Ministry of Education and Science of Ukraine
Petro Mohyla Black Sea National University

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Lecture notes on the discipline physiology (for foreign students)

The tutorial

PMBSNU
PUBLISHING HOUSE

Mykolaiv, 2021

UDC 612=111(076)
H 66

Recommended for publication by Petro Mohyla Black Sea National University Academic Council (protocol № 7 from 30.08.2021).

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H 66 Hilmutdinova M. Lecture notes on the discipline physiology (for foreign students) : the tutorial / M. Hilmutdinova, L. Chebotar. – Mykolaiv : Publishing house of PMBSNU, 2021. – 92 p.

ISBN 978-966-336-431-5

The tutorial "Lecture notes on the discipline physiology" is compiled in English for foreign students, contains basic theoretical material on all topics of the course "Physiology", its content is fully consistent with the working curriculum of the discipline "Physiology". It is recommended for use by students for independent work and in preparation for practical classes.

UDC 612=111(076)

ISBN 978-966-336-431-5

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Chapter 1.
PHYSIOLOGY AS A SCIENCE. THE CONCEPT OF EXCITABLE TISSUES

CONTENTS

1. ***Physiology* –** the doctrine of the functions and processes that take place in the body or its systems, organs, tissues and mechanisms of their regulation, ensuring the interaction of organism with the environment.

The object of study of physiology is the living organism and the functional processes that take place inside of the organism.

The task of physiology is to identify due to which mechanisms the function is realized. It is about determining the physiological significance of a function or process and clarifying the mechanisms of their regulation.

The main methods of physiological research are:

Observation is a method of studying the functions and structures of an organism without interfering with its activity.

Experiment is a method of studying the functions of an organism and its structures with interference in their activity – creating certain conditions. Experiments are divided into acute and chronic. Acute experiments involve the study of functions on isolated cells, organs, tissues, as well as in the whole body of anesthetized animals. Chronic experiments consist of surgical interventions that allow us to investigate functions in conditions that are close to physiological ones.

Simulation (modeling) is a method of exploring functions using programs that describe the activity of body systems or devices that simulate the activity of systems and have the same input and output indicators.

The human body is a holistic, complex, dynamic system that performs a variety of functions and has the following functional organization:

Cell is a structural and functional unit of the human body. Cells form tissues. ***Tissue –*** a collection of cells and intercellular substances, similar in structure and functions, have common origin. In the human body by morphological and physiological distinguish 4 types of tissues: epithelial, connective, muscular, nervous. The reason for the differences between the tissues is that their cells are structurally specialized to perform certain functions required by the body.

Organ – a part of the body that has a specific shape and structure, occupies a permanent position in the body and performs one or more specific functions. The organ consists of several types of tissues, but one prevails. Organs are integrated into system of organs.

The physiological system of organs – the union of organs to perform a specific function.

The functional system of organs – an amalgamation of organs or physiological systems to produce beneficial results for the body. For example, the supply of oxygen to cells and the removal of carbon dioxide from them is due to the joint activity of physiological systems of blood, blood circulation, respiration, which make up the gas transport functional system.

Homeostasis is a collection of coordinated reactions that ensure the maintenance or restoration of constancy of the internal environment of the body.

Homeokinesis is a set of processes that provide homeostasis. Homeokinesis maintains homeostatic constants within specified limits. The method of maintaining homeostatic constants within the specified limits is to counteract the deviations of homeostatic constants from the physiological norm. Examples of homeostatic control of given parameters (homeostatic constants): at the level of the body – blood pressure (BP), basal body temperature, volume of circulating blood; at the level of the intercellular space (for example, blood plasma) – the content of oxygen, carbon dioxide, glucose and many other substances; at the cell level – the volume of cells and their organoids, the concentration of ions (e.g., K^+, Na^+ and Ca^{2+}).

2. Cell membranes are composed mainly of phospholipids, proteins, and carbohydrate chains that form the glycocalyx. Phospholipids are located on both sides of the membrane and have "heads" formed by hydrophilic phosphorylated glycerol, to which are attached two "tails" of fatty acids, which are hydrophobic and inverted inside the membrane to each other, thus forming a double layer. Proteins are immersed in a double layer of phospholipids. Integral proteins are distinguished from proteins – they penetrate through the thickness of the membrane and form: ion channels through which ionized substances can pass; transport proteins – carriers for substances; ion pumps which, through active transport, transfer ions through the membrane against a concentration gradient.

Ion channels are integral proteins in the membrane of cells through which ions can pass. These channels can be open or closed. When ion channels are open, individual ions can pass through them, and when closed, ions do not pass. Opening or closing of ion channels is controlled by a gate: potential-dependent gate – open or close when membrane potential changes; chemo-dependent gates – open or close by the interaction of cytoreceptors of the membrane (surface proteins) with neurotransmitters, hormones and other chemicals.

The surface proteins located on the outer or inner surface of the membrane are represented by: receptor proteins located on the outer surface of the membrane and transmit information into the cell; enzymes located on the inner surface of the membrane, the activation of which changes the function of the cell; cytoskeleton components located on the inner surface of the membrane; glycocalyx formed by hydrocarbon chains of glycolipids and glycoproteins that attach to membrane proteins and lipids and cover the outer surface of the cell.

The most important functions of biological membranes are:

1. **Protective function:** Cell membrane protects the cytoplasm and the organelles present in the cytoplasm **Selective permeability:** Cell membrane acts as a semipermeable membrane, which allows only some substances to pass through it and acts as a barrier for other substances
2. **Absorptive function:** Nutrients are absorbed into the cell through the cell membrane
3. **Excretory function:** Metabolites and other waste products from the cell are excreted out through the cell membrane
4. **Exchange of gases:** Oxygen enters the cell from the blood and carbon dioxide leaves the cell and enters the blood through the cell membrane
5. **Maintenance of shape and size of the cell:** Cell membrane is responsible for the maintenance of shape and size of the cell.

3. ***There are three types of membrane transport: passive, active and vesicular. Passive transport*** occurs without the cost of energy by an electrochemical gradient. Types of passive transport:

Simple diffusion is a type of membrane transport of a substance through a membrane by concentration or electrochemical gradient (from a high concentration area to a low area).

Facilitated diffusion is a form of passive transport when substances pass through a membrane along a concentration gradient with the help of transport proteins, the amount of which affects the amount of diffusion flux.

Osmosis is the diffusion of a solvent through a semipermeable membrane by an osmotic gradient – to a place of greater concentration of solute, for which the membrane is impermeable. A semipermeable membrane is called one through which the solvent passes and no solute passes. Osmosis regulates the amount of water in the intercellular and intracellular space.

Active transport requires energy and occurs against a concentration or electrical gradient. Types of active transport:

Primary active transport is the transport of substances through the membrane against the electrochemical gradient due to energy. Primary active transport is due to the protein pumps located in the cell membrane (the most common sodium potassium, Na^+/K^+).

The best studied is the transport of Na^+ and K^+ – Na^+/K^+ – pump. This transport occurs with the participation of globular protein. The protein has three sites for Na^+ binding on the inner surface and two sites for K^+ binding on the outer surface. There is a high activity of ATPase on the inner surface of the protein. The energy generated by ATP hydrolysis causes the conformational changes of the protein, and three Na^+ ions are removed from the cell and two K^+ ions are introduced into it. This pump creates a high concentration of Na^+ in the extracellular fluid and a high concentration of K^+ in the cellular.

Secondary active transport – is due to the energy generated during the primary active transport, which led to different concentrations of substances on both sides of the membrane – the electrochemical gradient. There are two forms of secondary active transport. Simport occurs when both substances are transported through the cell membrane in the same direction by one energy-dependent carrier protein. Antiport, oncoming transport, occurs when two substances are transported through the cell membrane in the opposite direction by an energy-dependent carrier protein.

The vesicular transport is the transport of substances through the cell membrane by endocytosis or exocytosis. Endocytosis is the transport of a substance inside a cell by invagination of a membrane that forms a vesicle and transports the substance in that vesicle into the cell (phagocytosis). Exocytosis is the transport of a substance in the vesicle from the cell to the outside (excretion of neurotransmitters).

Ion channels are transmembrane proteins that form pores through the cytoplasmic and other biological membranes that help to establish and control electrical voltage across membranes of all living cells, allowing the movement of certain ions down the electrochemical gradient.

Ion channels regulate the flow of ions across the membrane in all cells. They are a protein molecule or a complex of several molecules that penetrate the lipid layer of the cell membrane through. Within the protein is a through hole, or pore, through which ions can move. It is time to open and close with the help of the motions of the protein molecule of the channel itself or of the auxiliary proteins – the so-called "gate mechanism". When the pores are opened, ions move through the channel, which causes the electrochemical gradient to move on either side of the cell membrane.

Thus, the channels are the conductors of passive transport. The movement of ions through the channel leads to a change in the membrane potential of the cell or the entry of new ions into the cell. This further changes the function of the cell.

Properties of ion channels: selectivity is the ability of a channel to selectively pass a certain type of ions; ***permeability*** is the ability of a certain ion to pass through the pore of the channel; ***conductivity*** is a value that indicates the number of ions that can pass through the channel pore per unit time.

The opening and closing of ion channels are the basis of the transmission of nerve impulses, and the conductivity of the channels is the basis of the operation of electrical synapses. Ion channels are involved in maintaining voltage in the mitochondria of eukaryotes and on plasma membrane prokaryotes, which is used to generate energy in the form of ATP, the primary "fuel" of cells.

Today there is no single classification of ion channels. Channels are classified by ion selectivity, by mechanism of activation, by sensitivity to chemicals, by genetic homology.

An ion pump is a multi-protein complex located on cell membranes that transports ions through a membrane against an electrochemical gradient using ATP or light energy. There are pumps that transfer only one type of ions, as well as ion pumps that transfer one type of ions in exchange for another.

Ion pumps support the cellular ion homeostasis required to perform physiological functions. The sodium-potassium pump maintains a high concentration of potassium ions and low levels of sodium ions in the cell cytoplasm. In nerve and muscle cells, this is required to generate the potential for action. In all animal cells, ion pumps maintain a low level of calcium ions in the cytoplasm and a high level of these ions in the endoplasmic reticulum, a cellular calcium depot. This is necessary for the cell's constant readiness to respond to the calcium signal.

Mitochondrial and plastid inner membrane ion pumps use the energy of electron movement along the electron transport chain to transfer hydrogen ions across the membrane.

4. ***Excitation*** is a complex biological process that occurs in excitatory tissues under the influence of the stimulus, which is accompanied by changes in metabolism, physical and chemical properties of tissues, the appearance of biocurrents and other changes that lead to a response specific to this type of tissue only.

Excitable tissues are structures that can spontaneously or in response to stimuli respond to excitations.

Properties of excitable tissues:

Excitability **–** the property of tissues to respond to irritation by the process of excitation, the spread of which on excitatory tissues leads to the manifestation of a specific reaction.

Conductivity **–** the ability of living tissue to conduct excitation waves.

Refractivity **–** a temporary decrease in the excitability of the tissue that occurs during its activity (temporary inability to respond to the irritant).

Lability **–** the ability of excitatory tissue to reproduce the maximum number of excitations per unit time.

Resting potential is the difference of potentials between the outer and inner surfaces of a cell membrane in a state of functional rest, characteristic of all cells of the body.

Action potential is a fast, actively spreading, phase oscillation of the membrane potential, which is usually accompanied by recharging of the membrane and occurs during excitation of the cell.

During the resting state the membrane potential arises because the membrane is selectively permeable to K^+. An action potential begins at the axon hillock as a result of ***depolarization***. During depolarization voltage gated sodium ion channels open due to an electrical stimulus. As the sodium rushes back into the cell the positive sodium ions raise the charge inside the cell from negative to positive.

If a threshold is reached, then an action potential is produced. Action potentials will only occur if a threshold is reached, as such they are described as "all or nothing". If the threshold is reached then the maximum response will be elicited.

Once the cell has been depolarized the voltage gated sodium ion channels close. The raised positive charge inside the cell causes potassium channels to open, K^+ ions now move down their electrochemical gradient out of the cell. As the K^+ moves out of the cell the membrane potential falls and starts to approach the resting potential.

Typically, ***repolarization*** overshoots the resting membrane potential, making the membrane potential more negative. This is known as ***hyperpolarization***. It is important to note that the Na^+/K^+ ATPase is not involved in the repolarization process following an action potential.

Every action potential is followed by a ***refractory period***. This period can be further divided into the ***absolute refractory period*** and the r***elative refractory period.*** This period occurs as once the sodium channels close after an AP, they enter an inactive state during which they cannot be reopened regardless of the membrane potential. This is known as the absolute refractory period.

Slowly the sodium channels come out of inactivation. This is known as the relative refractory period. During this period the neuron can be excited with stimuli stronger than one normally needed to initial an action potential. Early on in the relative refractory period the strength of the stimulus required is very high and gradually it becomes smaller throughout the relative refractory period as more sodium channels recover from inactivation.

The physiological role of action potential is that it provides excitation of the cell and the transfer of this excitation to other cells, as well as support or activation in specific cells of specific functions.

5. Nerve fibers are processes of nerve cells covered with a shell. Each fiber consists of an outgrowth of a nerve cell that lies in the center of the nerve fiber and is called an axial cylinder, and a shell formed by oligodendroglial cells (Schwann cells).

Depending on the presence or absence in the shell of myelin, which acts as a kind of insulator, nerve fibers are divided into:

Thin (not myelin) – they do not develop the myelin sheath, their axial cylinders are covered only by Schwann cells, they are part of the autonomic nerves and conduct nerve impulses at speeds up to 15 m/s.

Thick (myelin) – a thick shell is placed around the axial cylinder, which contains in the inner layers of myelin, the rate of transmission of nerve impulses is much higher – up to 120 m/s. Myelin fibers are found mainly in the peripheral nerves.

Myelin fibers are made up of segments and non-myelin gaps – nodes of Ranvier.

The nerve impulse spreads continuously over the non-myelin fiber, and along the myelin fiber jumps from one node of Ranvier to another one.

The mechanism of excitation on nerve fibers. In nerve myelin fibers excitation occurs only in nodes of Ranvier and seems to "jump" from one to another one, so the action potential spreads very quickly. An action potential that has arisen in one node of Ranvier is able to cause excitation not only in the gap lying nearby, but also in the adjacent 2–3 gaps. This creates a guarantee of fiber excitation if even 1–2 gaps lying nearby damaged.

In studying the conduct of excitation on nerve fibers, several necessary conditions and rules (laws) of the course of this process were established.

1. Anatomical and physiological integrity of the fiber. The conduction of electrical impulse is possible only in conditions of anatomical integrity of fibers. The cutting or any other injury of the membrane surface disrupts conduction. The same will occur during disruption of physiological properties of the nerve fibers (blockade by local anesthetics, sharp hypothermia, etc.).

2. Two sided conduction of excitation. The excitation which occurs in any region of the fiber can spread in two directions: from the center and to the center (acts only in conditions of isolated fiber).

3. The isolated conduction of excitation. In the peripheral nerve impulses spread on each fiber in isolation, that is, without passing from one fiber to another and having an effect only on those cells with which the end of the nerve fiber is in contact.

6. *Synapse* – structural and functional contact between two neurons, or a neuron and a working organ.

A synapse is a structural formation that ensures the transition of excitation from a nerve fiber to a muscle, nerve or glandular cell.

According to the final effect, synapses are excitable and inhibitory, according to the transmission mechanism, there are three types of synapses – electrical, chemical and mixed (chemical are the most common).

The synapse consists of a presynaptic and postsynaptic parts, between which there is a synaptic cleft. Each synapse has synaptic vesicles from which neurotransmitters can be released (chemicals which help electrical signal to pass through synapse).

Mechanism of synaptic transmission:

1. Action potential comes to the axon terminal
2. Na^+ channels open; depolarization causes the opening of voltage-dependent Ca^{2+} channels
3. Ca^{2+} enters the cell and causes the fusion of acetylcholine vesicles with the presynaptic membrane
4. Acetylcholine molecules diffuse through the synaptic cleft and bind to receptors on the postsynaptic membrane
5. When receptors bind to acetylcholine, cation channels open and depolarization of the postsynaptic membrane occurs
6. Depolarization causes an action potential in the postsynaptic membrane.
7. Acetylcholine is destroyed its components are captured by the presynaptic membrane. Acetylcholine and vesicles are processed.

Main function of the synapse is to transmit the impulses (action potential) from one neuron to another. On the basis of functions, synapses are divided into two types: excitatory synapses, which transmit the impulses (excitatory function); inhibitory synapses, which inhibit the transmission of impulses (inhibitory function).

Excitatory postsynaptic potential (EPSP) is the non-propagated electrical potential that develops during the process of synaptic transmission. When the action potential reaches the presynaptic axon terminal, the voltage-gated calcium channels at the presynaptic membrane are opened. Now, the calcium ions enter the axon terminal from extracellular fluid. Calcium ions cause the release of neurotransmitter substance from the vesicles by means of exocytosis. Neurotransmitter, which is excitatory in function passes through presynaptic membrane and synaptic cleft and reaches the postsynaptic membrane. Now, the neurotransmitter binds with receptor protein present in postsynaptic membrane to form neurotransmitter-receptor complex. Neurotransmitter-receptor complex causes production of a non-propagated EPSP.

Common excitatory neurotransmitter in a synapse is acetylcholine. EPSP is not transmitted into the axon of postsynaptic neuron. However, it causes development of action potential in the axon.

Inhibition of synaptic transmission is classified into such types:

Postsynaptic inhibition is the type of synaptic inhibition that occurs due to the release of an inhibitory neurotransmitter from presynaptic terminal instead of an excitatory neurotransmitter substance. It is also called direct inhibition. Inhibitory neurotransmitters are gammaaminobutyric acid (GABA), dopamine and glycine. Action of GABA development of inhibitory postsynaptic potential

Inhibitory postsynaptic potential (IPSP) is the electrical potential in the form of hyperpolarization that develops during postsynaptic inhibition. Inhibitory neurotransmitter substance acts on postsynaptic membrane by binding with receptor. Neurotransmitter-receptor complex opens the ligand-gated potassium channels instead of sodium channels. Now, the potassium ions, which are available in plenty in the cell body of postsynaptic neuron move to extracellular fluid. Simultaneously, chloride channels also open and chloride ions move inside the cell body of postsynaptic neuron. The exit of potassium ions and influx of chloride ions cause more negativity inside, leading to hyperpolarization. Hyperpolarized state of the synapse inhibits synaptic transmission.

Presynaptic inhibition occurs due to the failure of presynaptic axon terminal to release sufficient quantity of excitatory neurotransmitter substance. It is also called indirect inhibition. Presynaptic inhibition is mediated by axoaxonal synapses. It is prominent in spinal cord and regulates the propagation of information to higher centers in brain. Normally, during synaptic transmission, action potential reaching the presynaptic neuron produces development of EPSP in the postsynaptic neuron. But, in spinal cord, a modulatory neuron called presynaptic inhibitory neuron forms an axoaxonic synapse with the presynaptic neuron. This inhibitory neuron inhibits the presynaptic neuron and decreases the magnitude of action potential in presynaptic neuron. The smaller action potential reduces calcium influx. This in turn decreases the quantity of neurotransmitter released by presynaptic neuron. So the magnitude of EPSP in postsynaptic neuron is decreased resulting in synaptic inhibition.

Neuron is defined as the structural and functional unit of nervous system. Neuron is similar to any other cell in the body, having nucleus and all the organelles in cytoplasm. Neuron has branches or processes called axon and dendrites

Classification of neurons. Neurons are classified by three different methods: depending upon the number of poles (unipolar, bipolar, multipolar); depending upon the function (sensory and motor); depending upon the length of axon (Golgi type I neurons, Golgi type II neurons).

Neuron is made up of three parts: cell body, dendrite, axon. Dendrite and axon form the processes of neuron. Dendrites are short processes and the axons are long processes. Dendrites and axons are usually called nerve fibers.

7. In the human body, there are 3 types of muscle tissue: striated cardiac, striated skeletal and smooth. Each of them has the same list of properties which other excitable tissues have.

Cardiac muscle fibers are present only in the heart. They have very good blood supply and are much less fatigued than normal muscle tissue. The contraction of the cardiac muscle is independent of the will of the person. The structural and functional unit is cardiomyocyte.

Skeletal muscles make up 40 % of body weight and provide: body movement in space, movement of one part of the body relative to another, maintaining posture, movement of blood and lymph, heat production, exercise of inhalation and exhalation, motor activity, deposition of water and salts, protection of internal organs (such as abdominal organs). Muscle fibers are a structural and functional unit.

Smooth muscles provide the function of the hollow organs, the walls of which they form. In particular, they allow the contents of the bladder, intestines, stomach, gall bladder, uterus to be removed. Smooth muscles provide sphincter function – they create the conditions for maintaining the contents of the hollow organ in this organ, such as urine in the bladder, fetus in the uterus. The most important role is played by smooth muscles in the circulatory system and lymph formation – by changing the lumen of the vessels, they adapt regional circulation to local needs for oxygen, nutrients. Structural and functional unit are myocytes.

Muscle fiber. Muscles are composed of many elongated muscle fibers – functional units. They have a cylindrical shape and are parallel to each other. Muscle fiber is the result of the fusion of many cells. Each fiber is surrounded by a membrane – a sarcolemma (by structure – a normal membrane). Muscle fibers contain a large number of myofibrils. Each myofibril consists of protein filaments of two types – actin and myosin. There are many mitochondria between myofibrils. Myofibrils are divided into separate parts (sarcomeres), the average length of which is 2.5 microns. The sarcomeres are limited by Z-membranes. These membranes serve to attach actin filaments. Thick (myosin) filaments are located in the center of the sarcomere. The muscle fiber cytoplasm is called sarcoplasm and contains a network of inner membranes – the sarcoplasmic reticulum. Reticulum tanks are involved in the capture and release of Ca^{2+} ions.

Myosin molecules are arranged in the myosin filament in such a way that their "heads" are distributed evenly over the entire length. The actin filament consists of 2 helically twisted actin molecules. They include auxiliary proteins – tropomyosin and troponin. Both proteins interfere with the interaction of actin with myosin in the absence of Ca^{2+} ions.

Muscle contraction mechanism. The essence of the contraction mechanism is that when depolarizing the membrane of the muscle fiber, Ca^{2+} is released from the tanks, its concentration in the region of myofibrils increases 1000-fold. Ca^{2+} ions initiate contraction by binding to troponin C. In this way, the binding of troponin I to actin is significantly weakened, and as a result, the tropomyosin molecules shift sideways. After such a move, the myosin head binding sites are exposed. The myosin head is firmly bound to actin, the neck of the myosin molecule bends, pulling actin fiber between myosin. The myosin head is then detached from the actin and the cycle repeated. This splits ATP. The binding of one troponin molecule to the Ca^{2+} ion leads to the exposure of seven myosin binding sites. There are 50 such combs for full reduction, with the muscle contracting by 50 % of its original length.

Immediately after the release of Ca^{2+}, the sarcoplasmic reticulum begins to resume its supply by actively transporting it to the oblong portion of the mesh. This process is performed by the pump Ca^{2+}/Mg^{2+}-ATP-ase. Subsequently, Ca^{2+} passes through diffusion into terminal tanks, where it is stored until the next action potential. When the Ca^{2+} concentration outside the mesh is significantly reduced, then the chemical interaction between actin and myosin is terminated and the muscle relaxes.

Types of muscle contraction. In response to stimulation, the muscle performs mechanical work. Depending on the load modes, the following types of muscle contraction are distinguished:

1. Isometric contraction – contraction at constant muscle length. The length of the muscle remains constant, but its tension changes.
2. Isotonic contraction – contraction at constant muscle tension. Muscle tension remains constant while length decreases.
3. Mixed (auxotonic) contraction – a contraction that changes the length and tension of the muscle.

Depending on the frequency of stimulation, the following types of muscle contraction are distinguished:

1. Single – observed in response to a single stimulus or series of stimuli (if the interval between stimuli is greater than or equal to the duration of a single muscle contraction). There are the following periods of muscle contraction: latent period (the interval of time from the action of the stimulus to the beginning of reduction); period of contraction (during this period the length of the muscle decreases); period of relaxation (during this period the muscle relaxes, increasing its length to its original level).
2. Tetanic – observed in the conditions of summation of single muscle contractions (one contraction is superimposed on another). Such summation is possible if the muscle is irritated by a series of stimuli and each subsequent stimulus acts when the previous single contraction is not over (the interval between the stimuli must be shorter than the duration of the single muscle contraction).

There are the following types of tetanic contractions:

Incomplete tetanus – occurs on the basis of single contractions if each subsequent stimulus falls during the period of relaxation of a single muscle contraction. Therefore, the interval between stimuli in a series should be less than the duration of a single muscular contraction, but greater than the sum of the duration of the latent period and the period of truncation of a single contraction.

Complete tetanus – occurs on the basis of single contractions, if each subsequent stimulus falls into a latent period or a period of contraction of a single muscle contraction. Therefore, the interval between the stimuli in the series should be less than or equal to the sum of the duration of the single reduction latent period, but greater than the duration of the single reduction latency period.

Questions to consolidate theoretical material.

1. Describe structure and functions of cell membrane.
2. Describe the mechanism of active transport of substances through cell membrane.
3. Describe the mechanism of passive transport of substances through cell membrane.
4. List the various changes taking place during muscular contraction and explain the molecular basis of contraction.
5. Describe the neuromuscular junction and mechanism of transmission of electrical impulse through it.

Chapter 2.
PHYSIOLOGY
OF NERVOUS SYSTEM

CONTENTS

1. ***Reflex*** is a response of the body to external or internal stimuli, which is carried out with the obligatory involvement of the CNS. This is a functional unit of nervous activity.

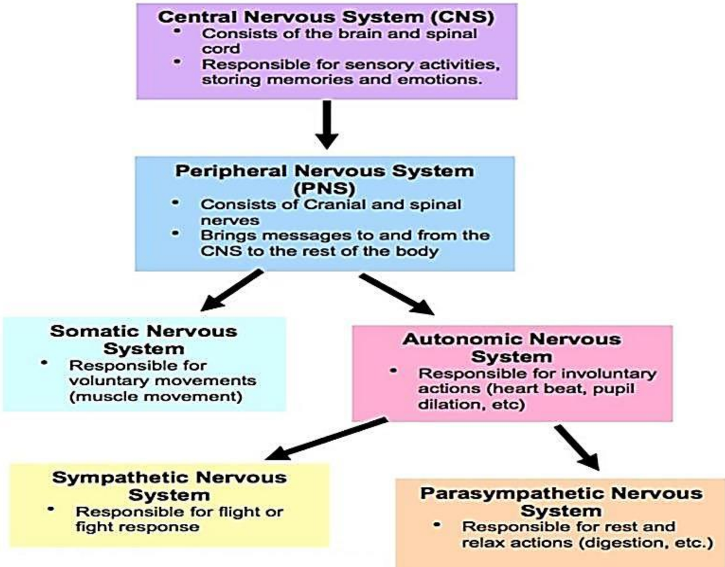
Classification of reflexes. Depending on the nature of biological reaction: food, defensive, motor, etc. Depending on the location of the center: spinal reflexes, reflexes of the brain. Depending on number of branches: somatic, visceral.

The reflex arc is the path along which a nerve impulse passes when a reflex occurs. The arcs are divided into simple (consisting of two neurons) and complex (more than two neurons). Reflex arc Components: receptor, afferent link, reflex nerve center, efferent link, working body (effector), feedback (positive, negative).

The nervous system is the main mechanism of regulation of the human body.

Nervous system functions:

1. Perception of external and internal stimuli and the organization of appropriate adaptive reactions.
2. Provides the relationship of individual organs and systems, coordinates and combines their functions.
3. Is an organ of mental activity.



2. ***The spinal cord*** **–** the first level of the CNS, is located in the bony canal of the spinal column from the level of the base of the skull to 1–2 lumbar vertebrae. The upper parts of the spinal cord pass into the brain, the lower ones end in a cerebral cone, the apex of which continues into a thin terminal thread.

Spinal cord has a segmental structure. ***Segment*** is a region of the spinal cord with anterior (ventral, motor) roots, which comes out of it, and posterior (dorsal, sensitive), which come inside, limited to one vertebra. Damage to the posterior roots causes loss of sensitivity of the corresponding areas of the body, and damage to the anterior roots – paralysis of the muscles (loss of movement).

Each segment receives afferent innervation from the corresponding segment of the human body and transmits efferent information to this segment. There are 31 segments (8 cervical, 12 thoracic, 5 lumbar, 5 sacral, 1 coccygeal segments).

The spinal cord has white and grey matter. The gray matter is located in the center, it contains a central canal filled with cerebrospinal fluid. On the cross-section of the spinal cord the gray matter has the butterfly-like or "H"-like shape, forms ventral and dorsal horns, represented by the bodies of the neurons. Segments of thoracic department and 2 upper lumbar segments has lateral horns also. Ventral horns contain motor neurons, dorsal contains interneurons, lateral horns contain centers of sympathetic department of ANS.

The white matter is located along the periphery of the gray matter. The white matter of the spinal cord is represented by processes of nerve cells that form 3 systems of pathways: ***short tracts*** connect spinal cord segments located at different levels; ***ascending (sensory) tracts*** are directed from the centers of the brain or to the cerebellum; ***descending (motor) tracts*** go from the brain to the cells of the anterior horns of the spinal cord.

The spinal cord performs the following functions: ***reflex function*** (is the center of simple motor reflexes); ***conductor function*** (provides communication of the spinal cord with the CNS departments which are located above).

The main reflexes of the spinal cord are:

Somatic reflexes are the motor reflexes of the limbs, trunk, or parts thereof.

1. Flexion reflex: clamping the fingers of hind paw of the frog, you can see that the paw flexes and pulls away from the stimulus;
2. Extensory reflex: pressing the sole of the pre-bent paw causes its extension and repulsion from the irritant;
3. Skin reflex: the hind paw of the animal goes to the irritated area of the skin and repeated rubbing tries to eliminate the irritant.

Stretching reflexes are reflexes that are triggered by skeletal muscle receptors or their tendons (proprioceptors) (for example: tendon and skin reflexes).

The dependence of the activity of the spinal cord on the effects of higher levels of the CNS is manifested if these effects stop. As a result of the cessation of the effects of the higher departments of the CNS on the spinal cord spinal shock develops a temporary cessation reflex activity of the spinal cord. In primates after the recovery of reflex activity of the spinal cord, some of the reflexes change compared to intact animals, and some do not recover at all. A leading mechanism in the development of spinal shock is the cessation of the activating effects of brain structures on spinal cord neurons. The higher the level of organization of the animal, the more important these effects are.

3. ***The brain is conventionally divided into 4 sections:*** hindbrain (medulla oblongata, pons and cerebellum); midbrain (cerebral peduncles, tectum); diencephalon (thalamus and hypothalamus); forebrain (two hemispheres, subcortical nuclei).

The medulla oblongata, the pons, the midbrain and partially the diencephalon are combined into the brain stem, with which the cerebellum is closely connected.

The hindbrain includes the medulla oblongata, the pons and the cerebellum, which is not a stem structure. The medulla oblongata is a direct continuation of the spinal cord.

In the medulla oblongata, in comparison with the spinal cord, there is no clear separation of gray and white matter. The accumulation of nerve cells leads to the formation of nuclei, which are the centers of reflexes. Of the 12 pairs of cranial nerves that connect the brain to the periphery of the body, 4 pairs (9-12) originate in the medulla oblongata: hypoglossal (12 pair), accessory (11 pair), vagus (10 pair), glossopharyngeal (9 pair).

The medulla oblongata performs 2 functions: reflex and conduction. The reflex function consists in the fact that in the medulla oblongata there are reflex centers: which are associated with the functions of the respiratory, circulatory and digestive systems; which provide the muscle tone necessary to maintain the posture, perform work acts, the distribution of muscle tone; protective reflexes (blinking, lacrimation, sneezing, coughing, vomiting).

The main role of the medulla oblongata is to ensure a constant composition of the internal environment of the body. The medulla oblongata regulates the work of the spinal cord, functionally unites the segments of the spinal cord, performs complex forms of adaptive reactions of the body to the environment.

The pons looks like a white shaft that connects the medulla oblongata to the legs of the midbrain. Performs reflex and conductive functions. Reflex function is provided by a pnemotaxic center that regulates respiration. The rhythmic change of inhalation and exhalation and the depth of respiration are regulated by the respiratory center of the medulla oblongata. In the pons lie the nuclei of 5–8 pairs of cranial nerves: 5 – trigeminal, 6 – abducens, 7 – facial, 8 – vestibulocochlear. Ascending and descending tracts passing through the pons provide a conductive function.

The cerebellum is a larger part of the hindbrain than the pons. This formation is located behind the medulla oblongata and pons. There are two hemispheres in the cerebellum and a worm in the middle. The surface of the cerebellum consists of gray matter – the cortex, which includes the bodies of nerve cells. Inside the cerebellum is a white matter that is the processes of these neurons.

The cerebellum has extensive connections with different parts of the CNS due to three pairs of peduncles. The lower peduncles connect the cerebellum to the spinal cord and medulla oblongata, the middle peduncles – to the pons and through it to the motor area of the cerebral cortex, and the upper peduncles – to the midbrain and hypothalamus.

The functions of the cerebellum have been studied during partial or complete removal, as well as by recording its bioelectrical activity at rest and during irritation.

Disorders of the cerebellum in humans: when standing with eyes wide sways strongly, when closed – falls, movements are uncoordinated. ***These syndromes include:***

- Atony – a decrease or loss of tone.
- Asthenia – rapid fatigue, decreased contraction.
- Astasia – loss of ability to merge tetanic contraction (trembling of the torso and limbs).
- Ataxia – loss of coordination, disorder of strength, amplitude, speed and direction of movement (gait drunk).
- Dezequilibrium – inability to maintain body balance.
- Adiadochokinesis is a disorder of the ability to make rapid movements with antagonist muscles (flex and extend the arm several times in a row).

Sometime after removal of the cerebellum, all motor disorders disappear, because the functions of the cerebellum are compensated by the cortex (its motor areas). Thus, the main functions of the cerebellum: coordination of movements, distribution of muscle tone, regulation of autonomic functions. The autonomic functions of the cerebellum are its effect on the state of the receptor apparatus and all parts of the brain. Through the sympathetic nervous system, it regulates metabolism in the brain and helps the nervous system to adapt to changing conditions.

Reflexes of the hindbrain:

Vegetative – regulate the function of the salivary glands, the coordination of acts of chewing and swallowing, breathing, circulation, lacrimation, sweating.

Somatic – divided into chain and tonic. Chain ensure chewing and swallowing. Tonic or postural is a group of reflexes that involve the structures of the medulla, hindbrain and midbrain; aimed at maintaining a particular position of the body (posture) or parts of it in space (the cervical is the tonic reflexes caused by the excitation of the proprioceptors of the neck muscles, the change of the position of the head – the change in the tone of the muscles of the flexors or extensors).

Vertebral (vestibular) reflexes – are divided into static and statokinetic. Static reflexes are mainly associated with excitation of receptors of the membranous labyrinth of the vertebra and provide maintenance of postures and balance of the body when changing its position in space – reflexes of postures, reflexes of straightening. Statokinetic reflexes are aimed at maintaining the posture in case of change of speed. These reflexes are caused by the excitation of the receptors of the semicircular canals, which occurs during the movement of the endolymph within the canals (nystagmus; reflexes of the elevator – when lifting in the elevator with the acceleration of the limbs are bent, and when lowering they are bent). All the reflexes of the hindbrain cause head restraint, sitting, standing and walking.

Midbrain is a small part of the brain stem, this department processes afferent information that enters the spinal cord and hindbrain. New information comes to this department from the visual and auditory receptors. Based on the processing of information from all these receptors, this department controls the state of the external and internal environment of the body. Important parts of the midbrain are: ***red nuclei*** (controls flexor and extensor muscles, regulation of automatic movements); ***quadruplet bodies*** (the four colliculi – two inferior, which are primary centers of hearing; two superior, which are primary centers of vision); ***nucleus of the trochlear*** (IV pair, provides movement of the eyeballs up and out) and ***oculomotor nerves*** (III pair, provides the lifting of the upper eyelid and eye movement in different directions, regulates the lumen of the pupil and the curvature of the lens); ***substantia nigra*** (regulates muscle tone and posture support, participates in the regulation of chewing, swallowing, blood pressure and respiration).

With the participation of midbrain motor nuclei, late-tonic reflexes of two types are performed: ***straightening reflexes*** – provide restoration of the broken pose. In animals with a neck, rectifying reflexes have 2 phases: head straightening reflex and torso straightening reflex; ***statokinetic reflexes*** – to maintain the posture of equilibrium when moving with acceleration; due to the processing of information from the visual and auditory receptors the motor nuclei of the midbrain provide the realization of ***orientation reflexes*** – in response to strong sound and light stimuli, the mesencephalic animal turns its head towards the stimulus, alert the ears – the animal appears to be preparing to respond to this stimulus.

To study the role of the hindbrain and midbrain in the regulation of locomotor function can be found in animals with decerebration – a cutting of the brain stem between the midbrain and hindbrain (below the red nucleus). After the operation of decerebration, the animal has a decerebral rigidity – an increase in the tone of the extensor muscles and a relative relaxation of the flexor muscles, which is explained by the cessation of the inhibitory effect of the red nucleus on the Deiters nucleus. In an experiment on cats, when the structures connecting the above nuclei are cut, the animals cannot perform flexion.

Reticular formation – this is anatomical formation in the central part of the brain stem which consisting of diffuse aggregations of cells of various types and sizes, which are thickly interlaced by numerous fibers passing in different directions. It has been established that the reticular formation is of the highest importance for regulating the excitability and tone of all divisions of the central nervous system. Through the descending reticulospinal tracts it is capable of exerting both an activating and an inhibitory influence on the reflex activity of the spinal cord. Through the ascending tracts it produces an activating influence on the cerebral cortex; impulses from the reticular formation and the nonspecific nuclei of the thalamus maintain the cortex in a wakeful state. And under its influence reflex reactions become stronger and more accurate.

The activity of the reticular formation, through which it can exert its ascending and descending influences, is sustained by the arrival of impulses through the collaterals of various afferent pathways. As a result, the most varied stimulation of the receptors affects its condition. In addition, its neurons are extremely sensitive to various chemical agents, hormones and certain metabolites. The reticular formation also receives impulses from the effector centers of the cerebral hemispheres and the cerebellum.

Both ascending afferent and descending efferent impulses interact in the region of the reticular formation. Circulation of impulses through its closed, circular neuronal chains is also possible. In that way the excitation of its neurones is maintained at a constant level, which ensures the tone and a definite degree of readiness for activity of the various parts of the central nervous system. In noting the importance of the reticular formation, it should be emphasized that the cortex regulates how far it is excited and that impulses arriving from the cortex are capable of governing its activity.

4. ***The main formations of the diencephalon are the thalamus and hypothalamus. The thalamus*** is a massive paired formation that occupies the bulk of the diencephalon, consisting of gray matter organized into nuclei; it is the center of all afferent impulses, it is the processing, integrating and switching center for all sensory information. The information from all receptors of the body except olfactory ones through it enters the cerebral cortex. From the thalamus impulses can go to the brainstem structures.

There are 2 functional types of nuclei in the thalamus:

Specific nuclei receive information, process it and transmit it to certain areas of the cerebral cortex, where sensations occur (auditory, visual, etc.).

Nonspecific nuclei do not have a direct connection with receptors, receive information through a large number of synapses. From nonspecific nuclei, information comes through the subcortical nuclei to neurons, which are located in different areas of the cerebral cortex, exciting them.

Also in the thalamus is the center of pain sensitivity.

The hypothalamus encompasses the following structures: gray hump, pituitary funnel, and papillae. There are 5 groups of nuclei of the hypothalamus: pectoral, anterior, middle, outer, posterior.

Forms numerous connections with various departments of the CNS and plays a leading role in the support of homeostasis, influences the regulation of the internal organs and endocrine system. It participates in the regulation of metabolism, functions of the digestive system and circulation, maintaining a constant body temperature, provides the formation of many behavioral reactions associated with hunger, saturation, thirst, sleep, sexual reactions. Provides adaptation of the organism to different conditions of existence. It is the center of vegetative functions.

Some hormones are produced by hypothalamus, them go to pituitary gland and form hypophyseal portal system.

The forebrain consists of hemispheres and a corpus callosum that connects them. **The cortex of the cerebral hemispheres** is the highest section of the central nervous system, the latest in development, and the most complicated in structure and function.

Sensory areas of the cerebral cortex. The cerebral cortex receives afferent impulses from all the receptors of the organism. Their direct transmitters to the cortex (except those coming from the olfactory receptors) are the nuclei of the thalamus and the adjoining formations where the third neurones of the afferent pathways are located. Pavlov called the cortical areas to which primarily afferent impulses are conveyed the central divisions of the analysers. The central divisions, or cortical representations, of many analysers coincide in space and partly overlap. The cortical regions in which they are situated are called sensory areas, and are the cortical projection of the peripheral receptive fields.

Representation of somatic and visceral sensitivity. In each cerebral hemisphere there are two areas of representation of *somatic* (skin and articulo-muscular) and *visceral* sensitivity, which are conventionally called the first and second somatosensory areas of the cortex. The first *somatosensory area* is situated in the postcentral gyms; in size it is considerably larger than the second area. It receives afferent impulses from the posterior ventral nucleus of the thalamus, which supplies information received by skin (tactile and temperature), atriculo-muscular, and visceral receptors on the opposite side of the body.

The projection area is determined by the number of cortical nerve cells taking part in the perception of stimuli from a particular receptive field. The larger the number of cells the more differentiated is the analysis of peripheral stimuli. The cortical projections of the receptors of the visceral afferent systems (alimentary tract, secretory apparatus, cardio-vascular system) are situated in the region representing the skin receptors of the corresponding parts of the body.

The *second somatosensory area* is situated below Rolando's fissure and extends to the upper edge of the Sylvian fissure; this area also receives afferent impulses from the posterior ventral nucleus of the thalamus.

Representation of visual receptors. The cortical ends of the optic analyzer, or *visual areas,* are situated on the medial surface of the occipital lobes of both hemispheres around the calcarine sulcus and the adjoining gyri. The visual areas are a projection of the retina; afferent impulses reach it from the lateral geniculate bodies in which the third neurones of the optic tract are situated.

Representation of auditory receptors. The cortical ends of the auditory analyzer are localized in the first temporal and transverse temporal *gyri of Heschl.* Afferent impulses are supplied to the area from the cells of the medial geniculate bodies (third neurones of the auditory tract) and convey information from the auditory receptors of the cochlea. The impulses arising in these receptors with perception of tones of various pitch are conveyed to different groups of cells of the auditory area.

Representation of taste receptors. According to Penfield, the cortical ends of the taste analyzer in man are situated near the Sylvian and circular fissures close to the cortical area, stimulation of which causes salivation. Afferent impulses are transmitted to it from the inferior posterior nucleus of the thalamus.

Representation of olfactory receptors. The olfactory tracts are the only afferent pathways which do not pass through the nuclei of the thalami. Their first neurones, the olfactory cells, are situated in the nasal mucosa, the second are in the olfactory bulb.

The processes of the second neurones form the olfactory tract which extends as far as the cells in the anterior part of the pyriform lobe where the cortical end of the olfactory analyzer is located.

Association areas of the cerebral cortex. The recording of induced potentials has shown that afferent impulses from the thalamic nuclei are not only conveyed to the sensory areas but are also simultaneously passed to the regions adjoining them. These regions are called association areas (or secondary sensory areas to distinguish them from the primary sensory areas described above), and lie along the margins of the latter, extending from 1 cm to 5 cm on all sides of them.

An important feature of the cells of association areas is their capacity to respond to stimulation of various peripheral receptors. For example, the secondary auditory area in cats has been found to con-lain sections in which potentials can be evoked not only by sounds but also by light or electrical stimuli applied to the skin, which indicates that afferent pathways carrying impulses from the various receptor systems converge in these areas.

Extirpation of association areas does not entail loss of the given type of sensitivity, but capacity to interpret the significance of the acting stimulus correctly is frequently disturbed. For example, stimulation of Brodmann's eighteenth and nineteenth fields in man. which are the secondary visual area, never causes blindness, but the patient becomes unable to appreciate his visual sensations, and in particular does not understand the meaning of words he reads.

Destruction of the secondary auditory area in the temporal region often leads to loss of capacity to understand the meaning of spoken words.

These facts point to the important role played by the association areas in the analysis and synthesis of stimuli in the cortex. This is also indicated by the fact that the area occupied by them has progressively increased in the course of evolution and is largest in man.

An important feature of the association areas in man, in contrast to sensory areas, is that their destruction leads only to a temporary derangement of a particular function. Later the remaining parts of the cortex take over the functions of the destroyed areas and compensate for the damage.

Motor areas of the cerebral cortex. As pointed out above the cortex contains nerve cells whose axons extend to the lower divisions of the central nervous system, the subcortical nuclei, the brain stem, and the spinal cord. Most of these neurones are concentrated in the precentral gyrus anteriorly to Rolando's fissure. This region is called the motor area. A characteristic feature of its cellular structure is the presence of giant Betz cells, processes of which within the pyramidal tract reach the internuncial and motor neurons of the spinal cord.

The spatial organization of the motor area in man. As can be seen, the motor *points* (i.e. the points on the cerebral cortex stimulation of which causes movement of definite muscles) are distributed irregularly. Their localization in the precentral gyrus corresponds to the sequence of sensory representation in the postcentral gyrus.

The motor points of the lower extremities are located above all the others; below them are those of the trunk muscles, further down those of the upper extremities, and lower still those of the musculature of the head. Since the descending motor tracts decussate, stimulation of all these points causes muscular contraction on the opposite side of the body.

In the motor area, as in the sensory, the largest zone is occupied by the representation of the muscles of the hands, face, lips, and tongue, and the smallest by the representation of the trunk and lower extremities. The fineness of control of the movements of any given part of the body corresponds to the scale of its cortical motor representation.

Questions to consolidate theoretical material.

1. What is a reflex arc? Describe its main parts.
2. Describe the classification of the nervous system.
3. What are the main elements of the central and peripheral nervous system.
4. Explain the general structure of the spinal cord, functions and reflexes.
5. Describe the general structure of various parts of the central nervous system, functions, reflexes.

Chapter 3.
NERVOUS REGULATION OF VISCERAL FUNCTIONS

CONTENTS

1. Structural and functional organization of the autonomic nervous system.
2. Sympathetic, parasympathetic and metasympathetic divisions, their role in the regulation of visceral functions, influences on organ functions.

1. ***The autonomic nervous system (ANS)*** is a collection of neurons of the brain and spinal cord involved in regulation of activity of the internal organs. The autonomic nervous system is a complex of central and peripheral nerve structures that regulate the functions of the internal organs and parameters of the internal environment of the body. The ANS includes: nerve fibers that innervate the internal organs; peripheral (extending beyond the CNS) nodes that contain clusters of neuron bodies; visceral centers of spinal cord, medulla oblongata and midbrain; higher visceral centers locate in the hypothalamus and the limbic system.

The sympathetic and parasympathetic nervous system is characterized by the following structure: central neurons, or rather they are called preganglionic neurons, located in the brainstem (parasympathetic) or in the spinal cord (in the thoracic section – sympathetic, in the sacral – parasympathetic neurons). Their processes – preganglionic fibers – go to the corresponding ganglia (sympathetic – to the paravertebral, along the spine, nearby, plexus forming chains, sympathetic trunks) and prevertebral (plexus around the internal organs)), where they end with synapses on postganglionic neurons. These neurons give axons that go directly to the organ. These axons are called postganglionic fibers.

2. ***Sympathetic, parasympathetic and metasympathetic departments of the ANS, their role in the regulation of autonomic functions***

METASYMPATHETIC NERVOUS SYSTEM. This department is a complex of micro-ganglionic formations located in the walls of internal organs that have motor activity. These are intramural ganglia in the stomach, intestines, bladder, heart, bronchi, cervix.

The metasympathetic system can transmit central influences – due to the fact that the parasympathetic and sympathetic fibers can contact the metasympathetic system and thus correct its influence on the objects of control, and can also act as an independent formation, because it has ready reflex arcs.

The function of the metasympathetic nervous system is based on a functional module: it is the cluster of neurons that are connected, which provide the function of the metasympathetic system. This module consists of cells-oscillators, sensory neurons, motor-neurons, and inter-neurons. The main cell of the module is an oscillator cell. It spontaneously excites at a certain rhythm, and its action potential is transmitted through a system of interneurons to the motor-neurons, which axons are in contact with a muscle cell.

SYMPATHETIC NERVOUS SYSTEM. Preganglionic neurons of the sympathetic nervous system are located in the lateral nuclei of the spinal cord, beginning with the 8th cervical segment and ending with the 2nd lumbar segment inclusive. Preganglionic fibers are interrupted in the upper cervical sympathetic node, which is one of the nodes of the sympathetic nervous system of the sympathetic trunk and is related to the paravertebral ganglia. From here to the muscles go postganglionic fibers.

Preganglionic neurons, which are the centers of regulation of vascular tone and sweat glands, are located throughout the sympathetic division. The bulk of the preganglionic fibers terminate in the paravertebral ganglia and here pass on to the postganglionic neurons, which axons (postganglionic fibers) reach the relevant organs. Part of the fibers transits through the paravertebral ganglia and is interrupted in the paravertebral ganglia. The cluster of prevertebral ganglia forms a plexus. The largest of them are solar, upper and lower mesentery. These are postganglionic fibers that directly affect the organ.

From the point of view of neurotransmitter processes in the sympathetic nervous system, the following processes occur: in preganglionic fibers in contact with postganglionic neurons acetylcholine is released. Acetylcholine interacts with H-choline receptors as a result what is the transfer of excitation from the preganglionic fiber to the postganglionic neuron. Postganglionic fibers of the sympathetic nervous system, as a rule, are adrenergic (norepinephrine is secreted in their endings). However, in postganglionic sympathetic fibers of the sweat glands, acetylcholine is released, which interacts with M-cholinoreceptors, when interacting with which the sweat glands are excited.

Norepinephrine must interact with adrenergic receptors to produce the effect. There are 4 types of adrenergic receptors. The ultimate effect of excitation of sympathetic fibers depends on which population of adrenergic receptors prevails in the organ on the postsynaptic membrane.

The sympathetic nervous system contributes to a significant increase in the performance of the body, performs **ergotropic function** – greatly increases the working capacity and vital reserves of the body. That is why the excitation of the sympathetic division of the ANS occurs every time during a period of stress. The involvement of the sympathetic nervous system in this reaction is carried out with the participation of higher autonomic centers and endocrine mechanisms. An important component of this reaction is the release into the blood of catecholamines (adrenaline and norepinephrine) from the adrenal medulla.

Physiological effects: pupil enlargement; increases heart rate and strength of contraction; narrows the majority of blood vessels (such effects on the heart and blood vessels leads to an increase in systemic blood pressure); dilates the bronchi, creates conditions for optimal ventilation; inhibits the secretory and motor activity of the digestive system; increases the efficiency of the skeletal muscles (due to changes in the metabolism and blood flow in the muscles); stimulates the release of hormones of the adrenal medulla; increases excitability of receptors and centers of cerebral cortex cells; alters metabolism in the body (stimulates glycogenolysis and lipolysis, breakdown of glycogen and fats, increase in blood glucose and fatty acids, substrate support for increased functioning of skeletal muscle and CNS cells).

PARASYMPATHIC NERVOUS SYSTEM. Central (preganglionic) neurons of the parasympathetic nervous system are located in the midbrain, medulla oblongata and in the lumbosacral department of the spinal cord. In the midbrain there are two parasympathetic nuclei belonging to the III pair of cranial nerves. In the medulla oblongata there are parasympathetic nuclei of VII, IX, X pairs of cranial nerves. In the lumbosacral department of the spinal cord are located parasympathetic neurons that form centers of urination, defecation, erection. The prevalence of exposure to the parasympathetic department is more limited than the sympathetic one. Almost all blood vessels do not have parasympathetic fibers. Exception: vessels of the tongue, salivary glands and genitals.

Like the sympathetic system, the parasympathetic has preganglionic neurons which axons go to the organ (postganglionic fibers). The ganglia of the parasympathetic nervous system are usually in the middle of the organ, so the preganglionic fibers are long and the postganglionic fibers are short. Postganglionic fiber contacts the organ.

In the preganglionic fibers of the parasympathetic nervous system, the neurotransmitter is acetylcholine, which interacts on the postsynaptic membrane of the postganglionic neuron with H-cholinoreceptors. Transmission of excitation from the preganglionic fiber to the postganglionic neuron in the parasympathetic system occurs in the same way as in the sympathetic nervous system. In the endings of the postganglionic fibers of the parasympathetic nervous system, unlike the sympathetic one, acetylcholine is secreted, and the receptors located on the postsynaptic membrane of the organ: M-cholinoreceptors.

In general, excitation of parasympathetic fibers leads to the restoration of homeostasis after stress, performs a **trophotropic function**, is activated at rest.

Physiological effects: narrowing of the pupils; reduction of heart rate, transition of heart to the mode of economic activity, active course of recovery processes in the myocardium; narrowing of the bronchi; activation of secretory and motor activity of digestive system organs, favorable conditions for digestion and absorption of nutrients, enhancement of recovery processes; increased insulin secretion, increased glucose utilization by cells, enhanced recovery processes.

Questions to consolidate theoretical material.

1. Give a general description of the autonomic nervous system and its components.
2. Describe the sympathetic part of the autonomic nervous system.
3. Describe the parasympathetic part of the autonomic nervous system.
4. Describe the metasympathetic part of the autonomic nervous system.
5. Compare the effects of the sympathetic and parasympathetic nervous system.

Chapter 4.
HUMORAL REGULATION OF VISCERAL FUNCTIONS

CONTENTS

1. ***The endocrine system,*** along with the nervous system, regulates and coordinates important life forms. This regulation is carried out using chemicals that secrete endocrine glands (endocrine glands). The endocrine glands have a diverse morphological structure. They develop from epithelial tissue, interstitial cells, neuroglia and nerve tissues. The endocrine system is based on glands – special internal organs that secrete specific substances. Glands are divided into:

1. The endocrine glands (endocrine) – do not have excretory ducts and secrete their products directly into the blood, lymph or other tissue fluids. These include: pituitary gland, pineal gland, hypothalamus, thyroid gland, parathyroid glands, thymus, adrenal cortex and medulla, islet pancreatic apparatus, ovaries, testicles, placenta.

2. Glands of external secretion (exocrine) – have their own excretory ducts, are able to secrete products on the surface of the body or in the cavity of organs. These include: salivary glands, sweat glands, sebaceous glands, lacrimal glands.

3. Glands of mixed secretion – can have their own ducts, as well as excrete products directly into the body's liquid tissues. These include the pancreas, the sex glands. They take part in slowly proceeding physiological processes: growth, metabolism, secretion of digestive juices, puberty.

The products of endocrine glands are called hormones.

Hormones are biologically active substances that in small quantities are capable of exerting a significant influence on the body.

By chemical nature, all hormones can be divided into 4 groups:

1) derivatives of amino acids;

2) peptides and proteins;

3) steroids;

4) fatty acids.

The following mechanisms are involved in the regulation of hormone secretion:

1. The presence of a specific metabolite in the blood (for example, increasing glucose levels causes the secretion of insulin by the pancreas, which lowers blood glucose levels).

2. The presence of another hormone in the blood (for example, the anterior pituitary hormones stimulate hormone secretion by other glands).

3. Stimulation by the autonomic nervous system (for example, when stressed cells the adrenal medulla begin to secrete adrenaline and norepinephrine).

Hormones have specificity and act only on cells, organs and tissues that have specific receptors for these hormones. Such organs, cells, and tissues are called "targets." When a hormone interacts with a receptor in the cytoplasm, nucleus or plasma membrane, a hormone-receptor complex is formed.

There are 4 mechanisms of action of hormones associated with the receptor:

1) action on the plasma membrane;

2) effect on the enzyme systems of the membrane;

3) effect on cellular organelles;

4) action on the gens.

The central organs of the endocrine system are the hypothalamus and the pituitary gland.

2. ***Hypothalamus.*** One of the most important functions of the hypothalamus is to regulate the activity of the pituitary gland.

In neurosecretory cells of the supraoptic and paraventricular nuclei of the hypothalamus, oxytocin and antidiuretic hormone (ADH), also called vasopressin, are synthesized. The hormones in the granules are transported by axons of neurosecretory neurons and released into the capillaries of the neurohypophysis (posterior lobe). ADH regulates the reabsorption of water in the kidneys and increases the muscle tone of the arterioles, thereby increasing blood pressure. Oxytocin stimulates the contraction of the muscles of the uterus and mammary glands.

In the medial hypothalamus (the hypophysotropic zone of the hypothalamus), hormones, which are supposedly hormones of hormones, are released. They are divided into stimulating (releasing factors – liberins) and inhibiting secretion (inhibiting factors – statins). In the hypothalamus, 5 liberins (thyreoliberin, somatoliberin, prolactoliberin, gonadoliberin, corticoliberin) and 2 statins (somatostatin, prolactostatin) are synthesized.

Once released from the nerve endings, the hypophysotropic hormones through the vessels of the hypothalamic-pituitary portal system enter the adenogipophysis (anterior lobe) and there affect the cells secreting tropic hormones. Tropic hormones, in turn, affect the peripheral endocrine glands.

The secretion of hypophysotropic hormones by the hypothalamus is regulated by the principle of negative feedback.

The endocrine glands and the hormones they produce

Gland	Hormones	The effect of hormones on the body
Anterior pituitary	Somatotropic (growth hormone)	Stimulates linear growth and body weight
	Thyrotropic	Causes thyroid hormone secretion
	Adrenocorticotropic	Causes adrenal cortex hormone secretion (first of all glucocorticoids)
	Gonadotropic (follicle-stimulating, luteinizing)	Cause sex hormone secretion
	Prolactin	Stimulates production and release of the milk by mammary glands
	Melanocyte-stimulating hormone	Stimulates skin pigment production (melanin)
Posterior pituitary	Antidiuretic hormone (vasopressin)	Increases the process of water reabsorption by nephron tubules
	Oxytocin	Stimulates uterus contractions during childbirth
Pineal gland	Melatonin	Inhibits the production of growth hormone; plays an important role in the regulation of the sleep-wake cycle, a powerful antioxidant, a cortisol antagonist
Thyroid gland	Triiodothyronine (T3), thyroxine (T4)	Stimulate oxidative metabolism; provide differentiation of brain structures in newborns
	Calcitonin	Reduces the content of calcium ions in the blood due to an increase in its intake in bone tissue
Parathyroid glands	Parathyroid hormone	Increase the content of calcium ions in the blood and stimulate its reabsorption in the kidneys, intestines
Thymus	Thymosin	Plays important role in carbohydrate metabolism, as well as in calcium metabolism,

Gland	Hormones	The effect of hormones on the body
		regulates the growth and development of the skeleton of the body; regulation of the immune response, affects the maturation of lymphocytes
Adrenal medulla	Catecholamines (adrenaline; noradrenaline)	Stimulate heart rate, expand the bronchi, inhibit the secretion and motility of the gastrointestinal tract; cause hyperglycemia and an increase in the content of fatty acids in the blood
Adrenal cortex	Glucocorticoids (cortisol)	Cause hyperglycemia due to gluconeogeneses increasing in the liver
	Mineralocorticoids (aldosterone)	Stimulate the reabsorption of sodium ions and the secretion of potassium ions in the tubules of the nephron
	Sexhormones (androgens)	Stimulate the development of secondary sexual characteristics, provide the implementation of sexual functions
Pancreas	Insulin	Reduces the level of glucose in the blood (stimulates its transportation into cells)
	Glucagon	Causes hyperglycemia by increasing the breakdown of glycogen in the liver
Sex glands: Ovaries	Estrogen	Regulates the menstrual cycle, the formation of secondary sexual characteristics during puberty
	Progesterone	Controls the processes of preparing the uterus for implantation of a fertilized egg; embryo development, lactation processes, provide the normal course of pregnancy
Testicles	Testosterone	Responsible for the formation of secondary sexual characteristics during puberty, the function of the male genital organs

Questions to consolidate theoretical material.

1. Give general characteristics to endocrine system.
2. Explain the classification of hormones.
3. Give an account of hypothalamo-hypophyseal relations.
4. Enumerate the hormones secreted by different glands and describe physiological effects.
5. What are the female and male sex hormones? Explain their actions.

Chapter 5.
PHYSIOLOGY
OF SENSORY SYSTEMS

CONTENTS

1. ***Sensory systems –*** a physiological apparatus capable of sensing information about the internal state of the body and all changes in the external environment. The concept of "sensory systems" was introduced by Ivan Pavlov.

The sensory system is a collection of peripheral and central structures involved in the perception and processing of information about signals of the external or internal environment and in obtaining about its representation (feeling, perception). All sensory systems consist of three main parts: ***peripheral or recepto***r (there is a transformation of the signal of the environment into an electrical process), ***conductive –*** it is processing information and conducting it to higher departments of the brain and, finally, ***central,*** which takes part in the final processing sensory information and appearance of feeling.

The receptor department is represented by specialized cells or free nerve endings, which are located in open areas of the skin, mucous membranes and respond primarily to adequate stimuli. However, the brain must know not only about changes in the environment, but also about what is happening inside the body. Therefore, the receptors are located in every internal organ and even in the brain (hypothalamus, medulla oblongata).

At the location of the receptors are contact and distant. Contact are excited by direct contact with the source of irritation (tactile receptors). Distant receptors receive information at some distance from the source of irritation (visual, sound, olfactory).

By localization, the receptors are: exteroreceptors – receptors located in the skin; proprioceptors – receptors located in muscles, joints and tendons; interreceptors – receptors located in the internal organs.

According to the adequacy of stimulation, the receptors are: chemoreceptors, mechanoreceptors, photoreceptors, nociceptors.

According to the mechanism of excitation, there are primary-sensitive and secondary-sensitive receptors. Primary receptors are free nerve endings. They perceive stimuli, turn them into excitation, and there is a receptor potential known as a kind of local potential. The receptor potential, having reached a critical level of depolarization, is converted into an action potential. Primary sensory receptors include skin, olfactory, and taste receptors.

Secondary sensitive receptors are functionally and structurally different. They contain a receptor cell around which are the sensitive nerve endings of the nerve cell. Under the action of the stimulus, the stimulus is perceived by the receptor cell, and a receptor potential arises in it, which leads to the release of a mediator. The latter causes depolarization of the postsynaptic membrane, which generates a generating potential, when it reaches a critical level of depolarization, there is an action potential. Secondary sensory receptors include visual, auditory, vestibular receptors.

Receptors have the following purpose:

1. Detection and recognition of signals.
2. Perception of irritation.
3. Conversion of signals into action potential.
4. Initial analysis of the received information.
5. Selection of useful information.

The conductor department of each sensory system usually includes 3 neurons. The first neuron is located in the spinal ganglion or in the ganglion of the cranial nerve, the second neuron is located in the structures of the CNS, the third neuron is located only in the switching nuclei of the thalamus. The conductor department detects and recognizes signals on the basis of which useful information is selected. Part of the received information is completely excluded, the other part is delayed for some time due to braking, the rest goes to the bark. Reticular nuclei and nonspecific pathways take part in information filtering. Structurally, this process is due to numerous branches, collaterals to different parts of the CNS and the cortex of the large hemispheres.

The center of each sensory system is located in the cortex. It has nuclear and scattered parts. The nuclear part of the analyzer is located in a specific projection field of the cortex, and the scattered part is located in the corresponding associative region. The brain is responsible for decoding, detecting, recognizing signals, constructing the image of the stimulus and forming sensory sensations. Detection is a selective analysis of individual features of the stimulus. This work is performed by neurons detectors of different levels, which are excited only by certain signs of the stimulus. Then the stimulus or signal is recognized by parallel analysis of all signs of the stimulus. After that, higher detectors create the image of a stimulus and at the same time a certain feeling is formed. The formation of sensation occurs in all parts of the analyzer and ends in the brain. According to the modality of the stimulus, independent sensations of touch, sight, hearing, smell, taste, cold, heat, pain, vibration, body position and limbs in relation to the torso are formed. On the basis of the totality of all sensations the sensory perception of information, its awareness, subjective attitude to it in the form of emotions is formed. As a result, there is a sensory experience, i.e. creates a memory of the stimulus.

Perception of information – is a reflection in the human mind of objects and phenomena of reality with their direct action on the sensory systems as a whole.

Classification of sensor systems:

1. Sensory systems associated with the senses (visual, auditory, vestibular, gustatory, olfactory).

2. Somato-visceral sensory systems (skin sensitivity, deep sensitivity, sensitivity of internal organs).

2. The somatic senses can be classified into three physiologic types: mechanoreceptive somatic senses, which include both tactile and position sensations that are stimulated by mechanical displacement of some tissue of the body; thermoreceptive senses, which detect heat and cold; pain sense, which is activated by any factor that damages the tissues. The tactile senses include touch, pressure, vibration, and tickle senses, and the position senses include static position and rate of movement senses.

2. ***Somatic sensations*** are also often grouped together in other classes, as follows. Exteroreceptive sensations are those from the surface of the body. Proprioceptive sensations are those having to do with the physical state of the body, including position sensations, tendon and muscle sensations, pressure sensations from the bottom of the feet, and even the sensation of equilibrium. Visceral sensations are those from the viscera of the body; in using this term, one usually refers specifically to sensations from the internal organs. Deep sensations are those that come from deep tissues, such as from fasciae, muscles, and bone. These include mainly "deep" pressure, pain, and vibration.

Detection and transmission of tactile sensations. Interrelations Among the Tactile Sensations of Touch, Pressure, and Vibration. Although touch, pressure, and vibration are frequently classified as separate sensations, they are all detected by the same types of receptors. There are three principal differences among them: touch sensation generally results from stimulation of tactile receptors in the skin or in tissues immediately beneath the skin; pressure sensation generally results from deformation of deeper tissues; vibration sensation results from rapidly repetitive sensory signals, but some of the same types of receptors as those for touch and pressure are used.

Tactile receptors. There are such different types of tactile receptors:

1. Free nerve endings.
2. Meissner's corpuscles.
3. Merkel's discs.
4. Ruffini's endings
5. Pacinian corpuscles.

Transmission of tactile signals in peripheral nerve fibers. Almost all specialized sensory receptors, such as Meissner's corpuscles, hair receptors, Pacinian corpuscles, and Ruffini's endings, transmit their signals in type Ab nerve fibers that have transmission velocities ranging from 30 to 70 m/sec. Conversely, free nerve ending tactile receptors transmit signals mainly by way of the small type Ad myelinated fibers that conduct at velocities of only 5 to 30 m/sec. Some tactile free nerve endings transmit by way of type C unmyelinated fibers at velocities from a fraction of a meter up to 2 m/sec; these send signals into the spinal cord and lower brain stem, probably subserving mainly the sensation of tickle. Thus, the more critical types of sensory signals – those that help to determine precise localization on the skin, minute gradations of intensity, or rapid changes in sensory signal intensity – are all transmit- ted in more rapidly conducting types of sensory nerve fibers. Conversely, the cruder types of signals, such as crude pressure, poorly localized touch, and especially tickle, are transmitted by way of much slower, very small nerve fibers that require much less space in the nerve bundle than the fast fibers.

Pain is a protective mechanism. Pain occurs whenever any tissues are being damaged, and it causes the individual to react to remove the pain stimulus.

Types of Pain. Pain has been classified into two major types: fast pain and slow pain. Fast pain is felt within about 0.1 second after a pain stimulus is applied, whereas slow pain begins only after 1 second or more and then increases slowly over many seconds and sometimes even minutes. Fast pain is also described by many alternative names, such as sharp pain, pricking pain, acute pain, and electric pain. This type of pain is felt when a needle is stuck into the skin, when the skin is cut with a knife, or when the skin is acutely burned. It is also felt when the skin is subjected to electric shock. Slow pain also goes by many names, such as slow burning pain, aching pain, throbbing pain, nauseous pain, and chronic pain. This type of pain is usually associated with tissue destruction. It can occur both in the skin and in almost any deep tissue or organ.

The pain receptors in the skin and other tissues are all free nerve endings. They are widespread in the superficial layers of the skin as well as in certain internal tissues, such as the periosteum, the arterial walls, the joint surfaces, and tentorium in the cranial vault. Most other deep tissues are only sparsely supplied with pain endings.

Pain can be elicited by multiple types of stimuli. They are classified as mechanical, thermal, and chemical pain stimuli.

In contrast to most other sensory receptors of the body, pain receptors adapt very little and sometimes not at all. One can readily understand the importance of this failure of pain receptors to adapt, because it allows the pain to keep the person apprised of a tissue-damaging stimulus as long as it persists.

Visual sensory system. About 90 % of information about the outside world enters the CNS through the visual sensory system. Due to this, the receptor itself is a complex organ that has the appropriate structures not only for perception, but also for the initial processing of information. The eye contains receptive receptors – rods and cones, four types of neurons and a complex auxiliary apparatus. Nerve centers, which provide the processing of visual information, also have a very complex structure.

Before the light wave reaches the receptor cells located in the retina, a beam of light passes through the cornea, lens and vitreous body, which form the optical system. As a result, light is refracted on the surface that separates these media. The task of the optical system of the eye is not only to focus the rays on the corresponding receptors of the retina, but also their filtration. The lens also absorbs infrared radiation. Ultraviolet rays are absorbed by the cornea and other media, so they do not reach the retina. To see an object, it is necessary that the rays from individual points of it be focused on the retina. This function is performed by the refractive media of the eye. The adaptation of the eye to the vision of distant objects is called accommodation. Accommodation is provided by a lens, the curvature of which can vary.

Refraction anomalies. In clinical practice, there are often two main defects in refraction – myopia and hyperopia. To get a clear image, the main focus of the eye should be on the retina. However, if the eye is longer or shorter in the longitudinal direction, then, despite the normal degree of refractive power of the optical apparatus, the rays parallel to the main optical axis will converge exactly on the retina. In myopia, such rays converge in front of the retina, and in hyperopia – behind it.

The retina is the inner lining of the eye. Here are photoreceptors (rods and cones), several types of nerve cells and a layer of pigment cells. In the center of the retina there is a central fossa (yellow spot), which has only cones, and a blind spot – the place of exit of the optic nerve. The blind spot has no photoreceptors. After passing through the optical system of the eye, light enters the retina, where it is perceived by receptor cells. Each receptor consists of a light-sensitive outer segment containing visual pigments and an inner one that includes the nucleus, mitochondria, and other subcellular structures. In photoreceptors there is an interaction of a quantum of light with the corresponding pigment.

Retinal neurons contain four types of cells: horizontal, bipolar, amacrine, ganglion. Photo-receptor cells use synaptic contacts to transmit signals to horizontal and bipolar cells. Bipolar cells in turn transmit impulses to the dendrites of horizontal cells. Ganglion cells give rise to the optic nerve.

At the base of the skull, both optic nerves merge, causing the nasal halves of the nerve fibers to move to the contralateral side. The crossed part of the fibers carries information about those parts of the retina to which the rays fall from the outer half of the cornea. Therefore, the optic nerve, passing through, carries information to each half of the brain mainly from the corresponding half of the visual field

The visual tract passes through the lateral geniculate bodies. However, part of the fibers before entering the lateral geniculate body gives a branch to the neurons of the upper tubercles of the quadriceps. The visual signal, passing through these structures and nuclei of the auxiliary visual tract, enters the nervous visual cortex, which is located in the occipital region of the cortex of large hemispheres.

Perception of colors. The human eye distinguishes not only the shape, surface or shades of gray. It can recognize waves in the range of 400 to 760 nm, which are a variety of colors. Each color has its own wave of a certain length. There are the following theories of color vision:

Three-component theory. It is believed that at the receptor level, color vision is provided by the fact that the retina has at least three types of cones, each of which functions as an independent receiver. Some cones contain a pigment that reacts to red, the pigment of other cones is sensitive to green, others – to purple.

Theory of opposing colors (Goering). It has been observed that when considering several colors, one can notice the appearance of some other color or the disappearance of some color. Based on this effect, Goering proposed the theory of opposing colors. He believed that there are four primary colors, on the basis of which we can distinguish their paired color contrasting combinations, such as green-red, yellow-blue. It is assumed that there are three types of cones, which perceive in addition to these two pairs also white and black. Other color sensations are born through a combination of these three combinations.

In recent years, when we learned to divert biopotentials from individual receptors and nerve cells, it was proved that both of the above theories were correct.

Auditory sensory system. For humans, the second after the visual value and volume of information obtained from the environment is the sensory auditory system. Receptors of the auditory analyzer belong to the secondary-sensitive. Receptor hair cells are contained in the curl of the inner ear on the middle stairs of the main membrane.

Receptor cells form the organ of Corti. Internal receptor cells of the organ of Corti are located in one row, and external – in 3–4 rows. On the part of the cell facing the tectorial membrane, near the inner receptor cells contains 30–40 relatively short hairs. Each cell of the outer row has 65–120 thin and long hairs. There is no functional equality between individual receptor cells. The formation of a spiral (cortical) organ is completed by a tectorial membrane, which is located above the hair cells.

The space of the middle ladder is filled with endolymph. Above the vestibular and under the main membranes, the space of the corresponding channels is filled with perilymph.

Before sound vibrations reach the inner ear, they pass through the outer and middle. The outer ear is used mainly for the perception of sound vibrations, maintaining humidity and temperature near the eardrum at a constant level.

Behind the eardrum begins the cavity of the middle ear, which is closed at the other end by a membrane with an oval hole. The air-filled middle ear cavity communicates with the nasal cavity of the pharynx through the Eustachian tube, which serves to equalize the pressure on both sides of the eardrum. The eardrum, perceiving sound vibrations, transmits them to the system of bones located in the middle ear (malleus, incus, stapes). Through them, the oscillations are transmitted to the membrane of the oval hole. The bone system amplifies the oscillations of the sound wave, but reduces its amplitude.

There are two muscles in the middle ear cavity. By affecting the tension of the eardrum, they limit the movement of the stapes and thus participate in the adaptation of the auditory receptor to the intensity of sound.

The oscillations of the membrane of the oval hole are transmitted to the perilymph of the vestibular ladder and through the parietal membrane to the endolymph. Along with the endolymph, the main membrane, on which the receptor cells touching the integumentary membrane are located, also oscillates. This leads to their deformation and the emergence of receptor potential. Cochlear nerve afferents are associated with receptor cells, the transmission of impulses to which occurs through a mediator.

The upper channel of the cochlea, or vestibular ladder, originates from the oval window and goes to the top of the curl. Here it is connected through a hole (helicotrema) with the lower channel (drum ladder), which starts from a round hole closed by a membrane. The membrane receives vibrations from the fluid (through the perilymph of the tympanic membrane). If there was no membrane, oscillations would be impossible because the fluid does not compress.

Excitation in receptor cells occurs when the deformation of the hairs that touch the integumentary membrane. The range of amplitude of oscillations of the endolymph depends on the amplitude of oscillations of the membranes. Of course, the higher the amplitude of the oscillations, the more cells are excited as the cells that lie deep begin to respond. As a result, at low oscillation intensities, only hair cells that lie on the surface are excited. In the case of increasing the amplitude increases the number of excited receptor cells.

The cochlear nerve reaches the ventral and dorsal cochlear nuclei. Next, the fibers go to the lower tubercles of the quadriceps and the medial geniculate body. Then they enter the metathalamus, and only then the sound pathways enter the primary sound zone of the cortex. Next to it are neurons that belong to the secondary sound zone of the cerebral cortex. The sound zone of the cortex is located in the temporal area of the cortex of the large hemispheres.

Questions to consolidate theoretical material.

1. Explain the importance of the sensory systems for humans.
2. What is an analyzer? List its parts.
3. Explain how visual sensory information is processed.
4. Explain how auditory sensory information is processed.
5. Describe the structure and function of the somatosensory system.

Chapter 6.
PHYSIOLOGICAL BASIS OF HUMAN BEHAVIOR

CONTENTS

1. The activity of the nervous system can be divided into lower and higher. The functions of the nervous system, aimed at regulating the vital functions of organs and systems, uniting them into a single organism, belong to the lower nervous activity. The functions that determine the behavior of the individual in the environment and its adaptation to changing environmental conditions, belong to the higher nervous activity.

The structural basis of higher nervous activity is the cerebral cortex and adjacent subcortical formations. At formation of behavior in a nervous system neural chains which are a basis of development of various reflexes, motivations, emotions and thinking are formed.

There are innate and acquired in the process of individual development of behavior. They are aimed at preserving the individual and the species.

Innate forms of animal and human behavior include unconditional reflexes, instincts, biological motivations and emotions.

Unconditional reflexes are formed and realized according to a strict genetic program. Most of them appear immediately after the creature is born. Some unconditional reflexes (for example, sexual) are formed after birth as the morpho-functional maturation of the nervous, endocrine and other systems.

Unconditional reflexes are species-specific, i.e. they are specific to representatives of a species. As a result, they are also called species reflexes. Unconditional reflexes are very stable; they persist not only during the life of the organism, but also during the existence of the species to which the animal belongs.

With the help of unconditional reflexes is a relatively constant connection of the organism with the environment.

Classification of unconditioned reflexes. Several classifications of unconditioned reflexes are proposed depending on the nature of the stimuli that cause them and the biological role, the level of CNS control, and so on. Thus, unconditioned reflexes are divided into motor, autonomic or visceral, protective and others.

Instincts play an important role in shaping the holistic behavior of animals. Instinct is a complex system of unconditional reflexes that are chain in nature, where the end of one reflex link is the beginning of another. In essence, instincts are a complex of simple unconditional reflexes. They are manifested by purposeful adaptive activity due to innate mechanisms.

Instincts are divided as follows: vital, or those that ensure the physical survival of the person; role, including gender, parental, territorial, hierarchical; self-development. The biological significance of instincts is not limited to the organization of animal behavior. They are the evolutionary basis for the formation of more complex forms of behavior.

Innate forms of behavior include biological motivations, "basic needs" that reflect changes in the internal environment of the body and are related to biological needs – hunger, thirst, sexual sensation and more.

Biological motivations – behavioral acts aimed at finding special stimuli in the environment. They provide satisfaction of the arisen certain internal needs. Biological motivations belong to the lower, simple or primary. In humans, on the basis of lower motivations, cognition, and lifelong learning, complex systems of higher, social motivations are formed, which differ from biological ones in content, purpose, and stability. The social motivations of a person include the desire for education, art, acquisition of a certain profession, and so on.

The nervous substrate of biological motivations is mainly the hypothalamic region of the brain, where the "centers" of hunger, sexual and protective behavior. Motivational excitations that arise here then radiate in an ascending direction to the limbic structures and cerebral cortex, mainly in its anterior parts, where programs of purposeful action are formed, which leads to the satisfaction of the original biological need.

Physiological properties of conditioned reflexes. Conditioned reflexes are individually acquired systemic adaptive reactions of animals and humans, which arise on the basis of the formation in the CNS of a temporary connection between the conditioned (signal) stimulus and any unconditioned reflex act. The biological significance of such a reflex lies in its signaling, i.e. in the acquisition by some indifferent stimulus of the role of a precautionary factor that signals the onset of further events and prepares the body to interact with them.

Conditioned reflexes differ in many ways from unconditioned ones. First of all, they are individual reflexes acquired during the life of the organism. Conditioned reflexes arise due to the formation of functional temporal connections, the laying of new nerve pathways in the higher parts of the CNS due to a specific closed function, which is an important physiological property of these parts of the brain. Conditioned reflexes are labile in intensity and duration. These are temporary reflexes. Due to the complexity of the reflex arc, conditioned reflexes have a longer latency period than unconditioned ones.

Conditioned reflexes can also cause inadequate stimuli (for example, the sound of a metronome can become a conditioned secretory or motor stimulus, although it has nothing to do with either secretory or motor activity).

Conditions required for the development of conditioned reflexes. The first condition for the formation of a conditioned reflex is a coincidence in time or some precedence of an indifferent (conditioned) stimulus to an unconditioned one, the so-called reinforcement. For example, the action of a conditioned stimulus (light bulb) and reinforcement (food). Only in this case there is a temporary connection in the cerebral cortex. As we can see, in contrast to unconditional reflexes, here a qualitatively new link is reinforcement, i.e. the coincidence in time of the action of conditioned and unconditioned stimuli. A prerequisite for temporary connection is also the active state of the cerebral cortex. During deep sleep or under anesthesia, conditioned reflexes are not produced. It is very difficult to produce conditioned reflexes with deep fatigue. An important condition for the formation of temporal connections is free from other activities, the state of the cerebral cortex during the development of a conditioned reflex. Therefore, all stimuli that cause vigorous activity of the cortex, interfere with the formation of a conditioned reflex.

Irritations can come from the environment as well as from internal organs (overcrowded bladder, rectum, stomach, uterus, etc.).

Conditioned reflexes are formed gradually, with repeated repetition of all the above conditions, and it happens in waves – they appear or disappear until they stabilize in intensity and regularity, which indicates the strengthening of conditioned reflexes.

2. Inhibition of conditioned-reflex activity, as well as the activity of the CNS in general, plays an exceptional role. Thanks to it, conditioned reflexes are specified in accordance with variable conditions or their temporary cancellation occurs if the conditioned stimulus has lost its signal value. Inhibition is also based on the ability to wait, maintain self-control, distinguish (differentiate) similar conditional signals, and so on. In addition, inhibition performs protective functions against nerve cells in the event of exposure to too strong conditioned stimuli. The inhibitory processes that occur in the cerebral cortex were divided by Ivan Pavlov into two groups: external, or unconditional, and internal, or conditional.

External (unconditioned) inhibition occurs immediately, does not require special development, is innate, as well as unconditional reflexes. It occurs when the operation of one of the centers of the cerebral cortex due to irritation of the afferent nerves comes into play another center. There is a kind of conflict, or competition between these nerve cells. Conditioned-reflex activity in each case can be delayed under the influence of external stimuli (appearance of new objects, sounds, smells, changes in lighting, etc.), which cause the orientational reflex. Orientational reflex is a factor of unconditioned inhibition, which is most common. With repeated action, the inhibitory effect of the stimulus weakens, it loses its inhibitory effect on conditioned reflexes.

Internal (conditioned) inhibition is specific to the cerebral cortex, requires the development, training of certain conditions. Initially, it occurs in the middle of the central nervous structures of the actual conditioned reflexes under the influence of their own conditioned stimuli, which act in special conditions. Hence its name – internal, or conditioned. The main condition for the occurrence of internal inhibition is that the action of the conditioned stimulus terminates the action of the unconditioned reflex, i.e. the reinforcement is canceled. Systematic exposure to a conditioned stimulus without combining it with an unconditioned one leads to a gradual weakening of the conditioned reflex, and subsequently to its disappearance. The weakening and disappearance of the conditioned reflex does not indicate the destruction, but only the rupture of the temporal connection, i.e. its inhibition. First, the disappeared reflex after a while is restored by itself. Secondly, it is restored in the case of external stimuli (so-called deceleration). Finally, the reflex is restored even with a single reinforcement.

3. Ivan Pavlov, studying human HNA, proved that the HNA of higher animals and humans are based on common mechanisms. However, human HNA is characterized by a greater degree of development of analytical and synthetic processes. The emergence of new features of human HNA was due to the fact that under the influence of human labor, a new system of stimuli in the form of words that denote various phenomena and objects of the world***. Ivan Pavlov created the doctrine of the first and second signaling systems.***

The first signaling system is the analytical-synthetic activity of the cerebral cortex, which is manifested in conditioned reflexes that are formed on any stimuli of the environment, except words. The first signal system is the basis for the direct reflection of objective reality in the form of sensations and perceptions.

The second signaling system is the analytical-synthetic activity of the cerebral cortex, which is manifested in speech conditioned reflexes, which are formed into peculiar stimuli – words. Ivan Pavlov considered the word – "signal of signals". The second signal system is a reflection of the surrounding reality by generalizing abstract concepts with words.

The first and second signaling systems are interconnected. The second one functions due to the information coming from the first signaling system, transforming it into specific concepts. The signal meaning of a word is determined not by a simple sound combination, but by a semantic one. The second signaling system provides abstract human thinking. It is socially conditioned. Outside society, without communication with other people, it does not develop in humans. With the advent of the second signaling system, a new principle of nervous activity appears – the abstraction and generalization of a large number of signals that enter the brain. This principle determines the infinite orientation of man in the world around him. The second signaling system is the highest regulator of various forms of human behavior in the environment. However, it correctly reflects the objective world only if it's consistent interaction with the first signaling system is constantly maintained.

Temperament, or type of nervous system, characterizes the innate properties and characteristics of mental activity of the individual. There are three main components in the structure of temperament – the general activity of the individual, his motor manifestations and emotionality.

Classification of temperaments. Studying the patterns of the brain, Ivan Pavlov was convinced of the ability to assess the individual characteristics of its functions on the basis of the doctrine of the types of the nervous system. Pavlov based his classification of types of nervous system, or temperaments, on the following main principles: strength, balance, and mobility of nervous processes (excitation and inhibition) in the cerebral cortex.

Thus, evaluating the above physiological properties of the nervous system, Pavlov identified four main types of nervous system of higher animals and humans:

1) strong, balanced, mobile;
2) strong, balanced, inert;

3) strong, unbalanced with the predominance of excitation processes over the processes of inhibition and with a mobile nervous system;

4) weak.

In the formation of types of the nervous system, the interaction between the first and second signaling systems and the balance between them become extremely important. This principle was laid down by Ivan Pavlov as the basis for the classification of special types of people. ***There were three main types – art, thinking and mixed.*** In a person belonging to the artistic type, the activity of the first signal system is especially pronounced (although it is dominated by the influence of the second signal system). For a person who belongs to the thinking type, is characterized by clear effects of the second signal system. In the mixed type, both signal systems operate to some extent equally. Especially human types can be considered as a consequence of individual variations in the functional asymmetry of the brain. The relative dominance of the right (non-verbal) hemisphere corresponds to the art type, and the left to the thinking type.

Questions to consolidate theoretical material.

1. What do you know about unconditioned reflexes?
2. What do you know about conditioned reflexes?
3. Compare the different types of inhibition of conditioned reflexes.
4. Describe the types of higher nervous activity. What are the first and second signaling systems?
5. What is temperament? What is the basis of the classification of types of temperaments?

Chapter 7.
BLOOD PHYSIOLOGY

CONTENTS

1. The concept of the blood system. Functions of the blood.
2. Blood composition and volume. Hematocrit index.
3. Plasma, its composition, the role of plasma proteins. Osmotic and oncotic pressures. Regulation of osmotic pressure constancy.
4. Acid-base state of blood, the role of buffer systems in the regulation of its stability.
5. Blood cells (erythrocytes, leukocytes, platelets).
6. The concept of blood groups and Rh factor.

1. ***The blood system*** is a collection of executive structures (plasma, blood cells), organs of blood formation (hematopoiesis) and blood destruction (old and defective elements) and regulation apparatus, the activity of which is aimed at maintaining adequate changes in the volume and constituents of blood components to ensure adaptive reactions of the body.

The blood system provides: the optimal amount of constituents of blood as units of transport per unit of blood volume; involved in maintaining homeostasis.

Circulating blood – is in a state of active circulation. Blood deposited – blood stored in the depot. Depot of blood in the body: – sinuses of the spleen and vessels with a low linear blood flow rate (venous vessels of the skin, gastrointestinal tract, lungs, etc.). The organs of hematopoiesis – red bone marrow, thymus, lymph nodes, spleen, lymphatic follicles of the digestive tract. Organs of destruction of blood elements – macrophagocytic system of an organism (liver, spleen). The nervous mechanisms of regulation provide a rapid change in the composition of the blood due to the redistribution of its elements (between the depot and the active circulation). Humoral mechanisms are aimed at stimulating hematopoiesis and cause slow but reliable changes in blood composition.

The blood system performs the following functions:

- Transport.

- Nutritive.
- Respiratory.
- Excretory.
- Transport of hormones and enzymes.
- Regulation of water balance.
- Regulation of acid-base balance.
- Regulation of body temperature.
- Storage.
- Defensive.

2. ***Blood consists*** of a protein-rich fluid known as plasma, in which are suspended cellular elements: white blood cells, red blood cells, and platelets. The normal total circulating blood volume is about 8 % of the body weight (5600 mL in a 70-kg man). About 55 % of this volume is plasma. Plasma is a straw-colored clear liquid part of blood. It contains 91 % to 92 % of water and 8 % to 9 % of solids. The solids are the organic and the inorganic substances

Hematocrit – the percentage of the blood cells (or more precisely, erythrocytes) in the blood. Under normal conditions, it is 40–48 % for men, 36–46 % for women. The value changes, first of all, when the water exchange changes.

3. ***The liquid portion*** of the blood, the plasma, is a remarkable solution containing an immense number of ions, inorganic molecules, and organic molecules that are in transit to various parts of the body or aid in the transport of other substances. Normal plasma volume is about 5 % of body weight, or roughly 3500 mL in a 70-kg man.

The plasma proteins consist of albumin, globulin, and fibrinogen fractions. Most of the plasma proteins are synthesized in the liver. The plasma protein content is about 70 g/l. Most of the plasma proteins are represented by low molecular weight albumins (about 40 g/l), and less by high molecular weight globulins (about 30 g/l). In addition, plasma contains about 3 g/l of fibrinogen.

Functions of plasma proteins:

1. Maintain oncotic pressure (30 mmHg).
2. Is a buffer system of blood.
3. Provide blood viscosity (to maintain blood pressure).
4. Prevent erythrocyte sedimentation.
5. Participate in blood coagulation.
6. Participate in immunological reactions (globulins).
7. Transfer hormones, lipids, carbohydrates, biologically active substances.

8. There is a reserve for the construction of tissue proteins.

Osmotic pressure – ensures the exchange of water between blood and tissues. Osmotic pressure is the force that drives the solvent through a semi-permeable membrane toward greater concentration. Osmotic pressure is provided mainly by inorganic substances of plasma.

Oncotic pressure – part of the osmotic created by proteins. It affects the exchange of water between the blood plasma and the intercellular fluid. It is mainly provided by albumins.

4. ***The active reaction of the blood (pH) is due to the ratio of H^+ and OH ions in it.*** Blood has a slightly alkaline reaction. pH of arterial blood – 7.4, venous – 7.35. Limits of change of pH compatible with life – 7.0–7.8. Stability of pH is necessary for the normal course of metabolism in cells (enzymes change their activity when changing pH).

The acid-base state of the blood depends on the ratio of the concentrations of H^+ and OH^- ions in the blood plasma. Despite the continuous flow of acidic and alkaline metabolic products into the blood, the pH of the blood remains at a relatively stable level. Maintaining this constancy is ensured by numerous physics-chemical biochemical and physiological mechanisms. In the blood there is a fairly constant relationship between acidic and alkaline components, it is commonly referred to as acid-base balance. If there is a shift of the active reaction in the acidic side, then this condition is called acidosis, in alkaline – alkalosis.

There are three main ways to maintain pH at a constant level: buffer systems of the fluid of the internal environment of the body and tissues; allocation of CO_2 by lungs; 3 – excretion of acidic or retention of alkaline products by the kidneys. Main organs which maintain the stable level of pH are liver and lungs. In the blood there are the following buffer systems: hemoglobin, carbonate, phosphate, protein.

Hemoglobin buffer system is considered to be the largest – up to 75 % of the total buffer capacity of blood. This system consists of reduced hemoglobin and its potassium salt. In tissues, the system of hemoglobin functions as alkali, preventing the acidification of blood due to the supply of CO_2 and H^+ ions. In the lungs, the hemoglobin of the blood behaves like an acid, preventing the leaching of blood after removal of CO_2.

Bicarbonate buffer system occupies the second place by force, and the first by the speed of response. Consists of carbonic acid and sodium bicarbonate or potassium bicarbonate. When excess acid, stronger than carbonic, is formed in the body, this acid reacts with the carbonic acid salt (with potassium or sodium bicarbonate). The result is a salt of this acid and a weak carbonic acid, which is poorly dissociated. Thus, the strong acid is replaced by a weaker acid – prevents the pH from changing. When excess alkaline compounds are formed in the body, they interact with carbonic acid to form bicarbonates – preventing changes in blood pH.

Phosphate buffer system formed by sodium dihydrogen phosphate (NaH_2PO_4) and sodium hydrogen phosphate (Na_2HPO_4). The first compound is poorly dissociated and behaves like a weak acid. The second compound has alkaline properties. When more acid is introduced into the blood, it reacts with sodium hydrogen phosphate, forming a neutral salt and increasing the amount of sodium dihydrogen phosphate. When introduced into the blood of a strong alkali, it will react with sodium dihydrogen phosphate to form sodium hydrogen phosphate.

Protein buffer system. Blood plasma proteins, due to their amphoteric properties, play a role in acid-base equilibrium. In an acidic environment, proteins react as alkalines, in the alkaline – like as acids.

5. ***Red blood cells (RBCs, erythrocytes) –*** biconcave disc shape, which is suited for gas exchange. The shape is flexible so that RBCs can pass though the smallest blood vessels, i.e., capillaries. Primary cell content is hemoglobin, the protein that binds oxygen and carbon dioxide. No nucleus and mitochondria. Do not move on their own, are carried with blood flow. Main function: transport oxygen from the lung to tissue cells and carbon dioxide from tissue cells to the lung. Are produced in the red bone marrow. Erythropoietin (is produced by renal cells) stimulates erythrocyte production in the red bone marrow. The average life span of erythrocytes is 120 days.

The number of cells in the blood: $4{,}0 – 5{,}0 \times 10^{12}$/l (♂);
$3{,}9 – 4{,}7 \times 10^{12}$/l (♀).

Increase in the number of red blood cells – erythrocytosis, decrease – erythropenia.

Erythrocytes contain hemoglobin. It is involved in the transport of O_2 and CO_2. The hemoglobin consists of protein and non-protein parts: globin and heme. The heme contains the Fe^{2+} atom. Hb content in men: 130–160 g/l; in women: 120–160 g/l.

The main types of hemoglobin are: HbA – adult hemoglobin (globin has 2 alpha and 2 beta chains); HbF – fetal hemoglobin (globin has 2 alpha and 2 gamma chains).

The features of the globin structure affect the affinity of Hb to oxygen. HbF has a greater affinity for oxygen than HbA, the fetal blood binds oxygen more strongly than the mother's blood, and in the placenta, fetal blood "picks up" oxygen in the mother's blood and drags it to herself. A few months after birth, HbF is almost completely (98 %) replaced by HbA.

In blood, hemoglobin can be in the form of several compounds:

1. Oxyhemoglobin – Hb + O_2 (in arterial blood).

2. Carbhemoglobin Hb + CO_2 (in venous blood).
3. Carboxyhemoglobin Hb + CO (carbon monoxide).
4. Methemoglobin (the heme Fe^{2+} converts into Fe^{3+}).

Hemolysis is the destruction of the erythrocyte membrane and the release of hemoglobin into the blood plasma. There are such types of it: osmotic, chemical, mechanical, thermal, biological.

White blood cells (WBCs, leucocytes) – the main function of leukocytes is to protect the body against any foreign matter. All leukocytes have a nucleus. Life span of several hours to several days (years for lymphocytes). The percentage of individual forms of leukocytes is called leukogram. Leukocytes are grouped into two major categories: granulocytes (contain specialized membrane-bound cytoplasmic granules, divided into neutrophils, eosinophils, and basophils); agranulocytes (lack obvious granules; divided into lymphocytes and monocytes). The number of cells in the blood: $4{,}0 – 9{,}0 \times 10^9$/l.

Platelets (thrombocytes) – colorless biconvex plates of irregular shape, surrounded by a membrane, without a nucleus. Life span – 8–12 days. They play an important role in blood clotting. In the blood platelets are in an inactive state. Their activation occurs as a result of contact with the damaged surface of the vessel and the action of some coagulation factors. Activated platelets secrete a number of substances that are necessary for hemostasis – platelet coagulation factors. The number of cells in the blood: $188 – 320 \times 10^9$/l. The increased level is called thrombocytosis, the decreased level is called thrombocytopenia.

6. *Blood groups.* In the blood plasma are antibodies that glue erythrocytes – agglutinins α and β. Antigens, agglutinogens A and B, are embedded in the erythrocyte membranes. Agglutinogens (antigens) are complexes of proteins, lipids and carbohydrates involved in the agglutination reaction. Agglutinins (antibodies) are proteins of the globulin fraction. The antigens from these sources are very similar to antigens A and B.

The reaction of agglutination of erythrocytes occurs when agglutinogens and agglutinins (A with α; B with β) meet with the same name. If this happens in a person's vascular bed, then a severe complication develops – hemotransfusion shock, which usually leads to death. ABO blood types were identified in 1900 by Karl Landsteiner (1930 Nobel laureate).

A person has 4 combinations of agglutinogens and agglutinins (ABO system):

- Group I (0): agglutinins α β.
- Group II (A): agglutinogen A, agglutinin β.
- Group III (B): agglutinogen B, agglutinin α.
- Group IV (AB): AB agglutinogens.

Rh Blood Groups. Erythrocytes may also have other agglutinogens. Among these, the Rh factor is of practical importance. 85 % of people have rhesus antigen and therefore their blood is rhesus positive (Rh+), 15 % of people do not have this rhesus antigen, that is, they have rhesus negative blood (Rh-). The Rh factor should be taken into account for blood transfusions (for repeated hemotransfusions, if the donor is Rh+ and the recipient is Rh-, and also in obstetric practice (if the woman is Rh- and the developing fetus is Rh+). There are no natural agglutinins in the Rh system, but when Rh-positive blood enters into the body with Rh-negative blood (maybe during pregnancy of Rh-negative woman with Rh-positive fetus; during transfusion of Rh-positive blood to recipient with Rh-negative blood) there is a production of immune antibodies to the Rh factor. These antibodies cause agglutination of erythrocytes (in the fetus – during pregnancy, in the donor – during blood transfusion).

Questions to consolidate theoretical material.

1. Describe the composition and functions of blood.
2. Describe the morphology, development and functions of leukocytes.
3. Describe the morphology, development and functions of erythrocytes.
4. Describe the morphology, development and functions of platelets.
5. What is this blood group and rhesus factor?

Chapter 8. PHYSIOLOGY OF CIRCULATION

CONTENTS

1. ***Blood circulation*** is the movement of blood in the circulatory system. Blood can perform its functions while in a state of constant motion, supported by the cardiovascular or circulatory system. The source of energy for the movement of the blood is the heart. The circulatory system provides metabolism between body tissues and the external environment and maintains the constancy of the internal environment (homeostasis).

Functions: 1) transport of nutrients to the place of their absorption; 2) transport of products of exchange from their place of formation to the organs of excretion; 3) gas transportation; 4) hormone transport; 5) transportation of the entire amount of protective substances; 6) transport of thermal energy.

The circulatory system ensures continuous blood circulation to the blood vessels. **There 2 types of circulation:**

Systemic circulation – begins from the left ventricle, from which the aorta originates. The aorta becomes large, medium and small arteries. The arteries pass into the arterioles, which end in capillaries. In the capillaries, blood gives oxygen and nutrients to the tissues, and from them into the blood enter the metabolism and carbon dioxide. The capillaries pass into the venules, from which the blood enters the shallow, medium and large veins. Venous blood enters the upper and inferior vena cava, which flows into the right atrium, where the systemic circulation ends.

Pulmonary circulation – begins from the right ventricle, from which blood enters the pulmonary trunk. The trunk is divided into two arteries that reach the right and left lungs. In the lungs, the arteries are divided into smaller arteries, arterioles, and capillaries. In the capillaries of the lungs, venous blood gives off carbon dioxide and is saturated with oxygen, becoming arterial. The pulmonary capillaries pass into the venules, which subsequently form veins. In the four pulmonary veins, the arterial blood enters the left atrium, where the small circle of circulation ends.

The heart is a hollow muscular organ that is cone-shaped. The heart is located in the chest cavity behind the sternum in the anterior mediastinum. The heart wall has 3 layers: epicardium, myocardium, endocardium. The surface of the heart cavity is covered with endothelium.

2. ***Physiological properties of the myocardium:***

- Rhythmicity – the ability of the heart to beat regularly without external stimulation.
- Excitability – the ability to respond to stimuli which may be mechanical, electrical or chemical.
- Conductivity – the ability to conduct impulse from one cell to another.
- Contractility – the ability to contract.
- Automaticity – the ability of heart cells to spontaneously depolarize and generate an action potential.

Electrical conduction system. The conduction system of the heart is a complex of anatomical formations of the heart (nodes, bundles and fibers), consisting of atypical muscle fibers (cardiac conductive muscle fibers) and ensuring the coordinated work of different parts of the heart (atria and ventricles), aimed at ensuring normal cardiac activity. Pacemaker is the structure of heart from which the impulses for heartbeat are produced. It is formed by the pacemaker cells called P cells. **Structure of electrical conduction system:** sinoatrial node (nerve impulse frequency – 60–80/min), atrioventricular node (nerve impulse frequency – 40–50/min), bundle of His (nerve impulse frequency – 30–40/min), right and left bundle branches, purkinje fibers (nerve impulse frequency – 15–20/min).

Sino-atrial node (SAN or SA node): the specialized region of tissue located in the upper right atrium that is specialized for automaticity. This region has the highest level of automaticity in the normal heart. It "sets the pace" for the rate at which the heart beats under physiological conditions. Two other regions in the normal heart (the AV node & Purkinje fibers) have a lower degree of automaticity, and can serve as backup pacemakers in the event of damage to the SA node, or blockage of conduction of action potentials from the SA node.

Atrio-ventricular Node (AVN or AV node): the specialized region of tissue located between the atria & ventricles that is specialized for slow conduction & behaves like an electrical filter in the presence of high atrial rates (e.g. atrial fibrillation).

Bundle of his & bundle branches: The His bundle extends from the distal end of the AV node & divides into smaller bundle branches in the left & right ventricles – terminating in Purkinje fibers. Specialized for rapid conduction of cardiac action potential.

Purkinje Fibers: A "spider web like" network of specialized, elongated cardiac cells that spread out over the inner surface of the ventricles (endocardium). They only weakly contract & are specialized for rapid conduction of action potentials to ventricular muscle.

3. Cardiac cycle is defined as the succession of coordinated events taking place in the heart during each beat. Each heartbeat consists of two major periods called systole and diastole. During systole, heart contracts and pumps the blood through arteries. During diastole, heart relaxes and blood is filled in the heart. All these changes are repeated during every heartbeat, in a cyclic manner.

Events of cardiac cycle are classified into two:

1. Atrial events.
2. Ventricular events.

Atrial events. Atrial systole is also known as last rapid filling phase. It is usually considered as the last phase of ventricular diastole. Its duration is 0.11 second. During this period, only a small amount, 10 % of blood is forced from atria into ventricles. After atrial systole, the atrial diastole starts. Simultaneously, ventricular systole also starts. Atrial diastole lasts for about 0.7 sec. This long atrial diastole is necessary because, this is the period during which atrial filling takes place. Right atrium receives deoxygenated blood from all over the body through superior and inferior vena cava. Left atrium receives oxygenated blood from lungs through pulmonary veins.

Ventricular events. Ventricular systole (0.27 sec.) consists of such stages: isometric contraction, ejection period. Ventricular diastole (0.53 sec.) consists of such stages: protodiastole, isometric relaxation, rapid filling, slow filling, last rapid filling.

Heart sounds. Are noises generated by the beating heart and the resultant flow of blood. There are 4 sounds. First: closure of AV valves at the beginning of isometric contraction. Second: closure of semilunar valves during protodiastole stage. Third: rushing of blood into ventricles during isometric relaxation period. Forth: contraction of atrial musculature causes that sound.

4. Hemodynamics is the study of movement of blood through circulatory system the movement of blood is characterized by two forces: the pressure difference at the beginning and end of the vessel and the hydraulic counteraction, which impedes the flow of fluid. The ratio of the pressure difference to the counteraction characterizes the volumetric velocity of the fluid flow. Volumetric fluid flow rate – the volume of fluid flowing through a vessel per unit time is expressed by the equation:

$$Q = (P1-P2)/R,$$

where Q – the volume of the fluid; P1-P2 – the pressure difference at the beginning and end of the vessel; R – resistance of the flow.

This dependence is the basic hydrodynamic law: the amount of blood flowing per unit time through the circulatory system is greater the greater the pressure difference at its arterial and venous ends and the lower the resistance to blood flow.

The basic hydrodynamic law characterizes a condition of blood circulation as a whole and a blood flow through vessels of separate organs.

The amount of blood flowing in 1 minute through the vessels of the systemic circulation, depends on the difference in blood pressure in the aorta and vena cava and on the total resistance to blood flow. The amount of blood flowing through the vessels of the pulmonary circulation is characterized by the difference in blood pressure in the pulmonary trunk and veins and the resistance to blood flow in the pulmonary vessels.

Factors determining volume of blood flow: pressure gradient, resistance to blood flow, viscosity of blood, diameter of blood vessels, velocity of blood flow.

Circulation time is the time taken by blood to travel through a part or whole of the circulatory system. If a substance is injected into a vein, the time taken by it to appear in the blood of the same vein or in the corresponding vein on the opposite side shows the total circulation time. Similarly, if the transit is from vein to the lungs, it shows the circulation time through pulmonary circuit and if it is from vein to capillaries, it shows the time for flow through pulmonary circuit, left heart and arteries to capillaries, i.e. the total circulation time minus the time for venous return.

Arterial blood pressure is defined as the lateral pressure exerted by the column of blood on wall of arteries. The pressure is exerted when blood flows through the arteries. Generally, the term ‘blood pressure’ refers to arterial blood pressure.

Arterial blood pressure is expressed in four different terms: systolic blood pressure, diastolic blood pressure, pulse pressure, mean arterial blood pressure.

Systolic blood pressure (systolic pressure) is defined as the maximum pressure exerted in the arteries during systole of heart. Normal systolic pressure: 120 mmHg (110 mmHg to 140 mmHg). Diastolic blood pressure (diastolic pressure) is defined as the minimum pressure exerted in the arteries during diastole of heart. Normal diastolic pressure: 80 mmHg (60 mmHg to 80 mmHg). Pulse pressure is the difference between the systolic pressure and diastolic pressure. Normal pulse pressure: 40 mmHg (120 – 80 = 40). Mean arterial blood pressure is the average pressure existing in the arteries. It is not the arithmetic mean of systolic and diastolic pressures. It is the diastolic pressure plus one third of pulse pressure. Normal mean arterial pressure: 93 mmHg. Mean arterial blood pressure = Diastolic pressure + 1/3 of pulse pressure.

Factors maintaining arterial blood pressure: cardiac output, heart rate, peripheral resistance, blood volume, venous return, elasticity of blood vessels, velocity of blood flow, diameter of blood vessels, viscosity of blood.

Arterial pulse is defined as the pressure changes transmitted in the form of waves through arterial wall and blood column from heart to periphery. When heart contracts, the blood is ejected into aorta with great force. It causes distension of this blood vessel and a rise in pressure. A pressure wave is produced on the elastic wall of the aorta. It travels rapidly from the heart and can be felt after a brief interval, at any superficial peripheral artery like radial artery at wrist. Pulse rate is the accurate measure of heart rate. Normal heart rate is 72/minute. It ranges between 60 and 100 per minute. The pulse is characterized by a number of signs that are determined by palpation. Features of pulse: frequency is the number of beats per minute; rhythm – the correct alternation of pulse beats; filling – the degree of change in the volume of the artery, is established by the strength of the pulse beat; tension – characterized by the force that must be applied in order to clamp the artery until the pulse disappears completely.

5. Regulation of circulation. Vasomotor center is the nervous center that regulates the heart rate. It is the same center in brain, which regulates the blood pressure. It is also called the cardiac center. Vasomotor center is bilaterally situated in the reticular formation of medulla oblongata and lower part of pons. **Vasomotor center is formed by three areas: vasoconstrictor area, vasodilator area, sensory area.**

Neurons of the vasomotor center regulate the tone of the vessels, maintain normal blood pressure, provide blood movement in the circulatory system and its redistribution in the body into separate organs and tissues, affect the processes of thermoregulation.

Vasoconstrictor area is situated in the reticular formation of medulla in floor of IV ventricle and it forms the lateral portion of vasomotor center. It is otherwise known as pressor area. Vasoconstrictor area increases the heart rate by sending accelerator impulses to heart, through sympathetic nerves. It also causes constriction of blood vessels. Stimulation of this center in animals increases the heart rate and its removal or destruction decreases the heart rate. Vasoconstrictor area is under the control of hypothalamus and cerebral cortex.

Vasodilator area is also situated in the reticular formation of medulla oblongata in the floor of IV ventricle. It forms the medial portion of vasomotor center. It is also called depressor area. Vasodilator area decreases the heart rate by sending inhibitory impulses to heart through vagus nerve. It also causes dilatation of blood vessels. Stimulation of this area in animals with weak electric stimulus decreases the heart rate and stimulation with a strong stimulus stops the heartbeat. When this area is removed or destroyed, heart rate increases. Vasodilator area is under the control of cerebral cortex and hypothalamus. It is also controlled by the impulses from baroreceptors, chemoreceptors and other sensory impulses via afferent nerves.

Sensory area is in the posterior part of vasomotor center, which lies in nucleus of tractus solitarius in medulla and pons. Sensory area receives sensory impulse via glossopharyngeal nerve and vagus nerve from periphery, particularly, from the baroreceptors. In turn, this area controls the vasoconstrictor and vasodilator areas.

The aortic and carotid reflexogenic zones play an important role in the regulation of neuronal activity of the vasomotor center. The receptor zone of the aortic arch is represented by the sensitive nerve endings of the depressor nerve (branch of the vagus nerve). In the carotid sinus region, there are mechanoreceptors associated with the glossopharyngeal (IX pair of cranial nerves) and sympathetic nerves. Their usual irritant is mechanical stretching as blood pressure changes. Mechanoreceptors are sensitive to pressure fluctuations. From these receptors, excitation enters the medulla oblongata. And then the reduction of pressure is achieved in two ways. The first is the suppression of the pressor department of the vascular center. The second way is that from the medulla oblongata excitation through the vagus nerve (X pair) enters the heart, the activity of the heart is suppressed, the blood pressure is reduced.

Chemical substances that affect the tone of blood vessels are divided into vasoconstrictor and vasodilator. Vasoconstrictors include the following substances: adrenaline, noradrenaline; vasopressin; renin, angiotensinogen, aldosterone, serotonin. Vasodilators include the following substances: histamine, acetylcholine, tissue hormones – kinins, prostaglandins.

The lumen of the blood vessels, their tone is regulated by both the nervous system and humoral factors.

Questions to consolidate theoretical material.

1. Explain functions of circulatory system.
2. Describe properties of cardiac muscle
3. Define cardiac cycle. Describe various events of cardiac cycle with pressure and volume changes.
4. Define arterial blood pressure. Describe the nervous regulation of arterial blood pressure.
5. Describe the structure and functions of vasomotor center.

Chapter 9. PHYSIOLOGY OF RESPIRATION

CONTENTS

1. Respiration is a complex process of oxygen supply to the body, its use in biological oxidation and carbon dioxide excretion. **The respiratory system includes:** respiratory tract; organs of gas exchange – lungs; pulmonary ventilation system – chest, respiratory muscles, respiratory center.

Stages of respiration: pulmonary ventilation; diffusion of gases from the alveoli into the blood of the pulmonary capillaries; transport of blood gases; diffusion of gases from blood into tissues; internal (tissue) respiration.

The first four stages are related to external respiration, the purpose of which is to absorb O_2 and remove CO_2 from the body. Pulmonary ventilation is the exchange of gases between atmospheric and alveolar air.

The mechanism of inhalation and exhalation.

The mechanism of inhalation and exhalation. The respiratory cycle consists of inhalation, exhalation and respiratory pause. The air enters and exits the lungs through the work of the intercostal muscles and the diaphragm. As a result of their contraction and relaxation, the volume of the chest cavity changes. The intercostal muscles are divided into 2 groups: external and internal. The diaphragm consists of annular and radial muscle fibers that are located around the central tendon.

Inhalation is an active process. External intercostal muscles contract, and internal intercostal muscles relax. The ribs move forward, moving away from the spine. At the same time the diaphragm shrinks, becomes flatter, its dome is lowered. All this leads to an increase in the volume of the chest cavity. As a result, the pressure in the pleural cavity becomes below atmospheric. The lungs are stretched and the pressure in them also becomes below atmospheric. Air enters the lungs and fills the alveoli until the pressure in the lungs is equal to the atmospheric pressure.

Exhalation can be passive. It occurs under the action of the elastic pull of the lung tissue and with the relaxation of the respiratory muscles, which provided breath. The volume of the thoracic cavity decreases, the pressure in the pleural cleft increases and along with the elastic thrust becomes higher than the intra-lung. The alveoli are compressed, the pressure in them becomes more than atmospheric and the air is expelled from the lungs. Exhalation is provided by the contraction of the abdominal muscles: oblique, transverse, straight.

Elasticity – the ability of the lungs to stretch. The elasticity of the lungs is significantly dependent on the surface tension of the fluid film covering the alveoli wall. As the volume of the alveoli decreases, the surface tension decreases due to the presence of a surfactant (a substance of lipid nature) in the fluid that covers the surface of the alveoli. If the surface tension did not decrease during exhalation, the alveoli would drop. Surfactants are produced by type II alveocytes. The surfactant plays an important role during human birth, protecting the lungs from repeated collapse. Surfactant deficiency is an important cause of neonatal respiratory distress syndrome (hyaline membrane disease), a serious lung disease that occurs in infants born before their surfactant system begins to function. A decrease in surfactant in smokers was detected.

Surfactant values: reduce surface tension in the alveoli; create an opportunity for the lungs to be restored at the first breath of the newborn; prevent terminal bronchioles from dropping; prevent overstretching of the alveoli; anti-edema action, antioxidant action; provide up to 2/3 of the elastic resistance of adult lung tissues and the stability of the respiratory zone structure; regulate the rate of absorption of O_2 at the boundary of the gas-liquid phase; regulate the rate of evaporation of water from the alveolar surface (regulation of water balance); possess bacteriostatic action; clean the surface of the alveoli from foreign particles.

2. ***Gas exchange in the lungs.*** The outer surface of the alveoli contacts the capillaries of the pulmonary circulation. The blood is separated from the alveolar air by the alveolar capillary membrane. Gas exchange occurs as a result of diffusion of oxygen from the alveolar air into the blood and CO_2 from the blood into the alveolar air. Only physically dissolved gases are involved in gas exchange. Dissolved gases are stimuli of chemoreceptors of tissues, vessels, brain. Diffusion depends on the difference in the partial

pressure of these gases in the alveolar air and their tension in the blood, the diffusion area, the diffusion coefficient.

The partial pressure is that part of the pressure that falls on the gas in the gas mixture. The partial pressure of oxygen in the atmospheric air is 158 mmHg; in alveolar air 108–110 mmHg; tension in venous blood flowing to the lungs 40 mmHg; and in the arterial blood of systemic circulation 100–107 mmHg; in tissues in the intercellular fluid 20–40 mmHg. This partial pressure difference causes the movement of O_2 from the lungs into the blood and from the blood into the tissues during respiration. As atmospheric pressure decreases, the partial pressure of O_2 decreases as well. This causes hypoxic hypoxia – a lack of O_2 in the tissues. With sufficient duration of this condition (stay in the mountains), for example, at an altitude of 3000 m above sea level, the partial pressure of O_2 in the alveoli is about 60 mmHg, which is sufficient for hypoxic irritation of chemoreceptors and increased lung ventilation. That increases the secretion of erythropoietin, which stimulates an increase in the number of red blood cells in the blood for two to three days.

The difference in partial pressures (P) also cause the movement of CO_2 from tissues to the external environment: PCO_2 in tissues of 48–80 mmHg; PCO_2 in venous blood 46 mmHg; PCO_2 in alveolar air of 40 mmHg; PCO_2 in arterial blood of 43 mmHg; PCO_2 in atmospheric air 0.3 mmHg

Knowing the concentration of O_2 in the inhaled and exhaled air, we can determine the amount of O_2 consumed per unit time.

Blood gas transportation. Oxygen in the blood is in two states: physically dissolved and chemically related to hemoglobin (HB + O_2). The compound is called oxyhemoglobin. Oxygen capacity is the maximum amount of oxygen that can be associated with 100 ml of blood. The amount of O_2 in the blood is due to the amount of dissolved O_2, the amount of hemoglobin in the blood and the affinity of hemoglobin to O_2.

Dissociation curve of oxyhemoglobin – nonlinear ratio in percent of O_2-transport force of oxygen saturation of hemoglobin to oxygen tension. The oxyhemoglobin dissociation curve is influenced by: pH, temperature, and concentration of 2,3-diphosphoglycerate. The oxygen utilization ratio indicates which part of the oxygenated arterial blood is consumed.

Carbon dioxide. A total of 100 ml of venous blood contains 58 ml of CO_2. In the arterial – 56 ml. CO_2 from tissues to the lungs is transported in 5 forms: 1) dissolved in plasma CO_2; 2) hemoglobin bound (carbhemoglobin); 3) in the form of carbonic acid; carbonic acid is formed in erythrocytes from carbon dioxide and water with the participation of the enzyme carbonic anhydrase; 4) in the form of potassium hydrogen carbonate in erythrocytes; 5) as sodium hydrogen carbonate in blood plasma.

3. Regulation of respiration. Respiration occurs spontaneously as a result of rhythmic impulse in motor neurons that innervate the respiratory muscles. The implementation of such activity depends on the influence of the brain. Rhythmic impulse of the brain, especially of the prenatal, which causes spontaneous breathing, is regulated by changes in arterial blood tension of CO_2, O_2 and H^+ concentration. Chemical adjusting mechanisms adapt the ventilation of the lungs to ensure the constant partial pressure of CO_2 in the alveolar air, the concentration of H^+ and the tension of O_2 in the blood. The respiratory minute volume is maintained proportionally to the level of metabolism primarily by the tension of CO_2 rather than O_2.

Nerve regulation of breathing is provided by two separate systems of mechanisms. One is responsible for voluntary and the other for involuntary (automatic) regulation.

The voluntary system is represented by the cerebral cortex, which sends impulses to the respiratory moto-neurons through corticospinal pathways.

The automatic system is contained in the pons and the medulla oblongata. From it, the nerve fibers pass to the diaphragmatic moto-neurons in the cervical (C3-C5) and the moto-neurons of the intercostal muscles in the thoracic department of spinal cord.

The area of the medulla oblongata associated with respiration is called the respiratory center. It is vital – breathing stops without it. It consists of 2 parts – an inhalation center (inspiratory) and an exhalation center (expiratory).

The medial, parabrachial nuclei, and the nucleus of the dorsolateral pathway form the pneumotaxic center. If you destroy this area or isolate it from the respiratory center, the respiration will be slower and respiratory volume will increase. The function of the pneumotaxic center is still not fully understood, but it can play the role of a switch between inhalation and exhalation, the regulator of the optimal ratio of duration of inhalation, exhalation and respiratory pause.

The main factor regulating breathing is the concentration of CO_2 in the blood. The effects of CO_2 on respiration depend mainly on its movement into the cerebrospinal fluid and interstitial fluid of the brain, resulting in CO_2 increasing the concentration of H^+ and stimulating receptors sensitive to H^+. At increased CO_2 concentration, the chemoreceptors, especially in the medulla oblongata, as well as the carotid and aortic bodies, send nerve impulses to the inspiratory center, which stimulates inhalation. The influence of central receptors on respiratory center activity is more powerful than peripheral ones. It is significant that the receptors of the carotid and aortic bodies are excited not only with increasing CO_2 tension and H^+ concentration, but also with decreasing O_2 tension.

When inhaled, the alveoli expand and the stretch receptors located in them and in the bronchial tree send impulses to the vagus nerve fibers into the expiratory center, which automatically inhibits inhalation.

After exhalation, the alveoli are not stretched, the receptors are not excited.

The expiratory center shuts off and the breath can start again.

Reflex regulation is also carried out by impulses that come from different extero- and interoreceptors. These include reflexes from the receptors of the respiratory mucosa, in the walls of the alveoli near the capillaries.

Questions to consolidate theoretical material.

1. List main functions of respiratory system.
2. Explain the transport of oxygen in blood.
3. Explain the transport of carbon dioxide in blood.
4. Describe the nervous regulation of respiration.
5. Describe the chemical regulation of respiration.
6. Explain the biomechanics of inhalation and exhalation.

Chapter 10. METABOLISM. THERMOREGULATION

CONTENTS

1. Energy metabolism is a property of every living cell. Energy-rich substances are absorbed, and the final metabolic products with a lower energy content are secreted by the cells.

Metabolic processes in which specific elements of the body are synthesized from food are called anabolism, and those metabolic processes in which the structural elements of the body decay or assimilation of food are called catabolism.

The amount of energy released during the combustion of a certain substance does not depend on the stages of its decay. Carbohydrates and proteins are known to produce an average of about 17.16 kJ/g (4.1 kcal/g) of energy. Fats have the highest energy ability. 1 g of fat gives 38 kJ/g (9.1 kcal/g) of energy.

The amount of energy spent by the body at rest and on an empty stomach is called the ***basal metabolic rate.*** The basal metabolic rate depends on the functions of the nervous and endocrine systems, the physiological state of internal organs, on external influences on the body. The basal metabolic rate can change with insufficient or excessive nutrition, prolonged physical activity, changes in climatic conditions, etc. For different people, the basal metabolic rate depends mainly on age, body weight, gender, height. The basal metabolic rate is impaired in diseases of the endocrine glands (for example, pathology of the thyroid gland or pituitary gland).

Methods for determining the intensity of metabolic processes: the direct calorimetry method (based on the direct determination of the heat released during the life of the body), the indirect calorimetry method (based on the study of the intensity of the metabolic processes by gas exchange).

Protein metabolism

It is known that a protein consists of amino acids. In turn, amino acids are not only a source of synthesis of new structural proteins, enzymes, substances of a hormonal, protein, peptide nature and others, but also a source of energy.

Approximately 70–90 g should be ingested with food per day in an adult. The amount of protein received also depends on the physical activity performed. The amount of protein broken down in the body is rated by the amount of nitrogen excreted from the body (with urine, sweat). This position is based on the fact that nitrogen is the part of proteins (amino acids). A condition in which the amount of nitrogen is equal to the amount removed from the body is called nitrogen balance.

A condition in which less nitrogen enters the body with food and more is excreted is called a negative nitrogen balance. In this case, protein breakdown prevails over its synthesis. A positive nitrogen balance is a condition in which the amount of nitrogen excreted from the body is much less than it is contained in food (it accumulates in the body).

Proteins in the body perform mainly a structural function. They are part of enzymes, hormones that regulate various processes in the body, carry out protective functions, determine the species and individual characteristics of the body. In addition, proteins are used as energy material, insufficient supply of them leads to the loss of internal proteins.

The regulation of protein metabolism is affected by the nervous system, pituitary hormones (growth hormone), thyroid gland (thyroxine), adrenal glands (glucocorticoids).

Carbohydrate metabolism

In the human body, up to 60 % of energy is satisfied due to carbohydrates. Carbohydrates also have a structural function. They are part of complex cellular structures. Carbohydrates enter the body mainly with plant foods (bread, vegetables, cereals, fruits) and are deposited mainly in the form of glycogen in the liver and muscles.

The process of formation and accumulation of glycogen is regulated by pancreatic hormone insulin. The process of splitting glycogen to glucose occurs under the influence of another pancreatic hormone – glucagon.

Blood glucose and glycogen stores are also regulated by the central nervous system. Impulses from the centers along the sympathetic nerves directly enhance the breakdown of glycogen in the liver and muscles, as well as the release of adrenaline from the adrenal glands. Adrenaline promotes the conversion of glycogen to glucose and enhances the oxidative processes in cells. Hormones of the adrenal cortex, pituitary and thyroid glands also participate in the regulation of carbohydrate metabolism.

The optimal amount of carbohydrates per day is about 500 g, but this value can vary significantly depending on the energy needs of the body.

Lipid metabolism

Lipids are complex organic substances, which include neutral fats, consisting of glycerin and fatty acids, lipoids (lecithin, cholesterol). In addition to fatty acids, lipoids include polyhydric alcohols, phosphates and nitrogen compounds.

Lipids play an important role in the life of the body. Some of them form the main component of cell membranes or are a source of steroid hormone synthesis. An adult needs 70–80 g of fat daily. Also fats dissolve and remove from the body the so-called essential fatty acids, as well as fat-soluble vitamins.

A significant role in the regulation of lipid metabolism is played by the central nervous system, as well as many endocrine glands (genital, thyroid, pituitary, and adrenal glands).

2. ***Thermoregulation*** – is a set of physiological processes that maintain the body temperature of an organism different from the ambient temperature.

Poikilothermy is the inability of organisms to maintain a constant body temperature (thermal homeostasis), so that their body temperature depends on the ambient temperature.

Homeothermy is the ability of organisms to maintain a constant body temperature (thermal homeostasis) regardless of the ambient temperature. This ability includes the ability to cool or heat the body. Animals with such ability mainly control their body temperature by regulating the metabolic rate.

Hyperthermia is a condition in which a person's temperature is above 37 °C. It occurs when the heat generated in the body does not have time to go beyond it, which leads to overheating of the body. This happens in cases when the temperature of the environment for a long time exceeds 37 °C. Under these conditions, the body mobilizes the mechanisms of heat transfer to the maximum; in humans, this is mainly the evaporation of sweat and increased ventilation of the lungs. At the same time, the vessels of the skin expand. The critical highest body temperature is 41–42 °C, which is accompanied by cerebral edema.

Hypothermia is a condition of the body in which the body temperature drops below that necessary to maintain normal metabolism and body functions. In the case of human hypothermia, this temperature is + 35.0 °C and lower. The critical lowest body temperature is 26–28 °C, accompanied by a sharp inhibition of the activity of the central nervous system neurons, fainting, cardiac arrest.

In warm-blooded animals, including humans, body temperature is maintained approximately constant due to biological homeostasis. But, under the influence of cold, the internal mechanisms of the body may not be able to make up for heat loss.

Temperature regulation consists in coordinating the processes of heat production (chemical thermoregulation) and heat transfer (physical thermoregulation).

Heat production processes. In all organs, due to metabolic processes, heat production occurs. The role of various organs in heat production is different. At rest, the liver accounts for about 20 % of the total heat production, 56 % for other internal organs, and 20 % for skeletal muscles; with physical activity on skeletal muscles – up to 90 %, on internal organs – only 8 %.

The regulation of heat production in muscles is associated with the influence of α-motor neurons on the function and metabolism of muscles, in other tissues – the sympathetic nervous system and catecholamines, and the action of hormones, especially thyroxine, which almost doubles the heat production. ***Heat transfer processes*** occur in such ways – radiation, convection, evaporation and thermal conductivity.

Thermoregulation system is formed in warm-blooded organisms. It regulates and maintains a constant level of optimal body temperature. Body temperature is controlled by specific thermoreceptors. They are divided into peripheral and central.

The center of thermoregulation is in the hypothalamus. The anterior section of the hypothalamus perceives information from peripheral and central thermoreceptors. The center of heat production is located in the nuclei of the posterior part of the hypothalamus. From here, through the sympathetic nervous system, impulses go that increase metabolism, narrow the vessels of the skin, and activate the thermoregulation of skeletal muscles. Hormones – adrenaline, norepinephrine, thyroxine, etc. also participate in these reactions. The heat transfer center is located in the nuclei of the anterior hypothalamus. From here come the impulses that expand the vessels of the skin, increase sweating, and reduce heat production.

Other parts of the central nervous system (reticular formation, limbic system, cerebral cortex) play a role in regulating body temperature. The inclusion of various heat transfer mechanisms occurs continuously, depending on specific conditions.

Questions to consolidate theoretical material.

1. Give characteristic to protein metabolism.
2. Give characteristic to carbohydrate metabolism.
3. Give characteristic to lipid metabolism.
4. Explain the concept of basal metabolic rate.
5. What is normal body temperature? Explain heat balance and regulation of body temperature.

Chapter 11.
PHYSIOLOGY OF DIGESTION

CONTENTS

1. ***Digestion* –** a set of mechanical, chemical and biological processes that take part in breakdown of complex nutrients to simple compounds that can be absorbed by the body; the initial stage of metabolism.

The digestive system includes organs which are intended for the intake, mechanical, chemical (enzymatic) processing of food, the absorption of its products, and the removal of undigested food. The digestive system provides the processes of chemical and physical processing of food. The digestive organs are connected into a single functional and anatomical complex that forms the digestive canal.

The main functions of the digestive system are: motor, secretory, excretory, absorption.

In the digestive system, both nervous and humoral mechanisms of regulation are equally important. The upper parts of the digestive system are dominated by nerve mechanisms, and the lower parts – humoral.

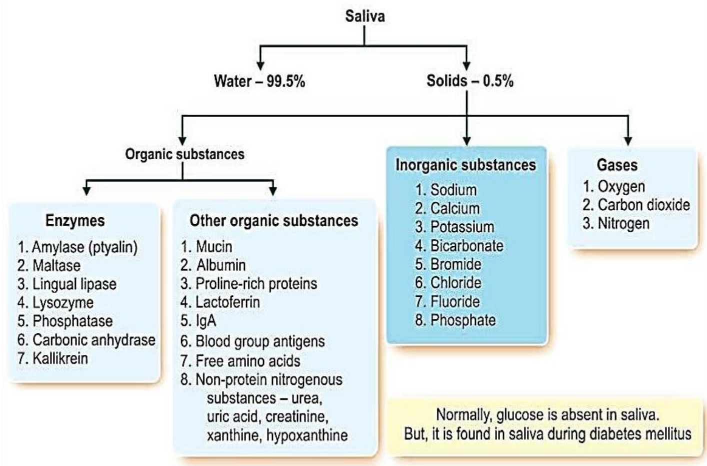
2. ***Digestion in the oral cavity***

Food processing begins in the mouth, where it is crushed, wetted with saliva and the formation of a food lump. The oral cavity – the initial department of the digestive system, performs the following functions:

1. Mechanical processing of food.
2. Moisturizing food with saliva.
3. Chemical processing of food occurs with the participation of saliva enzymes.
4. Disinfection – destruction microorganisms by saliva lysozyme.
5. Analysis of taste and temperature qualities of the food.
6. Absorption of some low molecular weight substances.

7. Formation of a food lump – a portion of food ready to be swallowed.

The composition and properties of saliva. An adult secretes an average of 1–2 liters of saliva per day. The level of pH of saliva is from 5.8 to 7.8.



Regulation of saliva secretion is carried out by a nervous and humoral way. Saliva secretion is a reflex process. Conditional reflexes (secretion of saliva) occur in response to visual, auditory and olfactory stimuli. They occur on the condition that these stimuli coincided with food intake earlier. The influence of conditioned reflex regulation on salivation is most powerful in comparison with other departments of the gastrointestinal tract. Unconditional reflexes (secretion of saliva) occur when substances act on the taste receptors of the oral cavity. The act of chewing affects the secretory function – the more intensive chewing, more the amount of saliva. The afferent pathways are represented by fibers of V, VII, IX, X of cranial nerves. The salivary center is located in the medulla oblongata.

Parasympathetic innervation of salivary glands. From the upper salivary nucleus, preganglionic fibers to the sublingual and maxillary glands come as a part of the tympanic line (branch of the facial nerve). In the sublingual and submandibular parasympathetic ganglia, excitation switches to postganglionic fibers that innervate the glands. From the lower salivary nucleus excitation by the preganglionic fibers in the composition of the glossopharyngeal nerve enters the ear node, switches to the postganglionic fibers in the composition of the ear and temporal nerve, which innervate the parotid gland. Excitation of parasympathetic fibers causes the secretion of a large amount of saliva, poor in organic substances.

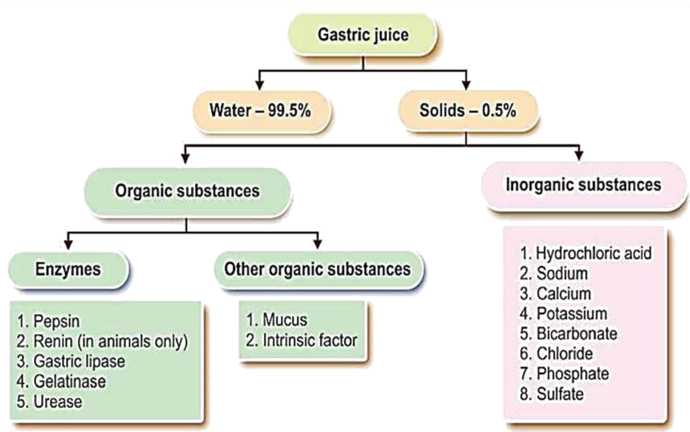
Sympathetic innervation of salivary glands. Preganglionic neurons of the sympathetic nerves localize in the lateral horns of II–VI segments of the thoracic department of spinal cord and postganglionic neurons in the upper cervical ganglia. Postganglionic fibers, along with vascular plexuses, reach the glands. Excitation of sympathetic fibers stimulates the secretion of a small amount of saliva that contains a lot of organic substances (enzymes).

Digestion in the stomach. From the esophagus, the food enters the stomach, where it undergoes further chemical and mechanical treatment. The stomach is a hollow muscular organ that consists of the bottom, the cardiac part, the body and the pyloric part (which connects to the duodenum). The mucous membrane is the inner layer of the stomach, which is represented by a single-layer cylindrical epithelium and mucous layer. Epithelial cells perform a secretory function. They produce mucus that covers the entire mucous membrane, protecting it from the action of digestive enzymes and mechanical irritation.

In the layer of mucous membrane, there are tubular gastric glands that produce gastric juice. In the submucosa are nets of arterial, venous, lymphatic vessels, as well as the submucosal nerve plexus. The muscular sheath is formed by two layers of smooth muscle. The outer layer is longitudinal, the inner layer is circular.

The stomach performs secretory, motor, absorption, excretory, secretory and bactericidal functions.

The composition and properties of gastric juice. Gastric juice is a colorless clear liquid. During the day, about 2.5 liters of juice are formed. It consists of enzymes, mucus, hydrochloric acid (HCl), minerals, water. The level of pH of the gastric juice is from 0.9 to 3.5.



Hydrochloric acid is the main inorganic substance of the gastric juice, it creates the optimal pH for the action of gastric juice enzymes, converts pepsinogen into pepsin; causes denaturation of proteins, promotes their enzymatic cleavage; promotes milk subsidence; has bactericidal properties; is a regulator of evacuation of the contents of the stomach into the duodenum.

Mucus is formed in the cells of the covering epithelium. Mucus also inhibits the secretion of gastric juice, protects the gastric mucosa from damage.

Regulation of gastric secretion.

Humoral and nervous mechanisms are involved in the regulation of gastric secretion. Gastric secretion is divided into 3 phases.

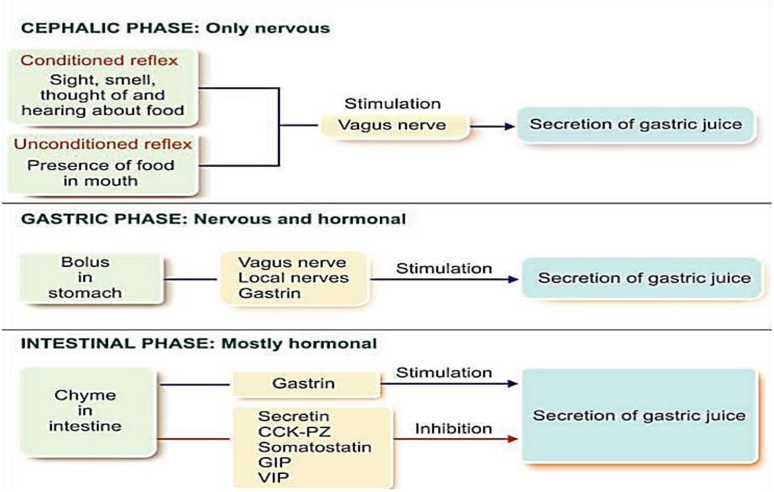
1. Cephalic phase of gastric secretion. Conditional reflex release of gastric juice is caused by the smell, appearance of food, the sound stimuli associated with cooking, etc. The nerve impulses upon excitation of the olfactory and auditory receptors enter the centers of sensory areas of the cerebral cortex, then into the food center of the medulla oblongata and by vagus nerve reaches glands of the stomach. The small amount of juice is secreted during this phase, which Ivan Pavlov called "appetizing". This juice has many enzymes.

After the food enters the mouth, unconditional secretion of gastric juice begins. From the receptors of the oral cavity, nerve impulses enter the food center of the medulla oblongata and from it by efferent nerve fibers to the glands of the stomach, increasing their secretory activity. Duration of the first phase of gastric secretion 30–40 min.

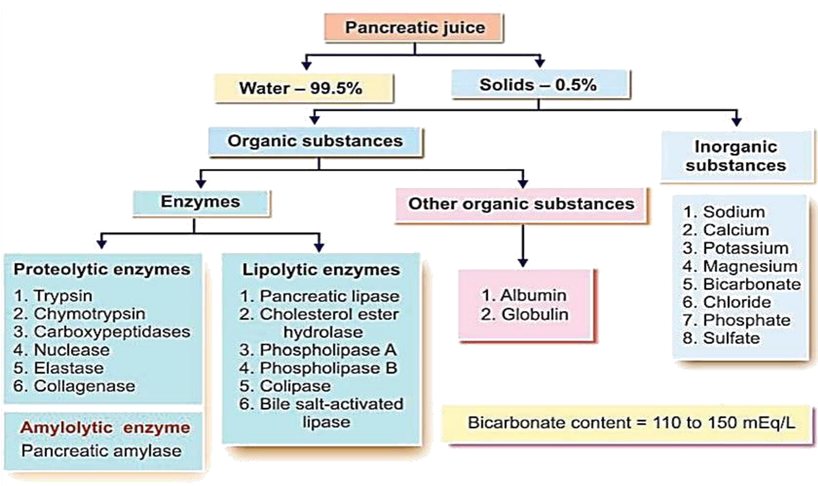
2. The gastric phase occurs when the food contacts the gastric mucosa. The phase lasts 3–4 hours. The second phase of gastric secretion is affected by substances that excite the gastric glands (gastrin, acetylcholine, histamine).

Gastrin, enters the bloodstream, is transported to the cells of the glands and excites their work, increasing HCl secretion. Stomach secretion is also caused by histamine, which is found in the nutrients and gastric mucosa. Histamine excites parietal cells that secrete HCl and inhibits secretion of the chief cells. Acetylcholine, which causes the release of histamine and gastrin, has a stimulating effect on the secretory cells of the stomach.

3. The intestinal phase of gastric secretion begins from the moment food enters the intestine. Chyme excites the receptors of the mucous membrane of the duodenum cavity and reflexively changes the intensity of gastric secretion. The effect on the secretion of gastric juice in this phase is made by the hormone enterogastrin.



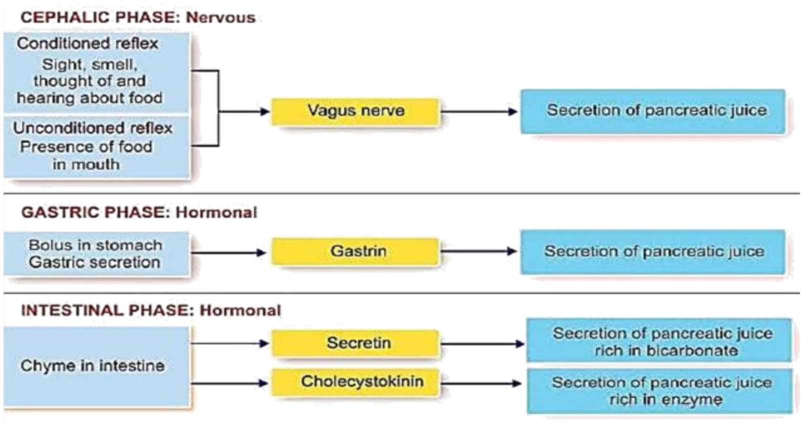
3. Composition and properties of pancreatic juice. Pancreatic juice is a colorless, clear liquid, the pH of human pancreatic juice is 7.8–8.5, the daily amount is 1.2–2.5 liters. The alkaline reaction is due to the presence of bicarbonates.



Regulation of pancreatic secretion is carried out by nervous and humoral mechanisms. The vagus nerve is the secretory nerve of the pancreas.

Sympathetic fibers inhibit pancreatic secretory activity. Humoral regulation of pancreatic secretion is carried out by the hormone secretin. It is formed from inactive prosecretin, which is produced by the cells of the mucous membrane of the duodenum and under the action of HCl becomes active. Enhances the secretion of pancreatic juice, the hormone cholecystokinin. The juice released under its action is rich in enzymes. Hormones such as gastrin, serotonin, insulin, and others also increase the secretion of pancreatic juice. Glucagon, calcitonin, somatostatin and others have an inhibitory effect on juice secretion.

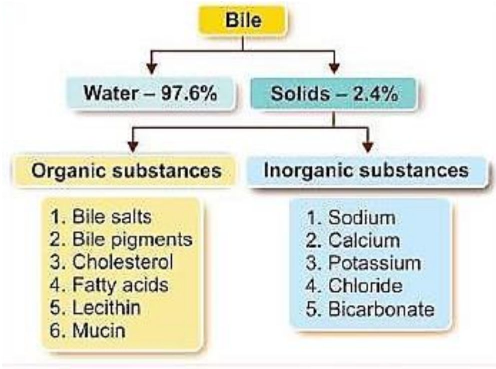
Nerve effects on the pancreas have a triggering effect, and hormones have a corrective effect. The latent (hidden) period of pancreatic juice secretion is 3 minutes. There are stages of pancreatic secretion.



Schematic diagram showing the regulation of pancreatic secretion

Composition and properties of bile. Bile is the secretion of liver cells. Bile functions: emulsification of fats; hydrolysis and absorption of fats and fat-soluble vitamins; increasing the activity of enzymes of pancreatic and intestinal juices; increased gastric motility; stimulation of motor and secretory function of the small intestine; regulation of pancreatic secretion; neutralization of acid chyme, inactivation of pepsin; protective function; creates optimal conditions for the fixation of enzymes on the surface of enterocytes; stimulates the proliferation of enterocytes; normalizes the intestinal flora; excretory function; ensuring immunity.

0.5–1.2 liters of bile is secreted per day in a healthy person. Getting it into the duodenum occurs only during digestion. Outside digestion, bile enters the gallbladder. Therefore, there are gallbladder and liver bile.



Composition of bile

4. ***Absorption in different parts of the digestive tract.*** Absorption is the process of transporting various nutrients into the blood and lymph through one or more barriers that form biological membranes.

Transport of macromolecules is carried out by phagocytosis, pinocytosis (endocytosis). A number of substances are transported by intercellular spaces. This is the penetration from the intestinal cavity into the internal environment of the body of a small amount of antibodies, allergens, enzymes, bacteria. Micromolecules: nutrient monomers and ions are transported by active and passive transport.

Absorption is almost absent in the oral cavity. Glucose, water, some drugs, poisons can be absorbed. H_2O, mineral salts, alcohol, glucose and a small amount of amino acids are absorbed in the stomach. Some substances are absorbed in the duodenum. The main processes of absorption occur in the jejunum.

Absorption in the small intestine depends on the contraction of its villi (enhanced by vilikinin). When the villi constract, the cavity of their lymphatic vessels is compressed, the lymph is squeezed out and the absorption effect of the central lymphatic vessel is created.

Absorption of fats requires bile, which emulsifies fats and activates lipase. Up to 20 % of fats are absorbed undigested. Glycerin is absorbed by resorption and endocytosis. Fatty acids together with bile form water-soluble complexes, which are adsorbed on the glycocalyx, on the surface of the villi bile acids are separated from fatty acids and returned to the intestine and in the ileum are absorbed into the blood. If there was no such cycle of bile acids, then 12 liters of bile would be needed to ensure the absorption of fats. Fatty acids enter the epithelial cell. Further absorption is carried out in two ways.

High molecular weight fatty acids in the enterocyte combine with glycerol. Triglycerides and cholesterol esters, coated with a layer of proteins, cholesterol and phospholipids, form chylomicrons. Chylomicrons are absorbed into the lymphatic vessels of the villi and enter the blood through the thoracic lymphatic duct. With the flow of blood chylomicrons enter the fat depot, where fat is formed.

The second way. Low molecular weight fatty acids from enterocytes enter directly into the blood capillaries and are transported as free fatty acids through the portal vein to the liver, where the synthesis of phospholipids, lipoproteins.

Absorption of carbohydrates. Carbohydrates are absorbed in the form of monosaccharides: glucose, galactose, fructose. A maximum of 120 g of glucose is absorbed per hour. Monosaccharides are absorbed in different ways (passive and active transport).

Absorption of proteins is carried out after their cleavage to amino acids. Enterocytes have 7 transport systems for amino acids. 5 of them depend on Na^+, 2 – on Cl^-. Di – and tripeptides are absorbed with the participation of H^+. Low molecular weight proteins can be absorbed passively by adsorption, by diffusion and by electrostatic forces. In newborns, proteins can be absorbed by pinocytosis. Thus, antibodies enter the body of the child with breast milk.

Absorption of water and mineral salts. The digestive system receives about 10 liters of water daily: 2–3 liters with food, 6–7 liters – with digestive juices. 0.1–0.15 liters is excreted in the feces. The bulk of water is absorbed in the upper small intestine by osmosis. Absorption of carbohydrates, amino acids, and especially mineral salts promotes the simultaneous absorption of water. Sodium and chlorine ions play a crucial role in water absorption. Water is absorbed in the large intestine, a small amount of glucose, amino acids, mineral salts.

5. ***Physiological basis of hunger.*** The centers of hunger and satiety are located in the diencephalon (hypothalamus).

There are several theories that explain the onset of hunger.

Glucostatic theory – the feeling of hunger is associated with a decrease in blood glucose.

Aminoacidostatic – a feeling of hunger is created by a decrease in the content of amino acids in the blood.

Lipostatic – neurons of the food center are excited by a lack of fatty acids and triglycerides in the blood.

Metabolic – the stimulus of the neurons of the food center are the products of the Krebs cycle metabolism.

Thermostatic – lowering the blood temperature causes a feeling of hunger. Local theory – the feeling of hunger arises as a result of impulses from mechanoreceptors of a stomach at its "hungry" contractions.

Satiety occurs as a result of violation of the neurons of the satiety center. There are primary or sensory satiety, and secondary or exchange. Sensory satiety is associated with inhibition of the lateral nuclei of the hypothalamus by impulses from the receptors of the mouth, stomach, caused by food. At the same time, the disruption of the neurons of the ventromedial nuclei of the hypothalamus leads to the entry of nutrients into the blood from the depot. Secondary, or metabolic satiety occurs 1.5–2 hours after a meal, when the blood enters the products of hydrolysis of nutrients.

Gastrointestinal hormones also play an important role in the onset of hunger and satiety. Cholecystokinin, somatostatin, bombesin and others reduce food intake. Pentagastrin, oxytocin and others contribute to the formation of hunger.

Under stress, the content of glucose in the blood decreases, there is a comstriction in the walls of the empty stomach, as well as reduced basal metabolism, catecholamines are released into the blood.

Appetite occurs under the influence of conditioned stimuli: the usual time of eating, thoughts about food, appearance, smell and taste of food, eating conditions. At the same time appetizing digestive juice is allocated.

The feeling of satiety is formed by the receptors of the cardiac zone of the stomach under the influence of the duration of food in the stomach, the fullness of the stomach, the concentration of glucose, triglycerides and free amino acids in the blood.

Questions to consolidate theoretical material.

1. Describe the composition, functions and regulation of secretion of saliva.
2. Describe the composition, functions and regulation of secretion of gastric juice.
3. Describe the composition, functions and regulation of secretion of pancreatic juice.
4. Describe the composition, functions and regulation of secretion of bile.
5. Describe the mechanism of formation of hunger and satiety.

Chapter 12.
PHYSIOLOGY OF EXCRETION

CONTENTS

1. The parameters of homeostasis that are maintained at a predetermined level by the excretory system are: constancy of osmotic pressure, constancy of the volume of circulating blood, constancy of pH level, normal content of metabolic products.

The main organ of the excretory system is the kidneys, because only with their participation it is possible to maintain the parameters of homeostasis. All other executive organs play an auxiliary role and excretion from the body: **lungs** take part in removal of volatile substances: CO_2, acetone, vapors of alcohol, ether, etc.; **skin and its glands –** products of nitrogen metabolism, some ions; the volume of excretion is small, but becomes more significant when the excretory function of the kidneys is damaged; **digestive canal and its glands** – salts of heavy metals (when poisoned by them), salts of iodine (with their excessive content in the body), products of nitrogen metabolism (their excretion becomes significant in violation of excretory function of the kidneys).

The kidneys are the main organ of the excretory system, since as soon as it excretes from the body in a large number of products of nitrogen metabolism, they maintain their concentration in the blood at a certain level. Participation in this process of the skin, digestive canal and their glands is not enough. That is why, with insufficient excretory function of the kidneys, the body suffers from uremia – an increased concentration in the blood of products of nitrogen metabolism.

Functions of kidneys:

1. Role in homeostasis (excretion of waste products, maintenance of water balance, maintenance of electrolyte balance, maintenance of acid-base balance).

2. Hemopoietic function (participation in the production of erythrocytes).
3. Endocrine function (kidneys secrete many hormonal substances).
4. Regulation of blood pressure.
5. Regulation of blood calcium level.

Features of blood supply to the kidneys:

Blood vessels of kidneys are highly specialized to facilitate the functions of nephrons in the formation of urine. In the adults, during resting conditions both the kidneys receive 1.300 mL of blood per minute or about 26 % of the cardiac output. Maximum blood supply to kidneys has got the functional significance. Renal arteries supply blood to the kidneys. Renal circulation has some special features to cope up with the functions of the kidneys. Such special features are:

Renal arteries arise directly from the aorta. So, the high pressure in aorta facilitates the high blood flow to the kidneys.

1. Both the kidneys receive about 1.300 mL of blood per minute, i.e. about 26 % of cardiac output. Kidneys are the second organs to receive maximum blood flow, the first organ being the liver, which receives 1.500 mL per minute, i.e. about 30 % of cardiac output.
2. Whole amount of blood, which flows to kidney has to pass through the glomerular capillaries before entering the venous system. Because of this, the blood is completely filtered at the renal glomeruli.
3. Renal circulation has a portal system, i.e. a double network of capillaries, the glomerular capillaries and peritubular capillaries.
4. Renal glomerular capillaries form high pressure bed with a pressure of 60 mmHg to 70 mmHg. It is much greater than the capillary pressure elsewhere in the body, which is only about 25 mmHg to 30 mmHg. High pressure is maintained in the glomerular capillaries because the diameter of afferent arteriole is more than that of efferent arteriole. The high capillary pressure augments glomerular filtration.
5. Peritubular capillaries form a low pressure bed with a pressure of 8 mmHg to 10 mmHg. This low pressure helps tubular reabsorption.
6. Autoregulation of renal blood flow is well established.

Structure of nephron. Nephron is the structural and functional unit of kidneys. All main processes which lead to urine formation take place in the nephron. Each nephron consists of such parts:

1. Renal body (malpighian body), consisting of a Bowman's capsule and a vascular glomerulus.
2. Proximal convoluted tubule.
3. Descending part of the loop of Henle
4. Ascending part of the loop of Henle.
5. Distal convoluted tubule.
6. Collecting duct.

2. Mechanisms of urine formation. The process of urinary formation is based on three processes: **filtration, reabsorption and secretion.**

Urine formation is a blood cleansing function. Kidneys excrete the unwanted substances along with water from the blood as urine. Normal urinary output is 1 L/day to 1.5 L/day.

When blood passes through glomerular capillaries, the plasma is filtered into the Bowman capsule. This process is called glomerular filtration. Filtrate from Bowman capsule passes through the tubular portion of the nephron. While passing through the tubule, the filtrate undergoes various changes both in quality and in quantity. Many wanted substances like glucose, amino acids, water and electrolytes are reabsorbed from the tubules. This process is called tubular reabsorption. And, some unwanted substances are secreted into the tubule from peritubular blood vessels. This process is called tubular secretion. Thus, the urine formation includes three processes: glomerular filtration, tubular reabsorption, tubular secretion. Among these three processes filtration is the function of the glomerulus. Reabsorption and secretion are the functions of tubular portion of the nephron.

Filtration occurs in the malpighian body – the union of the vascular glomerulus and Bowman capsule. Reabsorption takes place in all tubules of the nephron: proximal convoluted tubule, loop of Henle, distal convoluted tubule. In addition, the process of reabsorption passes through the collecting ducts. Secretion occurs in the proximal and distal convoluted tubules of the nephron and in the collecting ducts.

Glomerular filtration is the process by which the blood is filtered while passing through the glomerular capillaries by filtration membrane. It is the first process of urine formation. The structure of filtration membrane is well suited for filtration. When blood passes through glomerular capillaries, the plasma is filtered into the Bowman capsule. All the substances of plasma are filtered except the plasma proteins. The filtered fluid is called glomerular filtrate.

Glomerular filtration is called ultrafiltration because even the minute particles are filtered. But, the plasma proteins are not filtered due to their large molecular size. The protein molecules are larger than the slit pores present in the endothelium of capillaries. Thus, the glomerular filtrate contains all the substances present in plasma except the plasma proteins.

Glomerular filtration rate (GFR) is defined as the total quantity of filtrate formed in all the nephrons of both the kidneys in the given unit of time. Normal GFR is 125 mL/minute or about 180 L/day.

Pressures, which determine the GFR are: glomerular capillary pressure, colloidal osmotic pressure in the glomeruli, hydrostatic pressure in the Bowman capsule.

Factors affecting GFR:

1. Renal blood flow
2. Tubuloglomerular feedback
3. Glomerular capillary pressure
4. Colloidal osmotic pressure
5. Hydrostatic pressure in bowman capsule
6. Constriction of afferent arteriole
7. Constriction of efferent arteriole
8. Systemic arterial pressure
9. Sympathetic stimulation
10. Surface area of capillary membrane
11. Permeability of capillary membrane
12. Contraction of glomerular mesangial cells
13. Hormonal and Other Factors.

Tubular reabsorption is the process by which water and other substances are transported from renal tubules back to the blood. When the glomerular filtrate flows through the tubular portion of nephron, both quantitative and qualitative changes occur. Large quantity of water (more than 99 %), electrolytes and other substances are reabsorbed by the tubular epithelial cells. The reabsorbed substances move into the interstitial fluid of renal medulla. And, from here, the substances move into the blood in peritubular capillaries. Since the substances are taken back into the blood from the glomerular filtrate, the entire process is called tubular reabsorption.

Tubular reabsorption is known as selective reabsorption because the tubular cells reabsorb only the substances necessary for the body. Essential substances such as glucose, amino acids and vitamins are completely reabsorbed from renal tubule. Whereas the unwanted substances like metabolic waste products are not reabsorbed and excreted through urine.

Basic transport mechanisms involved in tubular reabsorption are of two types:

1. Active Reabsorption. Active reabsorption is the movement of molecules against the electrochemical (uphill) gradient. It needs liberation of energy, which is derived from ATP. Substances reabsorbed actively from the renal tubule are sodium, calcium, potassium, phosphates, sulfates, bicarbonates, glucose, amino acids, ascorbic acid, uric acid and ketone bodies.

2. Passive Reabsorption. Passive reabsorption is the movement of molecules along the electrochemical (downhill) gradient. This process does not need energy. Substances reabsorbed passively are chloride, urea and water.

Reabsorption of substances from tubular lumen into the peritubular capillary occurs by two routes:

1. Transcellular Route. In this route the substances move through the cell. It includes transport of substances from: tubular lumen into tubular cell

through apical (luminal) surface of the cell membrane; tubular cell into interstitial fluid; interstitial fluid into capillary.

2. Paracelluar Route. In this route, the substances move through the intercellular space. It includes transport of substances from: tubular lumen into interstitial fluid present in lateral intercellular space through the tight junction between the cells. Interstitial fluid into capillary.

Reabsorption of the substances occurs in almost all the segments of tubular portion of nephron. About 7/8 of the filtrate (about 88 %) is reabsorbed in proximal convoluted tubule. The brush border of epithelial cells in proximal convoluted tubule increases the surface area and facilitates the reabsorption. Substances reabsorbed from proximal convoluted tubule are glucose, amino acids, sodium, potassium, calcium, bicarbonates, chlorides, phosphates, urea, uric acid and water. Substances reabsorbed from loop of Henle are sodium and chloride. Sodium, calcium, bicarbonate and water are reabsorbed from distal convoluted tubule.

Tubular reabsorption is regulated by three factors:

1. Glomerulotubular balance is the balance between the filtration and reabsorption of solutes and water in kidney. When GFR increases, the tubular load of solutes and water in the proximal convoluted tubule is increased. It is followed by increase in the reabsorption of solutes and water. This process helps in the constant reabsorption of solute particularly sodium and water from renal tubule.

Glomerulotubular balance occurs because of osmotic pressure in the peritubular capillaries. When GFR increases, more amount of plasma proteins accumulate in the glomerulus. Consequently, the osmotic pressure increases in the blood by the time it reaches efferent arteriole and peritubular capillaries. The elevated osmotic pressure in the peritubular capillaries increases reabsorption of sodium and water from the tubule into the capillary blood.

Hormones, which regulate GFR are listed in table.

Hormone	Action
Aldosterone	Increases sodium reabsorption in ascending limb, distal convoluted tubule and collecting duct
Angiotensin II	Increases sodium reabsorption in proximal tubule, thick ascending limb, distal tubule and collecting duct (mainly in proximal convoluted tubule)
Antidiuretic hormone	Increases water reabsorption in distal convoluted tubule and collecting duct
Atrial natriuretic factor	Decreases sodium reabsorption
Brain natriuretic factor	Decreases sodium reabsorption
Parathormone	Increases reabsorption of calcium, magnesium and hydrogen Decreases phosphate reabsorption
Calcitonin	Decreases calcium reabsorption

3. Nervous Factor. Activation of sympathetic nervous system increases the tubular reabsorption (particularly of sodium) from renal tubules. It also

increases the tubular reabsorption indirectly by stimulating secretion of renin from juxtaglomerular cells. Renin causes formation of angiotensin II, which increases the sodium reabsorption.

Tubular secretion is the process by which the substances are transported from blood into renal tubules. It is also called tubular excretion. In addition to reabsorption from renal tubules, some substances are also secreted into the lumen from the peritubular capillaries through the tubular epithelial cells. Substances which can be secreted: paraaminohippuric acid (PAH), diodrast, 5-hydroxyindoleacetic acid (5HIAA), amino derivatives, penicillin.

Substances secreted in different segments of renal tubules:

1. Potassium is secreted actively by sodium-potassium pump in proximal and distal convoluted tubules and collecting ducts
2. Ammonia is secreted in the proximal convoluted tubule
3. Hydrogen ions are secreted in the proximal and distal convoluted tubules. Maximum hydrogen ion secretion occurs in proximal tubule
4. Urea is secreted in loop of Henle.

Thus, urine is formed in nephron by the processes of glomerular filtration, selective reabsorption and tubular secretion. With all these changes, the filtrate becomes urine.

Countercurrent multiplier system of the kidneys.

The countercurrent multiplier system of the kidney will provide if necessary: dilution of urine, that is, it removes a small amount of salts and metabolites in a large volume of water. In this case, a lot of urine is formed, and its specific gravity was low. This is how the kidneys work when there is an excess of water in the body, for example, when it is taken in excess concentration of urine, that is, a large amount of salts and metabolites are removed in a small volume of water. This produces urine with a high specific gravity.

The countercurrent multiplier system includes: Henle loop – its descending thin and ascending thick parts; distal convoluted tubule; cleaning tubes; straight vessels.

The system is called countercurrent multiplier, since most of its structural elements are parallel in the kidney substance (both parts of the loop of Henle, collection tubes, straight vessels), and the movement of fluids in them has the opposite direction.

3. Micturition. Micturition reflex. Regulation. Micturition is a process by which urine is voided from the urinary bladder. It is a reflex process. However, in grown up children and adults, it can be controlled voluntarily to some extent. The functional anatomy and nerve supply of urinary bladder are essential for the process of micturition.

Urinary bladder and the internal sphincter are supplied by sympathetic and parasympathetic divisions of autonomic nervous system whereas, the external sphincter is supplied by the somatic nerve fibers.

Preganglionic fibers of sympathetic nerve arise from first two lumbar segments (L1 and L2) of spinal cord. After leaving spinal cord, the fibers pass through lateral sympathetic chain without any synapse in the sympathetic ganglia and finally terminate in **hypogastric ganglion.** The postganglionic fibers arising from this ganglion form the **hypogastric nerve,** which supplies the detrusor muscle and internal sphincter. The stimulation of sympathetic (hypogastric) nerve causes relaxation of detrusor muscle and constriction of the internal sphincter. It results in filling of urinary bladder and so, the sympathetic nerve is called **nerve of filling.**

Preganglionic fibers of parasympathetic nerve form the **pelvic nerve** or **nervus erigens.** Pelvic nerve fibers arise from second, third and fourth sacral segments (S1, S2 and S3) of spinal cord. These fibers run through hypogastric ganglion and synapse with postganglionic neurons situated in close relation to urinary bladder and internal sphincter. Stimulation of parasympathetic (pelvic) nerve causes contraction of detrusor muscle and relaxation of the internal sphincter leading to emptying of urinary bladder. So, parasympathetic nerve is called the **nerve of emptying** or nerve of micturition. Pelvic nerve has also the sensory fibers, which carry impulses from stretch receptors present on the wall of the urinary bladder and urethra to the central nervous system.

External sphincter is innervated by the somatic nerve called **pudendal nerve.** It arises from second, third and fourth sacral segments of the spinal cord. Pudendal nerve maintains the **tonic contraction** of the skeletal muscle fibers of the external sphincter and keeps the external sphincter constricted always. During micturition, this nerve is inhibited. It causes relaxation of external sphincter leading to voiding of urine. Thus, the pudendal nerve is responsible for **voluntary control** of micturition.

Micturition reflex is the reflex by which micturition occurs. This reflex is elicited by the stimulation of stretch receptors situated on the wall of urinary bladder and urethra. When about 300 to 400 mL of urine is collected in the bladder, intravesical pressure increases. This stretches the wall of bladder resulting in stimulation of stretch receptors and generation of sensory impulses.

Sensory (afferent) impulses from the receptors reach the sacral segments of spinal cord via the sensory fibers of pelvic (parasympathetic) nerve. Motor (efferent) impulses produced in spinal cord, travel through motor fibers of pelvic nerve towards bladder and internal sphincter. Motor impulses cause contraction of detrusor muscle and relaxation of internal sphincter so that, urine enters the urethra from the bladder.

Once urine enters urethra, the **stretch receptors** in the urethra are stimulated and send afferent impulses to spinal cord via pelvic nerve fibers. Now the impulses generated from spinal centers inhibit pudendal nerve. So, the external sphincter relaxes and micturition occurs.

Once a micturition reflex begins, it is **self-regenerative,** i.e. the initial contraction of bladder further activates the receptors to cause still further increase in sensory impulses from the bladder and urethra. These impulses, in turn cause further increase in reflex contraction of bladder. The cycle continues repeatedly until the force of contraction of bladder reaches the maximum and the urine is voided out completely. During micturition, the flow of urine is facilitated by the increase in the abdominal pressure due to the voluntary contraction of abdominal muscles.

Spinal centers for micturition are present in sacral and lumbar segments. But, these spinal centers are regulated by higher centers. The higher centers, which control micturition are of two types, inhibitory centers and facilitatory centers.

Centers in midbrain and cerebral cortex inhibit the micturition by suppressing spinal micturition centers. Centers in pons facilitate micturition via spinal centers. Some centers in cerebral cortex also facilitate micturition.

Questions to consolidate theoretical material.

1. Describe the process of urine formation.
2. What are the different stages of urine formation? Explain the role of glomerulus of nephron in the formation of urine.
3. Give an account of role of renal tubule in the process of urine formation.
4. What is countercurrent mechanism? Describe the physiological basis of counter current mechanism in kidney.
5. Give an account of micturition. Explain the reflex.

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Комп’ютерна верстка, дизайн обкладинки *Н. Кардаш.*
Друк *С. Волинець*. Фальцювально-палітурні роботи *О. Мішалкіна.*

Підп. до друку 15.12.2021.
Формат 60×84 $^1/_{16}$. Папір офсет.
Гарнітура «Times New Roman». Друк ризограф.
Ум. друк. арк. 5,35. Обл.-вид. арк. 4,91.
Тираж 300 пр. Зам. № 6416.

Видавець і виготовлювач: ЧНУ ім. Петра Могили.
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Свідоцтво суб’єкта видавничої справи ДК № 6124 від 05.04.2018.