel crossed pea plants. The method of crossing and analysis of descendants is called hybridological method.

If the organisms are analyzed by only one pair of traits (only color of seeds), the cross is called monohybrid. G. Mendel denoted the traits of pea:

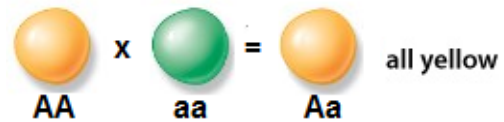
A — the allele of yellow seeds, a — the allele of green seeds, P — parents, G — gametes, × — crossing, F<sub>1</sub> — filial generation 1.

G. Mendel used pure lines of pea (i.e. homozygotes) which had alternative traits. He crossed homozygous plants of pea which had yellow seeds with plants having green seeds.

**P:** AA (yellow) × aa (green);

**G:** (A) (a)

**F<sub>1</sub>:** Aa — 100 % yellow



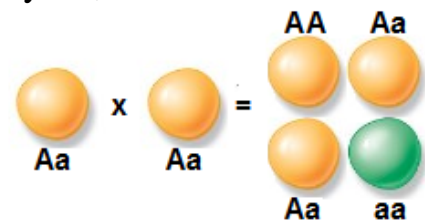
The result of the first experiment is heterozygous plants with yellow seeds. According to the results of the cross, G. Mendel formulated his first law — *the Law of Hybrid Uniformity*: if homozygous individuals differing in one pair of alternative characteristics are crossed and analyzed, their descendants are uniform (have same phenotype and genotype).

Then G. Mendel crossed those hybrids.

**P: (F<sub>1</sub>)** Aa (yellow) × Aa (yellow);

**G:** (A)(a) (A)(a)

**F<sub>2</sub>:** AA, 2Aa, aa.



Phenotypic segregation ratio was 3 : 1 (75 % : 25 %) (3 yellow : 1 green).

Genotypic segregation ratio was 1 : 2 : 1 (25 % AA : 50 % Aa : 25 % aa).

G. Mendel got <sup>3</sup>/<sub>4</sub> of plants with yellow seeds and <sup>1</sup>/<sub>4</sub> with green ones. There was homo- and heterozygotes among the plants with yellow seeds. On the ground of the experiment, G. Mendel formulated his second law — *the Law of Segregation*: if heterozygotes are crossed and analyzed by one pair of alternative characteristics, segregation ratio of phenotypes 3 : 1 and the ratio of genotypes 1 : 2 : 1 are observed in descendants.

### 3. DIHYBRID CROSS. THE LAW OF INDEPENDENT ASSORTMENT

A cross when organisms are analyzed by two pairs of alternative traits is called dihybrid. If more than two pairs of traits are analyzed, then the cross is called polyhybrid.

G. Mendel crossed homozygous plants with yellow smooth (dominant traits) and green wrinkled seeds (recessive traits).

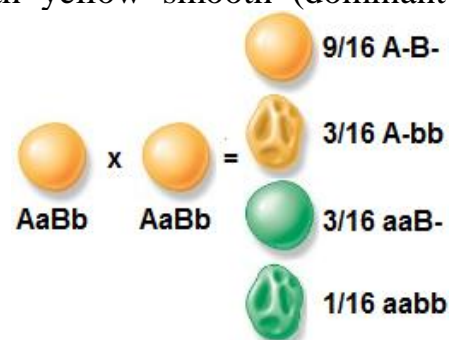
A — yellow seeds, a — green seeds

B — smooth seeds, b — wrinkled seeds

**P.** AABB × aabb

**G.** (AB) (ab)

**F<sub>1</sub>.** AaBb — 100 % yellow smooth.



Then G. Mendel crossed the hybrids:

**P. (F<sub>1</sub>). AaBb × AaBb**

**G.**       $\begin{matrix} \textcircled{AB} & \textcircled{Ab} \\ \textcircled{aB} & \textcircled{ab} \end{matrix}$        $\begin{matrix} \textcircled{AB} & \textcircled{Ab} \\ \textcircled{aB} & \textcircled{ab} \end{matrix}$

G	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	AAbb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

The law of hybrid uniformity still works in the first cross: all hybrids are uniform heterozygotes with yellow smooth seeds. Crossing these hybrids confirmed the law of segregation.

To write genotypes of all hybrids of the cross, Punnett square is used.

In the second generation, there are 9 groups of individuals with yellow smooth seeds (A–B–), 3 groups with yellow wrinkled ones (A–bb), 3 groups with green smooth ones (aaB–), and 1 group of plants with green wrinkled seeds (aabb).

Phenotypic segregation ratio in F<sub>2</sub> is 9 : 3 : 3 : 1 = (3 : 1)<sup>2</sup>.

If we count all phenotypes in the square considering only one trait, the segregation ratio would be:

12 yellow : 4 green — 3 : 1.    12 smooth : 4 wrinkled — 3 : 1.

In this cross, random combination of genes occurred and, consequently, individuals with new combination of traits appeared (green smooth and yellow wrinkled seeds).

On the ground of these data G. Mendel formulated his third law — *the Law of Independent Assortment*: if heterozygotes are crossed and analyzed by several pairs of alternative characteristics, independent assortment of gametes and genes is observed and consequently independent inheritance of traits.

Independent assortment of traits is possible due to:

- random divergence and combination of chromosomes during meiosis;
- random combination of gametes in fertilization.

Cytogenetic basis of the G. Mendel's laws is explained by the *hypothesis of purity of gametes*: Genes of a hybrid do not mix and are in pure allelic state. During meiosis, chromosomes diverge and only one allele of a gene passes to each gamete. Each chromosome carries its own genes to the gamete. Chromosomes are combined randomly during meiosis.

Significance of G. Mendel's laws:

- The laws are universal. They explain mechanisms of inheritance for all diploid organisms.
- The laws are statistical: they are shown up in large groups of individuals and allow to predict the probability of a definite trait in offspring.

#### 4. GENETIC LINKAGE. THE CHROMOSOME THEORY OF INHERITANCE

According to genetic investigations, the number of individual's genes is many times more than the number of its chromosomes. Consequently, each chromosome contains many genes. The group of genes which are in one and the same chromosome are inherited together and called linked genes. The group of genes situated in the same chromosome is called a linkage group.

In 1911, Thomas Morgan described the genetic linkage — joint transmission of several genes from parents to offspring. He carried experiments on fruit flies (*Drosophila*). They are convenient for experiments because:

- they have just a few chromosomes (8);
- they produce many descendants;
- they early reach sexual maturity, so many generations can be analyzed during relatively short period of time;
- it is possible to use hybridological method (crossing).

T. Morgan analyzed inheritance of such traits as body color and the length of wings: B — grey body, b — black body, V — normal (long) wings, v — vestigial (short) wings (fig. 33).

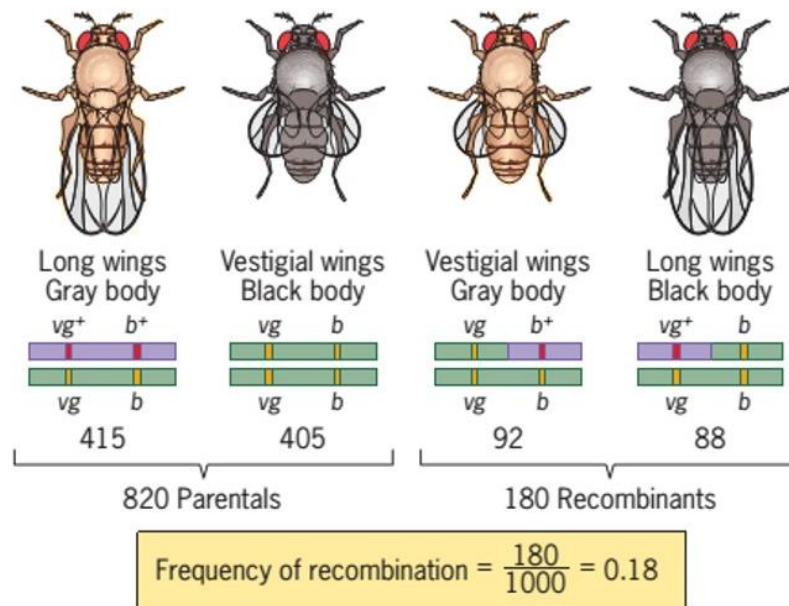
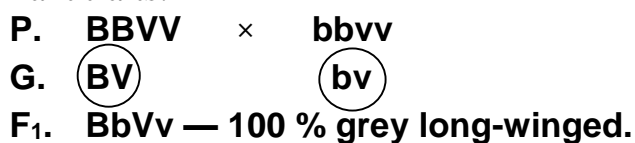


Fig. 33. Phenotypes and genotypes of fruit flies from T. Morgan's experiments

In the first experiment T. Morgan crossed homozygous flies which had grey body and normal wings (dominant traits) with black vestigial-winged flies (recessive traits). All hybrids of the first generation were uniform and had dominant traits:



That corresponded to the first Mendel's law.

In the second experiment, Thomas Morgan crossed recessive female and diheterozygous male *Drosophila*. It was reasonable to expect phenotypic segregation with the ratio 1 : 1 : 1 : 1, i.e. per 25 % of different phenotypes. However, he got two types of flies (50/50 %) which had parental traits. There were no individuals with new combinations of the traits:

P. **bbvv** × **BbVv**  
 G. (bv) (BV) (bv)  
 F<sub>1</sub>. **bbvv**      **BbVv**  
       **50%**        **50%**

T. Morgan supposed that genes of the body color and the length of wings are situated in the one and the same chromosome and are inherited together.

During the meiosis the chromosome containing the genes **BV** passes to one gamete while the chromosome carrying genes **bv** to the other one. That explains why diheterozygous male *Drosophila* forms not 4, but only 2 type of gametes.

That is how Thomas Morgan discovered the **genetic linkage** — joint inheritance of traits which are determined by genes situated in the same chromosome. Genetic linkage in the male *Drosophila* is complete and characteristics are always inherited together.

Though in one of other experiments T. Morgan crossed di-heterozygous female and recessive male *Drosophila* and observed different result:

P.        **BbVv**      ×      **bbvv**  
 G. (Bv) (bV) (BV) (bv)      (bv)  
 F<sub>1</sub>. **BbVv, Bbvv, bbVv, bbvv**  
       **41.5 %   8.5 %   8.5 %   41.5 %**

According to the G. Mendel's laws the number of flies with different phenotypes should be equal: per 25 %. But there were only 83 % of flies with 2 types of parental traits and 17 % with 2 new combinations of characteristics.

There was partial combining of parental traits. Genetic linkage was partial (incomplete) due to **crossing-over**. Crossing over is the process when homologous chromosomes exchange their same segments. It occurs in the prophase of meiosis I.

Morgan's experiments agreed with Boveri's and Sutton's **Chromosome Theory of Inheritance** and completed it:

1. Genes are situated in chromosomes in a linear order in definite loci. Alleles of the same gene are in identical loci of homologous chromosomes.

2. All genes of one chromosome compose a linkage group and are inherited together. The number of linkage groups is equal to the number of pairs of homologous chromosomes.

3. Crossing-over (exchange of identical segments) is possible between homologous chromosomes.

4. The frequency of crossing-over between two genes depends on the distance between these genes in the chromosome.

5. 1 % of crossing-over is equal to 1 centimorgan — a unit of the distance between genes that was named in honor of T. Morgan.

## 5. GENETICS OF SEX

**Sex** is the complex of all morphological, physiological and other characteristics of an organism which determine its reproductive role. Reproduction is the ability of organisms to create new individuals of their kind.

**Sexual dimorphism** is the sum of all morphological, physiological, biochemical and other differences (sexual characteristics) between males and females of the same species.

**Primary sexual characteristics** are the organs taking direct part in reproduction. They develop during the embryonic development. **Secondary sexual characteristics** develop under the action of sex hormones and appear during puberty (facial hair, peculiarities of voice and constitution and etc.).

**Human karyotype** consists of 46 chromosomes (23 pairs). Most of them are *autosomes* (22 pairs), the last, 23<sup>rd</sup> pair is called *sex chromosomes*. Autosomes are the chromosomes which are same in men and women (human has 22 pairs of autosomes). They do not determine the sex of the person. Autosomal genes determine most of human characteristics (hair color, skin color, height and others).

Unlike autosomes, sex chromosomes (also known as heterochromosomes) are different in men and women. They determine the sex of the person.

The sex chromosomes of women are two homologous X-chromosomes. In a man they are non-homologous X-chromosome and Y-chromosome (fig. 34). Such sex determination is typical not for all animals. In birds, males have same sex chromosomes (ZZ) and females have different sex chromosomes (ZW).

The sex which has same sex chromosomes (XX) is called *homogametic*; the sex with different heterochromosomes is *heterogametic* (XY).

The X and Y chromosomes of human have small homologous regions containing alleles of same genes. Though these chromosomes mostly have non-homologous (or differential) regions which contain different genes. The genes situated in the differential region of sex chromosomes are called sex-linked.

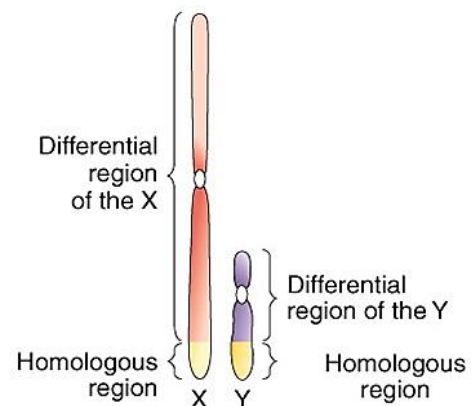


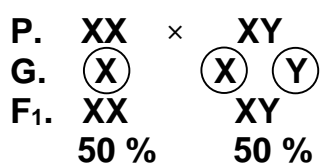
Fig. 34. Diagrams of the X and Y chromosomes

The genes in differential region of the X-chromosome are called *X-linked* (i.g. genes some alleles of which cause hemophilia and color blindness). The genes in differential region of the Y-chromosome are called *Y-linked (holandric)* The alleles of some holandric genes are known to cause skin membranes between fingers, hairs in ears.

Mendel demonstrated that sex of the organism is inherited in the same way as the other traits. If we denote male and female genotypes with sex chromosomes (X and Y) then we can see that the sex is inherited with segregation ratio 1 : 1.

Sex of a baby is determined at the moment of fertilization. If an ovum is fertilized by a sperm containing the X-chromosome, the sex of future baby is female.

If the sperm that fertilize the ovum carries the Y-chromosome, then the sex of the baby would be male.



Probabilities of formation of male and female zygotes are equal — 50/50 %.

## 6. VARIATION

**Variation** is the property of living matter to change. All the diversity of living organisms is possible only due to variation. This property helps populations to adapt to changes in their environments and survive.

The phenotype of any organism is the result of the work of genes under the action of the environment. In other words, phenotype depends on genotype and environmental factors. Various environmental factors have effect on the work of different genes and therefore the same genotype can produce different phenotypes in different environments. New characteristics may also develop when the environment affects genetic material of the individual.

There are two types of variation: phenotypic (non-hereditary) variation and genotypic (hereditary) variation.

**Phenotypic variation**, also known as *phenotypic plasticity*, is the change of the phenotype triggered by the environment without changes of the genotype. Such phenotypic modifications are organism's adaptations to the environment. For example, animals which live in cold climate have thicker coat than animals of the same species living in warm climate; leaves of many water plants growing in water and above water have different shape. Phenotypic plasticity does not affect the genotype, consequently, the changes are not inherited. Properties of phenotypic modifications:

- not inherited;
- reversible — can disappear after changes of the environmental conditions;

- massive involvement — similar modifications appear in all organisms that are exposed to the same factor (e.g. suntan);
- adaptability — modifications «adjust» the organism to some environmental conditions and are commonly useful for the organism;
- not matter for the natural selection as they are not inherited;
- predictable.

The range of possible changes is called *reaction norm* (reaction range). It is wide if the character changes within wide limits (volume of cow's milk, body mass) and narrow if it changes insignificantly (fat content of milk).

**Hereditary variation** is also called genotypic. Genotypic variation consists in changes of the phenotype caused by changes of the genotype. There are two types of this variation: combinative and mutational.

**Combinative variation** is the result of recombining parental genes in children. New gene combinations cause appearance of organisms with new phenotypes. For example, G. Mendel grown plants with yellow wrinkled seeds from the plants with yellow round and green wrinkled seeds.

Mechanisms of combinative variation:

1. Independent assortment of chromosomes and chromatids during meiosis;
2. Gene recombination during crossing-over;
3. Random combination of gametes in fertilization.

By making many different phenotypes, combinative variation provides adaptation of populations to changing environmental conditions.

**Mutations** (mutational variation) are the sudden heritable changes of genetic material. Mutations may affect the genetic material at different levels (fig. 35):

1. Some mutagens change the structure of a gene. They are called *gene mutations*. A change in a single base pair is called *point mutation*. They result in metabolic diseases such as hemophilia, phenylketonuria, daltonism (color blindness), albinism.

2. The structure of a chromosome can alter. Such mutations are called *chromosome mutations*. They lead to malformations — developmental defects of organs and organ systems (e.g., underdevelopment of a larynx, heart defects).

3. Some mutagens change the number of chromosomes. They are called genome mutations. They cause chromosomal diseases such as Down syndrome (extra 21<sup>st</sup> chromosome). The changes in chromosome structure or number are called chromosomal aberrations.

The properties of mutations are:

- are inherited as they change the genotype
- irreversible (constant);
- non-adaptive as they change genes randomly, without the «aim» of adaptation;
- individual as they are random and the same mutation seldom happens in two different organisms;

- the matter for the natural selection as they are inherited;
- not predictable.

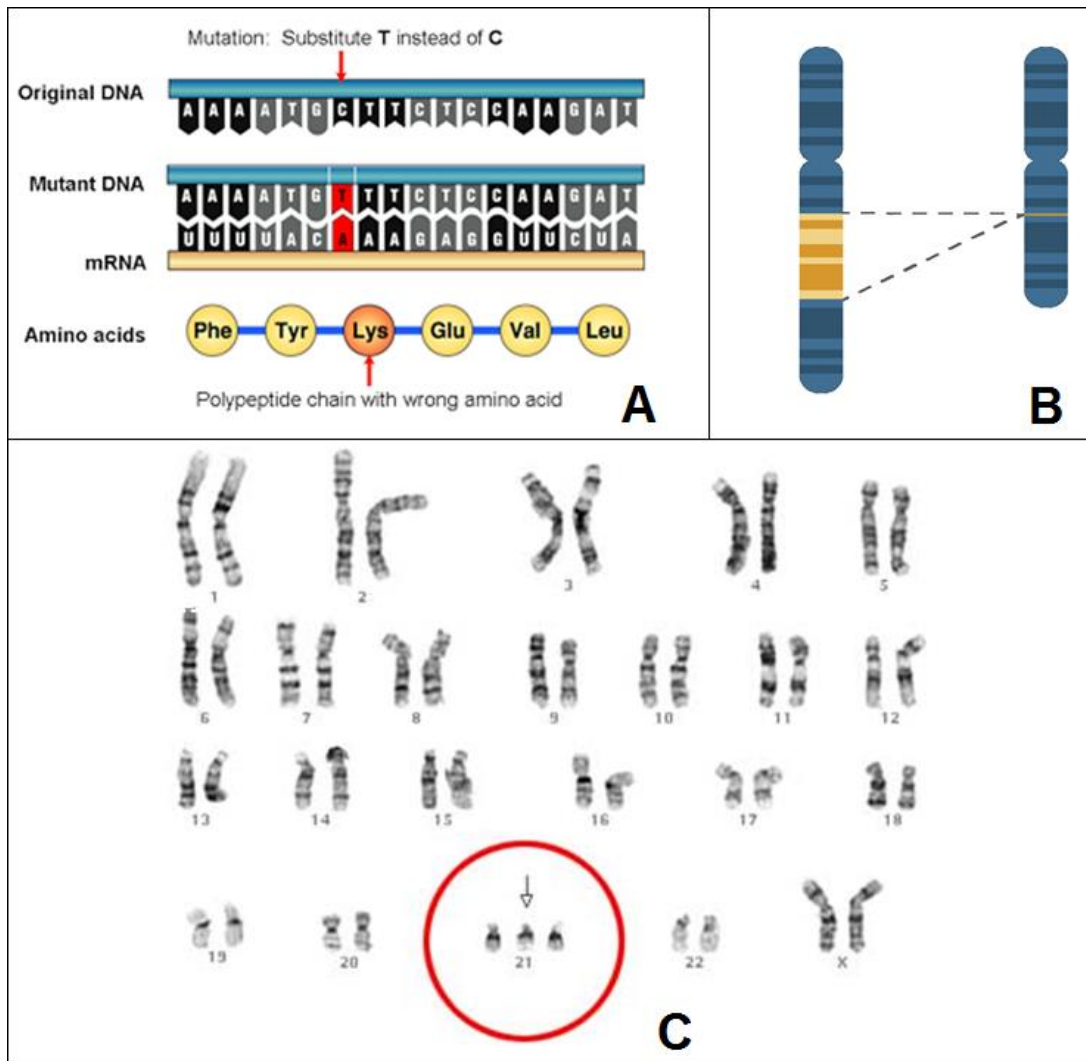


Fig. 35. Mutations:

A — gene mutation; B — chromosome mutation; C — genome mutation

Environmental factors causing mutations are called *mutagens*. They are:

1. Physical — ultraviolet rays, radiation, temperature.
2. Chemical — chemicals, hormones, enzymes, conserving agents, drugs.
3. Biological — viruses, metabolic products of bacteria, protists, helminthes.

## 7. THE GENETICS OF HUMAN

Human as well as other organisms is the study object of Genetics.

Human Genetics studies normal human genotype and karyotype and its changes in case of various genetic disorders, causes of the disorders, their prophylaxis and treatment. Human is complicated genetic object.

There are difficulties of studying human genetics:

- some methods are not applicable for human (i.g. hybridological method), experiments on human are not possible;
- many chromosomes (46) and genes (about 20–25 000);
- late sexual maturity, long alternation of generations (usually just a few generations are available for analysis);
- small number of children complicates statistical analysis;
- it is not possible to make same environment for all people.

Nevertheless, there are some advantages of studying human genetics:

- human is the most explored genetic object;
- international co-operation of scientists;
- great number of individuals.

Some methods of human Genetics are:

1. Genealogical analysis;
2. Karyotyping (cytogenetic method);
3. Biochemical tests.

**Genealogical analysis** is based on drawing up pedigrees (family tree, genealogy). It is analysis of a family with particular characteristic (e.g. genetic disorder) in order to reveal patterns of its inheritance. This method allows to reveal:

1. Whether or not the character is hereditary.
2. The inheritance type (dominant or recessive, sex-linked or autosomal).
3. Genotypes of family members.
4. Probability of giving birth to a sick child in a family.

The key for drawing pedigrees is shown in the fig. 36.

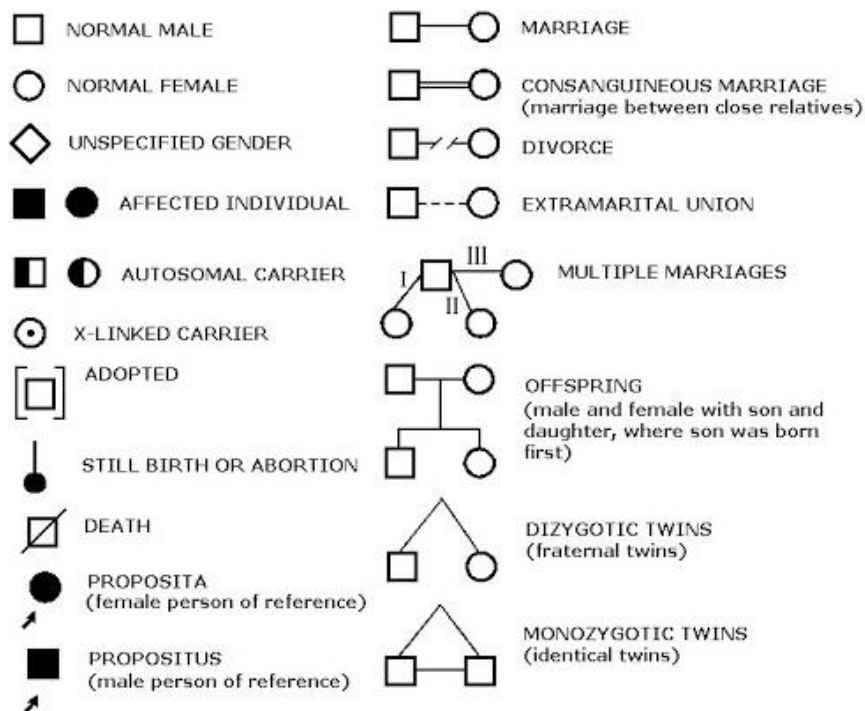


Fig. 36. Pedigree nomenclature

**Autosomal dominant inheritance:**

- sick children always have a sick parent (or both parents are sick);
- both men and women fall ill with equal frequency;
- if one of the parents is a dominant homozygote then the probability that the characteristic will be inherited by a child is 100 %; if both parents are heterozygous — 75 %, if one parent is heterozygous and the other is recessive homozygote — 50 %.

**Autosomal recessive inheritance:**

- sick children can be born by healthy parents (not always, but it is possible);
- both men and women fall ill with equal probability;
- if both parents are heterozygous then the probability that the characteristic will be inherited by a child is 25 %; if one parent is heterozygous and the other is a recessive homozygote — it is 50 %; if both parents are recessive homozygotes — 100 %.

**X-linked dominant inheritance** has the same signs as autosomal-dominant one. The key feature is the fact that a man having the X-linked dominant character can transmit the gene only to daughters (sons get his Y-chromosome).

**X-linked recessive inheritance:**

- mostly/only men fall ill;
- sick children can be born by healthy parents;
- if parents are healthy then probability giving birth to a sick child is 50 % for boys, and 0 % for girls (i.e. 25 %).

**Holandric (Y-linked) inheritance:**

- only men can have the character;
- such men are in all generations;
- if a father is sick then all his sons are sick and vice versa.

Ear hairs, skin membranes between toes are inherited in this type.

**Karyotyping (cytogenetic method)** is the technique allowing to see human chromosomes (fig. 37) extracted from the cells of blood or epithelium under the microscope. This method reveals the number of chromosomes, their structure, the genetic sex of the analyzed individual. Karyotyping is used for making the diagnosis of genome and chromosome mutations.

**Biochemical tests** can reveal the concentration of enzymes, amino acids and various metabolic products in specimens taken from healthy and sick persons. They help to confirm the diagnoses of metabolic diseases.

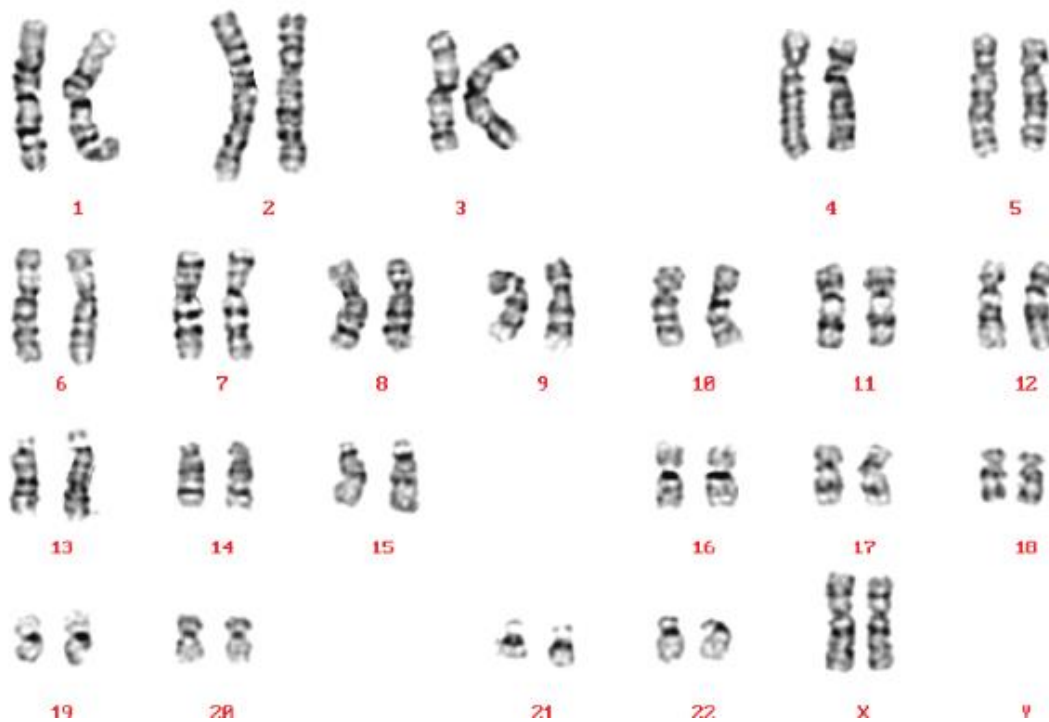


Fig. 37. The karyotype of human

## 8. THE HEREDITARY DISORDERS OF HUMAN

More than 6000 hereditary disorders are known at the present day. Medical genetics is the discipline that deals with hereditary disorders. These disorders are caused by changes of the genotype (mutations).

**Genome and chromosome mutations** cause human chromosome disorders such as Down, Shereshevsky–Turner, Klinefelter, X-trisomy, cri du chat syndromes.

**Down syndrome** (47, XX, 21+; 47, XY, 21+) is trisomy of the 21<sup>st</sup> chromosome (fig. 38, *a*). Trisomy is a genome mutation when 3 homologous chromosomes are present instead of 2 (47 chromosomes in a diploid set). Symptoms of the Down syndrome: intellectual disability, inward slant of the eyes, low-set ears. The life span is usually shorter than that of healthy people.

**Shereshevsky–Turner syndrome** (45, X0) is caused by a monosomy — the absence of the second sex chromosome (fig. 38, *b*). Phenotype is female. Symptoms: low height, short neck, underdeveloped primary and secondary sexual characteristics, sterility. Intellect is not affected.

**Klinefelter syndrome** (47, XXY) is caused by presence of extra X-chromosome in male karyotype (XXY instead XY, fig. 38, *c*). Such people may specific constitution, tall height, long extremities, underdeveloped primary and secondary sexual characteristics. If there are many additional X-chromosomes, they usually have lower intellectual abilities than healthy people.

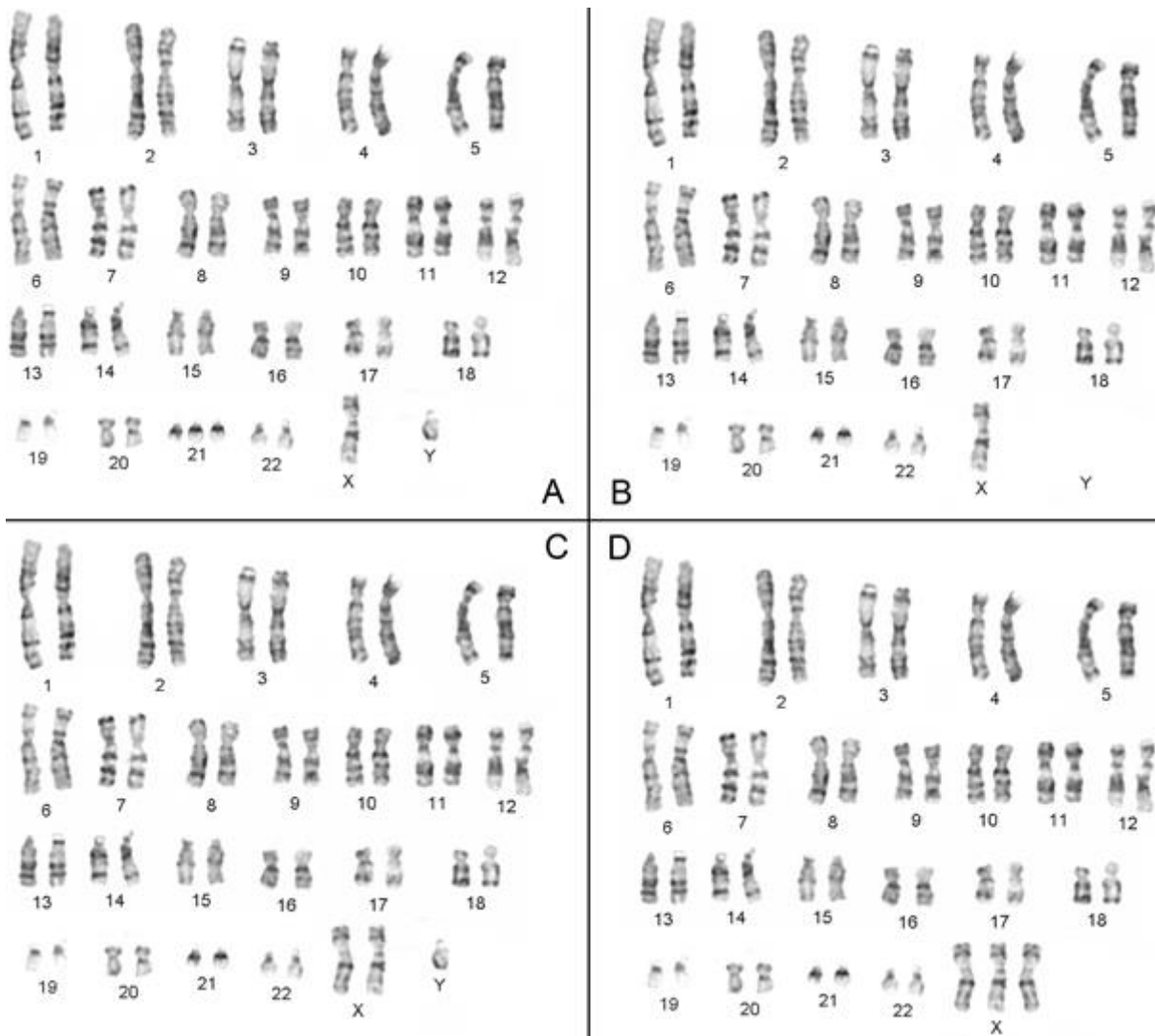


Fig. 38. Karyotypes at syndromes caused by monosomies and trisomies:  
 A — Down syndrome; B — Shereshevsky–Turner syndrome; C — Klinefelter syndrome;  
 D — X-trisomy syndrome

**X-trisomy syndrome** (47, XXX) is caused by the increase of the number of X chromosomes in females (additional X-chromosome, fig. 38, *d*). Such women usually do not have considerable physical features. Intellect is usually not affected. Such children have higher risk of speech and language delays and the delays of motor skills.

**Cat's cry (*cri du chat*) syndrome** (46, XX, 5p–; 46, XY, 5p–) is caused by loss of the segment of 5<sup>th</sup> chromosome's short arm. Due to the underdevelopment of the larynx, newborns have specific sound of cry which resembles cat's meowing. Other symptoms are arrested mental and physical development, deformed low-set ears, muscle hypotone.

**Gene mutations** cause metabolic diseases. Hereditary diseases caused by mutations of autosomal genes are albinism and phenylketonuria.

**Albinism** is caused by disturbance of amino acid exchange. Transformation of the amino acid tyrosine into a pigment melanin is impaired. Symptoms of albinism are milky-white skin, white hair and red pupils (due to absence of the pigment in the retina). Such people are very sensitive to ultraviolet rays.

**Phenylketonuria** is also caused by disturbance of amino acid exchange. The amino acid phenylalanine is not transformed into tyrosine and is transformed into phenylpyruvic acid. The disease affects nervous system. Sick children may have increased muscle tone, seizures, intellectual disability.

The disorders caused by gene mutation in the X chromosome are hemophilia and daltonism.

**Hemophilia** is the impairment of blood clotting. Daltonism (color blindness) is disturbance of color distinguishing. These diseases usually affect boys.

**Genetic counseling** is a medical discipline that strive to prevent birth of children with hereditary diseases.

Aims of genetic counseling are prophylaxis of hereditary diseases, consulting families and sick persons with hereditary disorders, defining the genetic risk (probability to give birth to a sick child) in a family, prenatal diagnosis of hereditary disorders and congenital malformations.

## SECTION 3

### THE ANATOMY AND PHYSIOLOGY OF HUMAN

#### 1. OVERVIEW OF THE HUMAN BODY. TISSUES, ORGANS AND ORGAN SYSTEMS

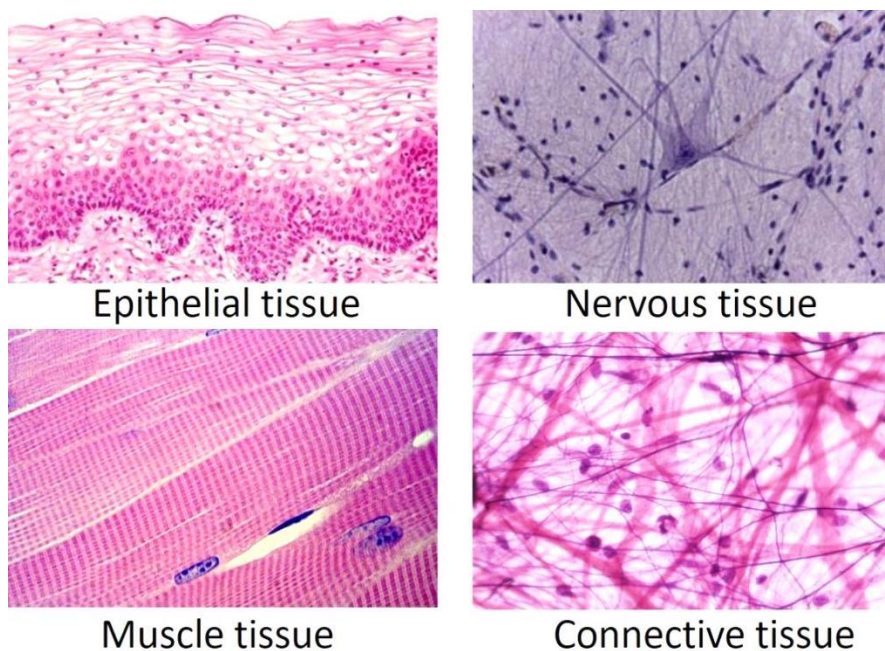
There are several medical sciences of human:

**Anatomy** is the science that studies the external and internal structure of the human body, its organs and organ systems.

**Physiology** is the science that studies the functioning and its regulation of the human organism, various tissues, organs and organ systems.

**Hygiene** is the medical science that studies conditions of human life and work to maintain human health and prevent diseases.

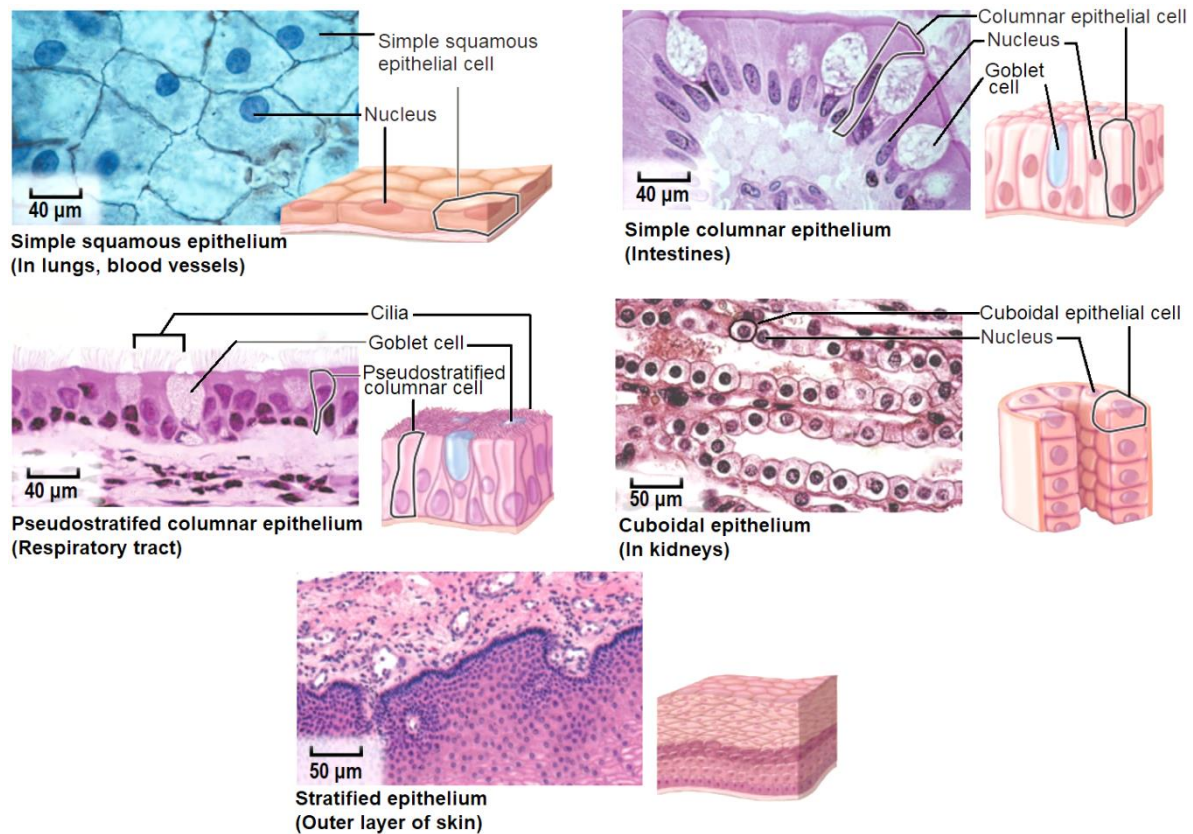
The human body consists of cells which form tissues. Tissue is a group of cells and the substance between them which are specialized for performing specific functions. The human body is composed of four types of tissues **epithelial, connective, muscle and nerve** (fig. 39).



*Fig. 39. Tissues of the human body*

**1. Epithelial tissue (epithelium)** covers the body, internal organs, majority of glands; it lines the cavities of the body. It has high level of regeneration due to mitosis. Epithelial cells are always attached to underlying layer of connective tissue. The cells are tightly packed — there is small volume of extracellular matrix or it is absent.

Types of epithelium according to the number of layers: *simple* (single-layer) and *stratified* (multilayer). According to the shape of cells in the superficial layer epithelium can be *squamous*, *cuboidal*, and *columnar* (fig. 40).



*Fig. 40.* Examples of epithelial tissue

**Functions of epithelial tissue are:**

- protective (barrier);
- metabolic (absorption and excretion of substances);
- secretory (gland cells of skin).

**2. Connective tissue** forms skeleton, subcutaneous fat, blood, lymph. It is an important element of all internal organs (fig. 41). The ability to regenerate is high. The cells of the tissue are widely spaced and thus leave much space for a high volume of extracellular matrix.

There are several types of connective tissue:

- hard connective tissue (bone, cartilage);
- dense fibrous connective tissue (ligaments, tendons);
- loose fibrous connective tissue (the dermis of the skin);
- adipose connective tissue (subcutaneous fat);
- liquid connective tissue (blood, lymph).

Some of the functions of connective tissue are:

- trophic (nutritional) function — exchange of substances and energy;
- protection — cells of the immune system belong to connective tissue;
- mechanical support — connective tissue forms bones, cartilage, ligaments and tendons;
- hematopoietic — red bone marrow produces blood cells;
- regeneration.

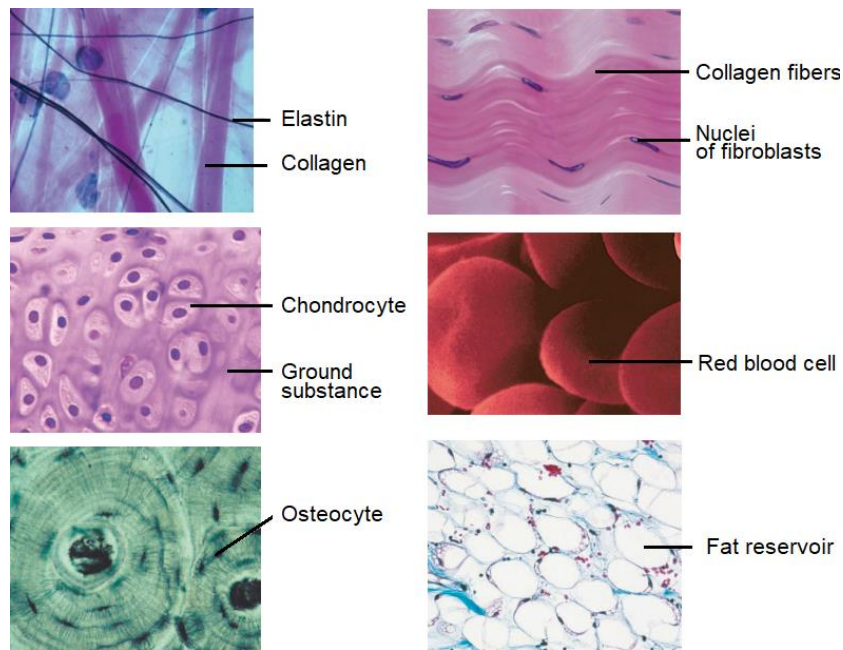


Fig. 41. Examples of connective tissue

**3. Muscle tissue** forms skeletal (striated) muscles and muscles of internal organs (such as wall of blood vessels). There are two essential properties of the muscle tissue: excitability and contractility. Excitability is the ability to perceive stimuli and respond to them. Contractility is the ability to change the length.

There are three types of muscle tissue:

- smooth muscles work involuntary, contract slowly and present in internal organs (walls of blood vessels, alimentary tract, urinary bladder and others);
- striated muscles are multinucleate, voluntarily controlled; form skeletal muscles;
- cardiac cells are not multinucleate, but are striated.

Muscle tissue performs motor function.

**4. Nervous tissue** forms the brain and spinal cord, ganglions, nerves. It consists of nerve cells — neurons which have two types of cytoplasmic processes (extensions): dendrites and axons. Cells of neuroglia are between neurons. Neuroglia performs nutritional, supportive and protective functions.

Nervous tissue has two *essential properties*: excitability and conductivity. Excitability is the ability to perceive stimuli and respond to them. Conductivity is the ability to transmit nerve impulse. The space or gap between processes of two neurons is called *synapse*.

***Functions of the nervous tissue are:***

- receptor — percept stimuli;
- conductive — transmits nerve impulses.

Tissues form organs. The **organ** is an anatomical structure which has particular shape, structure, location and performs specific functions (e.g., heart, lungs, stomach).

Organs have many various forms and are composed of several tissues. The stomach contains epithelial, connective, smooth muscle and even elements of nervous tissues. Bones are mostly composed of hard connective tissue though they have nerves, other types of connective tissue in their cavities, smooth muscles and epithelial cells in their blood vessels.

Organs that are responsible for the same functions are grouped into **organ systems** (fig. 42). These systems are widely studied by Anatomy. An organ system is a group of organs that have common origin and work together to perform certain task.

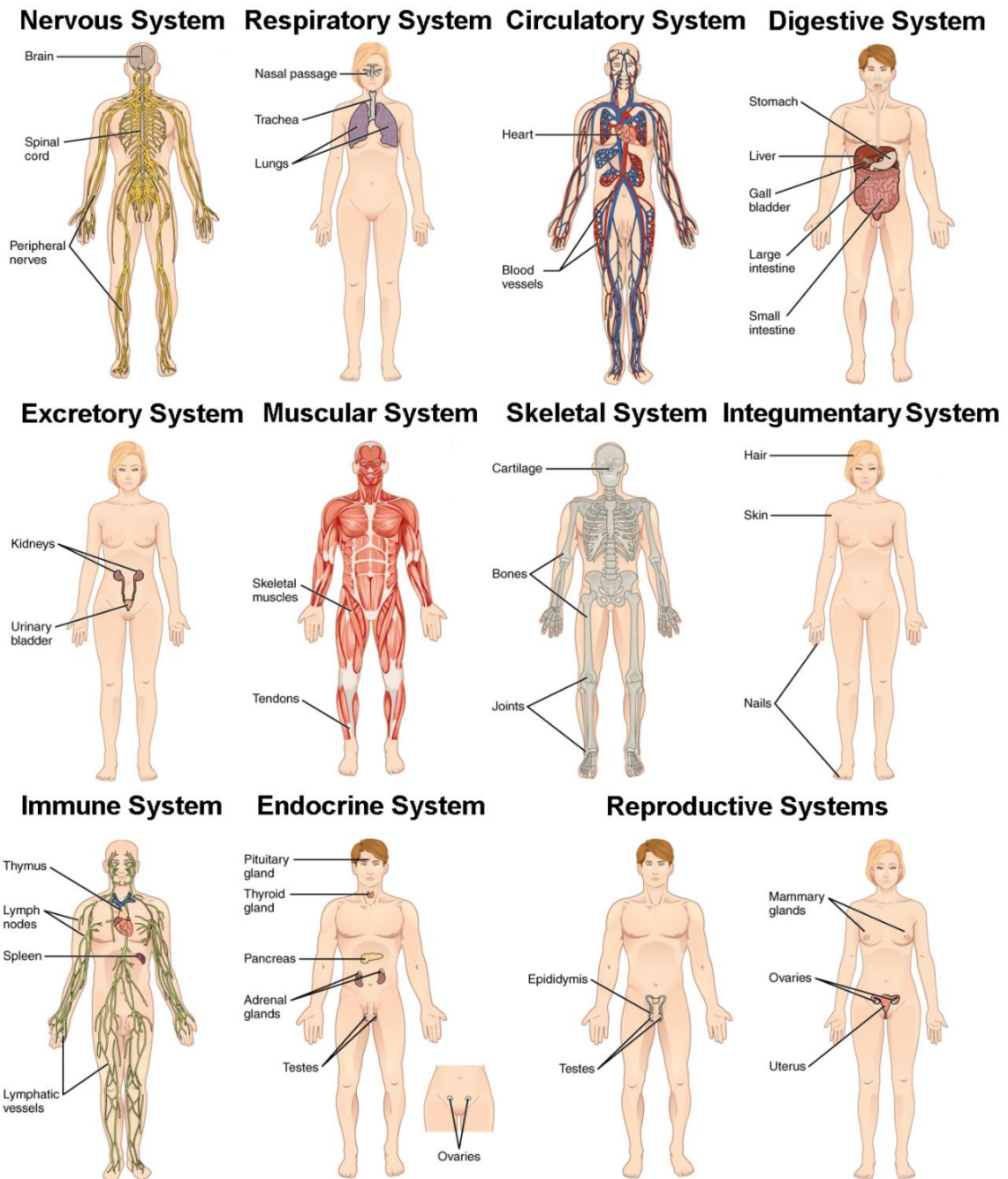


Fig. 42. Organ systems of the human body

There are:

**1. Skeletal system.** Skeleton (together with cartilage, ligaments and tendons) supports and protects the body and its organs.

**2. Muscular system.** It includes skeletal muscles and allows the body to manipulate the environment, provides locomotion, maintains posture, and produces heat.

Skeletal and muscular systems are often referred to as *musculo-skeletal* or *locomotor* system.

**3. Integumentary system** includes skin, hair, fat, nails and exocrine glands of the skin.

**4. Nervous system (NS).** Includes the brain, spinal cord, nerves, and ganglions. The nervous system allows perceiving, comprehending, and responding to the environmental signals.

**5. Circulatory system (cardiovascular system, CVS).** Its organs are heart and blood vessels. The function is pumping blood through the body to supply it with oxygen and nutrition and remove metabolic wastes.

**6. Respiratory system.** Includes the pharynx, larynx, bronchi and lungs.

**7. Digestive (gastrointestinal) system.** It includes digestive glands, mouth, esophagus, stomach, intestines. The system performs mechanical and chemical processing of food.

**8. Reproductive system** includes the female (ovaries, fallopian tubes, uterus, vagina, mammary glands) and male (testes, vas deferens, seminal vesicles and prostate) sex organs that provide human reproduction.

**9. Urinary system.** Its organs are kidneys, ureters, urinary bladder and urethra. The system is necessary for the fluid and electrolyte balance and excretion of urine. Reproductive and urinary systems referred sometimes to as genitourinary system.

**10. Endocrine system.** Provides chemical communication within the body using hormones made by endocrine glands such as the hypothalamus, pituitary gland, pineal body or pineal gland, thyroid, parathyroid and adrenal glands.

**11. Lymphatic system.** It is a network of lymphatic vessels and nodes involved in the transfer of lymph between tissues and the blood stream.

These systems form the **human body**. The body consists of body parts: head, neck, trunk, upper limbs (arms), lower limbs (legs).

The human body has thoracic and abdominal cavities which are separated by the diaphragm. Abdominal cavity contains stomach, intestines, liver and reproductive organs. The heart, largest vessels, lungs, trachea and esophagus are located in the thoracic cavity.

## 2. BONE TISSUE. THE STRUCTURE OF BONES

Bones together with muscles comprise the human musculoskeletal system. Chemical composition of bone: 50 % water, 12.5 % proteins, 21.8 % of inorganic salts and 15.7 % of carbohydrates and fats.

Bones are made of bone tissue (hard connective tissue) which consists of bone cells and extracellular matrix. The extracellular matrix of bones contains organic and inorganic components. The organic components include large number of fibers consisting of protein *collagen*. This protein provides elasticity of bones. The main inorganic component of bone extracellular matrix is crystals of the salt *hydroxyapatite*. It gives bones their strength.

Bone cells are of 3 types:

- *Osteocytes* are mature bone cells which surrounded with extracellular matrix;

- *Osteoblasts* are bone cells that become new osteocytes;

- *Osteoclasts* are cells of the bone that break down old osteocytes.

Bone tissue can be organized differently:

- *Spongy bone* looks similar to sponge: it consists of structures called *trabeculae* and spaces between them. These spaces are not empty: they contain *red bone marrow* which creates blood cells. Spongy bone forms bone's inside and is not exposed to the surface of bones.

- *Compact bone* is dense and homogenous. It forms predominantly the outer surfaces of bones. Compact bones consist of structural units called *osteons*. Osteon is a multilayer cylinder surrounding *Haversian canal* containing small blood vessels (fig. 43). Osteons contain osteocytes which are enclosed by extracellular matrix they produce.

According to the shape, bones are:

- Long bones: thighbone, humeral bone (upper arm), phalanges and etc.

- Short bones: carpals, tarsals.

- Flat bones: bones of the skull, sternum (breastbone), scapula (shoulder blade), ribs and etc.

- Irregular bones: zygomatic bone, mandible and etc. Such bones have characteristics of all previous groups.

Long bone (fig. 44) consists of elongated middle region called *diaphysis* and two terminal regions called *epiphyses*. Growth of bones in length is provided by cartilage which is situated between the diaphysis and epiphysis. In adults it ossified (turned into bone tissue) and the bones of adults do not grow.

Each epiphysis consists of spongy bone and contains red bone marrow which produces blood cells. An epiphysis has the region that is jointed with other bones and covered with smooth hyaline cartilage.

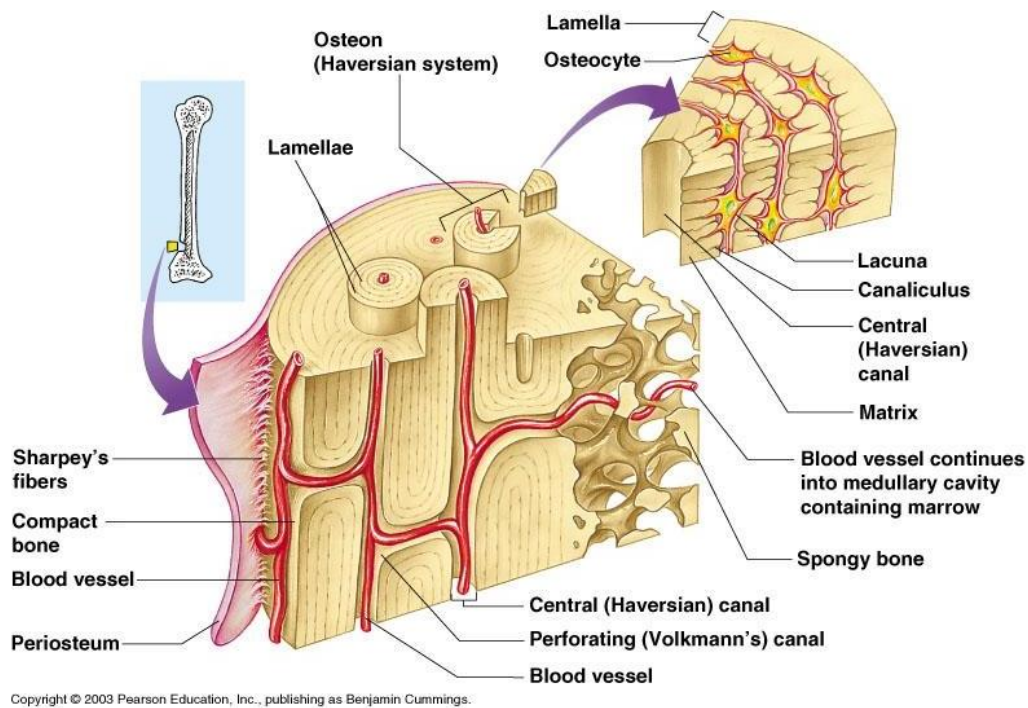


Fig. 43. Osteons in the compact bone

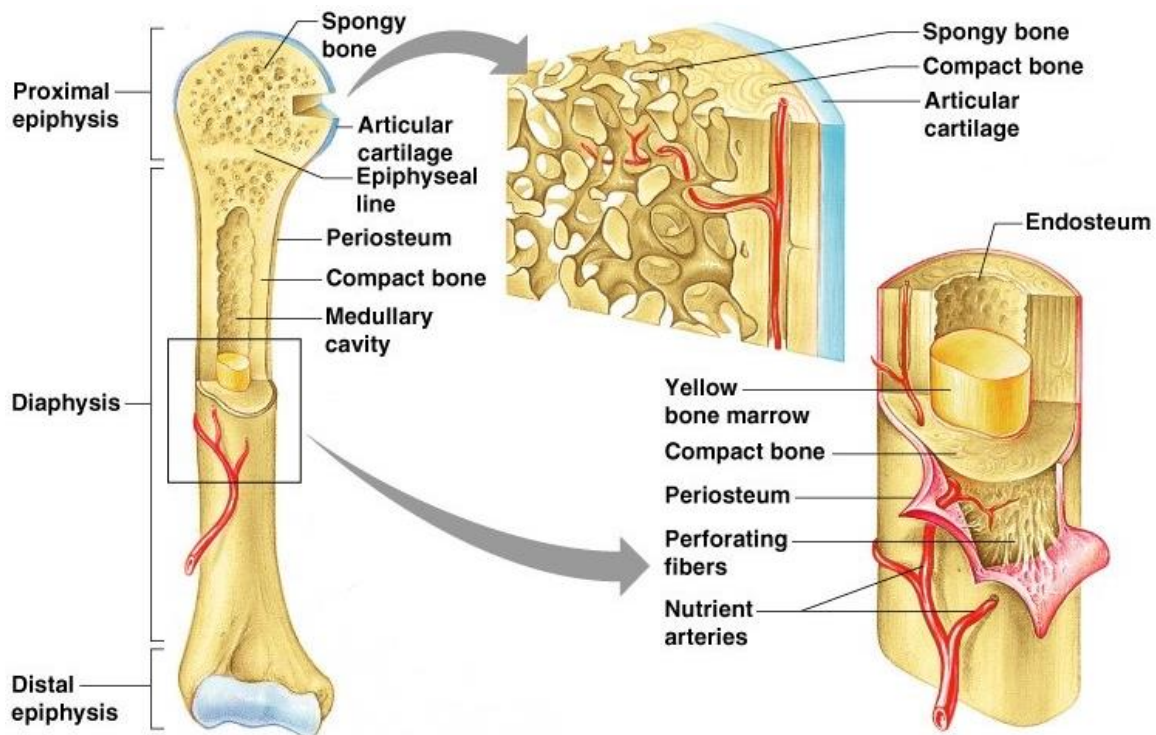


Fig. 44. The structure of long bone

The diaphysis has a cavity which is filled with adipose tissue — yellow bone marrow. The surface of the diaphysis is covered with *periosteum*. Periosteum contains nerves and blood vessels; it is connective tissue. Periosteum provides bone grows in thickness due to division of its cells.

Most of bones in the human body are connected to other bones. There are 3 types of bone connections:

– *Immovable* (synarthrosis) is a connection that allows very little or no movement. It occurs in two ways: bones may interlock via *sutures* (e.g. connection of skull bones) and *accretion* — fusion of bones (e.g. sacral vertebrae).

– *Semi movable* (amphiarthrosis) is a connection that allows slight mobility. In case of such connection two or more bones are fused with cartilage between them (connection of the sternum to ribs, vertebrae in the spine).

– *Movable* (diarthrosis). Movable connection of bones is called *synovial joint* (or *articulation*).

A synovial joint consists of *articular surfaces of bones, joint capsule, joint cavity* and *synovial fluid* (fig. 45). Such joint connects several bones. The surface of one bone might be convex (*ball*) and that of the other one is then concave (*socket*). Articular surfaces of bones are covered with cartilage which facilitates the movement of the bones.

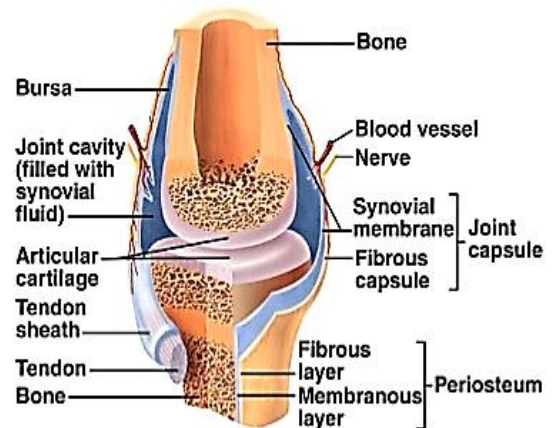


Fig. 45. The anatomy of synovial joint

Synovial joint is enclosed with the *joint capsule*. The cavity inside the capsule is called the *joint cavity*. It is filled with *synovial fluid* that reduces friction between bones.

Synovial joints are between the thigh bone and shin, between the bones of the upper arm and forearm. Examples of joints: knee, hip, shoulder, elbow and others. Synovial joints are fixed with ligaments.

### 3. THE SKELETON OF HUMAN

**Skeleton** is the passive part of the locomotory system. The human skeleton consists of more than 200 bones. The bones of the skeleton are grouped in 3 regions: *head skeleton* (skull), *axial skeleton* (skeleton of the trunk), *appendicular skeleton* (skeleton of limbs with their girdles).

The skeleton of the head is skull. It has two regions: the *neurocranium* (cerebral cranium) which encloses the brain, and *viscerocranium* (facial cranium). Eight bones comprise the *neurocranium* (fig. 46, a):

- 2 parietal bones;
- 2 temporal bones;
- frontal bone;
- occipital bone;
- ethmoid bone;
- sphenoid bone.

Fourteen bones and the hyoid bone form the *viscerocranium* (fig. 46, *b*):

- 2 maxillae (bones of the upper jaw);
- 2 zygomatic bones (cheekbones);
- 2 nasal bones;
- 2 lacrimal bones;
- 2 palatine bones;
- 2 inferior nasal conchae;
- mandible (lower jaw);
- vomer;
- hyoid (sublingual) bone.

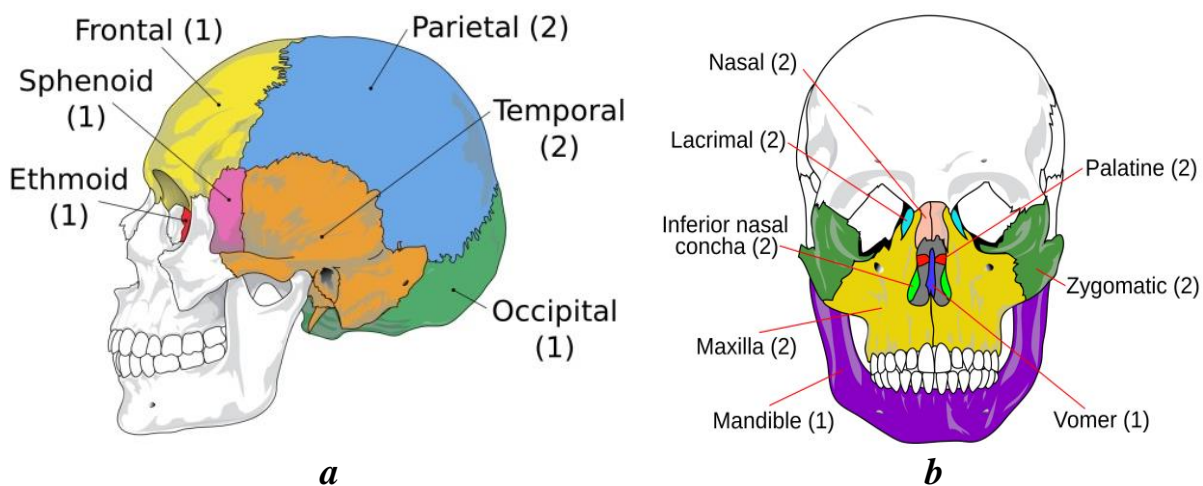


Fig. 46. Bones of the neurocranium (*a*) and visceral cranium (*b*)

All bones of the skull are connected via interlocking sutures (except the mandible which is connected with synovial joints).

**The axial skeleton** forms the *spine* and *thorax*. The spine (or *vertebral column*) is composed of 33–34 vertebrae and has 5 regions (fig. 47):

- cervical region (7 vertebrae);
- thoracic region (12 vertebrae);
- lumbar region (5 vertebrae);
- sacrum (the bone composed of 5 vertebrae which are fused together);
- coccyx (the bone composed of 4–5 vertebrae which are fused together).

Each vertebra consists of *body*, *arch*, and several *processes*. Between the vertebral bodies are *intervertebral discs*. They consist of fibrous cartilage. There is a hole between the vertebral body and vertebral arch. All those holes of vertebral column form *vertebral canal* where spinal cord is situated.

The first cervical vertebra is also known as the *atlas*. It has no body. The second one is the *axis*. It extends up into the atlas and allows the head to rotate from side to side on its axis. Human spine forms four physiological curves.

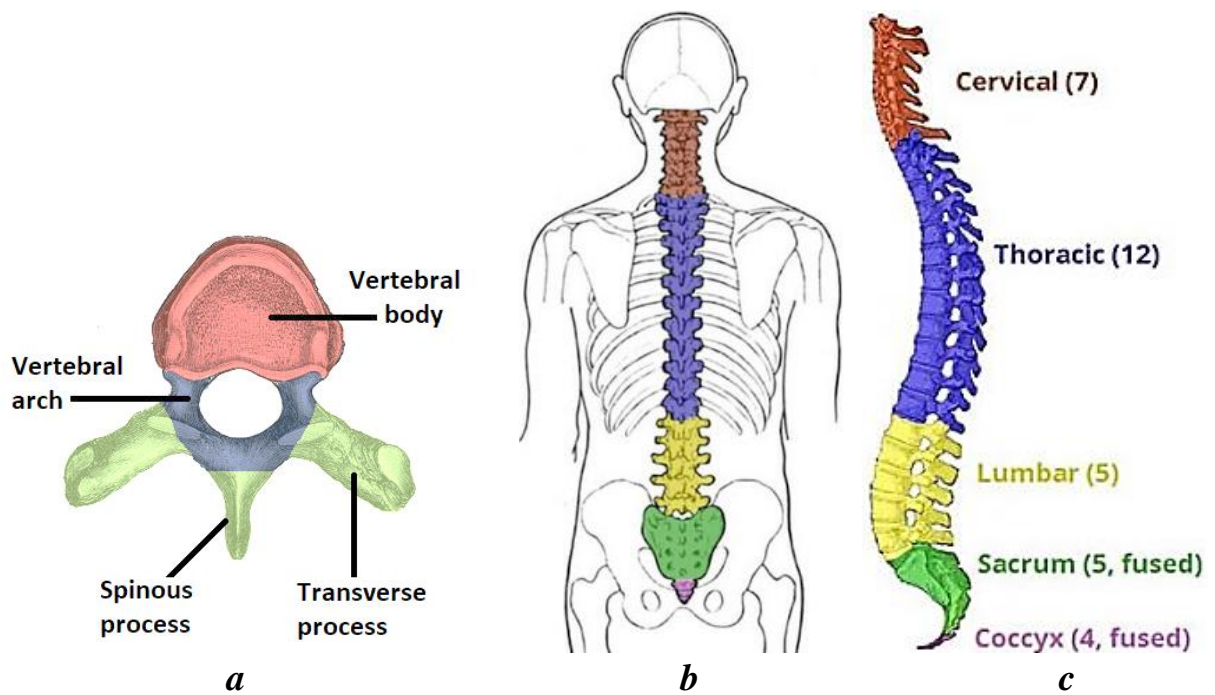


Fig. 47. The structure of human vertebra (a) and vertebral column (b, c)

– *Lordosis* is an anteriorly convex region of the spine. Human spine has cervical and lumbar lordoses.

– *Kyphosis* is the anteriorly concave region of the spine. Human spine has thoracic and sacral kyphoses.

These physiological curves reduce shocks while walking, jumping and running and increase the volume of the chest and pelvis.

Each of twelve thoracic vertebrae has a pair of ribs, i.e. human has 12 pairs of ribs. Thoracic vertebrae, ribs and sternum form the *chest* (or thorax, *thoracic cage*). There are 3 groups of ribs (fig. 48):

– *True (vertebrosternal) ribs* (1–7 pairs) — their anterior ends are attached to the sternum through cartilage.

– *False (vertebrochondral) ribs* (8–10 pairs) their front end joins the cartilage of the previous rib.

– *Floating ribs* (11–12) pairs are not connected with the sternum and other ribs. Their anterior ends freely lay in the tissues.

Chest contains the heart, great vessels, lungs, trachea, and esophagus. It is involved in the respiratory movements.



Fig. 48. Thorax

**The appendicular skeleton** includes bones of *girdles* and *limbs*.

*The pectoral girdle* consists of two *scapulae* and two *clavicles*.

*The upper limb* consists of the upper arm, forearm and palm. The bone of the upper arm is the *humerus*; the forearm includes *radius* and *ulna*. The bones of the palm are divided into 3 groups. Eight bones of the wrist (*carpals*) form the *carpus*. Distal to the carpals are the five *metacarpals*. Distal to the metacarpals are the fourteen bones of *phalanges*.

*The pelvic girdle* consists of two pelvic (coxal) bones grown to the sacrum.

*The lower extremity* consists of the upper leg, lower leg and foot. The bone of the upper leg is *femur*; those of the lower leg are *tibia* and *fibula*. The groups of bones in the foot are *tarsals* (compose tarsus), *metatarsals* (compose metatarsus), and *phalanges*.

**The functions of the skeleton:** it supports the body, protects underlying organs, and provides mobility of the body. Blood cells are formed in bones. Skeleton takes part in calcium balance.

#### 4. MUSCLE TISSUE

The other part of musculoskeletal system is muscles. Muscles are the active part of the system. Humans have more than 600 skeletal muscles. Together they may account about 40 % of a body weight. Muscles are composed of muscle tissue. There are 3 major types of muscle tissue:

**1. Smooth muscle tissue** consists of small elongated cells. Each cell has a single nucleus and contractile protein fibers — *myofibrils*. The length of such cell is on average 0.1 millimeter. Smooth muscle tissue is located in the walls of almost all regions of digestive system (from esophagus to large intestine) urinary bladder, bronchioles, bile ducts, uterus and blood vessels. The muscles which elevate hair, change the size of pupil and the shape of the lens in the eyes are also smooth. The contractions and relaxations of smooth muscles are involuntarily. The contraction of such muscles is slower than that of other muscles, but they tire more slowly.

**2. Striated skeletal muscle tissue** consists of cells called muscle fibers. A muscle fiber is several centimeters in length (may reach 10–12 cm) and 50–100  $\mu\text{m}$  in thickness. Such cells have many nuclei and many myofibrils. Myofibrils are long and consist of repeating regions with thin and thick fibers of proteins *actin* and *myosin*. The alignment of myofibrils in striated muscles (but not in the smooth ones) is ordered: there alternating regions containing mostly actin or mostly myosin. Because of this all the cell looks banded or *striated*. This appearance of cells gave the name to the tissue. Striated muscles work voluntarily, contract and tire more quickly than smooth muscles.

**3. Cardiac muscle tissue** is a specialized form of striated muscle tissue. The word «cardiac» means «of the heart». Cardiac muscle is named so because it is present only in the heart. The length of a cardiac muscle cell is approximately 0.1 millimeter, but the chains they form are long. Each cell has

one nucleus. Cardiac muscles work involuntarily. This muscle works all the life but does not tire as periods of contraction alternate with relaxations.

Muscle fibers of striated muscles form bundles called *fascicles*. A group of fascicles forms a skeletal muscle. There are thin layers of connective tissue covering fasciculi. A muscle is also covered with capsule consisting of connective tissue.

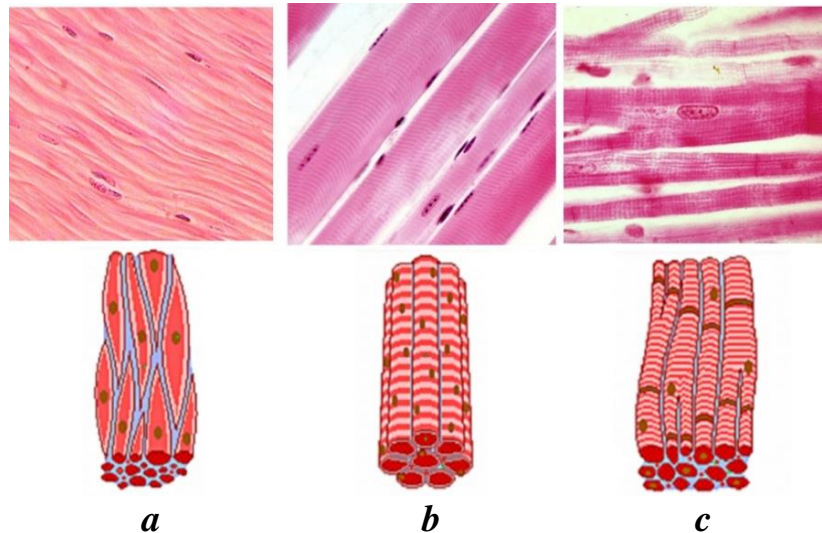


Fig. 49. Photographs and diagrams of smooth (a), skeletal (b) and cardiac (c) muscles

A muscle consists of the *belly* and *tendons* (fig. 50). Belly consists of muscle tissue while tendon is connective tissue. The tendons attach muscle belly to bones. All ends of muscles are commonly attached to bones though there are exceptions: mimic muscles (responsible for facial expressions) are also attached to skin.

According to the shape, the skeletal muscles are:

- long (muscles of limbs) and short (intercostal muscles);

- wide (muscles of abdomen);

- thick and thin (deep muscles of the back);

- biceps, triceps.

According to the function, skeletal muscles are:

- flexors — located in front of joint (biceps);

- extensors — located behind the joint (triceps);

- adductors — located medially from the joint;

- abductors — located outside from the joint;

- rotators are situated inwardly and outwardly.

According to the location, skeletal muscles are:

- muscles of the head (chewing or masseter, mimic);

- muscles of the neck;

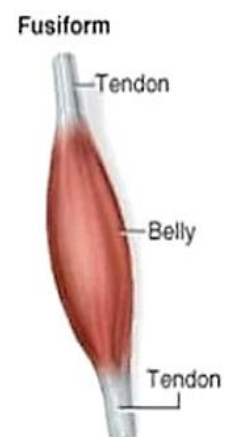


Fig. 50. Skeletal muscle

- muscles of the chest;
- abdominal muscles;
- muscles of the back (or dorsal muscles);
- muscles of the limbs and girdles.

Muscles contain blood vessels which feed them, nerves and nerve terminations (receptors).

The work of muscles is their contraction. It requires energy (ATP). Muscle work has a reflex character. *Reflex* is an automatic response of the body to a stimulus with participation of the nervous system. The environmental stimulus causes excitation of *receptors*. This excitation (impulse) is transmitted through the *sensory neurons* to *intercalary neurons* of the spinal cord and then through the *motor neurons* to the *muscle* (fig. 51). This causes contraction of the muscle.

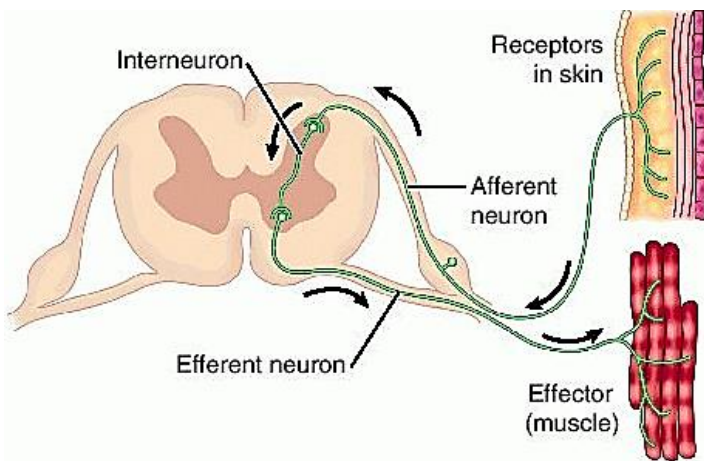


Fig. 51. Reflex arc providing muscle contraction

The path of the nerve impulse during this process is called a reflex arc. A reflex arc that controls muscles consists of receptor, sensory (afferent) neuron, intercalary neuron (interneuron), motor (efferent) neuron, and muscle (effector).

*Skeletal muscles are innervated by the somatic nervous system.* It provides voluntary control of muscles. In addition, the muscles are *innervated by the autonomic nervous system* that regulates their metabolism and contractility.

The central nervous system (CNS) has important role in the regulation of muscle activity: the midbrain regulates tonus of muscles and cerebellum provides balance and coordination.

*Functions of muscles:*

- shape the body (together with the skeleton);
- provide posture and movement of the body;
- provide breathing, eye movements, chewing, swallowing, facial expressions;
- participate in the formation of speech;
- provide joint stability and heat production.

## 5. INTERSTITIAL FLUID, LYMPH AND BLOOD

In 1878, a French physiologist Claude Bernard introduced the concept of the internal environment of the body.

All cells of the body require the supply of nutrients and O<sub>2</sub> and the removal of waste products. The connection between the respiratory, digestive, urinary organ systems and all the cells of the body is provided by means of internal environment of the body (blood, interstitial fluid, lymph).

**Interstitial fluid** is the fluid found between cells outside vessels. It originates from blood plasma after filtration through capillaries. It contains water, salts, all major groups of organic substances, coenzymes, hormones, cellular products and etc. In the organism of an adult its volume is approximately 20 liters. The fluid bathes and surrounds the cells of the body and provides a means of delivering materials to the cells, intercellular communication, and removal of metabolic wastes.

**Lymph** is transparent liquid in lymphatic vessels. Its chemical composition is similar to blood plasma, but it contains less proteins. It does not contain cells except lymphocytes. Lymph originates from interstitial fluid and moves through the lymphatic vessels (fig. 52). Numerous lymph nodes are located along lymphatic vessels. Lymphocytes arrive into the lymph from the lymphatic nodes. The largest lymph vessels fuse into the thoracic and right lymphatic ducts that empty into vessels joining the superior vena cava. About 1–3 liters of lymph return to blood per day.

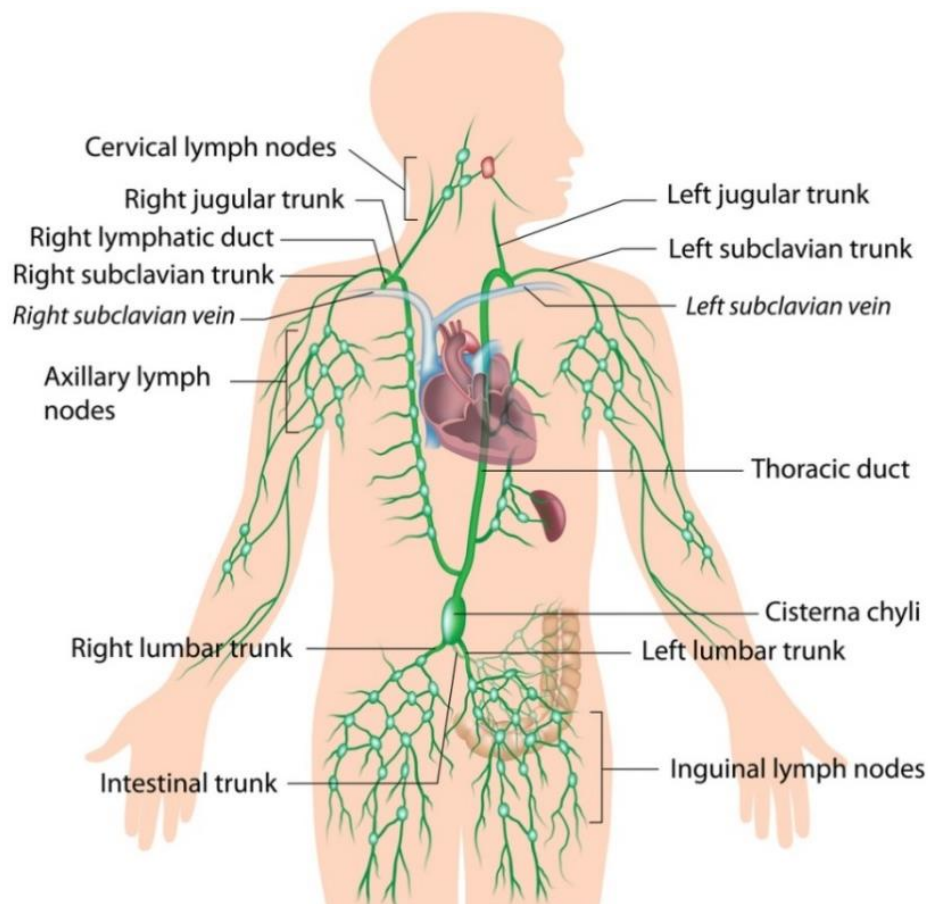


Fig. 52. Lymphatic system

Functions of lymph are distribution of water in the body (prevent edema) protection of the organism (immune response).

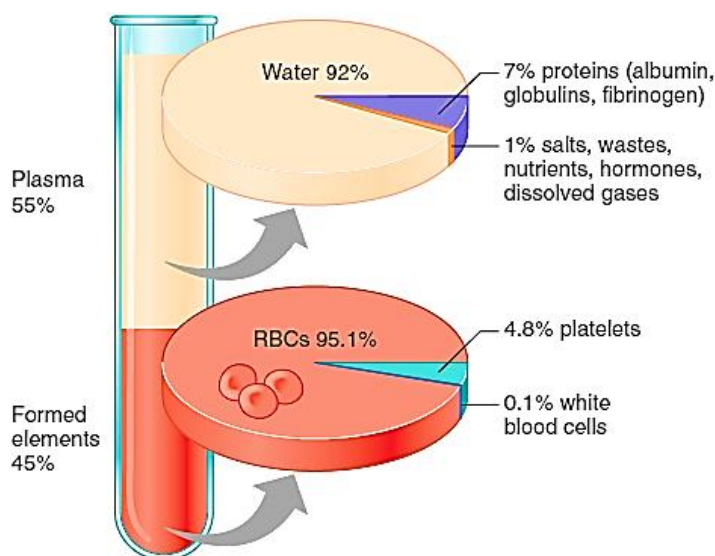


Fig. 53. The composition of blood

minerals (calcium, potassium, sodium) and organic substances (fats, proteins, carbohydrates).

There are 3 main types of blood cells: *erythrocytes*, *leukocytes* and *platelets*.

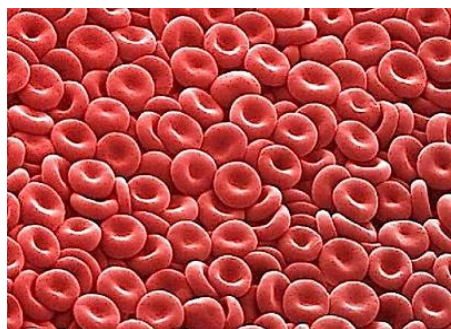


Fig. 54. Red blood cells

**Erythrocytes** or *red blood cells (RBC)*. Erythrocytes have a shape of biconcave disc 7–8  $\mu\text{m}$  in diameter (fig. 54). They have no nucleus as it is extruded from the cells as they mature. All the erythrocyte is filled with iron-containing protein hemoglobin which is able to hold oxygen and carry it to cells. Due to hemoglobin and its iron, blood is red. Red blood cells have high plasticity allowing them to squeeze through the capillaries without breaking.

As all blood cells, erythrocytes are produced in the red bone marrow. They circulate in blood approximately 120 days before being destroyed in the liver, bone marrow, or spleen. The iron from hemoglobin is recycled. One liter of blood contains  $4-5 \times 10^{12}$  erythrocytes.

The function of red blood cells is transport. They bring  $\text{O}_2$  from lungs to tissues and organs and take  $\text{CO}_2$  from tissues and organs to the lungs. Oxygen is transported by binding to hemoglobin, carbon dioxide can also bind with hemoglobin, but it also interacts with water forming  $\text{HCO}_3^-$  ions.

– Hemoglobin bound with  $\text{O}_2$  is called *oxyhemoglobin*.

– Hemoglobin bound with  $\text{CO}_2$  is called *carbhemoglobin* or *carbaminohemoglobin*.

**Blood** is a liquid connective tissue which is the main part of human internal environment. Its volume in the body of an adult is approximately 5–6 liters so it constitutes 7–8 % of body weight.

Blood consists of the liquid intercellular material that is called *plasma* (fig. 53) and formed elements (i.e. blood cells).

**Plasma** is colorless liquid which contains water (90–92 %),

– Carbon monoxide (CO) is a poison for human as it can tightly bind with hemoglobin and form *carboxyhemoglobin*. As the bond of CO with hemoglobin is very strong it is not easily broken and does not let hemoglobin bind with oxygen. Accumulation of carboxyhemoglobin in blood may cause death. CO has no color or smell and even low concentrations of this gas are life threatening.

**Leukocytes** or *white blood cells*, *WBC* (fig. 55) are of several types: *basophils*, *eosinophils*, *neutrophils* (they are called *granulocytes* because of their appearance), *monocytes*, *lymphocytes* (they are *agranulocytes*). Leukocytes have irregular shape. Unlike erythrocytes, they have nucleus. Sizes of different white blood cells vary from 6 to 25 micrometers. Leukocytes can move due to extensions of the cytoplasm called *pseudopodia*. There are approximately  $4.5\text{--}9 \times 10^9$  of white blood cells in one liter of blood of a healthy adult man (most of them are neutrophils).

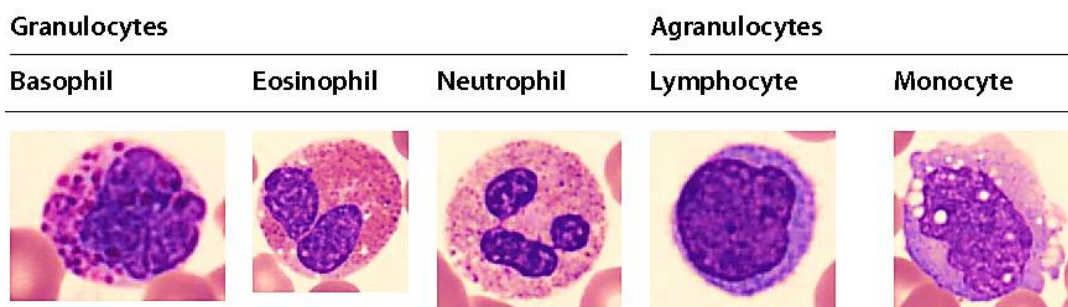


Fig. 55. White blood cells

Leukocytes are produced in the red bone marrow and mature in spleen, thymus and lymph nodes. Granulocytes may live 2–4 days, agranulocytes can live much longer.

White blood cells are components of the *immune system* which protects the body from pathogens such as bacteria or viruses from foreign macromolecules, foreign bodies, tumors. Different white blood cells can engulf foreign objects by phagocytosis or release enzymes from granules in their cytoplasm. One type of lymphocytes (*B cells*) produce protective proteins called antibodies. Antibodies can bind to foreign molecules to neutralize them and facilitate their phagocytosis.

**Thrombocytes (platelets)**. One liter of blood contains  $150\text{--}450 \times 10^9$  platelets. Like erythrocytes, they do not have nucleus. Their shape is irregular; sizes are of 2–5 micrometers (fig. 56). Thrombocytes are formed in the red bone marrow by special cells. Their life span is 8–11 days. Destruction of platelets occurs in the spleen.

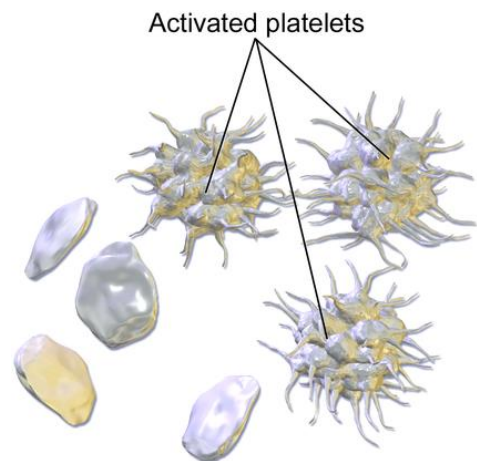


Fig. 56. Thrombocytes

Function of thrombocytes is participating in blood coagulation (clotting) to protect the body from blood loss during bleedings.

Functions of blood are transport, protection and regulation.

Transport function consists in carrying the following:

– oxygen (O<sub>2</sub>) from the lungs to all tissues and carbon dioxide (CO<sub>2</sub>) in opposite direction;

– nutrients from the digestive tract and storages to the rest of the body;

– waste products to the liver and kidneys to detoxify and excrete them;

– hormones from the glands in which they are produced to their target cells;

– heat to the skin to help regulate body temperature.

Protective function is the role of the blood in inflammation:

– leukocytes (white blood cells) destroy invading microorganisms and cancer cells;

– antibodies and other proteins destroy pathogenic substances;

– platelet factors initiate blood clotting and help minimize blood loss.

Regulative function of the blood is its control of:

– pH by interacting with acids and bases;

– water balance by transferring water to and from tissues.

## 6. CIRCULATORY SYSTEM.

### THE STRUCTURE AND FUNCTIONING OF THE HEART

**Circulatory (cardiovascular) system** is the system which circulates blood. Its structural components are the heart and blood vessels.

**The heart** is a muscular organ which is the central organ of the circulatory system. It is located in the thoracic cavity (at the left) in a sac which is called *pericardium*. The pericardium consists of connective and epithelial tissues. It secretes a fluid that reduces friction during heart beating. Therefore, the function of the pericardium is to protect the heart.

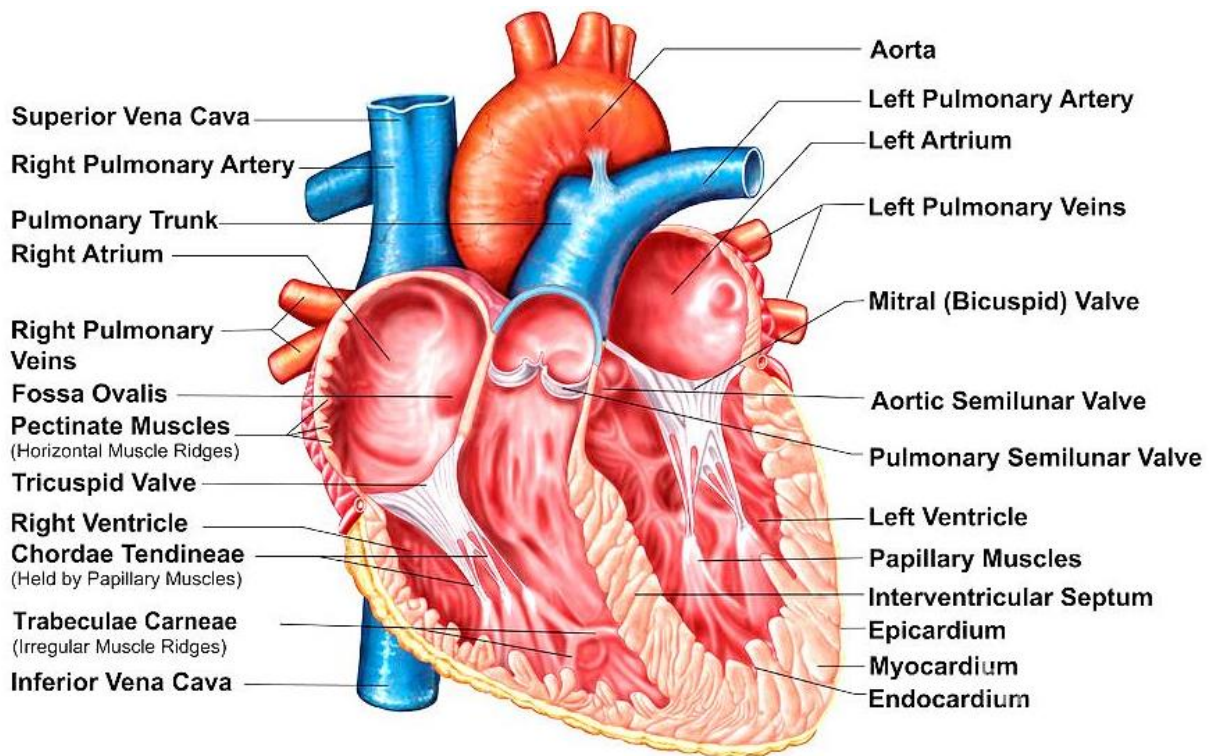
Weight of the heart is 200–300 grams. The wall of the heart consists of 3 layers:

– *endocardium* is the inner layer made of epithelial tissue;

– *myocardium* is the thickest middle layer which consists of cardiac striated muscle tissue;

– *epicardium* is the outer layer that consists of connective tissue covered with epithelium.

The human heart has four chambers: *left and right atria and left and right ventricles* (fig. 57). There are openings with cuspid valves between the atria and ventricles. The valve between the left atrium and the left ventricle is bicuspid (has two cusps). It's another name is *mitral valve*. Between the right atrium and right ventricle is *the tricuspid valve* (has three cusps).



*Fig. 57. The anatomy of the heart*

Blood is always pumped from atria to the ventricles and tendon threads that keep the valves prevent reverse movement of blood from ventricles to the atria. Due to these tendons the valves can open only to the ventricles.

Each chamber is connected with large blood vessels:

- *superior and inferior vena cava* join the right atrium;
- *4 pulmonary veins* deliver blood to the left atrium;
- *pulmonary trunk* begins from the right ventricle and then divides into *2 pulmonary arteries*;
- *aorta* carries blood from the left ventricle.

The heart muscle is fed with blood due to 2 coronary arteries which branch from the aorta.

*There are semilunar valves* between the pulmonary trunk (*pulmonary valve*) and right ventricle and between left ventricle and aorta (*aortic valve*). Semilunar valves do not allow blood return from these vessels back to the ventricles.

The work of the heart is its contraction. It works rhythmically and does 70–75 beats per minute (at rest). Consequently, one cardiac cycle lasts approximately  $60/75 = 0.8$  seconds. Cardiac cycle consists of three phases:

1. *Atrial systole* (contraction of the atria) — *0.1 sec*. Both atria contract and blood they contained is pumped to the ventricles.

2. *Ventricular systole* (contraction of the ventricles) — *0.3 sec*. Ventricles contract and eject their blood to the vessels (aorta and pulmonary trunk).

3. *Diastole* (total relaxation) — 0.4 sec. During this period, atrium and ventricles are relaxed and blood from atria fills the ventricles (fig. 58).

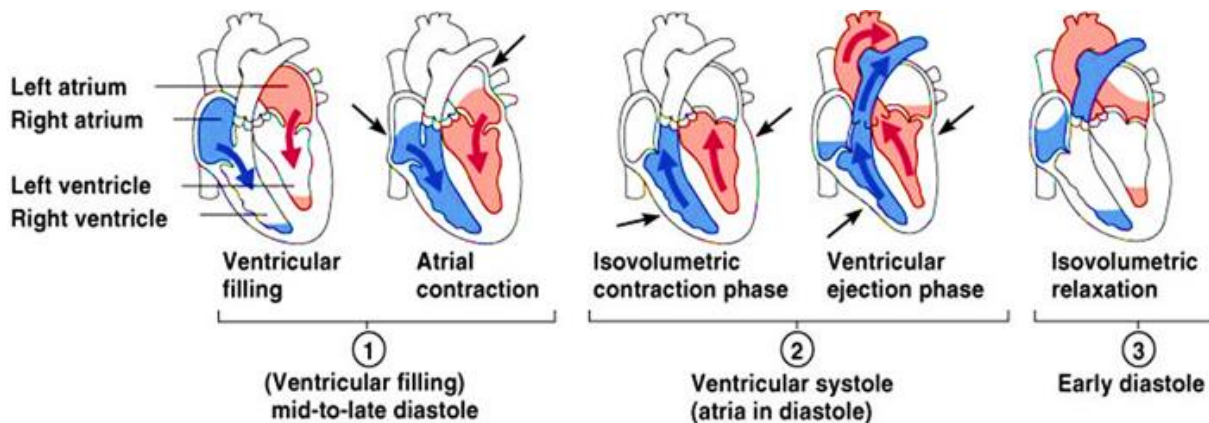


Fig. 58. The stages of the cardiac cycle

Period including systole of the atria and ventricles plus the overall pause is cardiac cycle. During the cardiac cycle, the atria work 0.1 seconds and are relaxed 0.7 seconds. Ventricles work 0.3 seconds and rest 0.5 seconds. Therefore, the heart does not get tired and works all life.

The work of the heart is regulated by *the autonomic (vegetative) nervous system*. The sympathetic nervous system enhances and accelerates the heartbeat. The parasympathetic nervous system slows the heart. There are biologically active substances such as hormones and ions which regulate heart functioning.

Regulation of the heart with participation of hormones is called *humoral regulation*. Epinephrine (adrenal hormone) and calcium ions enhance the heart functioning. Acetylcholine and potassium ions depress the heart activity.

## 7. THE STRUCTURE OF BLOOD VESSELS. CIRCULATION OF BLOOD IN THE BODY

Heart contracts to pump the blood to the blood vessels. There are three types of blood vessels (fig. 59) in the circulatory system: arteries, capillaries and veins.

**Arteries** are the vessels that carry blood from the heart to organs and tissues. The largest artery in the human body is the aorta (2.5 cm diameter). In arteries, the blood moves under high pressure. Arterial wall has three layers: the outer one is made of the connective tissue; the middle layer consists of smooth muscles and elastic fibers; the inner one is epithelial tissue. Such walls are strong and elastic. Large arteries branch out into smaller arteries; they branch out into arterioles and the arterioles into capillaries.

**Capillaries** are the smallest blood vessels which connect the small arteries and veins. Their wall consists of a single layer of epithelial cells. Diameter of

capillaries is about 7 micrometers and wall thickness is about 1 micrometer, length 0.2–0.7 mm. The total cross-section area of all capillaries of the body is 6300 m<sup>2</sup>.

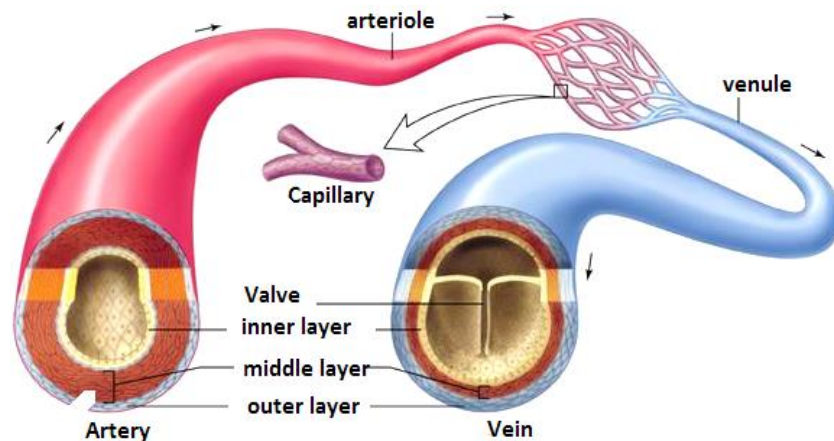


Fig. 59. Blood vessels

Exchange of substances and gases occurs through the capillary walls:

- O<sub>2</sub> and nutrients diffuse from blood to tissues;
- various metabolites (including metabolic wastes) and CO<sub>2</sub> from tissues enter the capillaries.

**Veins** are the vessels that carry blood from the organs and tissues to the heart. On the analogy of arteries, the wall of veins has three layers: the layer of connective tissue, of muscle tissue, of epithelial tissue. Vein wall is thinner than the arterial wall. The blood pressure in the veins is much lower than in arteries and even negative in the vena cava. To prevent reverse blood flow, veins have semilunar valves.

The movement of blood through the vessels is called circulation. All the vessels in the human body belong to systemic (greater) and pulmonary (lesser) circulations.

**The systemic circulation** (fig. 60) begins in the left ventricle and ends in the right atrium. The left side of the heart contains arterial (oxygenated) blood.

Arterial blood contains nutrients and a lot of oxygen. During the contraction of the left ventricle, arterial blood is pumped into the aorta and then through arteries to organs. Arteries of the organs branch out into capillaries. Oxygen and nutrients pass into the tissue through the capillary walls while metabolites and carbon dioxide are absorbed.

Capillary blood is collected in small veins which unite into two large veins — the superior vena cava and inferior vena cava. These veins carry venous blood into the right atrium. The right side of the heart contains venous (deoxygenated) blood. Venous blood contains a lot of metabolites and CO<sub>2</sub>. There is arterial blood in all the arteries of the systemic circulation, and venous blood in all the veins.

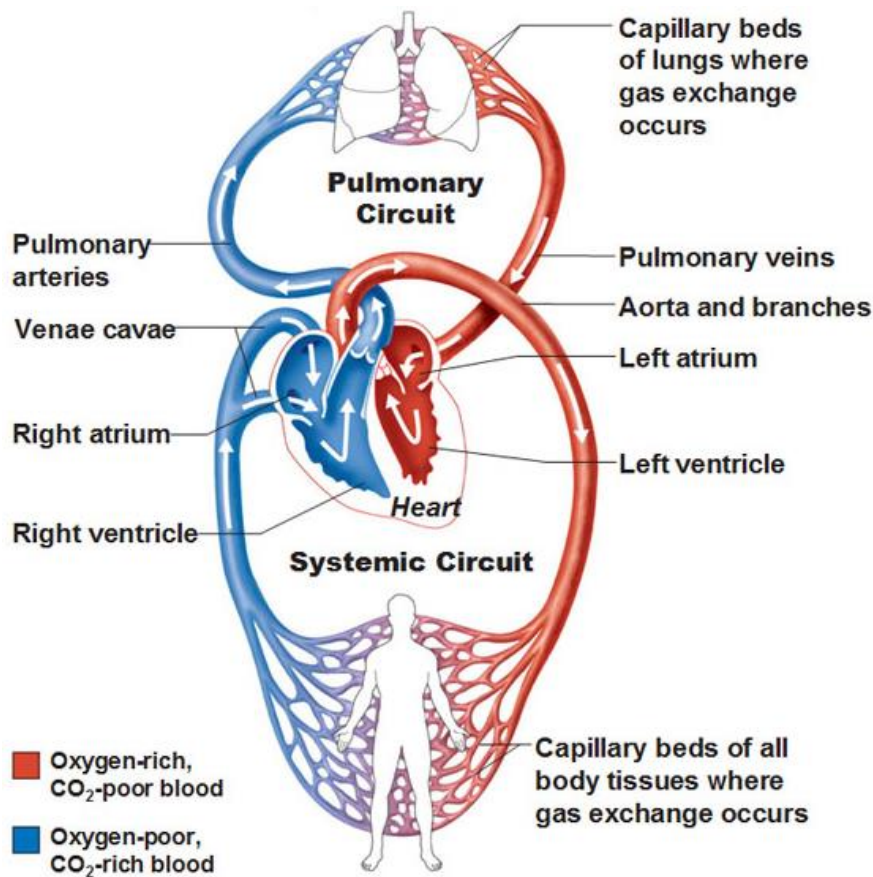


Fig. 60. Pulmonary and systemic circulations

**The pulmonary circulation** starts from the right ventricle and ends in the left atrium. From the right ventricle, venous blood is pumped in the pulmonary trunk which split into two pulmonary arteries carrying blood to two lungs. In the lungs, arteries branch into smaller arteries, then into capillaries. Capillaries surround the alveoli, where gas exchange takes place: exit of carbon dioxide and absorption of oxygen.

Arterial blood comes back to the heart by the four pulmonary veins and gets to the left atrium. There is venous blood in all arteries of the pulmonary circulation and arterial blood in the veins.

## 8. RESPIRATORY SYSTEM

**Breath (respiration)** is a process that provides the gas exchange between the organism and the environment. As a result, oxygen enters the cells and carbon dioxide is removed. The respiratory system is the organ system which provides the exchange of gases between the organism and the environment. It consists of respiratory tract (airways) and respiratory organs (lungs).

**The respiratory tract** includes the *nasal cavity, pharynx, larynx, trachea, bronchi* and *bronchioles*.

Air passes through the nostrils and enters the *nasal cavity*. The nasal cavity is divided into the right and left halves by an osteochondral partition. Each half has three nasal passages (meatuses). The canal of lacrimal gland opens to the lower nasal passage. Epithelial membrane of the nasal cavity contains cilia, glands and many blood vessels. Epithelial cilia and mucus of the glands clean the air of dust and hold microbes; blood warms the air. The nasal cavity contains olfactory receptors perceiving various odors.

Air passes from the nasal cavity into the **pharynx** (nasopharynx, oropharynx, laryngopharynx) and other parts of the pharynx, then into the larynx. Openings between the nasal cavity and the nasopharynx are called choanae.

**The larynx** consists of cartilage and muscles (fig. 61) and its cavity is covered by mucous membrane (mucosa).

The epiglottic cartilage (epiglottis) closes the entrance to the larynx during swallowing. There are 9 cartilages in the larynx:

- thyroid cartilage, cricoid cartilage and epiglottis (single cartilages);
- 2 arytenoid, 2 corniculate and 2 cuneiform cartilages (paired cartilages).

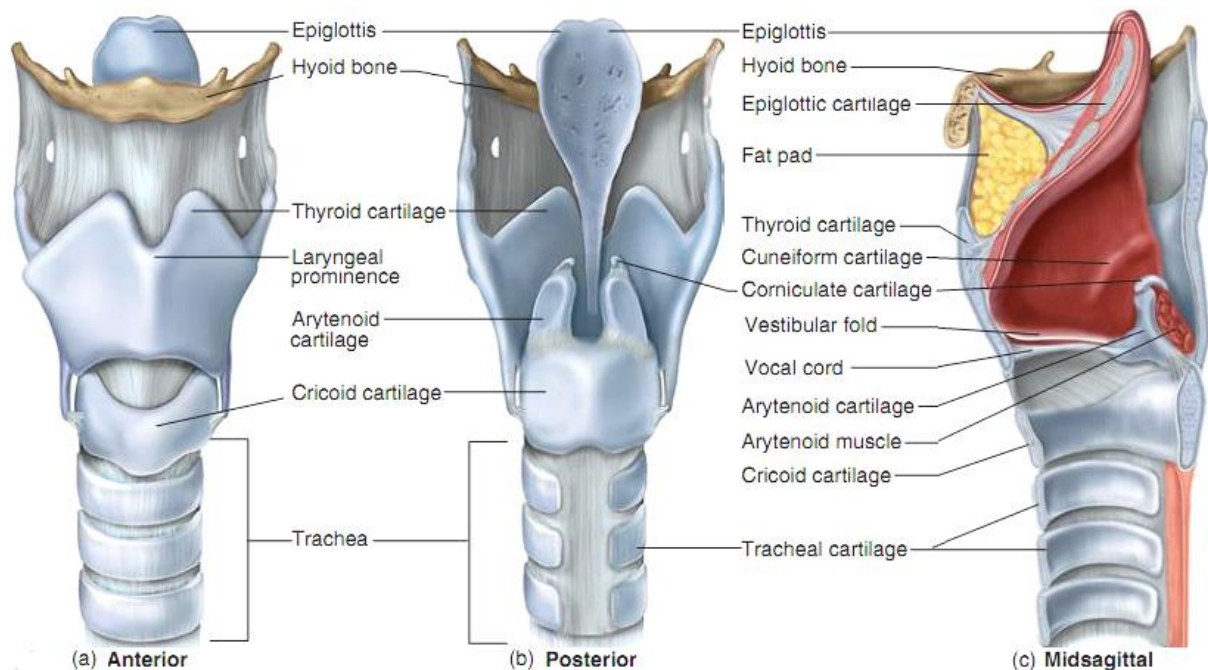


Fig. 61. The anatomy of larynx

There is a vocal apparatus in the larynx. It consists of vocal cords and glottis. The vocal cords are stretched from the arytenoid cartilages to the thyroid cartilage. The hole between the vocal cords is called a glottis. Voice occurs as a result of vibrations of the vocal cords during expiration.

At the level VI–VII cervical vertebrae, the larynx proceeds into the **trachea** — a tube which consists of 16–20 cartilaginous semirings. Its length is approximately 10–13 centimeters.

The end of the trachea divides into **two bronchi** which consist of cartilaginous rings. The bronchi enter the right and left lungs. In the lungs, the bronchi branch out to form the bronchial tree. These smallest bronchi branch into **bronchioles**. The walls of the bronchioles have smooth muscle cells. At the ends of the bronchioles are the **alveoli**. Alveolar diameter is 0.2–0.3 mm. Their walls consist of a single layer of epithelial cells. Lungs contain 300–400 million alveoli. In the alveoli gas exchange occurs — they are surrounded with blood capillaries.

**Lungs** (fig. 62) are in the thoracic cavity. Each lung has *apex* and *base*. Bronchi, blood vessels and nerves enter the lungs through the roots of lungs on the medial surface. Lungs consist of *lobes*: the right lung has three lobes, the left one — 2 lobes.

A serous membrane *pleura* covers the lungs. The pleura consists of two layers: the external (parietal), which lines the chest, and internal (visceral) covering the lungs. Between the layers is a pleural cavity filled with pleural fluid.

Inhaled air with O<sub>2</sub> enters the alveoli. Gas exchange occurs according to the diffusion law. Gases go from the region of higher partial pressure to the region of lower partial pressure. Oxygen from the alveoli enters the blood and bind with the protein hemoglobin while carbon dioxide come out of blood to the alveoli and then removed from the body with exhaled air through the bronchioles, bronchi, trachea, larynx, pharynx and nasal cavity. During the gas exchange taking place in the lungs blood becomes arterial (oxygenated).

Arterial blood leaves lungs and through the pulmonary veins enters left atrium of the heart. It is then pumped into the left ventricle and then into the aorta. Through the arteries of the systemic circulation, blood goes to the internal organs and tissues. Gas exchange occurs between arterial blood and cells of internal organs: oxygen goes from the blood to the cells while carbon dioxide goes from the cells to the blood and bind with hemoglobin to form carbhemoglobin (carbaminohemoglobin). Blood becomes venous (deoxygenated).

Venous blood is collected into upper and lower cava veins from the veins of the systemic circulation and then flows into the right atrium, right ventricle. The ventricle pumps the blood into the pulmonary trunk, pulmonary arteries and alveolar capillaries of the lungs.

Gas exchange in the lungs is possible due to breathing movements — inhalation and exhalation. An adult makes 16–18 breaths per minute. Intercostal muscles, chest muscles and diaphragm are involved in the respiratory movements.

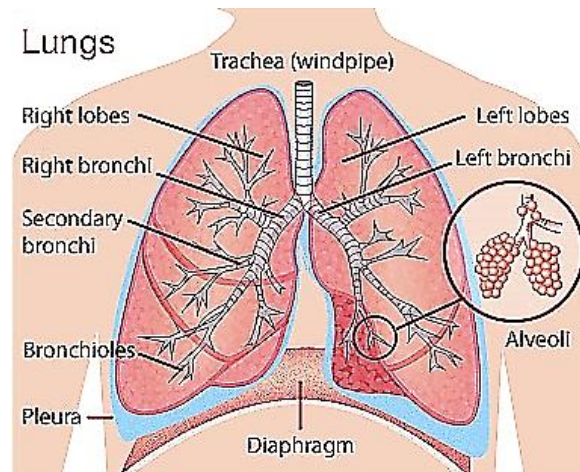


Fig. 62. The anatomy of lungs

*During the inhalation*, contraction of external intercostal muscles and diaphragm occurs. Intercostal muscles elevate the ribs to increase the volume of the chest and thus the volume of the lungs. The pressure in the lungs becomes lower than the atmospheric pressure. This makes the air go to the lungs through the airways. *During exhalation* external intercostal muscles and diaphragm relax. The ribs are omitted and the volume of the thorax and lungs decreases. This increases the pressure in alveoli and makes the air leave the lungs.

The medulla oblongata provides the *nervous regulation* of respiration (the respiratory center is situated there). Inhalation reflexly causes exhalation and vice versa. *Humoral regulation* of respiration is associated with the concentration of carbon dioxide in the blood. Increasing the concentration of carbon dioxide increases the excitability of the respiratory center and causes rapid breathing.

The main function of the respiratory system is a gas exchange between the organism and environment.

## 9. DIGESTIVE SYSTEM

**Digestive system** is the system which breaks down food mechanically and chemically, performs further absorption of useful substances and removal of undigested material. The chemical processing of food occurs under the action of enzymes made by digestive glands. Mechanical processing is performed by teeth and muscles of the digestive tract.

The digestive system consists of digestive tract (alimentary canal) and digestive glands (fig. 63).

The regions of the alimentary tract are *mouth, oral cavity, pharynx, esophagus, stomach, small intestine* and the *large intestine* which ends with *anus*. The digestive glands are salivary gland, pancreas, liver, glands of the stomach and intestine.

**The oral cavity** is bordered by lips, cheeks, palate, tongue and muscles of the mouth bottom. There are teeth on the upper and lower jaws. Adult humans have 32 teeth: 8 *incisors*, 4 *canines*, 8 *premolars* and 12 *molars* (fig. 64). A **tooth** consists of 3 regions: *crown, neck* and *root*. Teeth are laid down during embryonic development, but commonly absent in newborns. First baby teeth (or milk teeth) usually appear in 5–6 month after the birth. From the age of 6 years, they start to replace by permanent (secondary) teeth.

There is a cavity inside of the tooth. Its content is called a *pulp*. Pulp consists of loose fibrous connective tissue, blood vessels and nerves. Other parts of the tooth consist of *dentin*, which is covered by *enamel* on the crown. On the neck and root, dentin is covered with *cementum*. The shape of teeth of different types corresponds to their role in food mastication.

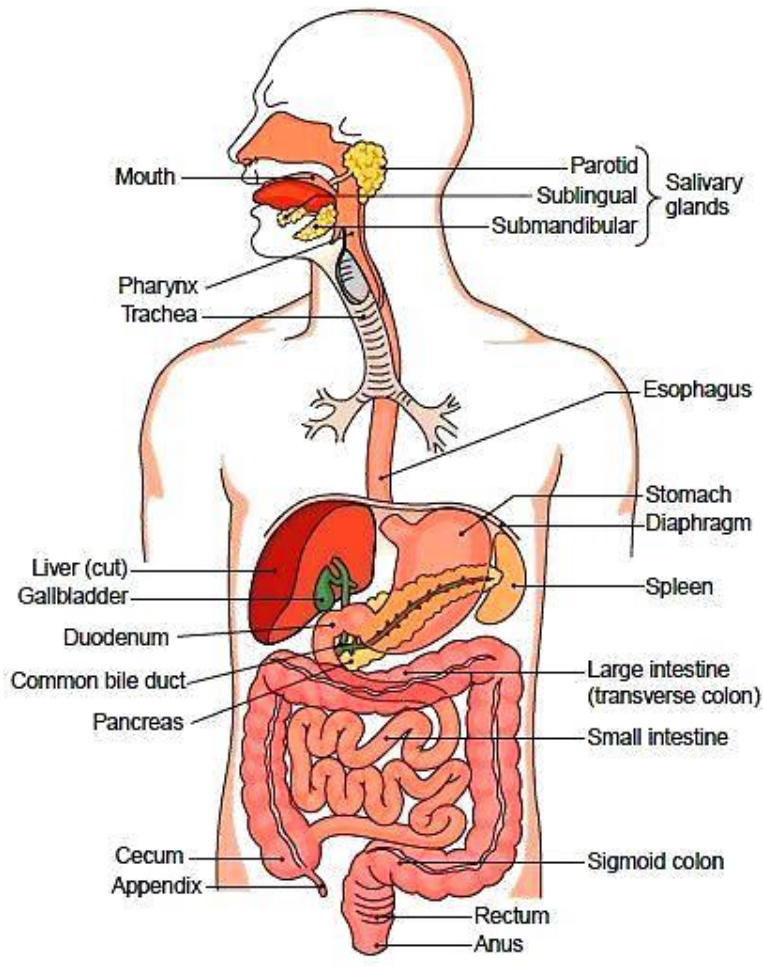


Fig. 63. The anatomy of the digestive system

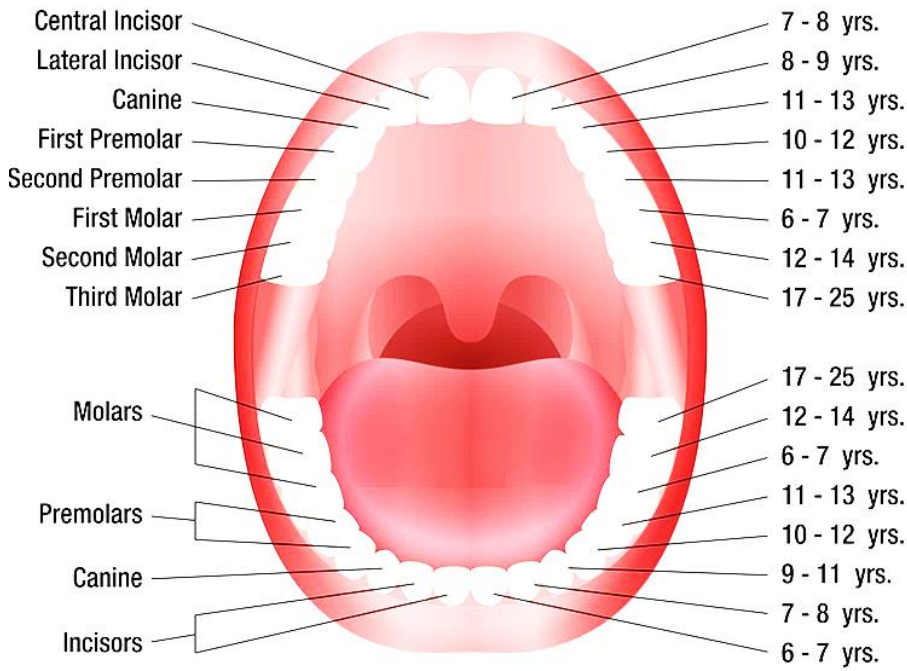


Fig. 64. Human teeth

In the oral cavity is **tongue** — a muscular organ covered with a mucous membrane. The tongue regions are *root*, *body* and *apex*. The mucosa of the tongue has taste buds — groups of cells including taste receptors. Humans can feel five tastes: sweetness, sourness, bitterness, saltiness and umami (the taste of glutamic acid). The tongue manipulates food in the mouth, determines the taste and the food temperature, participates in the swallowing and formation of speech.

There are four pairs of salivary glands: *parotid*, *submandibular* and *sublingual*, *tubarial* (the last one was discovered in 2020). Their ducts open in the oral cavity. They secrete saliva which moistens food and contains digestive enzymes.

Functions of the oral cavity are:

- breaking food into small particles by mastication, mixing it with saliva;
- beginning chemical processing;
- determining the taste of food;
- formation of bolus (ball-like mixture of food and saliva) and swallowing.

*Ingestion (swallowing)* is a reflex act which propels bolus to the esophagus. During swallowing, muscles of the pharynx contract, the epiglottis closes the entrance to the larynx and food bolus moves into the esophagus. The center of swallowing is situated in the medulla oblongata.

**Esophagus** is a muscular tube that links the pharynx with the stomach. Its length is about 25 centimeters. Contraction of esophageal muscles pushes bolus into the stomach.

**Stomach** (fig. 65) is a muscular organ located in the upper left quadrant of the abdomen below the diaphragm. Its volume is 1.5–2 liters. The regions of the stomach are *fundus*, *cardia*, *body*, and *pylorus*.

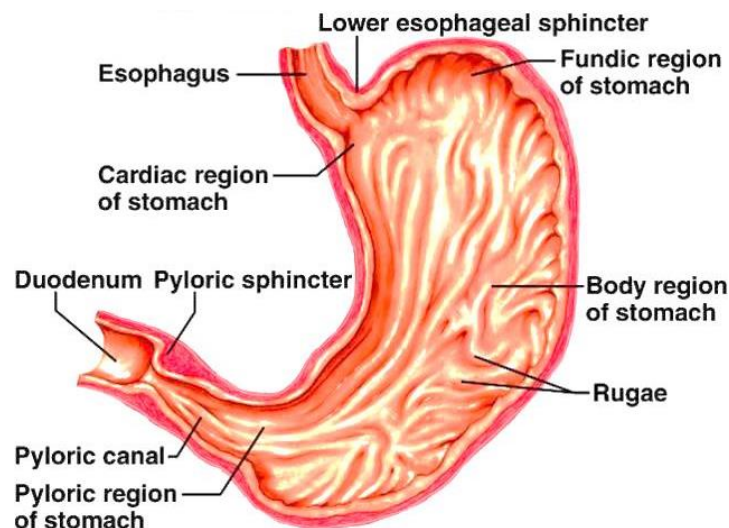


Fig. 65. Longitudinal cross-section of stomach

The curved left and right sides of the stomach are called the *lesser* and *greater curvatures*.

The wall of the stomach consists of three layers: connective tissue (outer), muscle tissue (middle), epithelial tissue (inner).

The gastric mucosa (inner layer) forms folds (rugae). The muscles of the stomach wall are composed of three layers: longitudinal, circular and oblique.

There are glands producing *gastric juice* in the gastric mucosa:

- *chief cells* secrete enzymes *pepsin* and *chymosin*;
- *parietal cells* secrete *hydrochloric acid*;
- the cells of the *mucous neck* secrete *mucus*.

**Small intestine** (fig. 66) consists of 3 regions: *duodenum*, *jejunum* and *ileum*. Its total length is 5–7 meters. The length of the duodenum is 25–30 centimeters. Ducts of two digestive glands — pancreas and liver — open into the duodenum to release their secretion.

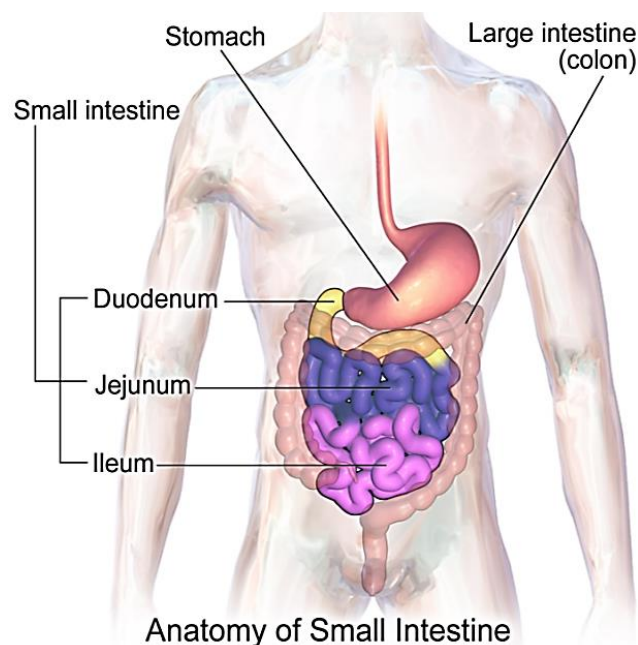


Fig. 66. Regions of the small intestine

The wall of the small intestine has three layers: mucosa, muscular and serous layers. To increase the surface of the intestinal wall, mucosa forms about 30 million small finger-like projections called *villi*.

Each villus contains blood and lymph vessels and is covered with a simple epithelium. Its function is absorption of nutrients.

The mucosa contains glands that secrete *intestinal juice*. Smooth muscles of the intestinal wall have two layers: the inner (circular) and external (longitudinal). Their contraction propels food through the intestine.

**Liver** (fig. 67) is the largest gland in the body — its weight is about 1.5–2 kg. It is located in the upper right quadrant of the abdominal cavity below the diaphragm. The liver consists of four lobes.

A *porta hepatis* (Latin «liver gate») is located on the bottom of the liver in the center. Vessels, nerves and bile ducts enter the liver here.

**Gallbladder** (biliary vesicle, cholecyst) is a pear-shaped sac attached to the lower surface of the liver. Its function is to store bile. Its volume is 40–70 ml.

Bile is a yellowish-green fluid produced by liver cells. Main components of bile are water, bile salts, bile pigments, and cholesterol.

Bile salts act as emulsifying agents in the digestion and absorption of fats. The liver of an adult produces approximately 500–1200 ml of bile per day.

Bile is produced continuously and stored in the gallbladder.

On eating, it is released to the small intestine through the bile duct and enters the duodenum.

Functions of the liver are:

- protective (barrier) — cleaning the blood of toxic substances;
- production of bile;
- synthesis of blood proteins;
- storage of glycogen;
- participation in metabolism of proteins, fats and carbohydrates.

**Pancreas** is the digestive gland which produces pancreatic juice. It is situated in the abdominal cavity behind stomach. Its length is 12–15 cm (fig. 68).

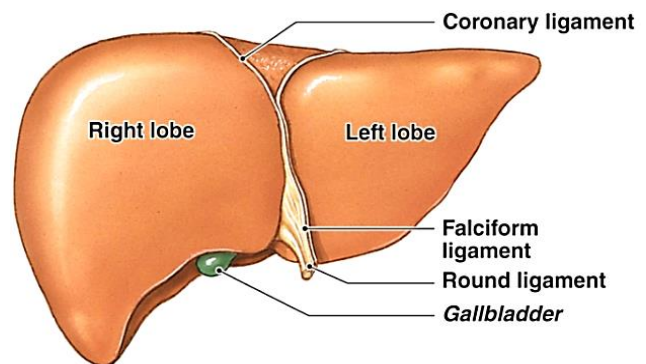


Fig. 67. Liver

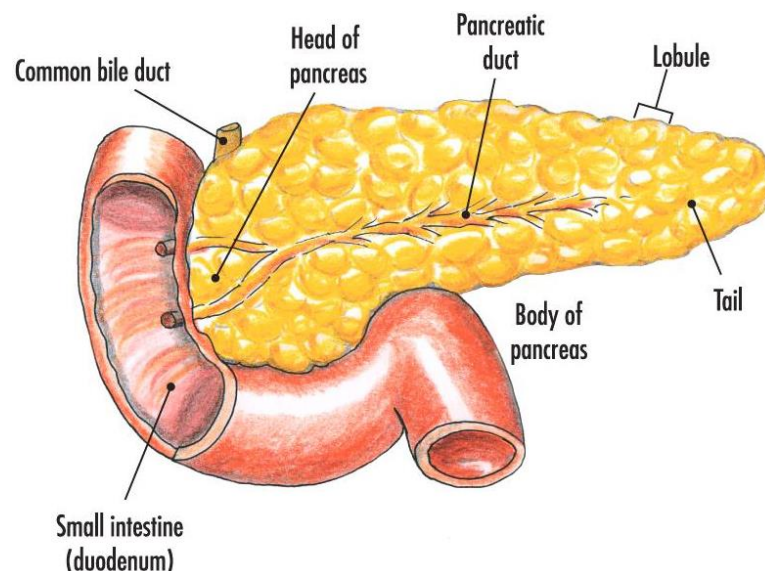


Fig. 68. The anatomy of pancreas

The pancreas consists of a head, body, and tail. *Pancreatic juice* produced by pancreatic cells contains digestive enzymes. It is released into the duodenum while eating.

**Large intestine** is the terminal region of the intestine. The length of the large intestine is 1.5–2 m, diameter of 4–8 cm. Its regions are *cecum*, *ascending colon*, *transverse colon*, *descending colon*, *sigmoid colon*, *rectum* and *anal canal* (fig. 69). Muscular layer of the large intestine is bigger than that of the small intestine. There cecum has a small outgrowth which is called *appendix*. The mucosa of the large intestine has a large number of goblet cells (they produce mucus) but does not have any villi.

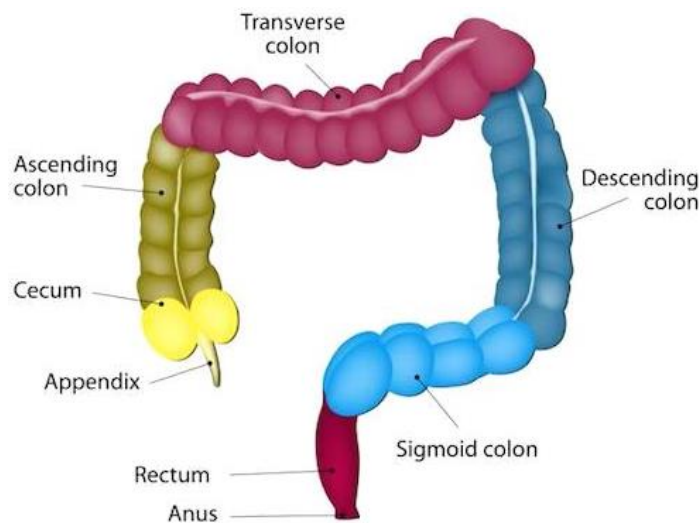


Fig. 69. Regions of the large intestine

*Functions of the large intestine* are the absorption of water and electrolytes and the elimination of feces from the organism.

## 10. DIGESTIVE ENZYMES. SECRETIONS OF DIGESTIVE GLANDS

Enzymes are proteins-catalysts: they speed up (*catalyze*) chemical reactions. Digestive enzymes catalyze reactions of food breakdown in the digestive tract. Digestive enzymes are produced by the salivary glands, stomach, pancreas, and intestine.

### **Properties of digestive enzymes:**

1. *Specificity*. Each enzyme breaks down certain nutrients (fig. 70).
  - *Proteases* such as pepsin, chymosin, trypsin, chymotrypsin, enterokinase, aminopeptidase, carboxypeptidase can break down only proteins.
  - *Lipases* are enzymes that break down lipids.
  - *Glycosidases* such as amylase, maltase and, lactase break down carbohydrates.
  - *Nucleases* breakdown nucleic acids.

2. *Sensitivity to chemical environments.* Many amino acids of proteins have positively and negatively charged chemical groups. Changes in H<sup>+</sup> and OH<sup>-</sup> balance may neutralize that charge which can be necessary for protein's functioning. An enzyme of gastric juice pepsin is active only in acidic environments. Intestinal enzymes require alkaline environments.

3. *Sensitivity to temperature.* If temperature changes, enzymes become less active. Increase in temperature may cause denaturation of proteins. This means that proteins lose their normal tridimensional structure necessary for their functioning.

4. *High reactivity.* A small amount of enzymes can break large amounts of compound.

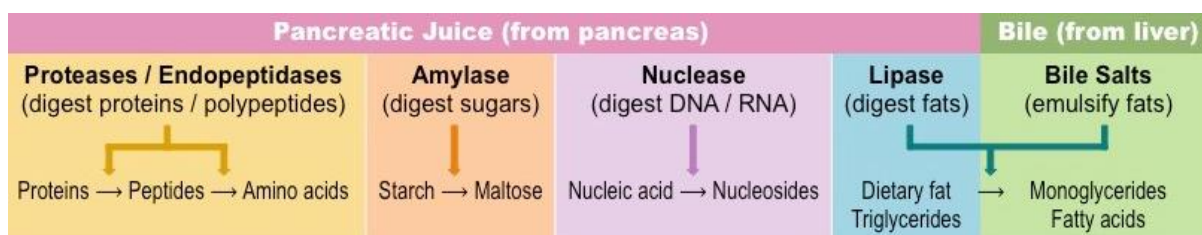


Fig. 70. Groups of digestive enzymes and their effects

**Digestion begins in the mouth.** Saliva, the liquid secretion of salivary glands consists of water (99 %) minerals and organic substances. The volume of saliva produced by an adult depends on the food and is 500–1500 ml per day.

*Salivary enzymes are:*

- ptyalin (amylase);
- maltase.

These enzymes break starch into monosaccharaides (ptyalin into maltose and maltase into glucose). Salivary enzymes require weakly alkaline environment. Apart from digestive enzymes, saliva contains the bactericidal enzyme lysozyme.

**In the stomach,** digestion occurs under the action of gastric juice. This juice contains hydrochloric acid (HCl) and *enzymes:*

- pepsin that breaks down complex proteins into simpler peptides;
- chymosin that curdles milk proteins;
- lipase that acts on the emulsified fats (milk).

These enzymes are active only in the acidic environment. Digestion in the stomach lasts approximately 5–6 hours.

Gastric secretion is controlled by *neural and humoral regulation.* Humoral regulation of gastric juice is provided by hormone gastrin, which is released into the blood by the gastric mucosa. The center regulating digestion is situated in the medulla oblongata.

Substances that are absorbed in the stomach are glucose, water, dissolved salts, and some medicine.

Further digestion of nutrients occurs in the small intestine.

**Pancreatic juice** and bile are secreted into the duodenum. Pancreatic juice is alkaline. It contains *enzymes*:

- trypsin and chymotrypsin that break down proteins into smaller peptides;
- lipase that breaks down fats into glycerol and fatty acids;
- amylase and maltase that break starch;
- nucleases break down nucleic acid into nucleotides.

**Bile** does not contain enzymes. Functions of bile:

- emulsifies fats — breaks them up into small drops;
- activates intestinal enzymes;
- facilitates the absorption of fats and fat-soluble vitamins;
- stimulates the contraction of the smooth muscle of the intestinal wall;
- kills microorganisms.

**Intestinal juice** is secreted by the glands of mucosa of the small intestine. It is alkaline. The volume of the juice released per day is about 2 liters.

Intestinal juice *contains 22 enzymes*:

- proteases such as aminopeptidase, carboxypeptidase break down proteins into amino acids; enterokinase activates trypsin;
- glycosidases such as amylase, maltase, lactase break down carbohydrates;
- lipases break down fats;
- nucleases digest nucleic acids.

In this region of the intestine digestion is finished.

Various substances are absorbed in the small intestine. Glucose and amino acids are absorbed *into the blood vessels of villi*. Glycerol and fatty acid are absorbed by villi, transformed into fats and then *enter the lymphatic vessels*. Absorption continues in the **large intestine**. Water, mineral salts and some toxins are absorbed there. Toxic substances are detoxified in the liver. There are numerous bacteria in the large intestine. They break down some compounds and synthesize vitamins (such as B<sub>1</sub>, B<sub>9</sub>, B<sub>12</sub>, K). The large intestine forms stool that is excreted through the anus.

## 11. EXCRETORY SYSTEM. INTEGUMENTARY SYSTEM

The prior function of the excretory system is maintaining normal volume and composition of body fluids. To perform it, body excretes waste products such as ammonia, uric acid, urea, water, various salts. This is done mostly by the urinary system. Apart from the urinary system, excretion of metabolic wastes is performed by skin, respiratory and digestive systems.

**The organs of the urinary system** are two kidneys, two ureters, urinary bladder and urethra (fig. 71).

**Kidneys** are the organs that filter blood, remove the wastes and excrete them with urine. They are the primary organs of the urinary system.

Kidneys are located one on each side of the vertebral column. Each kidney of an adult has length about 10 cm and weight of 150 grams. It is roughly bean-shaped with an indentation called hilum on the medial side. A ureter, renal arteries and veins, nerves, lymphatic vessels enter the kidney in this region. Each kidney is covered with a capsule of connective tissue.

The outer reddish region next to the capsule is the renal cortex. It surrounds a darker reddish-brown region called the renal medulla. There are renal corpuscles of nephrons in the renal cortex and tubules of the nephron in the renal medulla (fig. 72).

The renal medulla consists of 15–20 renal pyramids, which look striated because they contain straight tubular structures and blood vessels. Pyramids open into the renal pelvis — the central region of the kidney.

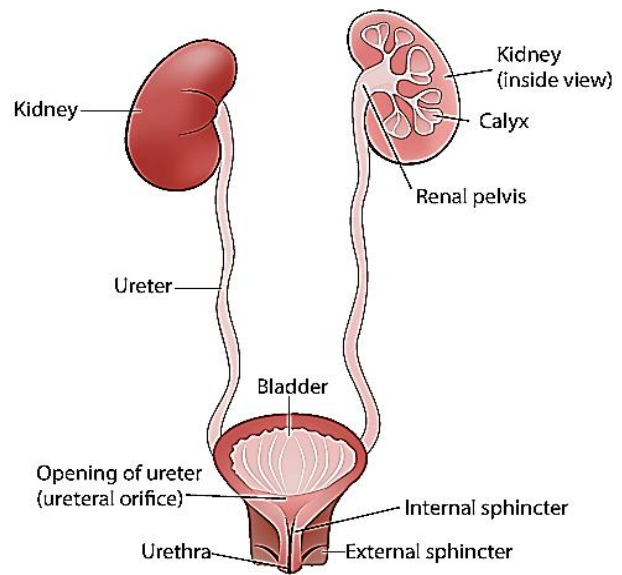


Fig. 71. Female urinary system

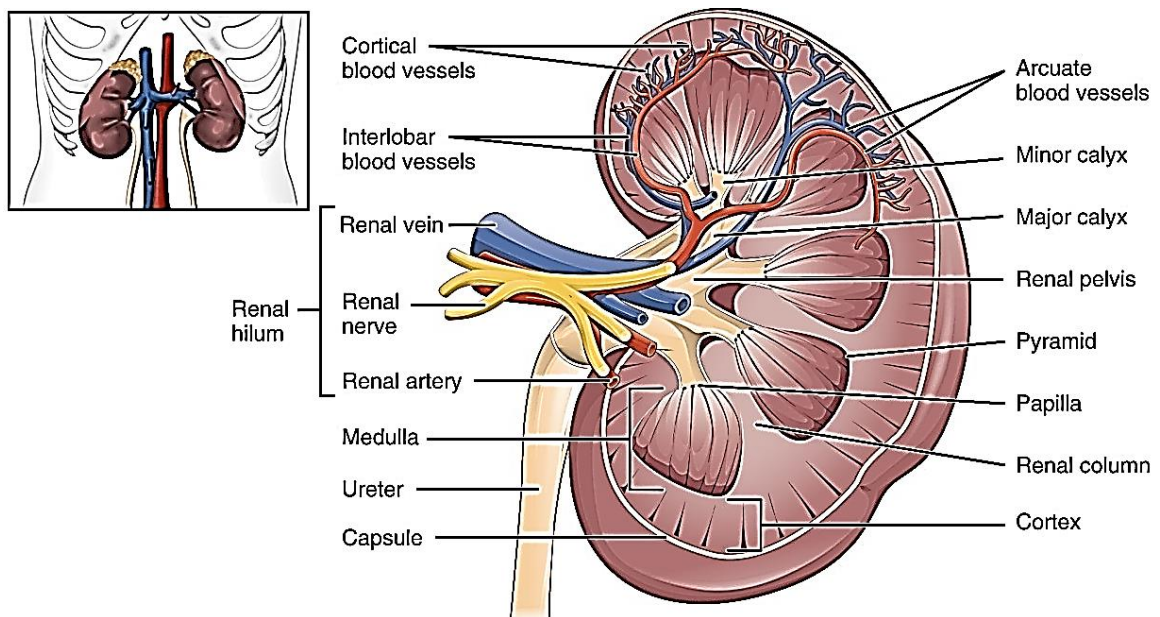


Fig. 72. The anatomy of kidney

The structural and functional unit of the kidney is a *nephron* (fig. 73).

Each kidney contains over a million nephrons. The nephron consists of two parts: a renal corpuscle and a renal tubule. The tubule consists of one layer of epithelial cells. The renal corpuscle consists of a cluster of capillaries, called the *glomerulus*, surrounded by a double-layered epithelial cup, called

the *Bowman's capsule*. The capsule is situated in the renal cortex. The proximal convoluted tubule comes from the capsule and goes to the renal medulla. In the medulla, it forms a loop of Henle (the middle part of the tubule). The loop turns to the renal cortex, and there forms a distal convoluted tubule which runs into collecting ducts. The collecting ducts are open into a renal pelvis.

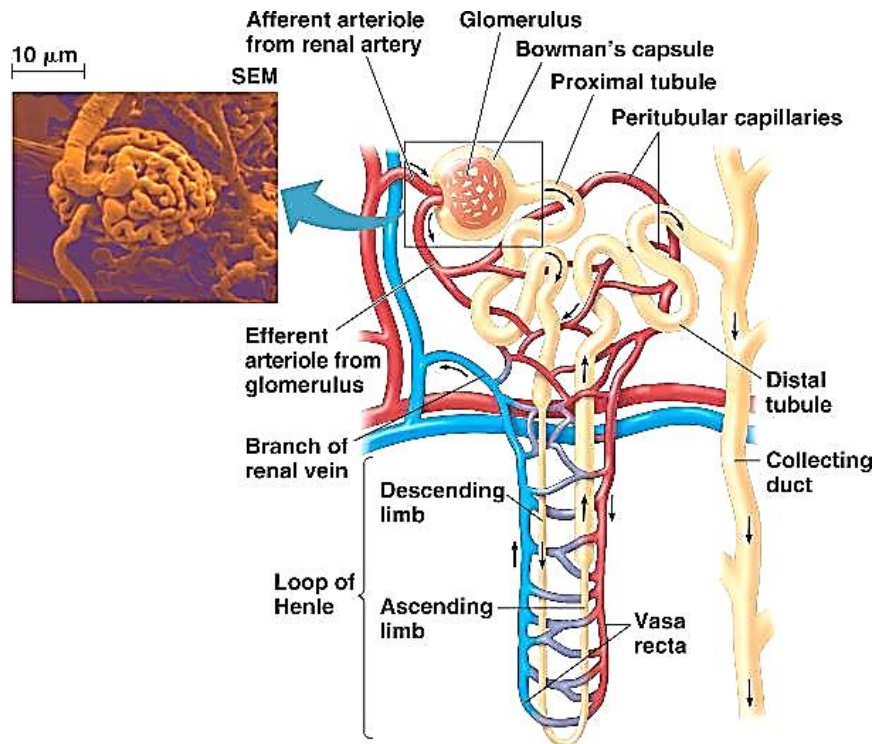


Fig. 73. The structure of nephron

Urine containing metabolites is produced by the kidneys. Its formation occurs at 2 stages and is based on 3 processes:

**1. Filtration** (formation of primary urine) occurs in the capsule of the nephron. Primary urine is formed during filtration of blood plasma of blood capillaries in the capsule. Approximately 150–180 liters of primary urine is formed in the organism per day. Composition of the primary urine is similar to blood plasma, but has no proteins. Primary urine contains waste products and many substances essential for the body (glucose, amino acids, and mineral salts).

**2. Reabsorption** (formation of secondary urine) occurs in the tubules of the nephron. From the capsule of the nephron, primary urine flows into convoluted tubule where reabsorption of water, glucose, amino acids, ions, sodium, and potassium into the blood occurs. Due to reabsorption, the volume of secondary urine produced every day is about 1.5 liters. Secondary urine contains water, urea (main nitrogen-containing product of urine), ammonia, uric acid, ions of sodium, potassium, calcium, magnesium.

**3. Tubular secretion** is the transport of waste substances from capillaries to the renal tubules. The direction of this transport is opposite to reabsorption.

Urine formation is regulated by the nervous system and hormones. Micturition center is located in the spinal cord.

**Ureters** are small tubes that carry urine from the renal pelvises to the urinary bladder. Their length is about 25 cm.

**Urinary bladder** is a hollow muscular sac collecting urine. Its volume is about 700–750 ml.

**Urethra** is a thin-walled tube through which urine is excreted from the urinary bladder to the outside.

**Functions of kidneys:**

- maintaining the volume of body fluids;
- maintaining homeostasis;
- participating in control of the acid-alkaline balance;
- regulating the blood pressure;
- regulating the metabolism of carbohydrates and proteins;
- secretion of biologically active substances (angiotensin, erythropoietin, prostaglandins, renin).

**Skin** is the integument of the human body. The area of the skin of an adult is 1.5–1.6 m<sup>2</sup>. **Skin consists of three layers** (fig. 74):

1. **Epidermis** is the outermost layer of the skin composed of squamous cells. This layer can be of two distinct types: thick skin (palms, feet) and thin skin (most of the body).

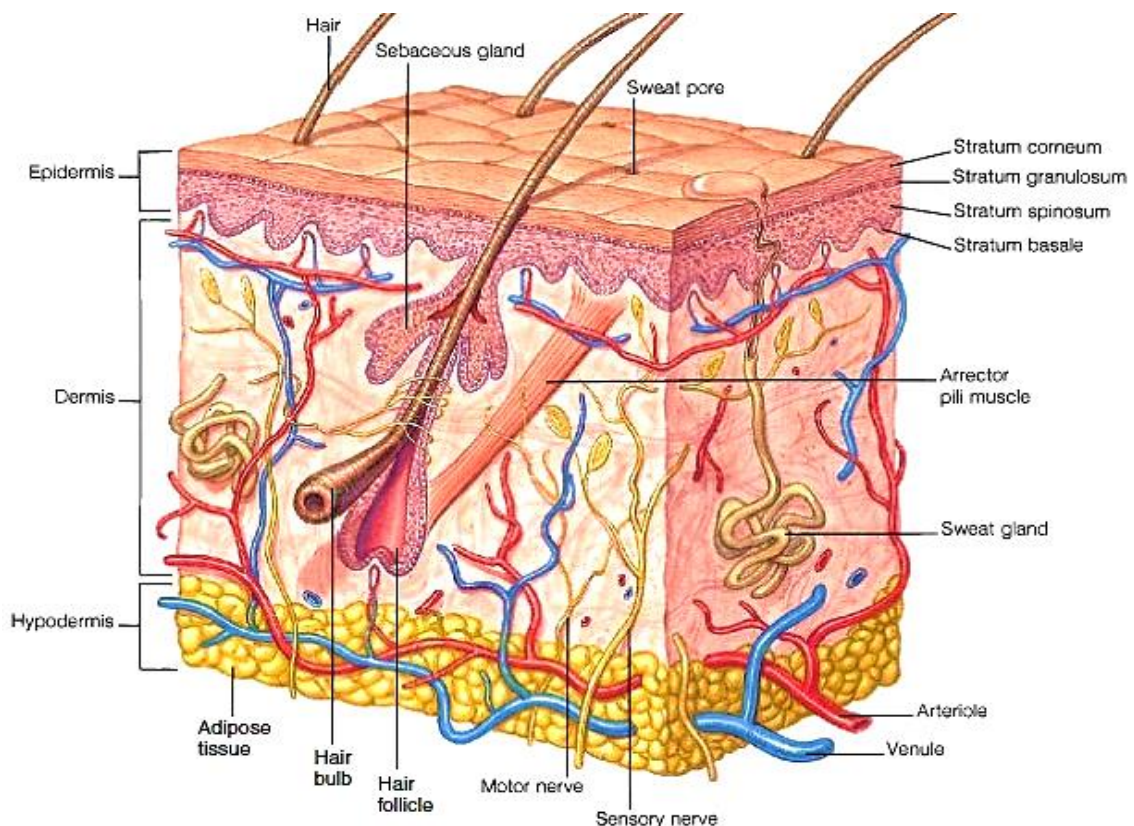


Fig. 74. The structure of the skin

2. *Dermis* is the second and the thickest layer of skin that is located deeper than the epidermis.

3. *Hypodermis* (subcutaneous tissue) lowermost layer of the body integument that helps to insulate the body and cushion internal organs.

Other components of the skin are hair, nails, sweat glands, oil glands, blood vessels, lymph vessels, nerves and muscles.

**Epidermis** is epithelial tissue. Its thickness is 0.07–2.5 mm. There are 5 layers in the epidermis. The outer layer is *stratum corneum* (consists of keratinocytes), the lowermost one is the *stratum basale* (consists of basal cells and melanocytes). The stratum corneum consists of dead cells. Basal layer consists of living cells. These cells constantly divide to produce new cells that are pushed upward to form the layers above. Basal cells ultimately transform into new keratinocytes, which replace the older ones that die and are shed off. Within the basal layer are melanin-producing cells known as melanocytes. Melanin is a pigment that helps to protect the skin from harmful ultraviolet solar radiation. The epidermis has sensory nerve terminals (receptors). Nails, hair and the glands of skin are derivatives of epidermis.

**Dermis** is the thickest layer of skin (0.5 to 5 mm). It consists of papillary and reticular layers. The papillary layer consists of loose fibrous connective tissue and forms protrusions into the epidermis. It contains blood and lymph vessels, receptors, fibers providing strength and elasticity to the skin. Under the papillary layer is the reticular layer. It contains sebaceous and sweat glands, hair follicles.

*Sweat glands* regulate body temperature by transporting water to the surface of skin where it evaporates to cool down the skin. Such gland consists of a body and excretory duct. The human organism has 2–3 million sweat glands. A lot of them are on the face and hands. Sweat glands secrete sweat. Sweat contains H<sub>2</sub>O, ammonia, urea, mineral salts.

*Sebaceous (oil) glands* secrete oil (sebum) that helps to waterproof the skin and protects it against microbes. They are attached to hair follicles.

*Hairs* are derivatives of skin. A hair consists of a hair bulb, root and stem. Hair follicles are tube-shaped cavities that enclose the hair root and provide nourishment to the hair. Vessels and nerves enter the hair follicle. Muscles attached to the hair follicle raise the hair.

**The hypodermis** is composed of fat and loose connective tissues; this layer of skin insulates the body and protects internal organs from injury.

***Functions of skin:***

- protection of the organism from the harmful mechanical, chemical, microbiological external factors;
- thermoregulation;
- metabolic (involved in metabolism of vitamin D, urea, water and salt balance);
- it is the organ responsible for the sense of touch (due to tactile, thermal and pain receptors).

## 12. NERVOUS SYSTEM. SPINAL CORD

**Nervous system** regulates the body's responses to internal and external stimuli. Functions of the nervous system are:

- regulates the functioning of all organs and systems;
- connects the body with the environment;
- unites parts of the body into a single unit;
- it is the center of all mental activity including thought, learning, and memory.

The nervous system consists of nerve tissue. Nerve tissue is composed of *neurons and neuroglia*. Neuron (fig. 75) is a nerve cell.

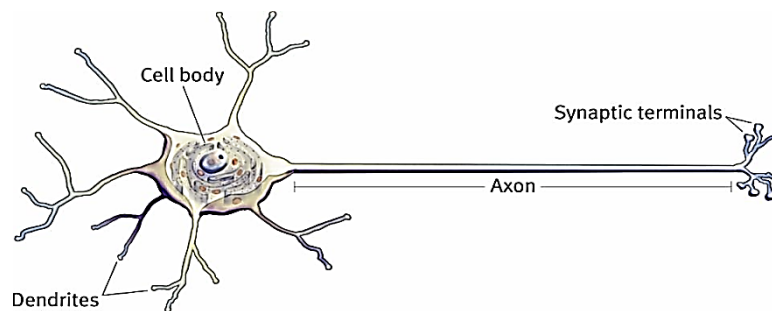


Fig. 75. Neuron

It has processes that project from the cell body — dendrites and axon. Dendrites are usually (but not always), short and branching. This increases their area to receive signals from other neurons. Dendrites are afferent processes because they transmit impulses to the cell body. The number of dendrites of the neuron varies. There is only one axon that projects from each cell body. It is usually elongated and it is called an efferent process because it carries impulses away from the cell body.

Anatomically, the nervous system is divided into *the central (CNS) and peripheral (PNS) nervous system*. The central nervous system includes the brain and spinal cord (fig. 76). The peripheral nervous system consists of ganglions, nerves and nerve endings. Ganglion is a group of neurons that are outside the central nervous system. In the organs and tissues, nerves form receptors (nerve endings).

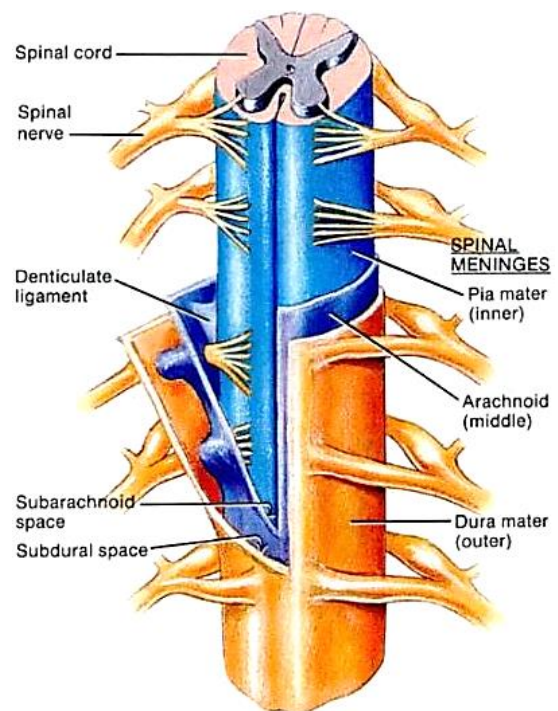


Fig. 76. The anatomy of the spinal cord

By the *physiological action*, the nervous system *is divided into somatic and autonomic (vegetative) NS*. The autonomic nervous system regulates the function of internal organs: heart, blood vessels, stomach, liver, lungs and kidneys. It can be sympathetic and parasympathetic. The somatic nervous system innervates skeletal muscle, skin, and organs of sense.

**Spinal cord** is situated in the vertebral canal. The cord is covered with three membranes (meninges): external (dura), medium (arachnoid) and internal (pia). The space between the arachnoid and pia is filled with cerebrospinal fluid. There are longitudinal grooves on the anterior and posterior surfaces of the spinal cord. They border the right and left halves of the spinal cord. The length of the spinal cord is 41–45 cm, its diameter is approximately 1 cm. In the cross section, the spinal cord appears oval in shape and has two layers (fig. 77).

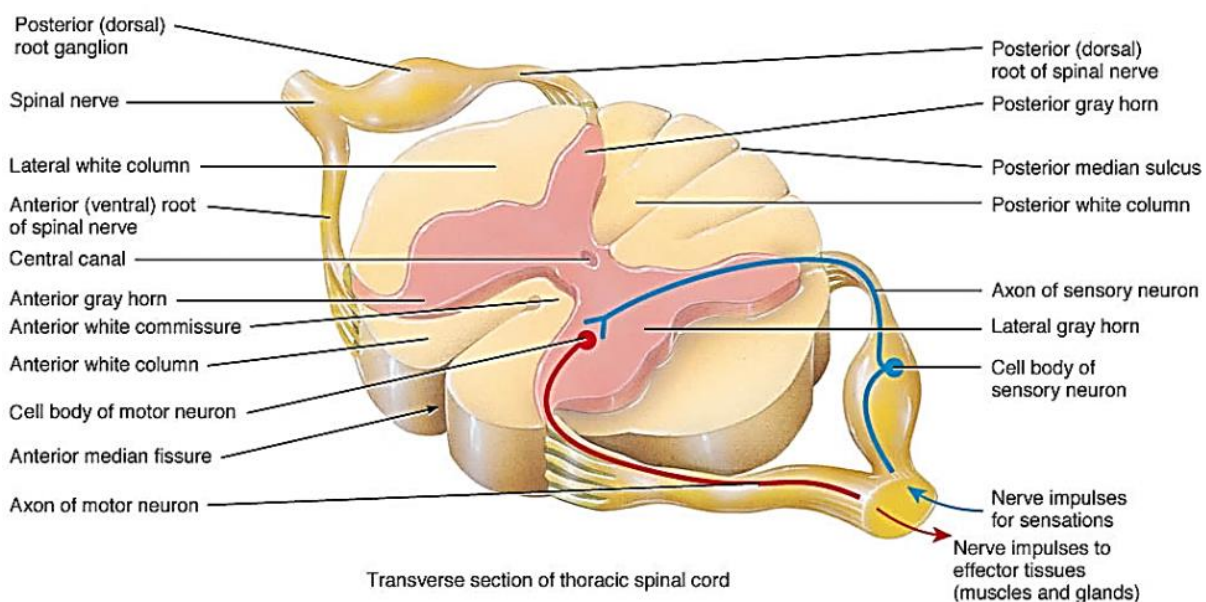


Fig. 77. Transverse section of the thoracic region of the spinal cord

Body and dendrites of neurons are located in the brain and spinal cord, ganglions and form gray matter. Axons of neurons form the white matter of the brain and spinal cord and nerves.

*Gray matter* is situated in the center. It has the shape of a butterfly. In its center there is the *central canal* of the spinal cord, which contains cerebrospinal fluid. Gray matter has *anterior and posterior horns* and in the thoracic region, in addition, *lateral horns*.

Axons of sensory neurons (the visible fibers they form are posterior roots) enter posterior horns and transmit excitation into the spinal cord. *The bodies of sensory neurons* are in the spinal ganglions (fig. 78).

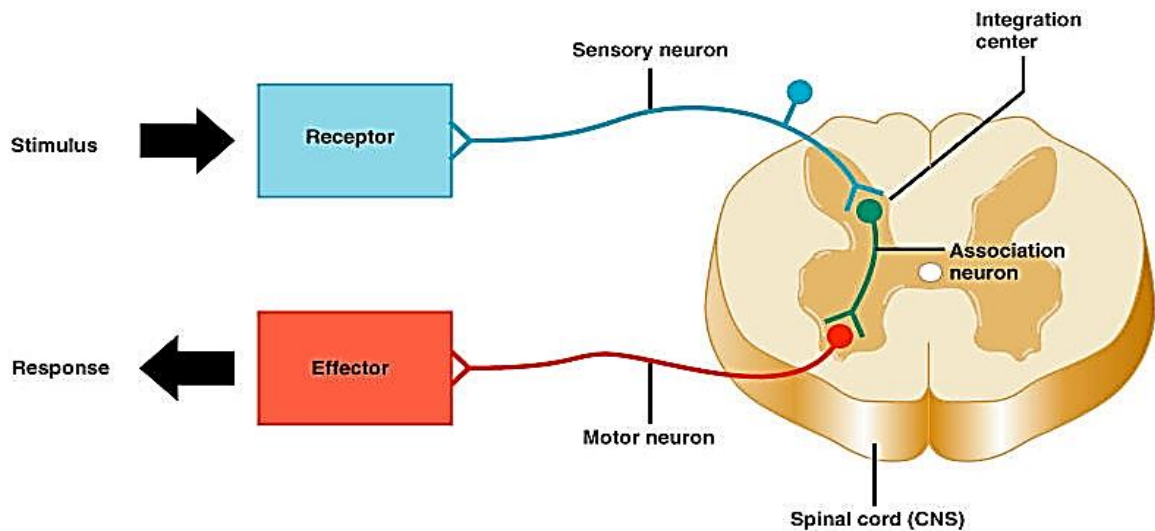


Fig. 78. Reflex arc

There are bodies of *intercalary (association) neurons* in the posterior horns that trigger excitation to motor neurons. *The bodies of the motor neurons* are located in the anterior horns. Long processes (axons) leave them to form the anterior (motor) roots. Excitation is transferred to the working organ through these roots.

The second layer of the spinal cord is made of *white matter*, which is disposed around the gray matter. It is formed by the axons of neurons. The nerve fibers of the white matter form spinal tracts. They connect the spinal cord to the brain. There are ascending (sensory) spinal tracts and descending (motor) tracts. The ascending tract transfers excitation to the brain, the descending — from the brain to the organs.

The spinal cord has *31 pairs of spinal nerves*.

Each nerve has anterior and posterior roots. Posterior (dorsal) roots composed of processes of afferent (sensory) neurons. Ventral (anterior) roots contain processes of efferent (motor) neurons. The anterior and posterior roots form a *mixed spinal nerve*. Spinal nerves pass from the vertebral canal through the intervertebral foramina. The spinal cord has two thickening (cervical and lumbar), in the regions where the spinal nerves of upper and lower extremities arise.

*Functions of the spinal cord:*

- conductive. The spinal cord conducts impulses from the receptors to the brain (by sensitive tracts) and from the brain to all parts of the body (by motor tracts);

- reflex. The spinal cord has centers of sweating, pupil dilatation, diaphragm contractions, micturition, elimination of feces from the intestine and sexual function.

The spinal cord is controlled by the brain.

### 13. THE BRAIN

**The brain** is situated in the neurocranium of the skull. The average volume of the brain is 1350 cubic centimeters. Twelve pairs of cranial (cerebral) nerves come out of the brain. The brain consists of five regions: *telencephalon*,



Fig. 79. Regions of the brain

*diencephalon* (together they are forebrain), *mesencephalon* (midbrain), *metencephalon* and *medulla oblongata* (together they are hindbrain) (fig. 79). Like the spinal cord, the brain is covered with three membranes: *dura mater* (consists of connective tissue and has a protective function), *arachnoid* (contains nerves and blood vessels), *pia mater* (rich in blood vessels). There is cerebrospinal fluid between the arachnoid and pia.

**Medulla oblongata** (myelencephalon) connects the brain and spinal cord. It is made of white matter with immersed nuclei of gray matter. The fourth cerebral ventricle (cavity with cerebrospinal fluid) is situated there.

Functions of the medulla oblongata are:

- Conduction of impulses from the spinal cord into the overlying parts of the brain and back;
- The medulla contains centers of the vital functions such as breathing, heartbeat, tone of vessels, protective reflexes (cough, sneeze, blink, vomiting) and digestive reflexes (sucking, salivary secretion, secretion of gastric juice, etc.).

**Metencephalon** includes the *pons* and *cerebellum*.

The *cerebellum* is situated above the medulla oblongata. It consists of two hemispheres, which are connected by the *vermis* (Latin for «worm»). The hemispheres are covered with *cortex* which consists of gray matter and has *sulci* (grooves). The *pons* controls eye movement, muscle contraction that provides facial expressions.

*Function of the metencephalon are:*

- Conduction of impulses from the medulla oblongata into the overlying parts of the brain and back.
- Cerebellum contains the coordination centers of movements, balance and body posture, regulation of muscle tone.

**Midbrain** (mesencephalon) is situated between the diencephalon and pons. It consists of *quadrigenina* (Latin «four-twins») and *cerebral peduncles* (Latin for «legs of the brain»). There is a narrow canal which connects the 4<sup>th</sup> and 3<sup>rd</sup> cerebral ventricles in the center of the midbrain (aqueductus).

*The functions of the midbrain:*

- Conducts impulses from the metencephalon to the diencephalon, from the cerebral cortex to the medulla oblongata and the spinal cord.

– Midbrain has the centers regulating muscle tone and posture, the centers innervation the eye muscles, subcortical centers of vision (upper colliculi) and hearing (lower colliculi).

**The diencephalon** (interbrain) is situated above the midbrain below the cerebral hemispheres. It includes the thalamus and hypothalamus and contains the third cerebral ventricle. The hypothalamus releases neurohormones that regulate the pituitary gland. The pituitary gland regulates the work of other endocrine glands.

*The functions of the diencephalon:*

– Conducts excitation from the lower parts of the brain to the cerebral hemispheres and back.

– The *thalamus* contains subcortical centers of all kinds of sensitivity except smell (sight, hearing, touch, taste). There are centers participating in regulation of emotions and mental activity. The *hypothalamus* contains the centers which regulate metabolism, homeostasis, and activity of cardiovascular system, centers of digestion, thirst, hunger, body temperature, sleep and arousal.

**Cerebrum** (telencephalon) includes the *cerebral hemispheres* (about 80 % of the mass of the brain) connected with *corpus callosum*. Two more cerebral ventricles are situated there on the left and right sides (lateral ventricles).

Cerebral hemispheres are covered with the cortex made of gray matter. The thickness of the cortex is approximately 2–4 mm. It consists of 14 billion nerve cells that form six layers. Under the cerebral cortex is white matter where the bodies of neurons (basal ganglia) are situated. The cortex has sulci (fissures) and gyri (curves). They increase the area of the cortex, which is 2000–2500 cm<sup>2</sup>. Three deep sulci divide the cortex into *the frontal, temporal, parietal and occipital lobes* (fig. 80). The lobes of the cortex contain different zones: the visual area is in the occipital lobe, the area of processing sensory information from skin and muscles is situated in the parietal lobe, auditory area is located in the temporal lobe.

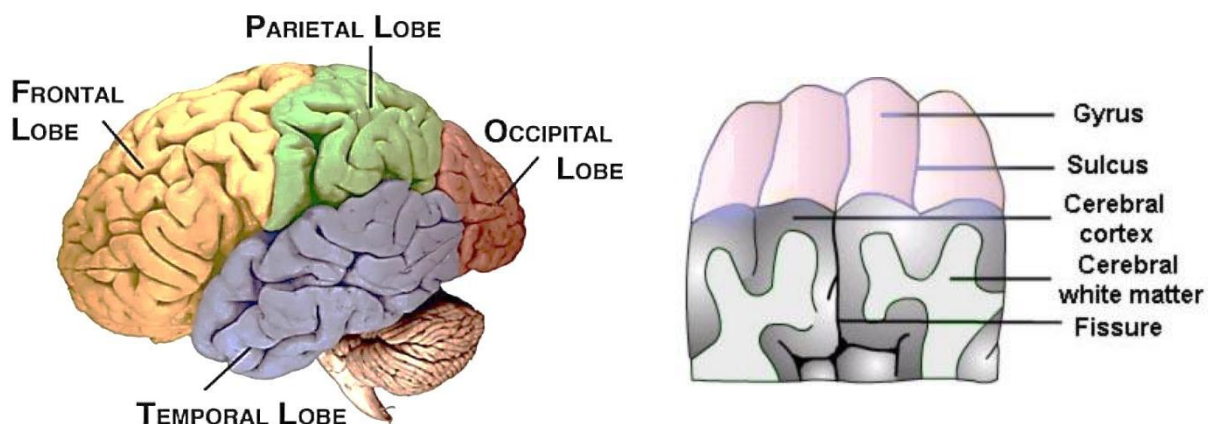


Fig. 80. Lobes and the structure of the cerebral cortex

*The functions of the cerebral cortex are:*

- regulation of all the regions of the brain and spinal cord;
- analysis of the information received by the sense organs;
- it is the center of conditioned reflexes;
- it is responsible for learning, thinking, memory and speech.

#### 14. SENSE ORGANS. THE ORGAN OF SIGHT

**Sense organs** are organs which receive signals from the environment and transmit them to the central nervous system. Sense organs help to orient in the environment. Human has the organs of sight, hearing, smell, touch, taste and equilibrium.

An analyzer is a system that receives, transmits and analyzes information about the external and internal environment of the body.

**Any analyzer consists of 3 parts:**

1. *The peripheral* part is receptors of sense organ;
2. *The conducting* part is the nerves which transmit excitation (impulse) from a sense organ to the cerebral cortex;
3. *The central* part is the area of the cerebral cortex, which analyzes received information.

**The organ of vision** consists of eyes and auxiliary apparatus: eyebrows, eyelashes, eyelids, lacrimal glands, eye muscles. The auxiliary apparatus protects the eyes from dust, snow, mechanical and chemical damage. The eyeball is situated in the orbit of the skull. Eye wall has *three membranes*:

- outer — fibrous tunic (sclera, cornea);
- medial — vascular tunic (choroid, ciliary body, iris);
- inner — internal tunic (retina).

The front transparent part of the **fibrous tunica** is *the cornea*; the rest of the tunica forms the dense part called *sclera*.

**Vascular membrane** has many blood vessels. The inner side of the choroid contains pigment cells. Its front part forms the *iris* which contains a pigment that stains eyes in different colors — blue, brown, black. There is *the anterior chamber* of the eye filled with fluid between the cornea and the iris. The round hole in the iris is *pupil*. There is a transparent biconvex *lens* behind the pupil. Behind the lens is *vitreous body*. Between the iris and the lens is *posterior chamber* of the eye which is filled with fluid.

Image of the object focuses on the **retina**. The retina contains two kinds of photoreceptors — *rods and cones*. There is about 7 million cones and 130 million rods in the retina (fig. 81). The rods contain visual pigment *rhodopsin* and perceive twilight. The cones have pigment *iodopsin* and perceive daylight and colors in bright light.

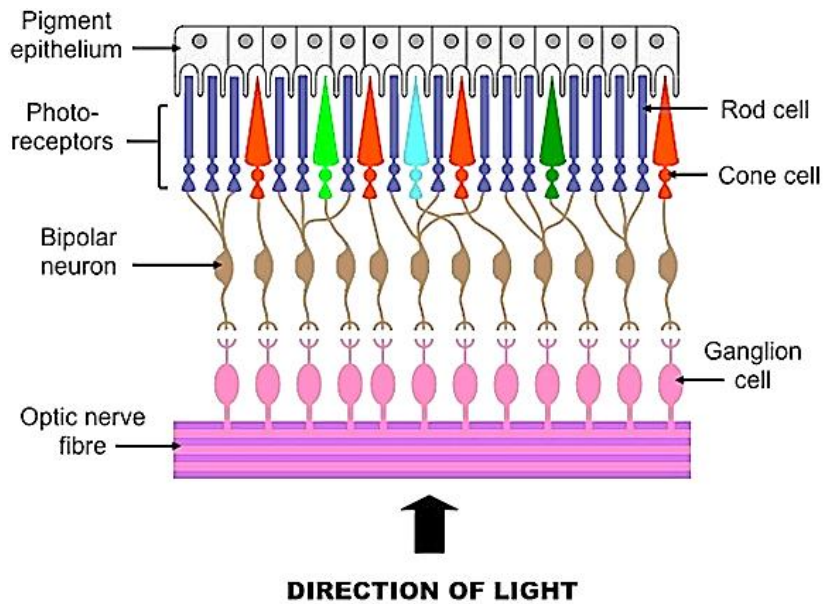


Fig. 81. The structure of retina

In the opposite of the pupil, retina has a *macula lutea* («yellow spot»). The macula is a region of the retina which has a lot of receptors (cones). Near yellow spot, there is a region that has no photoreceptors. This area is called *the blind spot*. Blind spot is a point where the *optic nerve* exits the retina (fig. 82).

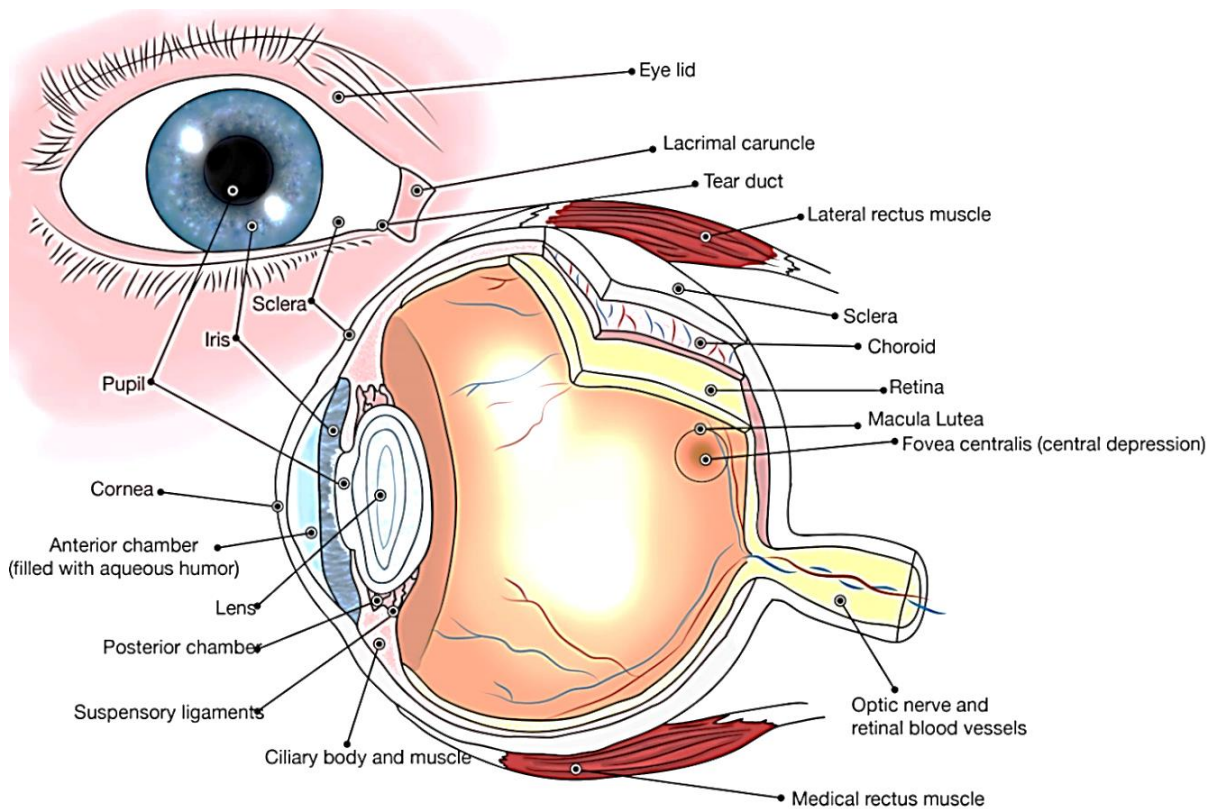


Fig. 82. The anatomy of eye

Transparent structures of the eye through which light rays pass are an optical system of the eye. The system includes the cornea, fluid of anterior chamber, pupil, fluid of posterior chamber, lens, and vitreous. The main structures of the optical system are the cornea and lens. The mechanism of sight:

1. Light rays pass through the cornea, anterior chamber, pupil, posterior chamber, lens, vitreous body and fall on the retina.

2. Photoreceptors of the retina perceive visual stimuli.

3. The optic nerve conducts the impulse from receptors into visual area of the cortex (the occipital lobe) which analyzes visual stimuli.

4. A person can see things around.

If the light rays cannot be focused on the surface of the retina, vision impairments occur:

*Myopia (near-sightedness)*. Light rays are focused in front of the retina. A person can see well only close situated objects;

*Hyperopia (long-sightedness)*. Light rays are focused behind the retina. A person can see well only far objects.

## 15. THE ORGAN OF HEARING

It is commonly known that the organ detecting sound is an ear, but it also provides balance and body position.

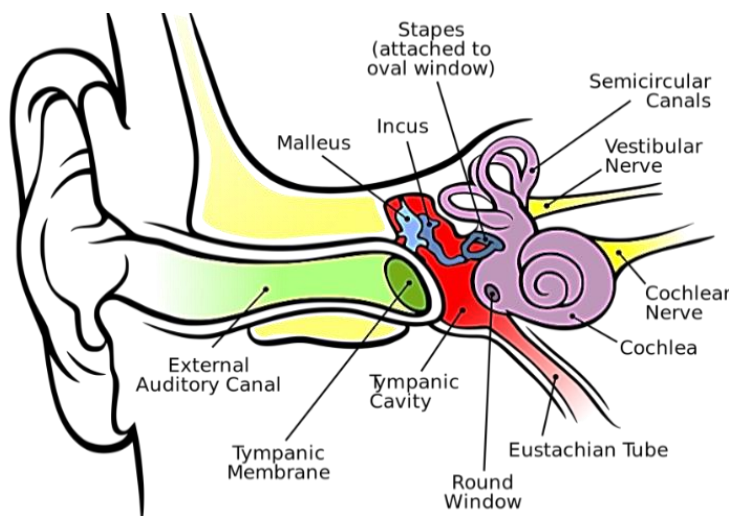


Fig. 83. The anatomy of the ear

The organ of hearing consists of three parts: the outer, middle and inner ears (fig. 83). Receptors of hearing organ are the peripheral part of the auditory analyzer.

**Outer ear** includes the *auricle*, *external auditory canal*, *tympanic membrane* (or *eardrum*). The auricle consists of cartilage covered with skin. It collects sound. The external auditory canal is a tube approximately 30 millimeters in length.

There are glands that secrete earwax which retains dust and bacteria. The eardrum is a thin membrane that perceives sound waves. It is the border between the outer ear and the middle one.

**Middle ear** consists of a cavity of volume about  $1 \text{ cm}^3$  (*tympanic cavity*). Tympanic cavity is connected with the nasopharynx by the *Eustachian (acoustic) tube*. The acoustic tube equalizes pressure on both sides of the eardrum.

There are 3 *auditory ossicles (bones)* in the tympanic cavity. These ossicles are called *malleus, incus and stapes* (Latin «hammer», «anvil», «stirrup»). They are connected to each other and conduct the vibrations from the eardrum to the inner ear. The malleus is connected with the eardrum and the stapes is connected to the membrane of the inner ear which is called the *oval window*.

**The inner ear** is located inside of the temporal bone of the skull. It contains the organ of hearing (*cochlea*) and the organ of equilibrium (*semicircular canals*). *Cochlea* is situated in spirally twisted *bony canal* (fig. 84). Two membranes (*vestibular* and *basilar*) divide this canal into 3 *scalae* (ducts):

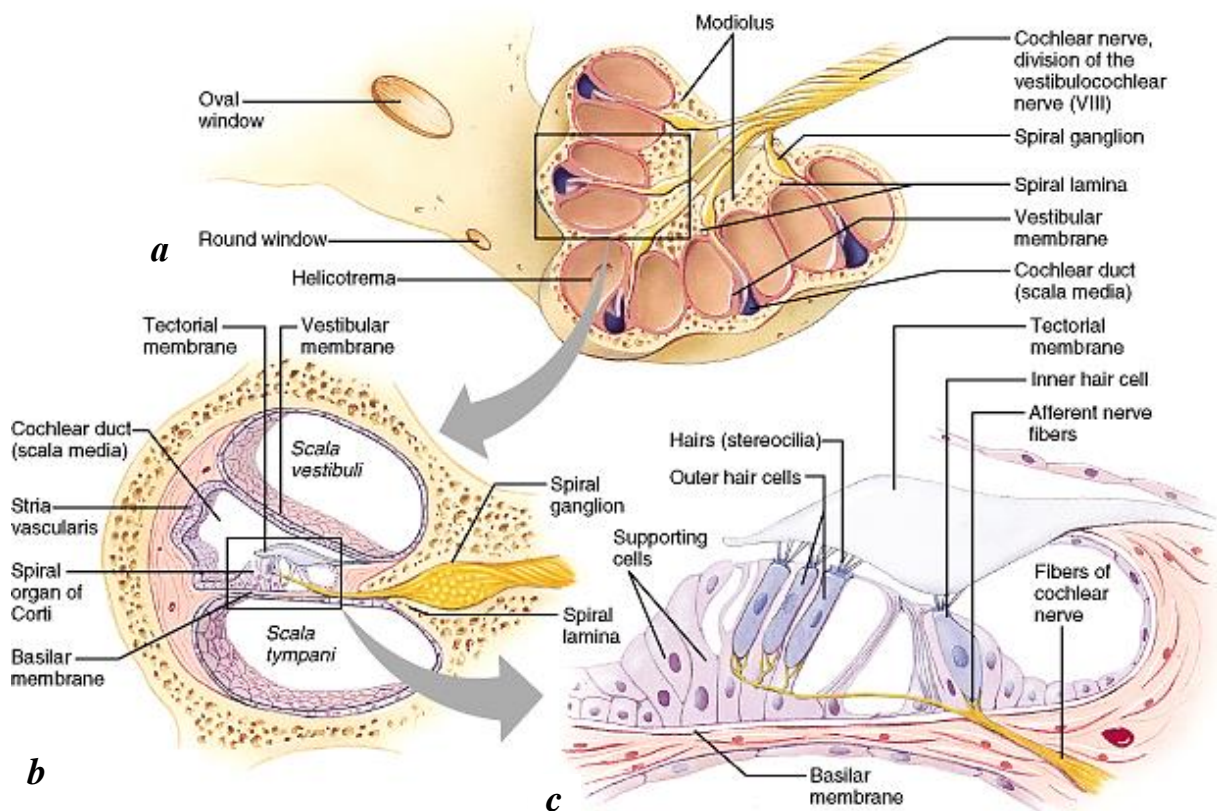


Fig. 84. The anatomy of cochlea:

*a* — cross-section of cochlea, *b* — ducts of the inner ear, *c* — organ of Corti

1. The *cochlear duct* is in the middle between the vestibular and basilar membranes. It is filled with *endolymph* and contains *the organ of Corti* which perceives sound and transforms it into nerve impulse.

2. The *vestibular duct* is separated from the cochlear duct with the vestibular membrane. It is filled with *perilymph*.

3. The *tympanic duct* is separated from the cochlear duct with the basilar membrane. It is filled with *perilymph*.

On the basilar membrane is *organ of Corti*. It is the sensory organ of the cochlea which is composed of sensory cells called *hair cells*, nerve fibers

that connect to them, and supporting structures. The hair cells have hair-like structures at ends opposite to basilar membrane. These structures contact another membrane — *tectorial membrane*. The tectorial membrane covers the organ of Corti in the cochlear duct.

**The mechanism of hearing** (fig. 85):

1. Sound waves are collected by auricle. They pass through the external auditory canal and cause vibrations of the eardrum;
2. Vibrations of the eardrum are conducted by the ossicles: malleus → incus → stapes. The ossicles increase the intensity of sound up to 20 times;
3. Vibrations of stapes are transmitted to the oval window;
4. Vibrations of the oval window cause vibrations in the perilymph and endolymph;
5. The vibrations in the perilymph and endolymph cause traveling waves along the basilar membrane;
6. The motions of the basilar membrane bend and stimulate the hair cells of the organ of Corti. I.e. nerve impulse appears in the receptors;
7. The nerve conducts the impulse from the cochlea to the temporal lobe of the cerebral cortex where center of the hearing is situated;
8. The temporal lobe of the cerebral cortex analyzes the acoustic signal.

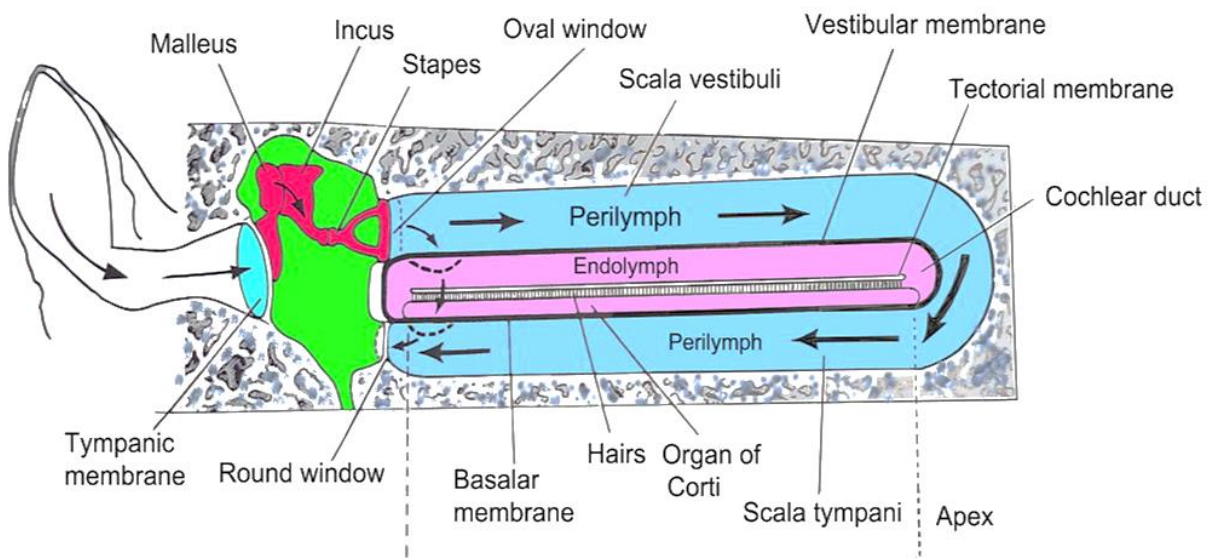


Fig. 85. The mechanism of hearing

Hearing organ allows orientation in the environment and communication with other people, hearing music, speech and etc.

## 16. REPRODUCTIVE SYSTEM. THE STRUCTURE AND PRODUCTION OF GAMETES

**Reproduction** is the property of organisms to create new individuals of the same species. Due to reproduction new generations can replace old ones. Thus reproduction provides the continuity of life and is the basis for existence of the species.

Functions of the reproductive system of human are:

- production of gametes (ova and sperms);
- providing meeting of these gametes;
- nutrition of a developing embryo and fetus;
- production of hormones.

The reproductive system consists of internal and external genital organs.

**Male internal genital organs** (fig. 86) are 2 *testes* and their *epididymides* (singular — *epididymis*), *vasa deferentia* (singular — *vas deferens*) with seminal vesicles and *prostate*.

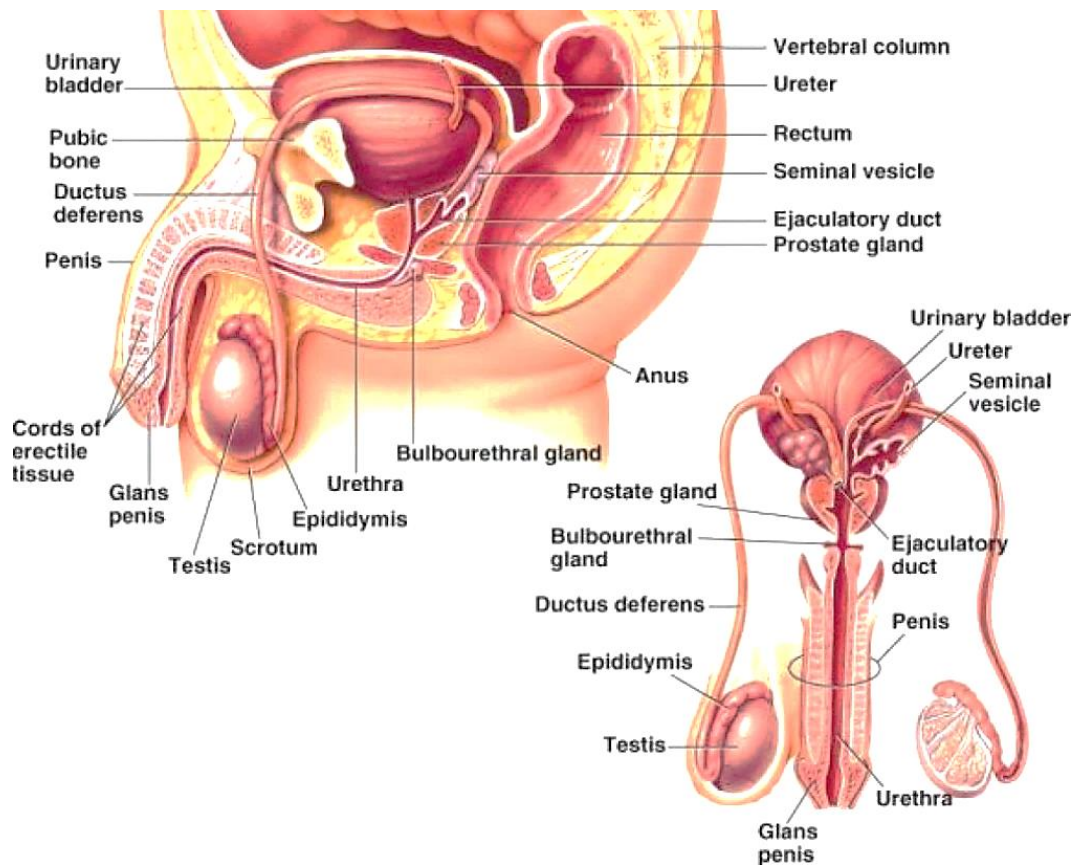


Fig. 86. Male reproductive system

**Male external genitalia** are *penis* and *scrotum*.

*Testes* are male sex glands. They are located in the *scrotum*. Testes produce sperms and male sex hormones (such as *testosterone*). Their size is about 3–5 cm, weight is 15–30 g.

**Female internal genital organs** (fig. 87) are 2 *ovaries*, *fallopian tubes*, *uterus* and *vagina*.

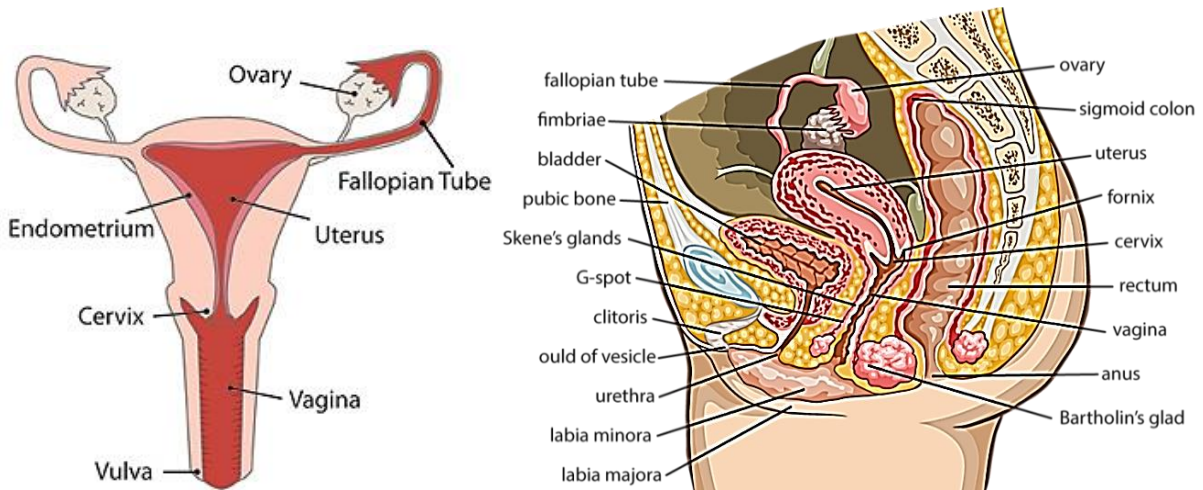


Fig. 87. Female reproductive system

**Female external genitalia** are *labia majora*, *labia minora*, *clitoris*.

**Ovaries** are female sex glands forming female gametes (ova) and female hormones (estrogens). They are located in the abdominal cavity. They mature in 12–15 years. The length of the ovary is 3–4 cm; the weight is 6–7 grams.

**Fallopian tubes** have a length of 10–12 centimeters, fertilization occurs there. **Uterus** is a muscular hollow organ where the fetus develops.

The process of formation of gametes is called gametogenesis (table 1). The gametogenesis of female gametes is called oogenesis.

Table 1

**Gametogenesis**

Genetic information	Cells names	Spermatogenesis	Ovogenesis	Cells names	Periods
2n2chr	Spermatogonia			Ovogonia	Proliferation (mitosis)
2n2chr	Primary spermatocytes			Primary ovocytes	Growth
1n2chr 1n1chr	Secondary Spermatocytes			Secondary ovocytes	Maturation (meiosis)
1n1chr	Spermatids				Transformation
1n1chr	Spermatozoa			Ovum	

Formation of ovocyte takes place once a month from puberty (12–13 years) and up to 45–50 years old.

***Ovogenesis consists of periods:***

1. During the period of proliferation diploid ovogonia (set of chromosomes is  $2n2chr$ ) divide by mitosis to multiply.

2. During the period of growth, ovogonia accumulates nutrients, grow and transform into primary ovocytes (set of chromosomes is  $2n2chr$ ).

3. During the period of maturation primary ovocytes begin meiosis. After first meiotic division the primary ovocyte divides into two haploid cells (set of chromosomes is  $1n2chr$ ) a large secondary ovocyte and a small polar body. During the second meiotic division, the secondary ovocyte form the ovum (set of chromosomes is  $1n1chr$ ) and a new polar body.

*The human ovum* has a spherical shape, its size is about 0.13 mm (fig. 88). It contains a nucleus with haploid set of chromosomes, cytoplasm with organelles and nutrients (yolk). The egg cell is immobile. It is covered with two layers (primary and secondary).

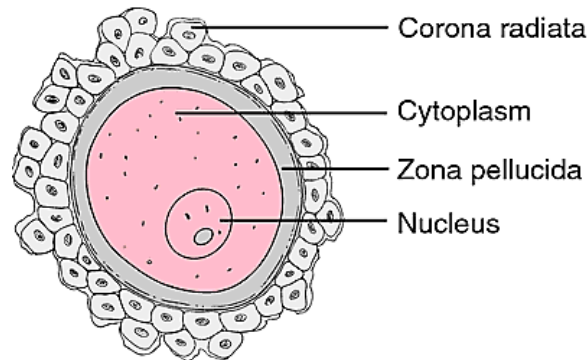


Fig. 88. Ovum

The formation of male gametes is spermatogenesis. Formation of sperms occurs since the puberty to old age.

***Spermatogenesis includes the following periods:***

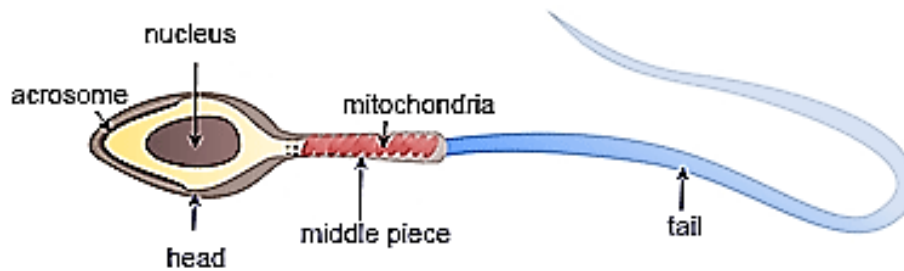
1. During the period of proliferation diploid spermatogonia multiply by mitosis. Chromosome set doesn't change ( $2n2chr$ ).

2. During the period of growth spermatogonia transform into primary spermatocytes ( $2n2chr$ ).

3. During the period of maturation, the primary spermatocytes divide by meiosis. After the first meiotic division each primary spermatocyte form 2 haploid secondary spermatocytes ( $1n2chr$ ). After the second meiotic division, each secondary spermatocytes divides into 2 spermatids ( $1n1chr$ ). Consequently, each primary spermatocyte form four spermatids;

4. During the period transformation (formation) the spermatocytes transform into the spermatozoa (sperms). Chromosome set does not change and is  $1n1chr$ .

Spermatozoa consist of a head, midpiece and tail (fig. 89). The head contains the haploid nucleus and an acrosome (modified Golgi apparatus). The midpiece contains centriole and mitochondria. Sperms are much smaller than ovum, their length is 55 micrometers (head is about 5 micrometers in size).



*Fig. 89. Spermatozoon*

Egg cell and sperm, fuse during fertilization to transform into a zygote. The zygote contains a diploid set of chromosomes ( $2n$ ). In the mother's body, the zygote begins development into the embryo and fetus. This development occurs in the uterus.

## SECTION 4 MICROBIOLOGY AND ZOOLOGY

### 1. PROKARYOTES: BACTERIA

There are two major groups of living organisms: *prokaryotes* and *eukaryotes*. Eukaryotes are plants, animals, fungi, protists.

**Bacteria** (singular — bacterium) belong to prokaryotes. The structure of prokaryotic cell is much simpler than that of eukaryotes. Prokaryotes do not have a nucleus and membrane-enclosed organelles and do not divide by mitosis or meiosis. Though types of metabolism of prokaryotes are much more diverse than those of eukaryotes.

Bacteria are unicellular (i.e. consisting of one cell) organisms. Their sizes are from 0.2 to 13 micrometers. Average bacterial cell is considerably smaller than average eukaryotic cell.

Bacteria live everywhere. Almost any environment has many types of bacteria. Bacteria are present even in the soil to the depth of about 3 kilometers and in the air at an altitude of about 12 kilometers. Large numbers of bacteria can live in any material that can be used as a source of food. Optimal conditions necessary for most of bacteria are the temperature between 0 and +35–40 °C, presence of water, nutrients. Many bacteria also need oxygen.

**Structure of bacterial cell** (fig. 90). Shapes of bacteria may vary. Sphere-like bacterium is called *coccus* (plural — cocci), rod-like bacterium is *bacillus* (plural — bacilli), comma-shaped one — vibrio, spiral-like one — *spirillum* (plural — spirilla).

Many types of bacteria can move, others cannot. The ability of living organism to move itself to new locations is called *locomotion*. Common locomotory organelle of bacteria is *flagellum* (plural — flagella). It is a long filament which waggles and pulls the cell forward. Different bacteria may have one or several flagella which are often attached to the same side of the cell, but they may cover its entire surface.

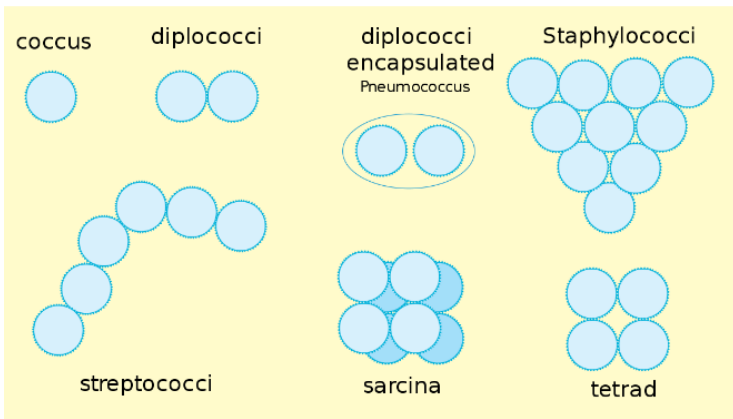
Eukaryotic cells also may have flagella, though the structures and the mechanism of movement of bacterial and eukaryotic flagella are absolutely different.

Common coverings of bacteria are *plasma membrane*, *cell wall* and *capsule* (fig. 91).

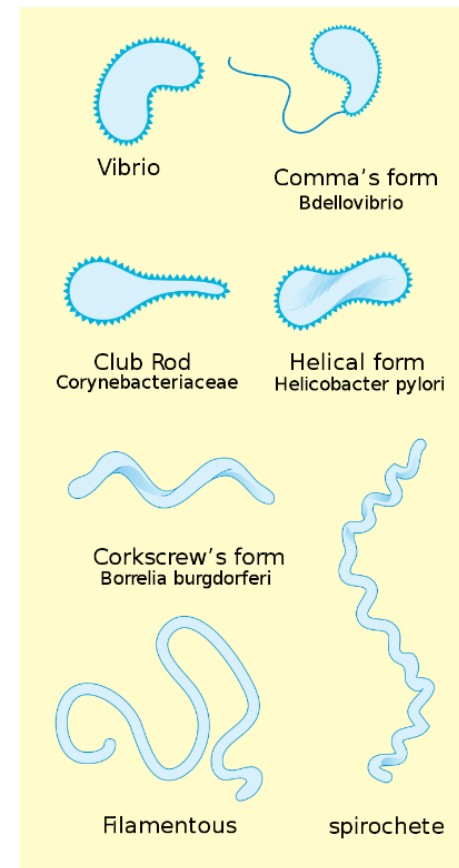
Cell wall is the outer covering of bacterial cell. It consists of *peptidoglycan* — a polymer composed of sugars and amino acids.

Capsule is a covering of bacterial cell consisting of polysaccharides. More than 90 % of capsule's mass is water. Such capsule can protect the cell from desiccation. The capsule of disease-causing bacteria protects them from the cells and proteins of the immune system.

## Cocci



## Others



## Bacilli

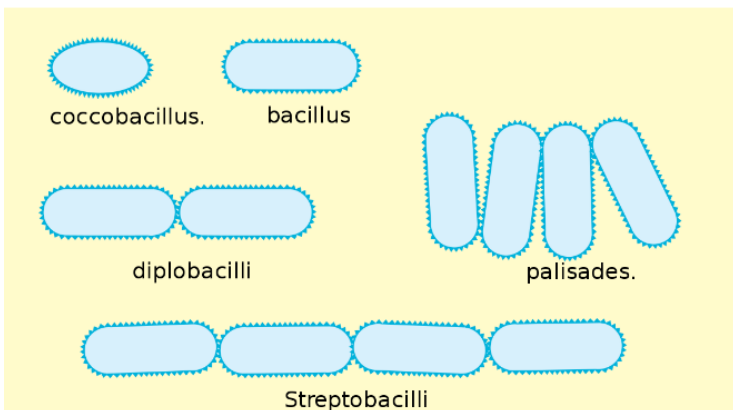


Fig. 90. Types of bacteria according to their shape

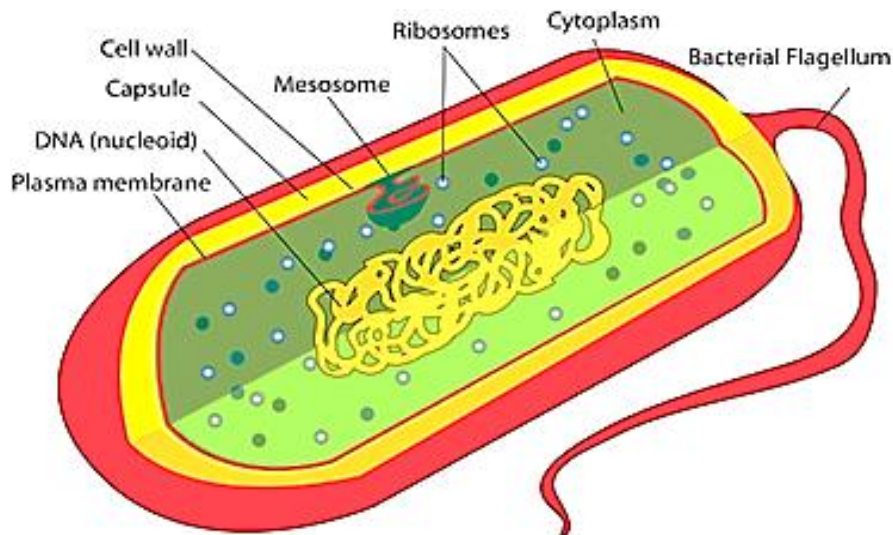


Fig. 91. The structure of bacterial cell

There are two major groups of bacteria: *gram-positive* and *gram-negative* bacteria. This classification is based on specific staining. Gram-positive bacteria stain dark violet or purple. The gram-negative bacteria stain red. This is due to different structure in their cell walls.

Many bacteria have long protein projections called *pili* (singular — *pilus*) on the surface. Pili of disease-causing bacteria may help them to attach to host surfaces.

The genetic information of bacteria is in a single circular DNA. Bacteria do not have nucleus and their DNA is situated in the cytoplasm and attached to the plasma membrane. The region of the cytoplasm containing the circular bacterial DNA called *nucleoid*. Apart from the nucleoid, bacteria may have a number of small circular DNA — *plasmids*.

As all living organisms, bacteria have *ribosomes* — the organelles which make proteins.

Bacteria do not have membrane-enclosed organelles, but it was found that bacteria have invaginations of the plasma membrane called *mesosomes*. Although it was thought that they can perform functions related to membrane-bound organelles, mesosomes might be artifacts formed due to damage of membranes after chemical fixation (it is necessary for microscopy) and they do not exist in living bacterial cells.

According to feeding type (assimilation), bacteria are *autotrophic* and *heterotrophic*. The autotrophic ones synthesize organic compounds from inorganic substances for themselves (use inorganic substances as a source of carbon). They can use energy of the sun (such bacteria are *photosynthetic*) or energy of chemical reactions (such bacteria are *chemosynthetic*).

Bacteria that use ready-made organic compounds are heterotrophic bacteria (use other organic substances as a source of carbon). For instance, lactic-acid bacteria transform sugars into the lactic acid. Another example of heterotrophs are bacteria-parasites. They feed on organic compounds of living organisms.

According to dissimilation type, bacteria are *aerobes* and *anaerobes*. Aerobic bacteria (an example is tubercle bacillus) require oxygen for living while anaerobic ones live only in mediums without oxygen (examples are drumstick bacillus and lactic-acid bacteria).

*Reproduction of bacteria* occurs asexually by binary fission (a cell simply divides into two). In favorable environmental conditions, bacteria can divide every 20–30 min and produce more than 600 million new bacteria from one cell in one day.

There is a sexual process called *conjugation* in some bacteria. During this process, two bacteria form a cytoplasmic «bridge» (*pilus*). Through pilus, the donor cell shares particular DNA with the recipient cell. Such gene transfer may help some genes to spread in bacterial population.

If environmental conditions are unfavorable, many bacteria may transform into *spores*. The spore is an inactive bacterial cell resistant to multiple physical and chemical factors. In this form, bacteria may survive for many years.

**Significance of bacteria.** Significance of bacteria in the nature is great. They help to recycle carbon, nitrogen and other elements of organic substances.

Humans found the way to use bacteria for making food: sour crème, cheese, vine and etc; in chemical industry they are used for synthesis of alcohols, acetone, acetic acid and other chemicals; in medicine bacteria are the source of some antibiotics, vitamins, enzymes, hormones.

Many bacteria are harmful for human. They spoil food, cause diseases of human, animals and plants. Parasitic bacteria are pathogenic agents of cholera, plague, tuberculosis, tonsillitis and a vast number of other diseases. Such ones are known as *malignant (pathogenic) bacteria*. Human can be infected by the contact with sick persons, by water and food containing bacteria or their spores.

Many *methods of controlling the diseases* elaborated such as illuminating the hospital wards with ultraviolet rays. Surgical tools and bandage material are processed with solution of hydrogen peroxide or with high temperature. To prevent infection, control of water and food purity is performed. Important factor to prevent diseases is vaccination.

## 2. KINGDOM PROTISTS. PARASITIC PROTISTS

The science *Taxonomy* (Systematics) studies the classification of living organisms. Units of taxonomy are *taxons* (for example species, phylum, kingdom). The smallest unit of biological classification is species (fig. 92). For example, *Homo sapiens* — wise man. The largest taxonomy unit is kingdom; the next lesser taxon is phylum.



The kingdom of mostly single-celled eukaryotic organisms different from animals, plants and fungi is called the kingdom *Protista*.

This kingdom includes the following phyla:

1. *Sarcomastigophora*. Examples — *Amoeba* (fig. 93), *Euglena* (fig. 94), *Giardia* (fig. 95, a), *Entamoeba histolytica*, *Giardia*.
2. *Ciliata*. Example — *Paramecium caudatum* (fig. 95, b).
3. *Apicomplexa*. Example — *Plasmodium* (malaria parasite).

Fig. 92. Taxonomic units

Many protists such as *Amoeba*, *Euglena*, *Paramecium* are free-living. They live in the soil and water. Their «body» is just one cell performing the functions of the entire organism. *Euglena* and *Paramecium* have constant cell shape and amoeba can change its shape.

The cell coverings of protists are diverse. For example, amoeba is covered only with the plasma membrane, *Euglena* and *Paramecium* have a special thin layer supporting the cell membrane called pellicle. Like all eukaryotic cells, protists have *organelles* — parts of the cytoplasm which function like organs of multicellular organisms.

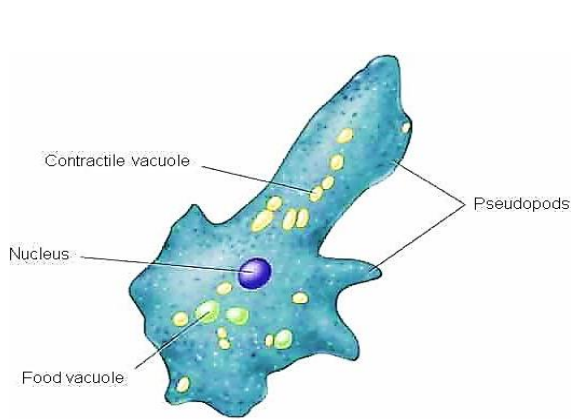


Fig. 93. Amoeba

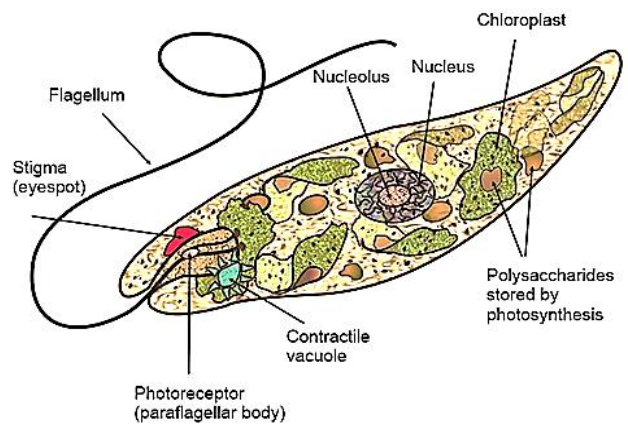
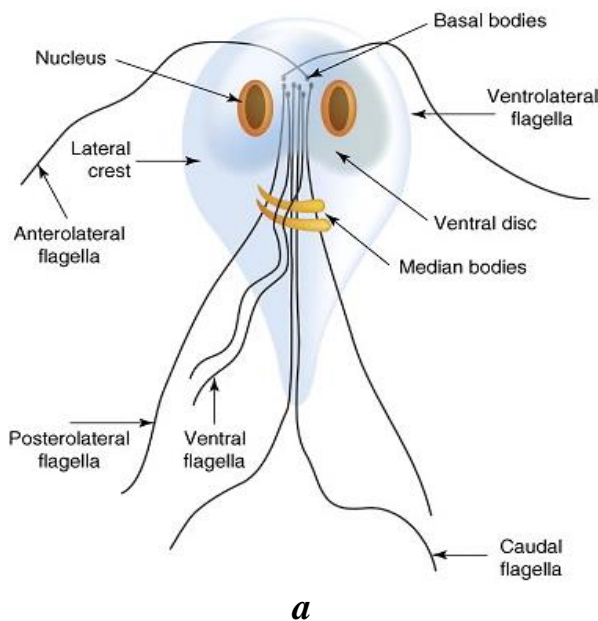
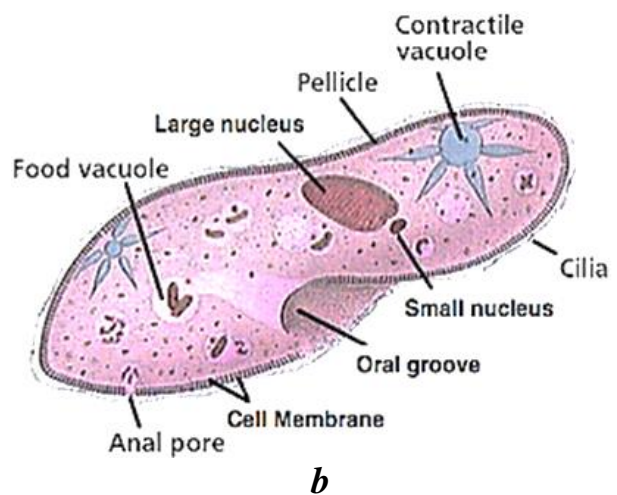


Fig. 94. Euglena



a



b

Fig. 95. Giardia (a) and Paramecium caudatum (b)

Locomotion of protists can be performed by different organelles. *Amoeba* can form cytoplasm projections called pseudopodia. The locomotory organelles of *Euglena* is a long thread called *flagellum*. *Paramecium* is covered with numerous short structures called *cilia*. They are similar to flagella in structure, but are much shorter and more numerous.

The cytoplasm of protists has two layers. The outer layer is dense and homogeneous. It is called *ectoplasm*. The inner one is liquid and granular, it is *endoplasm*. The endoplasm contains various organelles.

Like most of eukaryotic cells, *Euglena* and *Amoeba* contain one nucleus. *Paramecium* has two nuclei: the large one is called *macronucleus*, the small one is micronucleus. The *macronucleus* is a vegetative nucleus which regulates all activities of the cell. The *micronucleus* is the generative nucleus involved in the sexual process.

According to the feeding type, protists are autotrophs and heterotrophs. *Amoeba* and *Paramecium* are heterotrophs. *Euglena* is both autotrophic and heterotrophic (it has chloroplasts). *Amoeba* feeds by phagocytosis. It surrounds food particles with pseudopodia which fuse at ends and enclose the particles in vesicles called *food vacuoles*. Undigested remains of food are removed from the cell by exocytosis. Being the most structurally complicated protists, ciliates «swallow» food particles by phagocytosis through the *oral groove* and «mouth» (*cytostome*). Remains of food are removed by exocytosis through the *anal pore*.

Some protists have organelles that help them to remove excess of water — *contractile vacuoles*.

Breathing of protists occurs via diffusion through their surface.

*Reproduction* of protists is asexual and occurs by mitosis. Some protists can divide by meiosis and then haploid cells merge. *Paramecium* has sexual process (but not reproduction!) that is called conjugation. During conjugation two ciliates connect, their macronuclei disappear, the micronuclei divide by meiosis. Each ciliate gains own and foreign haploid micronucleus, they merge and form new nuclei. This process increases genetic diversity of ciliates.

If the environmental conditions become unfavorable, protists form *cysts*: cell shrinks, drops or draws-in its locomotion organelles, stops feeding and forms protective covering. The covering protects the cell from drying out, low temperature and toxic substances. Cysts also help protists to spread on.

Like all living organisms, protists have capability to respond to various external influences (*irritability*). The form of irritability in protists is *taxis*. For example, *negative chemotaxis* is observed when ciliates leave the regions with high concentration of salts; *positive phototaxis* is movement of euglena to the light.

**Parasitic protists.** Organisms, which live at the expense of other organisms, receive food from them and harm them, are called parasites. The person or an animal where the parasite lives is called the *host* of a parasite. Parasites cause diseases of the host.

Many parasitic protists have no digestive vacuoles and absorb ready-made nutrients through the plasma membrane. Metabolic products are also excreted through the membrane. Examples of parasitic protists will be described next.

*Giardia* causes the disease called *giardiasis* in humans. The parasite belongs to the phylum *Sarcomastigophora*. It is a pear-shaped cell flattened on one side. *Giardia* has two nuclei and eight flagella. Cysts of the parasite enter the body with water or dirty fruits and vegetables. In the human body, giardia lives in the duodenum and causes their inflammation. The disease can be diagnosed by finding the parasite in stools.

*Entamoeba histolytica* also belongs to the phylum *Sarcomastigophora* and causes *amoebiasis* in human. Cysts of amoeba enter human body with contaminated food and water. The parasite damages the intestinal wall and small

blood vessels. Most common symptom of amoebiasis is diarrhea with blood. The parasites spread by forming infective cysts with four nuclei, which pass to the exterior with stools. These cysts can get to another organism and cause the disease. The disease can be diagnosed by finding the parasite in stools.

*Plasmodium* belongs to phylum *Apicomplexa*. This parasite causes *malaria*. The disease is transmitted by the bite of an infected female mosquito of the genus *Anopheles*. Parasites from the mosquito's saliva pass into the blood of human. Then parasite travels to the liver where it multiplies. Such asexual reproduction of plasmodia is called *schizogony* — one cell divides into many daughter cells.

Later such reproduction repeats many times in red blood cells. After schizogony, plasmodium destroys red blood cells or liver cells and releases itself with toxic metabolic products into the bloodstream. When it happens, sick people have increase in body temperature (fever). Malaria is a severe disease which often causes death.

There are special diagnostic methods for these diseases. Microscopy is the most common method used to detect the malaria parasite. A blood specimen is studied under the microscope in order to find the parasite in red blood cells.

### 3. PHYLUM PLATYHELMINTHES (FLATWORMS)

About 18 000 species are described. Free-living flatworms live in water and soil; parasites are in the human and animal organisms.

**The phylum *Platyhelminthes* has the following classes:**

1. *Eddy worms (Turbellaria)*. For example, planaria. They are free-living.
2. *Flukes (Trematoda)*. Examples are liver fluke (lat. *Fasciola hepatica*) and cat liver fluke (lat. *Opisthorchis felineus*). All flukes are parasites.
3. *Tapeworms (Cestoda)*. Examples: pork tapeworm (Lat. *Taenia solium*), beef tapeworm (Lat. *Taeniarhynchus saginatus*). Tapeworms are parasites.

Body sizes of flatworms are from 1 millimeter to 20 meters in length. Bodies can have shapes of leaves or tapes. They have *bilateral (double-sided) symmetry*.

Flatworms *develop from 3 germ layers* — ectoderm, endoderm and mesoderm.

The body of flatworms is covered with the *dermomyuscular wall*. Its outer layer is simple epithelium. Below this layer, 3 layers of smooth muscles (circular, diagonal and longitudinal) are situated. Locomotion (movement) of flatworms is provided by contraction of muscles. In eddy worms, cilia also participate in locomotion.

The parasitic flatworms have *suckers and hooks* — special organs which help them to attach to the host's body.

**Internal anatomy.** Flatworms have no body cavity (fig. 96). The space between organs is filled with connective tissue which develops from the third

germinal layer (mesoderm). It performs structural function, participates in metabolism and regeneration. Flatworms have digestive, excretory, reproductive and nervous systems (fig. 97).

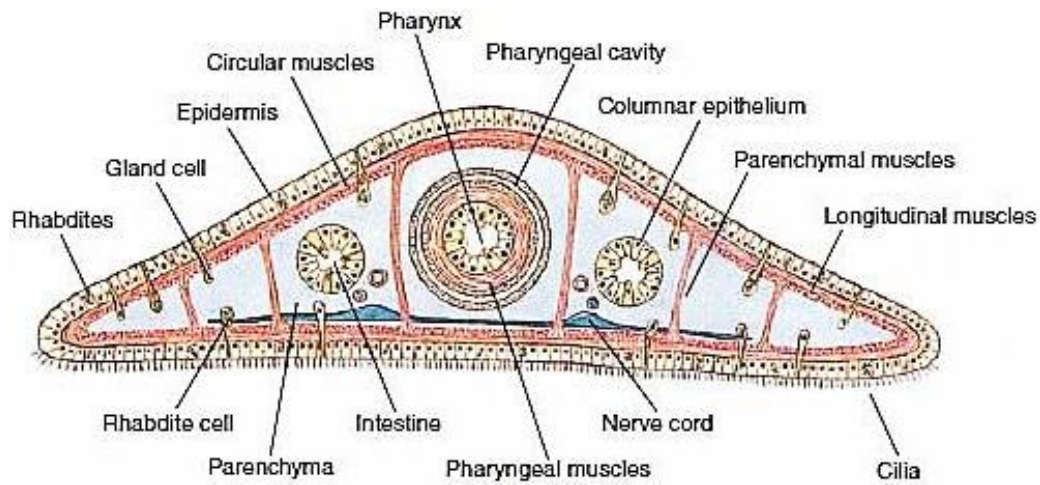


Fig. 96. The cross-section of flatworm

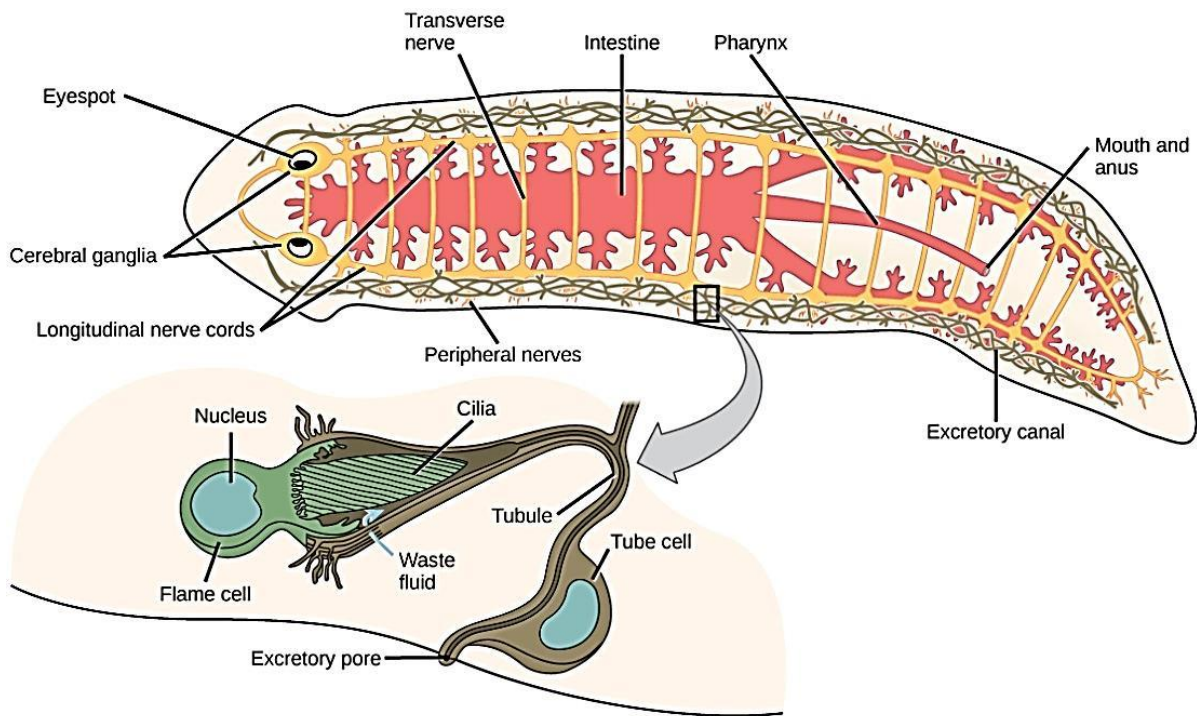


Fig. 97. The anatomy and excretory system of planaria

Tapeworms are the parasites which have no digestive system. Eddy worms and flukes have digestive system consisting of foregut and midgut. The foregut includes mouth and pharynx. Digestion and absorption of nutrients occur in the midgut. Eddy worms have no hindgut with anal opening. Their undigested material is expelled through the mouth. Planaria has a muscular pharynx which is able to turn out from the mouth to swallow food.

The excretory organs are *protonephridia*. They begin in the connective tissue with star-shaped cells with cilia. These cells collect liquid metabolic products. Short channels extend from the star-shaped cells and open into a general excretory duct that ends with excretory opening.

Flatworms have no circulatory and respiratory systems. Gas exchange occurs through body surface. Transport of gases, nutrients and dissimilation products are performed by connective tissue.

The nervous system of flatworms consists of two ganglia and several nerve cords which extend along the body. Flatworms have sensory organs of touch and chemical senses. Some flatworms have organs sensitive to light.

Reproduction is sexual or asexual. Flatworms are *hermaphrodites*. This means that they have male and female sex organs (testes and ovaries). Eggs develop inside the body. Special glands feed these eggs and secrete substances forming their capsules. There is a complex system of organs containing eggs and releasing them to the environment.

Eddy worms multiply sexually (but also can multiply asexually by *fragmentation* when their bodies are divided). Sexual reproduction is more common than asexual because it increases the genetic diversity of population. This is necessary for survivability of species.

Free-living worms such as planarians have direct development. Young planarians leave eggs which are laid in cocoons. Parasitic flatworms are characterized by high fertility and complex life cycles. During such life cycle, larva develops and changes hosts.

#### 4. CLASS TREMATODA (FLUKES)

Parasitic worms of any phylum and class which cause diseases are called helminthes. The diseases caused by helminths are helminthiases.

There are about 10 000 flukes. All of them are parasites of animals and humans.

In this chapter, anatomy of flukes is considered by an example of a liver fluke (lat. *Fasciola hepatica*).

*Fasciola hepatica* (fig. 98) has leaf-shaped body which can reach 3–5 cm in length. It has oral and ventral suckers.

*Fasciola hepatica* lives in the liver ducts of many mammals, especially ruminants and humans. It attaches to the wall of the bile duct by suckers.

All the organs of the liver fluke develop from three germ layers — ectoderm, endoderm and mesoderm.

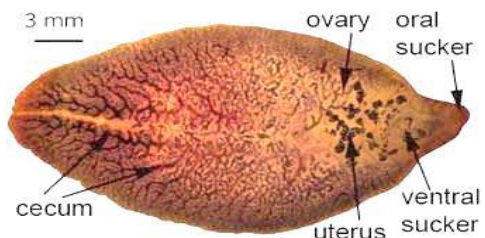


Fig. 98. *Fasciola hepatica*

The outer layer of the *dermo-muscular body wall* is the epithelium *tegument*. It protects the *Fasciola hepatica* from the action of host enzymes. Below the tegument are three layers of smooth muscles (circular, diagonal and longitudinal). The space between organs is filled with connective tissue.

*Digestive system* consists of a foregut (mouth and pharynx) and midgut. Two branches of the midgut are strongly branched. Flukes have no hindgut with an anal opening and regurgitate undigested remains of food through the mouth.

*Excretory organs* are protonephridia. *Circulatory and respiratory systems are absent*.

The *nervous system* of flukes consists of two cerebral ganglions and several nerve cords. Nerve cords extend along the body. Flukes have organs sensitive to touch and chemical substances.

*Reproductive system*. Flukes are hermaphrodites. They have complex life cycles. The life cycle (fig. 99) of a liver fluke includes two hosts and several stages of larvae. The organism where sexual reproduction of mature fluke occurs is called the definitive host. The *definitive hosts* of the liver fluke are cattle and humans.

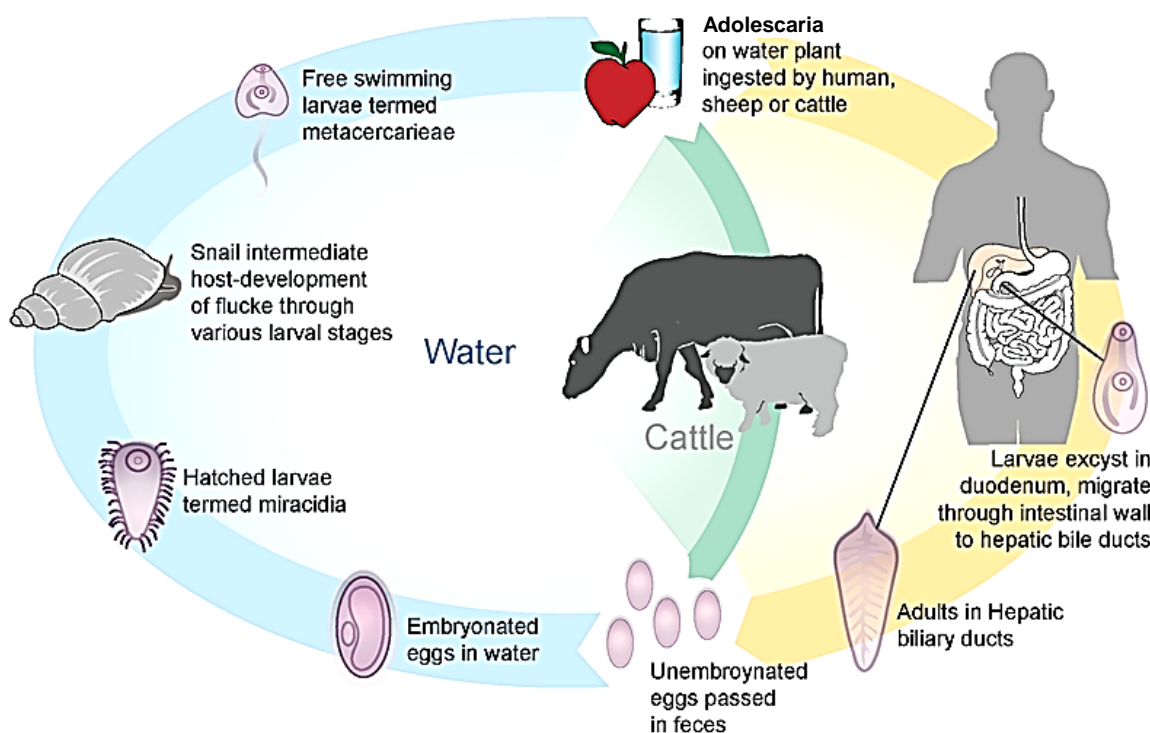


Fig. 99. The life cycle of *Fasciola hepatica*

The definitive host excretes the fluke eggs from the intestine to the environment. If eggs get to water, they continue their development. A larva with cilia — *miracidium* — comes out of the egg. The miracidium has to get into the *intermediate host* — freshwater snail. In the intermediate host the parasite reproduces asexually.

The miracidium passes through several stages of development in the body of the snail. Mobile larva with a tail comes out from the snail in the water. It is called *cercaria*. Cercaria attaches to water plants and covers with a dense shell. It transforms into a dormant larva called *adolescaria*. The adolescaria are swallowed by the cattle or sometimes humans during drinking non-boiled water from reservoir, and also eating the vegetables and fruit which are washed up with this water. In the duodenum, the adolescaria transforms into the *fluke* and gets to the liver. Then the *Fasciola hepatica* destroys the bile ducts and liver tissue. This cause inflammation in the liver and impair the bile excretion.

The disease caused by the liver fluke is called *fascioliasis*. It refers to helminthiases. Methods of prevention the disease are prophylaxis.

***The prophylaxis of fascioliasis includes measures:***

1. Do not drink water from open reservoirs and do not wash vegetables with such water.

2. Elimination of the intermediate hosts (snails).

3. Prevent the pollution of reservoirs with human and animal feces.

4. Revelation and treatment people affected with the disease.

Beside the *Fasciola hepatica*, there are many other flukes: *a lung fluke* which parasitizes in the airways and lungs of human; *a cat liver fluke* lives in the human liver; *blood flukes* parasitize in the large veins of the abdominal cavity.

## 5. CLASS CESTODA (TAPEWORMS)

Approximately 5000 tapeworms are described. All tapeworms are parasites of animals, including humans. Tapeworms live in their digestive systems.

**External anatomy.** As is seen from the name of the class, tapeworms have tape-like body shape. Its length is from 1 mm to 10–18 m. The body consists of *scolex* (head), *neck*, and *strobila* (segmented body). Commonly tapeworms have suckers and hooks on the head. These organs are used for attachment to the host's body.

Tapeworms have the dermo-muscular body wall and no body cavity. Its external layer is tegument which protects the parasite from digestive system of the host.

**Internal anatomy.** Tapeworms have no circulatory, respiratory and digestive systems. Nutrients are absorbed from the host's intestine by the body surface (tegument) with help of *microtriches*. The microtriches are outgrowths of the tegument which increase the body surface for better absorption of nutrition.

*The excretory organs* are protonephridia.

*The nervous system and sense organs* are poorly developed.

Tapeworms are *hermaphrodites*. They have complex life cycles, several larval stages and several hosts (definitive and intermediate).

A representative of tapeworms is beef tapeworm (Lat. *Taeniarhynchus saginatus*).

**External and internal anatomy of *Taeniarhynchus saginatus*.** An adult worm is up to 10 meters in length. The scolex has *four suckers but no hooks* (fig. 100). The neck is the tapeworm's growth zone which forms new (immature) segments. The parasite grows all its life. Segments of the middle of the body contain both male and female reproductive systems. Such segments are called mature (or hermaphroditic). Segments in the rear end of the body are gravid. Such segment contains uterus with large amount of eggs.

The **life cycle** of beef tapeworm is complex (fig. 101).

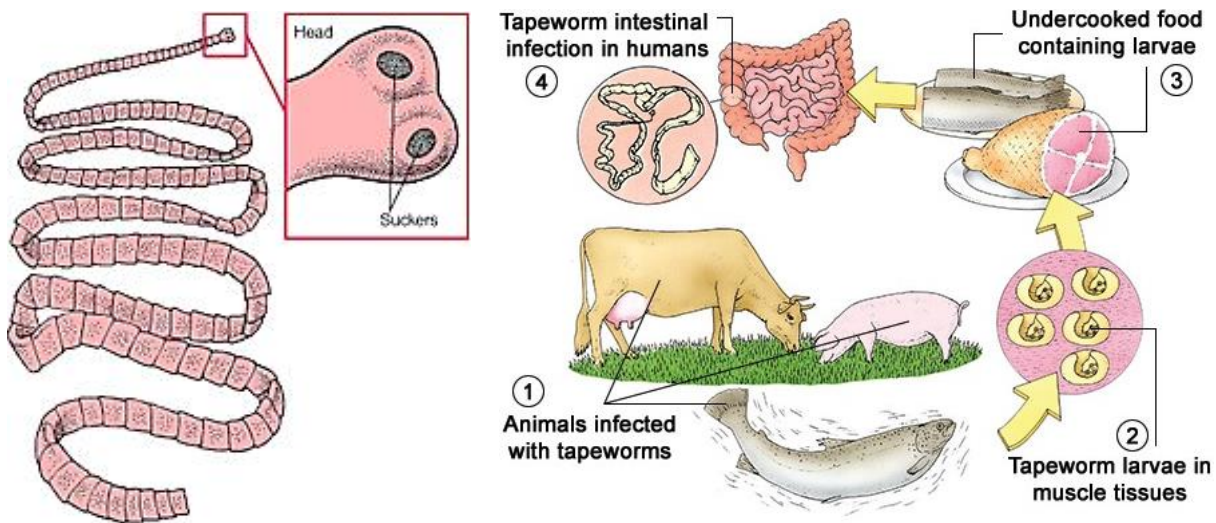


Fig. 100. *Taeniarhynchus saginatus*

Fig. 101. The life cycle of tapeworms

The *definitive host* of the beef tapeworm is human. Mature segments with eggs separate from the worm's body and are excreted with feces. Cattle is the *intermediate host* which swallows the eggs with contaminated grass. In the small intestine, a larva with hooks called *oncosphere* leaves the egg. With hooks it perforates the intestinal wall and get to the blood vessels. The larvae can move to all parts of the body by the circulatory system, and finally settle in skeletal muscles. Inside skeletal muscles the second larval stage is formed. It is called the *mease* (*cysticercus*).

Cysticercus looks like a little sphere containing the head of a young beef tapeworm. Humans can become infected by eating raw or undercooked meat with cysticerci. In the small intestine of humans, the cysticerci develop into adult worms.

*Taeniarhynchus saginatus* absorbs nutrients in the human body; its suckers destroy the intestinal mucosa; metabolic products of tapeworm are toxic for humans. All of these changes in the human body lead to the development of the disease. The group of diseases caused by tapeworms is called *cestodoses*.

Prophylaxis of cestodosis:

1. Proper cooking of beef;
2. Identification and treatment of affected persons.

There are many other tapeworms causing human diseases, e.g. pork tapeworm (*Taenia solium*), broad tapeworm (*Diphyllobothrium latum*), dwarf tapeworm (*Hymenolepis nana*) can parasite in the small intestine of human.

## 6. PHYLUM NEMATHELMINTHES (ROUNDWORMS)

The phylum *Nemathelminthes* has five classes that include more than 15 500 described species. The most significant class of the phylum is *Nematoda*.

There are free-living nematodes living in fresh and sea water, soil, decomposing matter and parasites which may live in plants, in the body of human and other animals.

**External anatomy** (fig. 102). Bodies of nematodes are not segmented. They appear round in cross section and for this are called roundworms. The body length of different nematodes varies from a few millimeters to several meters.

The anterior end of the body has mouth and the posterior one has anal opening. The ventral side of nematodes has an opening of excretory system. In addition, there is a genital opening approximately in the middle of the body of females at the ventral side.

Roundworms have *dermo-muscular body wall*. Its external layer is cuticle which has no cellular structure and mostly consists of proteins. In parasites it provides resistance to digestive enzymes and immune system of the host. The cuticle is secreted by the underlying layer of epithelial tissue that is called hypodermis. The innermost layer in the body wall of nematodes is a single layer of longitudinal muscles. Contractions of these muscles bend the body and cause serpentine movements.

**Internal anatomy.** Body cavity is *primary (pseudocoel)*. This is the body cavity developing from the primary cavity in embryo which has no mesodermal lining. The cavity contains fluid which bathes digestive system, reproductive organs and the body wall. Fluid performs the function of hydrostatic skeleton and passively transports substances within the body. Roundworms have no circulatory and respiratory systems.

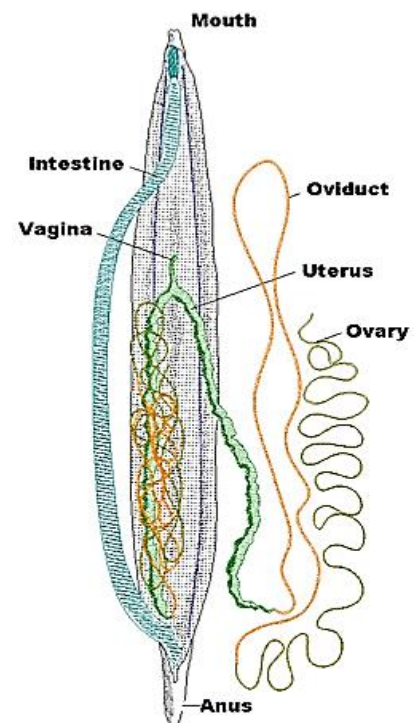


Fig. 102. The anatomy of *Ascaris lumbricoides*

The *digestive system* (fig. 103) of nematodes consists of three regions: foregut (mouth, pharynx and esophagus), midgut and hindgut which ends with the anus. In some species the mouth is surrounded by cuticular lips, others have cuticular outgrowths — teeth.

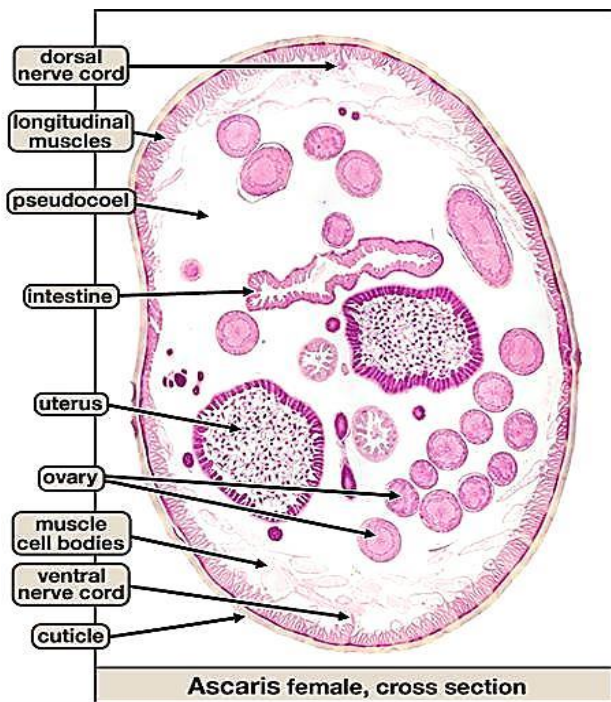


Fig. 103. Cross-section of a female *Ascaris lumbricoides*

Free-living roundworms feed on decaying organic matter and small invertebrates. Intestinal parasites feed on tissues and fluids of the internal environment of the host. Undigested food is removed through the anus.

*The excretory system.* Ammonia is released through the body surface. There are also 1–2 large gland cells similar to protonephridia. There are two lateral channels extending from them. The channels end blindly within the body but have excretory pore on the anterior ventral body surface. In addition, liquid products of metabolism are neutralized by phagocytic cells, which are located along the excretory channels.

*The nervous system* consists of two cerebral ganglions, circular nerve

ring surrounding the pharynx and 4 nerve cords. Dorsal and ventral nerve cords are developed better. Roundworms have *organs sensitive* to touch and organs of chemical senses.

*Reproductive system.* Most roundworms have separate sexes. Sexual dimorphism is expressed: males are smaller than females, and the rear end of the male body is coiled on the ventral side. The reproductive system has the form of tubes.

The male reproductive system is unpaired and consists of testis, seminal duct and ejaculatory duct. The female reproductive system is paired and consists of two ovaries, two oviducts, two uteri and one unpaired vagina.

Reproduction is sexual, insemination is internal. *Development is indirect* (with metamorphosis). It often occurs without a change of hosts and the larva develops in soil or water. Development is accompanied by molting. Some species tend to viviparity. Parasitic roundworms are characterized by complex life cycles.

*Significance of roundworms:* They are components of ecosystems and are food for many other organisms. They participate in soil formation, many of them are causative agents of parasitic diseases.

*Ascaris lumbricoides* is a parasitic nematode which affects humans. The length of a female is 15–40 centimeters; that of a male is about 15–25 cm. Living parasites are of white-pink color. Their bodies are cylindrical and tapered at ends. Sexually mature individuals live in the small intestine.

**Life cycle.** A fertilized female lays up to 240 000 eggs per day. They are passed to the environment with feces. If conditions are favorable (temperature 20–25 °C, humidity, presence of oxygen), a larva develops in the egg in 2–3 weeks and the egg becomes infective. An infective egg can be ingested by a human host with unwashed vegetables, fruit and water. Larvae hatch from the eggs in the small intestine, perforate its wall and migrate through the blood vessels. They migrate through the liver, right atrium and right ventricle and reach lungs. From alveoli, larvae ascend into bronchioles, bronchi, trachea and get into the pharynx where they are swallowed. Larvae migration lasts about 2 weeks. In 3 months, they transform into sexually mature forms in the small intestine. The life span of the mature *A. lumbricoides* is about 1 year.

*Ascaris* causes the disease *ascariasis*. These parasites consume nutrition from the host organism. The larvae injure the intestine wall, blood vessels and respiratory tract and excrete toxic metabolic products.

**Prophylaxis of ascariasis:**

1. Observance of individual hygiene.
2. Washing the vegetables and fruits.
3. Protecting food from flies and cockroaches.
4. Preventing pollution of the soil and water with feces;
5. Revealing and treatment of infected persons.

There is a number of other parasitic roundworms such as *pinworms*, *guinea worms*, *filariae*. Diseases caused by roundworms are called *nematodoses*.

## 7. PHYLUM ARTHROPODA

**The phylum *Arthropoda*** is the most numerous one in the whole nature. More than 1 million species belong to arthropods.

Habitat of arthropods are land, air, soil and water. The phylum includes free-living species and parasites of human, animals and plants.

**The phylum *Arthropoda* consists of three classes:**

1. *Crustaceans* (crawfishes, langoustes and shrimps);
2. *Arachnids* (spiders, scorpions, ticks and mites);
3. *Insects* (flies, butterflies, beetles, mosquitoes and others).

Most of arthropods have bodies made of segments. The range of body sizes is from 0.1 mm to 1 m; ***Segments form body regions:***

- three: head, thorax, abdomen (insects);
- two: cephalothorax, abdomen (crawfishes (fig. 104) and arachnids).

Bodies of ticks (and mites) are solid and do not have regions.

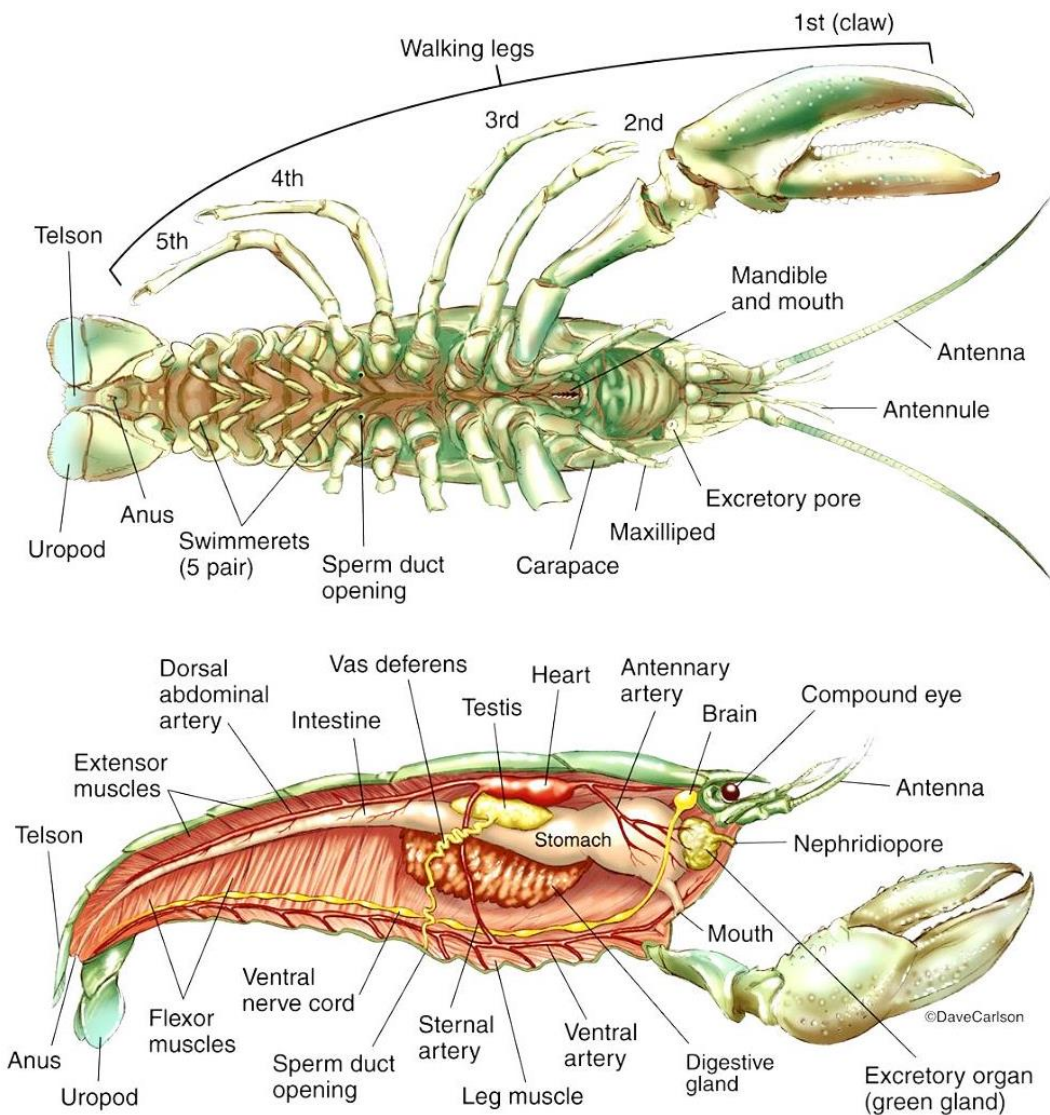


Fig. 104. The anatomy of crawfish

**Body coverings.** Arthropods are covered with organic compound *chitin*. It is an exoskeleton that protects and supports the arthropod's body. Striated muscles are also attached to such chitinous exoskeleton.

As the chitin limits the growth of arthropods, they periodically undergo molting when they leave their chitin and replace it with a new one.

**Organs of locomotion.** All arthropods have jointed appendages (consist of segments). They can be modified to perform various functions: walking, feeding, protection from enemies and etc. Arthropods of different classes have different number of walking legs: crustaceans have 5 pairs, arachnids have 4 and insects — 3.

**Internal anatomy.** The body cavity is formed by confluence of the primary and secondary body cavities. Such cavity is called *mixocoel*. It is filled with fluid called hemolymph. It is colorless liquid functions of which are similar to both those of blood and interstitial fluid.

*The digestive tract* consists of 3 regions (foregut, midgut, hindgut). They are differentiated into regions (esophagus, stomach and etc.) There is a complex apparatus of appendages near the mouth. They are specialized for different types of feeding.

*The excretory organs* are green and coxal glands (in crustaceans and arachnids respectively) or *Malpighian tubules* (in insects and arachnids). Malpighian tubules are outgrowths of the gut between the midgut and hindgut.

Insects have *fat body* — the organ which performs many metabolic functions such as storage of glycogen and lipids, and, in addition, accumulates some metabolic wastes.

*The circulatory system* of arthropods consists of a heart and, in spiders, a number of vessels. The heart is located at the dorsal side of the abdomen (fig. 105). Hemolymph (blood of arthropods) is colorless or blue. As soon as the circulatory system is open, hemolymph passes from the heart to the body cavity and bathes the organs.

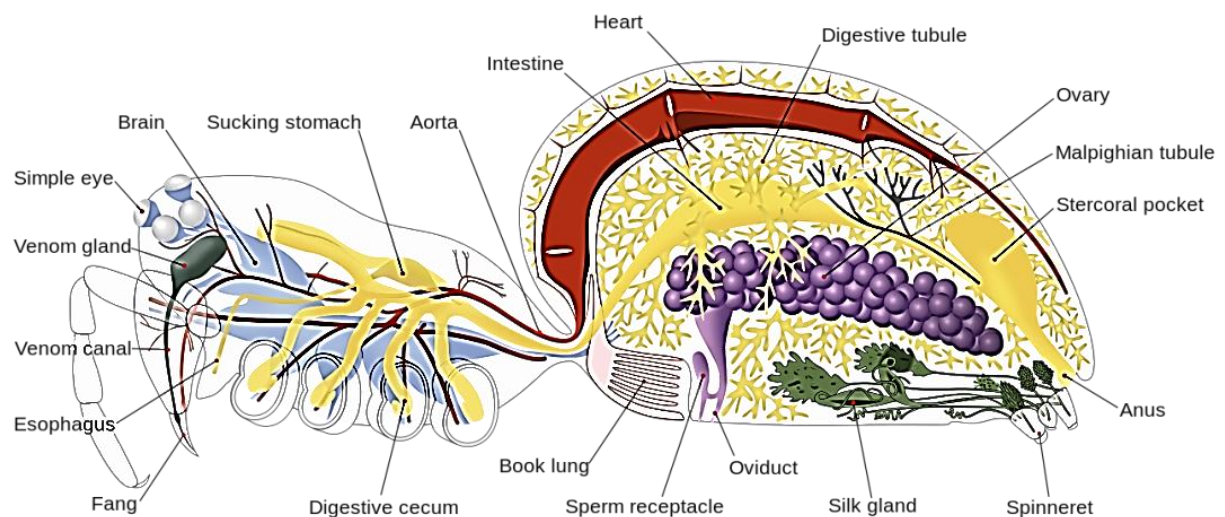


Fig. 105. The anatomy of spider

*The respiratory organs* of arthropods are various: aquatic ones breathe with gills while the terrestrial ones use book lungs or trachea.

*The nervous system* includes a cerebral ganglion («the brain»), circumpharyngeal nerve ring and ventral nerve cord. All *sense organs* are developed in arthropods: the organs of sight, smell, touch, taste, hearing, and equilibrium.

*The reproductive system.* Arthropods have separate sexes. Males and females are different in body sizes and color. Such difference between different genders of one species is sexual dimorphism.

Reproduction of arthropods is sexual. *Development is direct or indirect (with metamorphosis).* Direct development is observed when individuals which hatch from eggs are similar to adults. It is typical for spiders. Indirect development is

characterized by transitional stages between the egg and the adult. *Metamorphosis* of the indirect development can be of two types: complete or incomplete. The first type consists of 4 stages: *egg, larva, pupa, adult*. Such metamorphosis is characteristic of flies, butterflies and mosquitoes. The second one, the incomplete metamorphosis, includes just 3 stages: *egg, larva and adult* — the stage of pupa is absent. Such development is characteristic of bugs and lice.

## 8. CLASS ARACHNIDA

**The class Arachnida** (arachnids) includes about 75 thousand species.

Arachnids are terrestrial animals. Most of species are free-living, some of them are parasites of human and animals.

The class includes **spiders, scorpions, ticks and mites** (the name for some arachnids belonging to the same subclass with ticks; i.e. mites can be considered as a type of ticks). Body sizes are from 0.3 mm (itch mite) to 30 cm (bird spider).

**External anatomy.** Bodies consist of two regions: cephalothorax and an abdomen. The cephalothorax carries 6 pairs of appendages, two of them are near the mouth. The first pair is two *chelicerae* and the second pair is two *pedipalps*. Spiders paralyze their prey with venom. The ducts of venomous glands open at the tips of chelicerae. Holding the prey is performed by pedipalps which are also organs of taste and touch. Pedipalps of scorpions are transformed into long chelae. The other 4 pairs of arachnids' appendages are long and thin walking legs with little claws.

Abdomen is not segmented and does not have any appendages, but there are respiratory, genital and anal openings. There are also spinning glands inside of the abdomen where spider silk is synthesized. Spiders use it to weave a web for hunting, a nest and a cocoon.

*Body covering.* The body of the spider is covered with cuticle which is saturated with chitin. It is an exoskeleton that protects and supports the body. Below the cuticle, hypodermis and striated muscles are found.

**Internal anatomy** (fig. 106). *Digestive system* includes foregut, midgut, hindgut. Predatory arachnids eat other organisms, parasites may feed on host's blood or plant juices. Digestion starts outside the digestive system: enzymes of salivary glands are injected into the prey. Muscular pharynx and pumping stomach help the spider to suck in liquid food. Ducts of the liver open into the midgut. Branches of the midgut also extend into the abdomen and surround other bodily structures. This large and extended digestive tract allows spiders to survive for many days without feeding. The process of digestion completes there. Undigested remains of food are passed through the hindgut and eliminated through the anal opening.

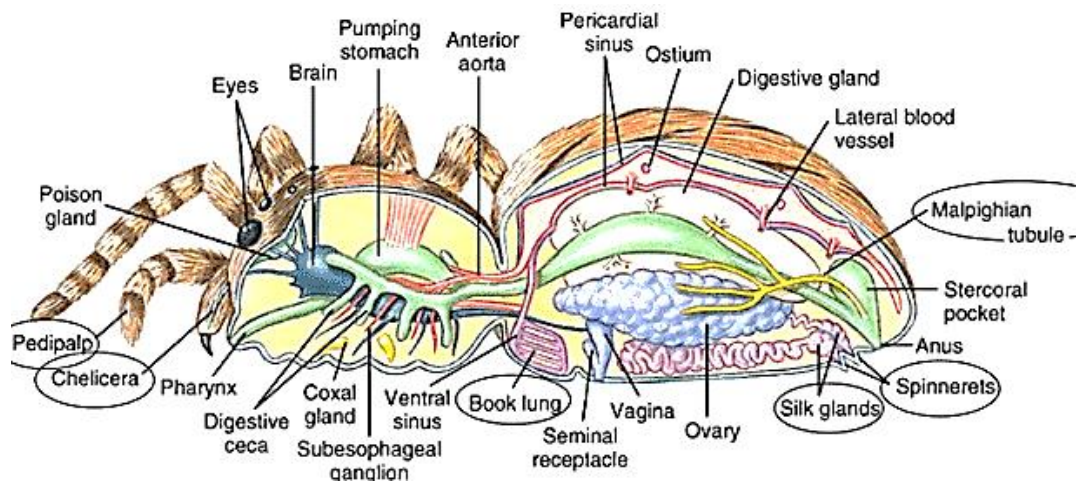


Fig. 106. The internal anatomy of spider

*Excretory organs* of arachnids are *coxal glands* and *Malpighian tubules*. Coxal glands open on the body surface near the walking legs while the Malpighian tubules join into the digestive tract between the midgut and hindgut.

*The circulatory system* of arachnids is open. The tubule-shaped heart is situated at the dorsal side of the abdomen. Hemolymph is pumped from the heart to the body cavity where it bathes the respiratory organs.

*Respiratory system* of arthropods includes book lungs and trachea. Book lungs are respiratory organs that lay in the anterior of the abdomen. Tracheae are tubules found in its posterior side; they are open outwards by openings called spiracles.

*Nervous system* consists of a cerebral ganglion, ventral nerve cord and nerves. Sensory organs: simple eyes situated on the cephalothorax; there are also organs of smell and chemical sense.

*Reproductive system.* Arachnids have sexual reproduction and separate sexes. Fertilization is internal. Gonads (sex glands) are paired, they are located in the abdomen. Development of spiders is direct: female lays eggs to the cocoon made of spider silk and little spiders hatch from it in spring. Scorpions are viviparous. Ticks develop with metamorphosis.

**Ticks and mites.** The class Arachnida has the order Acari which includes ticks and mites. They are small arachnids with body sizes 0.3–0.5 cm or less, but after feeding with blood they can dilate to 1 cm. Ticks live in the soil and bird nests, they are parasites of human, animals and plants. Ticks have no body regions, their chelicerae and pedipalps may form capitulum for biting and blood meals. Their anatomy is simplified: many ticks have no circulatory system and no eyes. Ticks eat plant juices or host's blood. Their reproduction is sexual, development goes with incomplete metamorphosis.

Ticks and mites are significant for medicine. Ticks of the families *Ixodidae* and *Argasidae* feed on blood of animals or human and can transmit encephalitis or typhus.

*Itch mites* live in the human skin. Their sizes are about 0.3 mm. Females gnaw through the skin forming tunnels where they move and lay eggs. This causes severe itching. This disease is called scabies. First of all, mites inhabit skin between fingers and at the lower regions of the abdomen and then they spread across the whole body. Preventing the disease is possible by observing the hygiene rules: do not use someone else's dress, gloves, shoes, bedclothes.

## 9. CLASS INSECTA

**The class *Insecta*** includes about 1 million species.

*Habitat.* Insect inhabit land, soil and air.

*Way of life:* Most of species are free-living, some of them are parasites of humans and animals.

Bodies have sizes from 1–2 mm to 30 cm. *Body covering* of insects is cuticle consisting of chitin, there are hypodermis and striated muscles below the cuticle. During molting, the organism sheds its old chitinous exoskeleton, which is then replaced by a new one. Insect bodies grow only at such periods. *Body regions* are head, thorax and abdomen. The head carries a pair of antennae, eyes and mouthparts.

*Organs of locomotion* are 3 pair of segmented appendages at the ventral side of the thorax and one or two pairs of wings at its dorsal side. Some parasitic insects such as lice and fleas do not have wings.

**Internal anatomy** (fig. 107). *Digestive system* includes foregut, midgut and hindgut. Foregut begins with mouth. There is a complex apparatus of appendages near the mouth — *mouthparts*. They are specialized for different types of feeding. The appendages of the mouthparts are upper and lower labia (lips), a pair of maxillae (lower jaw) and a pair of mandibles (upper jaw). The structure of mouthparts depends on manner of feeding: beetles feeding on solid food have chewing mouthparts (chewing insects), mosquitoes feeding on blood have piercing and sucking mouthparts (piercing and sucking insects).

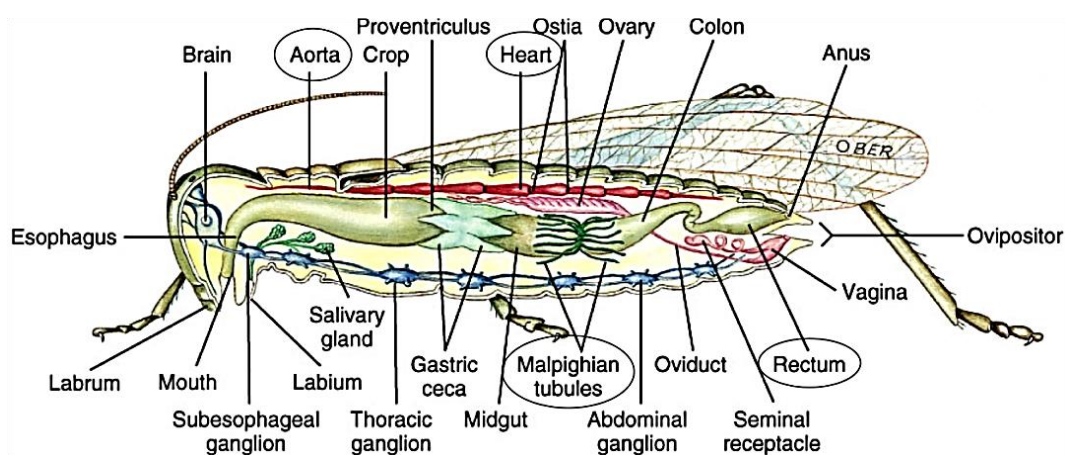


Fig. 107. The internal anatomy of grasshopper

The foregut includes the mouth, pharynx, esophagus, crop, proventriculus. Ducts of salivary glands open into the oral cavity. The midgut includes the ventriculus (stomach) with gastric ceca. The posterior region of the digestive tract is hindgut. Insects have no liver. Digestive enzymes are released by the wall of the midgut. Digestion and absorption of nutrition also occur in the midgut.

*Excretory organs* are *Malpighian tubules*. The Malpighian tubules are open into the digestive canal between the midgut and hindgut. Insects have *fat body* which is the organ performing many metabolic functions such as storage of glycogen and lipids. In addition, some metabolic wastes can be accumulated there.

*Circulatory system* is open. The heart having the shape of a tubule lies in the abdomen at the dorsal side above the gut. Colorless blood of insects is called hemolymph. It delivers nutrition to organs and tissues, participates in excretion of metabolic wastes and performs protective function.

*Respiratory system* of insects is represented by *trachea*. They are branching tubules bringing oxygen to all organs and tissues. Openings of the trachea are called *spiracles*. They are situated on the sides of the abdomen and thorax.

*Nervous system* of insects is complex. It composed of cerebral ganglion, ventral nerve cord and nerves. The cerebral ganglion is highly developed and is often called the brain. It is responsible for complex behavior of insects. It consists of 3 regions forebrain, midbrain and hindbrain. Hindbrain innervates mouthparts, midbrain — antennae, forebrain — eyes.

Insects have developed *sense organs*. Organs of sight are compound eyes (also known as facet eyes) on the head. Such eyes are made of many little eyes. Besides, the head carries antennae performing functions of touch and smell organs. Some insects have also hearing organs.

*Reproductive system*. Insects have sexual reproduction and are of separate sexes. A pair of reproductive glands are in the abdomen. Development of insects occurs with incomplete or complete metamorphosis. The first one is typical for cockroaches and grasshoppers, the second one is typical for beetles and butterflies.

**Significance of insects.** In the nature insects are necessary origin of food for other animals; the great number of them are pollinators of flowering plants. Many of them eliminate other harmful insects. Humans use insects for scientific researches and as origin of medicine (bee venom, propolis). In some cases, insects can be used as a source of food (honey).

Insects-parasites have medical significance. Some of them cause human diseases e.g. lice causing pediculosis. Others are carriers of diseases, for example, fleas are carriers of bacteria causing plague, the mosquitoes of the genus *Anopheles* are carriers of the protists causing malaria. Many insects are venomous (e.g. bees and wasps).

## 10. PHYLUM CHORDATA

**The phylum Chordata** includes approximately 50 000 species.

Chordates are widely spread around the whole world. Various species have different sizes, morphology and way of life. A considerable number of them are predators. Chordates have complex anatomy and behavior. The bodies have bilateral symmetry. All their organ systems develop from 3 germ layers: endoderm, mesoderm and ectoderm. Body cavity is secondary. It is called *coelom*.

**General anatomic peculiarities.** All chordates have *skin*. Its outer layer is epidermis that is epithelial tissue, the inner layer is dermis made of connective tissue.

*Embryos of all chordates have axial supporting organ notochord.* In most of adult chordates, it is replaced with a spine.

Above the notochord is *nerve tube*. Its cavity is *neurocoel*. Nerve tube is the origin of the brain and spinal cord. Chordates have developed sensory organs: sight, smell, taste, hearing, touch.

Below the notochord is *the alimentary tube*. It consists of anterior, middle and posterior regions. The anterior region of the tube has pharyngeal slits (gill slits) In aquatic animals they give rise to breathing organs — *gills*. Terrestrial chordates breathe with *lungs*. Their gill slits develop into other organs.

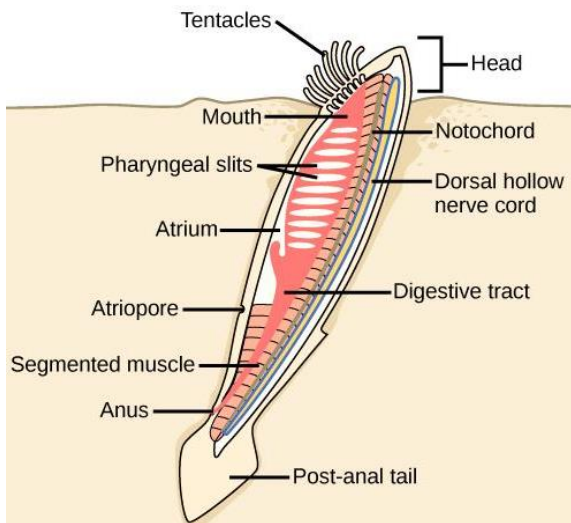


Fig. 108. The anatomy of lancelet

The *circulatory system* is closed and composed of one or two circulations (fig. 108). The heart is situated at the ventral side below the alimentary tube.

The *excretory organs* of chordates are nephridia or kidneys. Higher chordates may have mesonephric (primordial) kidneys or metanephric (pelvic) ones.

*Reproductive system.* Reproduction of chordates is sexual. Most of them have separate sexes. Development can be direct or indirect.

### **Taxonomy of chordates.**

The phylum is divided into two subphyla: *acranials* (includes the class lancelets) and *cranials* (includes classes cartilaginous fishes, bony fishes, amphibians, reptiles, birds and mammals).

*Acranials* means «have no skull». The subphylum is represented by the class *lancelets* which have no skull and brain. Lancelets are one of the simplest chordates, though they have all typical anatomical peculiarities of chordates.

Lancelets inhabit the sand at the bottom of ponds.

**External anatomy.** Lancelet has streamline body shape, its length is approximately 4–8 cm. The body regions are head, trunk and tail. *Body covering* is skin consisting of simple (single-layer) epidermis and jelly-like dermis. Skin has glands producing mucus. Due to the absence of pigment cells, body coverings are transparent. Skin creases form fins that are organs of locomotion. There are segmented muscles that lay in the body as two tapes.

**Internal anatomy.** The notochord is the axial skeleton.

*Nervous system* is a nerve tube lying above the notochord. It has a cavity called *neurocoel*. The anterior end of the nerve tube has olfactory cells. There are photosensitive cells in the nerve tube.

*Feeding.* Lancelets are inactive filter feeders. The oral cirri near the mouth propel water containing small organisms to the mouth. Water is removed through gill slits. Food passes into the pharynx and then to the digestive tract where it is digested. Undigested remains are excreted through the anal opening.

Pharyngeal wall has about 100–150 pairs of *gill slits*. Breathing of the lancelet occurs at the same time with feeding. Gas exchange occurs in the vessels of gill slits.

*Excretory organs* are tube-shaped nephridia lying segmentally alongside the pharynx.

*Circulatory system* is closed; pulsing ventral aorta substitutes the heart. Blood is colorless due to the absence of respiratory pigments.

*Reproductive system.* Reproduction of lancelets is sexual. They have separate sexes. There are 25 pairs of gonads alongside the pharynx. Fertilization is external, development occur in the water. Development is indirect.

At the end of 19th century Russian biologist A. Kovalevsky defined similarities of lancelets with vertebrates and invertebrates:

**Similarities of lancelets with invertebrates:** bilateral symmetry; 3 germ layers; single-layer epithelium; segmental localization of muscles, gonads and nephridia; low differentiation of the digestive system; passive feeding; absence of the brain and heart.

**Similarities of lancelets with vertebrates:** notochord; nerve tube above the notochord; alimentary tube below the notochord; gill slits; the central pulsing blood vessel is in the abdominal side.

## 11. CLASS OSTEICHTHYES (BONY FISHES)

About 28 000 species belong to the **class Bony fishes**.

**External anatomy.** Body of fishes consists of head, trunk and tail. Its shape is streamline. The organs of locomotion are fins. There are paired and single fins. Pectoral (breast) and ventral (abdominal, pelvic) fins are paired. Their function is turning the body and maintaining its equilibrium. Dorsal (back), anal (proctal) and caudal fins are single. They provide body stability and locomotion (fig. 109).

The *body covering* is skin with bony scales. The skin consists of stratified epidermis covering the dermis. Simple unicellular glands produce mucus which facilitate swimming and protect the fish from pathogens causing diseases.

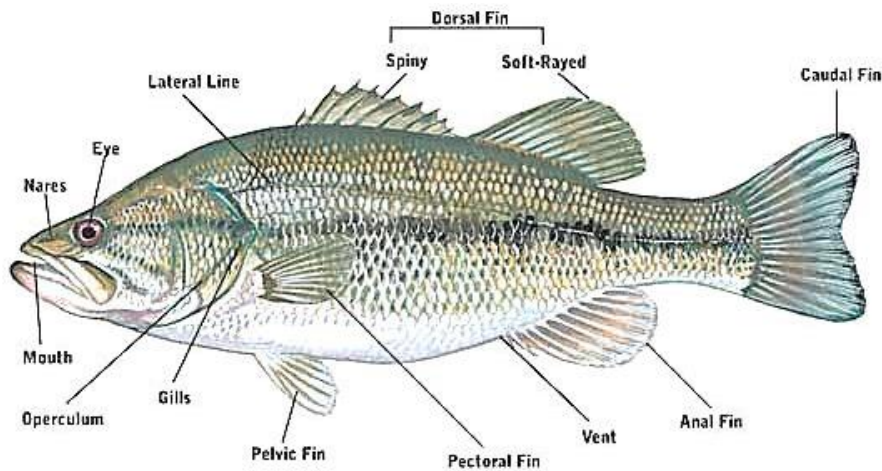


Fig. 109. The external anatomy of fish

**Internal anatomy.** The *skeleton* of fishes is made of bone and cartilage. It supports the body and all organs. Two massive “tapes” of muscles are attached to the bones. There are skeletons of the head, trunk and fins. The head skeleton is skull grown together with the spine and thus forming immovable connection. The skull consists of a neurocranium and visceral cranium. The neurocranium protects the brain and sense organs while the visceral cranium is associated with digestive and respiratory organ systems. The trunk skeleton is the spine. It consists of vertebrae and includes truncal and caudal regions. Truncal vertebrae have ribs.

The *digestive system* includes mouth, pharynx, esophagus, stomach, small and large intestine and ends with anus (fig. 110). There are jaws with teeth in the oral cavity. The wall of the pharynx has openings called gill slits. Fishes have digestive glands such as liver (with a gallbladder) and pancreas.

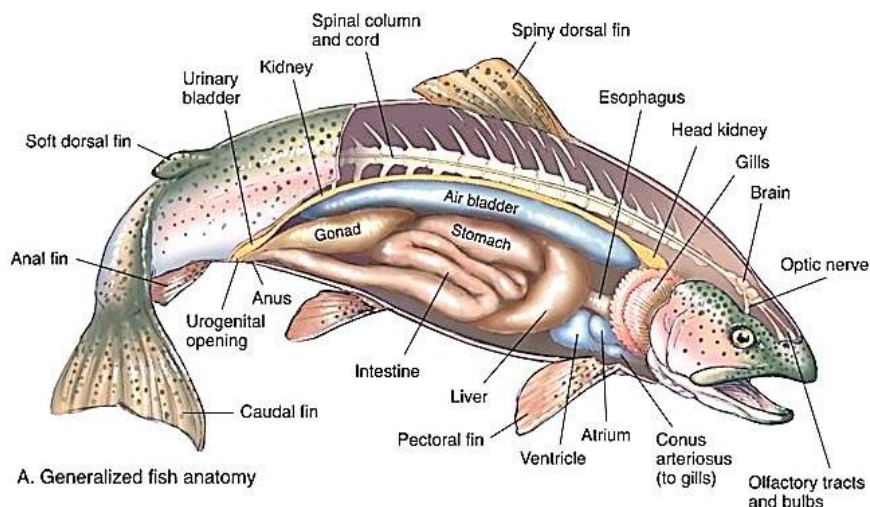


Fig. 110. The external anatomy of fish

Specific organ of fishes is a *swim bladder*. It is an outgrowth of the esophagus which is filled with gases. Fishes increase the volume of gases to ascend and decrease it to descend in water.

*Excretory organs* of fishes are two mesonephric kidneys situated in the dorsal side of the body cavity. They form urine which passes to the urinary bladder through ureters and then excreted from the body through the urethra.

*The circulatory system* is closed. There is only one circulation. The heart of fishes consists of one atrium and one ventricle (two-chambered heart). It is filled with venous (unoxxygenated) blood.

*The respiratory organs* of fishes are gills where gas exchange occurs. Fishes breathe with oxygen that is dissolved in the water.

*The central nervous system (CNS)* consists of the brain and the spinal cord. The brain consists of 5 regions: telencephalon, diencephalon, mesencephalon, metencephalon and medulla oblongata. The most developed one is the midbrain where centers of sight are found. The cerebellum that is responsible for complex motions of fish is also well-developed. Fishes have all *sense organs* (sight, hearing, smell, taste and touch).

*The organs of sight* are eyes that have spherical lenses and flat corneas. It explains why fishes can clearly recognize only closely situated objects (up to 15 m).

*The hearing organ* of fishes is simple. It consists of inner ear that is not connected with the environment. Due to high density of water sound waves are conducted by skull bones and perceived by the ear.

Another especial organ of a fish is a lateral line that feels the direction of water current.

*Reproductive system.* Reproduction is sexual, fishes have separate sexes. External fertilization with further indirect development occur in water. The larva hatching from the egg of fish is called fry.

## 12. CLASS AMPHIBIA

**The class *Amphibia*** counts about 8100 species. Amphibians were first terrestrial chordates on Earth. Their development occurs in the water and adults live on the land. There are 3 orders in the class *Amphibia*:

1. *Anura* (frogs and toads).
2. *Caudata* (salamanders and newts).
3. *Apoda* (Gymnophiona, caecilians).

Body regions of amphibians are head, trunk, two pairs of limbs and sometimes tail. The limbs are five-fingered.

*Body covering* is skin. Its layers are epidermis and dermis. The skin of amphibians is thin. It has many blood vessels and glands producing mucus. This makes the skin of amphibians wet.

Amphibians have the *skeleton* of the head, axial skeleton (skeleton of trunk) and the skeleton of limbs. The head skeleton (skull) consists of a neurocranium and visceral cranium. It is movably connected with the spine. The axial skeleton has spine which consists of cervical, truncal, sacral and caudal regions (4 regions). The Anura (tailless amphibians) lack the caudal region. Ribs and chest are absent.

The skeleton of a forelimb is composed of the bones of upper arm, bones of forearm and bones of the palm.

The bones of the pectoral girdle are sternum (breastbone), coracoids, clavicles (collar bones) and scapulae (shoulder blade).

The skeleton of the hind limb includes femur (hip), tibia with fibula (shin) and bones of foot.

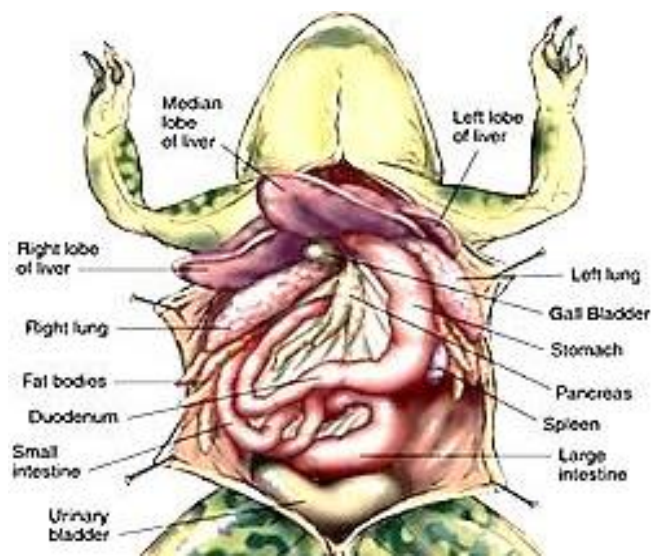


Fig. 111. The internal anatomy of frog

The *digestive system* (fig. 111) begins from the oropharyngeal cavity with a tongue and small teeth on the upper jaw. Eyes participate in swallowing food. They are drawn-in to the oropharyngeal cavity by muscles for pushing a portion of food. Amphibians have salivary glands but the saliva has no digestive enzymes and thus just moistens the food. Digestion begins in the stomach and is finished in the small intestine. Other glands of the digestive system are the liver and pancreas. The terminal region of the gut is cloaca through which undigested remains of food are eliminated.

The *excretory organs* are mesonephric kidneys. Kidneys and the urinary bladder open into cloaca.

The *respiratory organs* of larvae of amphibians are gills while adult animals breathe with lungs and body surface. The wall of lungs is thin and has numerous blood vessels. Respiratory tract consists of only by laryngotracheal chamber with vocal apparatus. Air is pumped to the lungs by contraction of muscles of the oropharyngeal cavity.

*Circulatory system.* The heart of amphibians is three-chambered. It consists of two atria and one ventricle. There are systemic and pulmocutaneous (Lat. “lungs” and “skin”) circulations. The first one begins from the ventricle. It carries oxygenated blood to all tissues and then venous blood returns to the right

The pelvic girdle is made of pelvic bones.

The most developed *muscles* in amphibians are those of hind limbs, head, abdomen and oral cavity.

The *digestive system* (fig. 111) begins from the oropharyngeal cavity with a tongue and small teeth on the upper jaw. Eyes participate in swallowing food. They are drawn-in to the oropharyngeal cavity by muscles for pushing a portion of food. Amphibians have salivary glands but the saliva has no

atrium. Blood of the pulmocutaneous circulation is pumped from the ventricle to the lungs and skin and then back to the left atrium. All organs except the brain are supplied with mixed blood. The brain is supplied with arterial blood.

The *body temperature* of amphibians depends on the environmental temperature. Such organisms are called cold-blooded (poikilotherm) animals.

*Nervous system.* The brain of amphibians consists of 5 regions: telencephalon, diencephalon, mesencephalon, metencephalon and medulla oblongata. The telencephalon is developed better than that of fishes and has two hemispheres. Cerebellum is developed less than that of fishes. It is associated with simplicity of their movements and low mobility.

Amphibians have all types of *sense organs*. They include the organs of sight, hearing, smell, taste and touch. Eyes can see the objects that are relatively far. It is possible due to a biconvex lens and convex cornea. There are upper and lower lids and nictitating membrane near the eyes. The lids protect the eyes from desiccation. The hearing organ consists of inner and middle ears. The middle ear is separated from the environment by an eardrum and contains one ossicle. Olfactory function is performed by nostrils. There are taste receptors on the tongue and touch receptors on the skin. Aquatic and larval amphibians have lateral line.

*Reproductive system.* The reproduction is sexual, sexes are separate. Fertilization is external and occurs in water. The development is indirect.

The larva of amphibians (tadpole) and is similar to a little fish: it has streamline shape, fins, gills, two-chambered heart, one circulation, lateral line. That is the evidence that fishes are ancestors of amphibians (fig. 112).

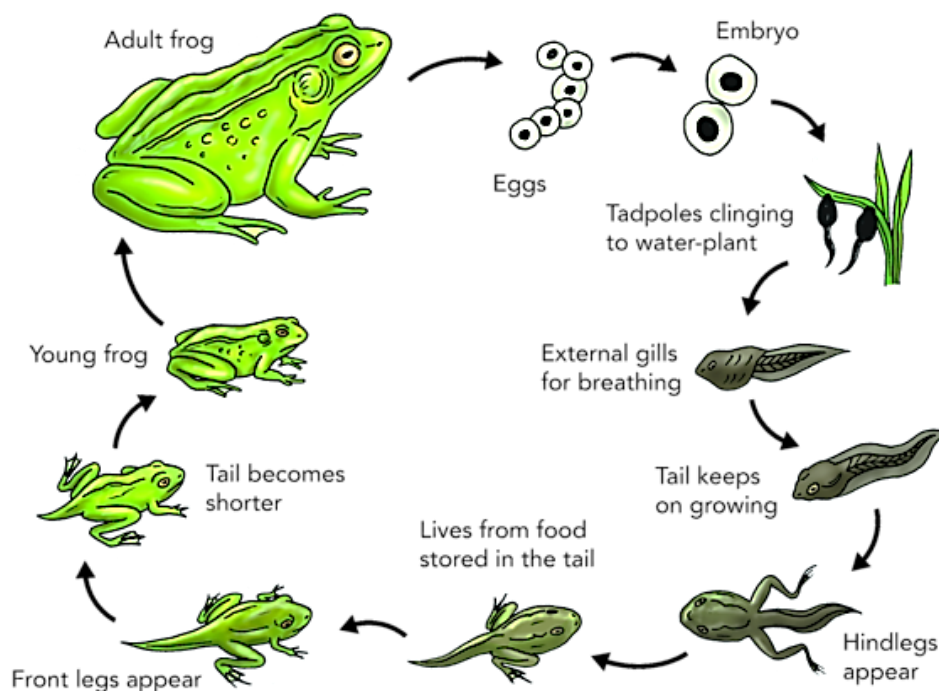


Fig. 112. The life cycle of frog

### 13. CLASS REPTILIA

**The class Reptilia** includes approximately 7500 living species. Reptiles often live in regions with warm climate. As soon as development of reptiles occurs on land, they are true terrestrial vertebrates.

**Orders of the class Reptilia:**

- the order *Squamata* (lizards and snakes);
- the order *Crocodylia* (alligators and crocodiles);
- the order *Chelonia* (turtles).

**External anatomy.** The *body regions* are the head, neck, trunk, tail and also two pairs of five-fingered limbs (apart from snakes that have no limbs). Lizards are able to drop their tail in case of danger and grow it again later. The process in which an organism restores its lost organs or parts is called *regeneration*. Bodies of turtles are covered with a shell consisting of bony scales anchored in the dermis. Turtles have short limbs and long movable neck.

The skin of reptiles has epidermis and dermis. It is covered with corneous scales and has no glands. Such skin prevents water loss and protects the body, but restricts body growth, so reptiles have to shed their skin periodically. This phenomenon is called molting.

The *skeleton* of reptiles is composed of the skull, the axial skeleton and the skeleton of limbs with girdles. The skull has oblong shape and consists of neurocranium and visceral cranium. It is connected with the spine movably. Reptiles are first chordates who evolved hard bony palate which separated nasal and oral cavities. The spine which is a trunk skeleton consists of cervical, thoracic, lumbar, sacral and caudal regions (5 regions). There is a chest consisting of thoracic vertebrae, ribs and breastbone.

**Muscles** of reptiles are more developed than those of amphibians. There are new groups of muscles: those of neck, fingers, intercostal, subcutaneous.

The spine of snakes has only truncal and caudal regions because the skeleton of limbs is absent. They also have no sternum and thus chest.

The skeleton of a pectoral girdle in other reptiles is has sternum (breastbone), coracoid bones, clavicles (collar bones) and scapulae (shoulder blade).

Forelimb includes bones of the upper arm, forearm and palm.

The pelvic girdle is composed of pelvic bones.

The skeleton of a hind limb includes femur (hip), tibia with fibula (shin) and bones of foot. There are claws on the fingers.

**Internal anatomy.** The *digestive system* of reptiles includes the oral cavity with teeth, pharynx, esophagus, stomach, small and large intestines. There is a primitive cecum between the large and small ones. The terminal segment of the digestive system is cloaca through which undigested food remains are eliminated. The digestive glands are salivary glands, liver and pancreas (fig. 113).

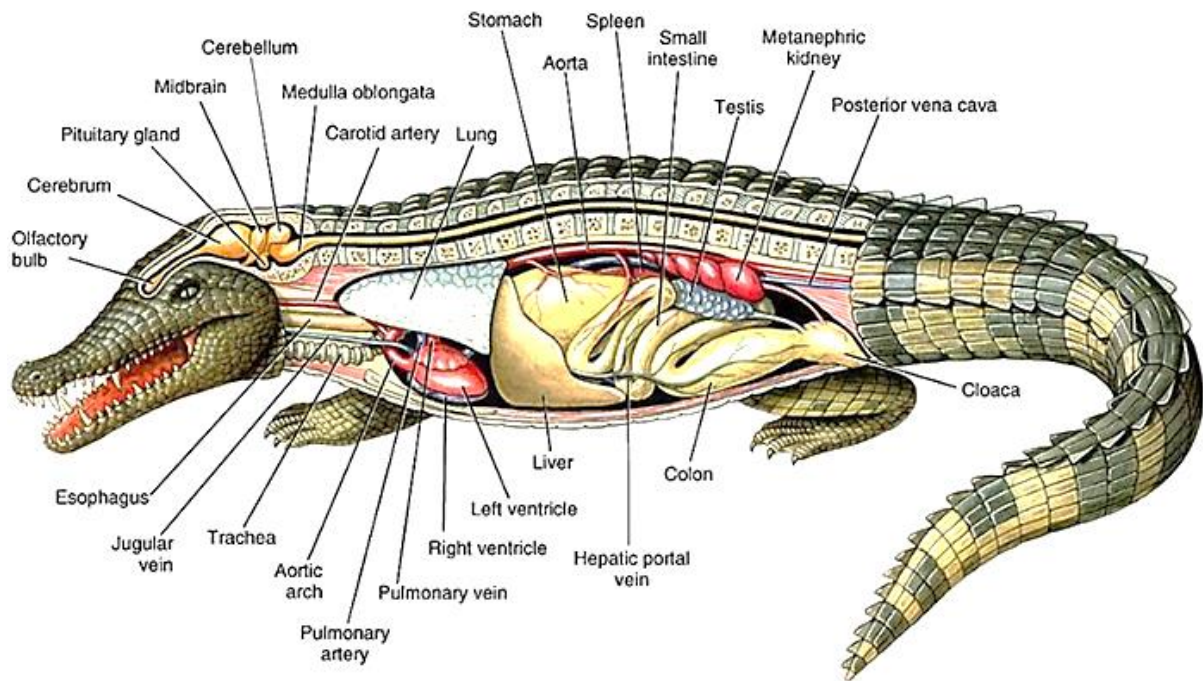


Fig. 113. The internal anatomy of crocodile

Reptiles are mostly predatory animals. Their food includes small invertebrates, fishes, and birds. Turtles feed on plant food.

*The organs of the excretory system* are paired pelvic kidneys. Ureters and urinary bladder open into the *cloaca*.

*Respiratory organs* are lungs. They have more septa than those of amphibians. Air passes there through respiratory tract: nasal cavity, larynx, trachea and two bronchi.

*Circulatory system* has two circulations. Most of reptiles have three-chambered heart with an incomplete septum in the ventricle. Crocodiles have four-chamber heart due to the complete septum. Systemic circulation starts in the ventricle (in crocodiles — left ventricle). Blood passes through all tissues and returns to the right atrium of the heart. In the pulmonary circulation, blood is pumped from the ventricle to the lungs and back to the left atrium. All organs (except the brain and forelimbs) are fed with mixed blood. The brain is supplied with arterial blood.

*Reptiles are cold-blooded (poikilotherm)*, they cannot maintain their body temperature and have to use environmental warmth.

*Nervous system.* The brain consists of 5 regions: telencephalon, diencephalon, mesencephalon, metencephalon and medulla oblongata. Cortex appeared on the hemispheres of the telencephalon. Cerebellum is developed better than that of amphibians. That explains their high mobility.

Reptiles have *all kinds of sense organs*. Their eyes have eyelids. The shape of the lens change and eyes can focus on an object. Hearing organ consists of inner and middle ears, the middle one is separated from the environment by an

eardrum. There is one ossicle. There are touch receptors on the tongue and smell receptors in the nasal cavity.

*Reproductive system.* Reptiles have sexual reproduction and separate sexes. Fertilization is internal, development is direct. Females lay eggs to the sand.

The eggs of reptiles contain much nutrients (yolk). The embryo of a reptile develops in the aquatic environment of the egg. It is possible due to an embryonic membrane called *amnion*. It provides protection from injuries and drying-out.

## 14. CLASS MAMMALIA

**The class Mammalia** includes about 5400 species. They inhabit water, land and air. Mammals are higher vertebrates. *Subclasses of the class Mammalia are:*

**1. The subclass *Prototheria (Yinotheria):***

– echidna, long-beaked echidna, platypus. They are the most primitive mammals (have cloaca, lay eggs).

**2. The subclass *Theria* includes 2 infraclasses.**

**The infraclass *Marsupials*** (newborns are poorly developed and are carried in a pouch): kangaroos, koalas, possums, marsupial wolves.

**The infraclass *Placentals*** (intrauterine development):

- the order *Insectivores*: moles, hedgehogs, muskrats;
- the order *Chiropterans*: vampires, bats, fruit bats;
- the order *Rodents*: mice, rats, gophers, beavers, squirrels;
- the order *Lagomorphs*: hares, rabbits;
- the order *Carnivores*: bears, cats, dogs, wolves;
- the order *Pinnipeds*: seals, walruses;
- the order *Cetaceans*: blue whales, dolphins;
- the order *Even-toed ungulate*: deer, roe deer, cows, pigs;
- the order *Odd-toed ungulate*: rhinos, zebras, horses;
- the order *Proboscideans*: African and Indian elephants;
- the order *Primates*: gorillas, chimpanzees, lemurs.

**Peculiarities of mammals:** hair covering, viviparity, breast-feeding, developed nervous system, complex behavior, diaphragm.

**External anatomy.** *Bodies consist* of the head, neck, trunk, tail and two pairs of limbs equipped with claws.

*Body covering.* The skin of mammals consists of stratified epidermis, dermis and subcutaneous fat (subcutaneous adipose tissue). This fat tissue helps to maintain body temperature. Mammals have hair coat which protects the body and retains warmth. Hairs are derivatives of skin: they develop from epidermis alongside with claws, nails, most of horns, toes and various glands (sweat, lacteal, sebaceous glands).

*The skeleton* consists of 3 parts: the skull, axial skeleton and the skeleton of limbs with girdles. The spine consists of 5 regions: cervical, thoracic, lumbar, sacral and caudal. The cervical one is developed well and provides high mobility of the head. All mammals have chest.

– The pectoral girdle consists clavicles and scapulae (shoulder blade). In some mammals the clavicle may be reduced or absent.

– The forelimb has bones of the upper arm, forearm and palm.

– The pelvic girdle is composed of pelvic bones.

– The skeleton of hind limb includes femur (hip), tibia and fibula (shin) and bones of foot.

The most developed *muscles* are those of the back, limbs and girdles. There is a sheet-like muscle diaphragm that divides the body cavity into two (thorax and abdominal ones).

**Internal anatomy** (fig. 114). *Digestive system.* The digestive tract consists of oral cavity, pharynx, esophagus, stomach, small and large intestines with anus. There is a cecum (blind intestine) with appendix. The oral cavity of mammals is surrounded with lips. Teeth are not uniform, but differentiated into incisors, canines, premolars and molars. Milk teeth replace with permanent ones. Mammals have developed tongue and digestive glands.

*Excretory organs* are two pelvic kidneys, ureters and urinary bladder. Urine is excreted through the urethra.

*Circulatory system.* Mammals have four-chamber heart which consists of two atria and two ventricles. The right half of the heart contains venous (unoxxygenated) blood, the left one is filled with arterial (oxygenated) blood. There are two circulations. Venous and arterial bloods are completely separated and all organs of mammals receive oxygenated blood. *Mammals are warm-blooded (homoiothermal) animals.* Their body temperature is constant and does not depend on the environment.

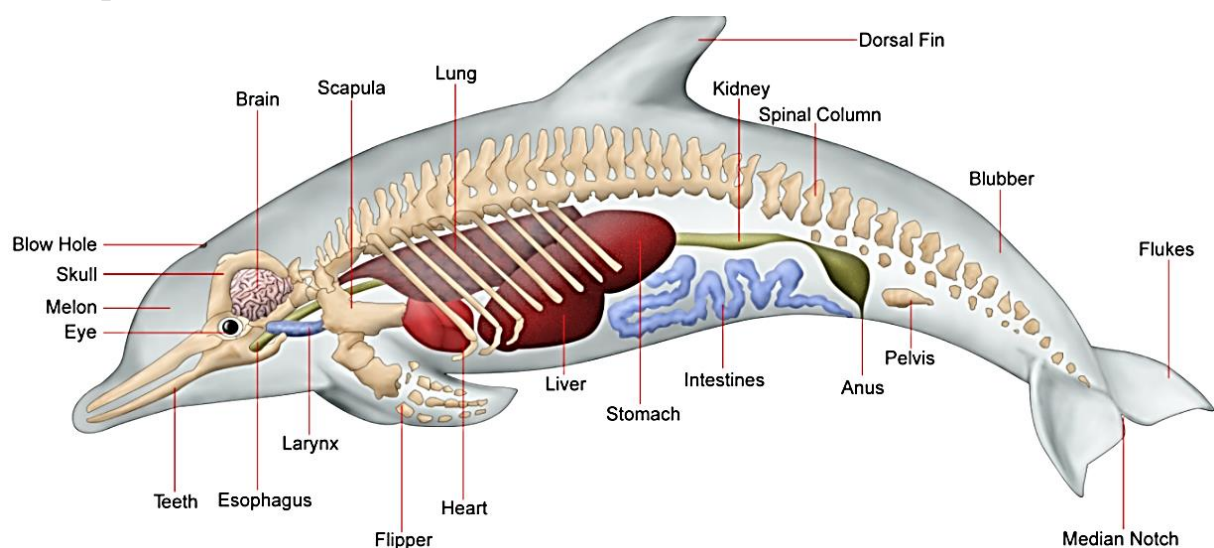


Fig. 114. The internal anatomy of dolphin

*Respiratory system.* Air passes to the nasal cavity through nostrils, then it goes to the lungs through the respiratory tracts (nasopharynx, larynx, trachea, bronchi). In the lungs bronchi branch out and form a bronchial tree.

Lungs have alveolar structure. Alveoli are little vesicle-like cavities. Gas exchange occurs there. Respiratory movements are performed by intercostal muscles and the diaphragm.

*Nervous system.* The brain of mammals consists of 5 regions. The volume of the telencephalon is high. It is covered with well-developed cerebral cortex which is the main part of the nervous system. The cortex controls functioning of the whole organism and is responsible for complex behavior.

Hearing organ consists of inner, middle and outer ears. There are three ossicles in the middle ear: malleus, incus and stapes. There are developed organs of sight, taste, smell and equilibrium.

*Reproductive system.* Mammals have sexual reproduction and separate sexes. Fertilization is internal. The embryo develops in the mother's organism. It is intrauterine development. Young animals are fed with mother's milk (breastfeeding). Most of mammals are placentals. They develop in the uterus. Nutrition and gas exchange are provided by the placenta which is an organ connecting organisms of fetus and mother. Parental care is observed in all mammals.

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