**(Slide 1) Lecture 2**

**Physiology of the Central Nervous System. Part 1.**

**(Slide 2)** Lecture plan:

1. Function and structure of the nervous system.
2. Basic properties of nerve centers.
3. Mechanisms of reflex process coordination.
4. Inhibition in the central nervous system.
5. Functions of the spinal cord, medulla oblongata, varilian pons and midbrain.
6. Muscle tone, its reflex nature and functional significance.

**(Slide 3)** The nervous system is a complex network of structures that permeate the entire body and provide self-regulation of its vital activity due to the ability to respond to external and internal influences (stimuli).

**The nervous system is comprised of two major parts, or subdivisions, the central nervous system (CNS) and the peripheral nervous system (PNS).** **The CNS includes** the brain and spinal cord. The brain is the body's "control center". The CNS has various centers located within it that carry out the sensory, motor and integration of data. These centers can be subdivided to Lower Centers (including the spinal cord and brain stem) and Higher centers communicating with the brain via effectors. **The PNS** is a vast network of spinal and cranial nerves that are linked to the brain and the spinal cord. It contains sensory receptors which help in processing changes in the internal and external environment. This information is sent to the CNS via afferent sensory nerves. **The PNS is then subdivided into the autonomic nervous system and the somatic nervous system.** **The autonomic** has involuntary control of internal organs, blood vessels, smooth and cardiac muscles. **The somatic** has voluntary control of skin, bones, joints, and skeletal muscle. The two systems function together, by way of nerves from the PNS entering and becoming part of the CNS, and vice versa.

**(Slide 4)** Human Nervous System Overview. **Video.**

**(Slide 5)** The main functions of the central nervous system are as follows:

**1. Management of the activity of the musculoskeletal system.** The CNS regulates muscle tone and, through its redistribution, maintains a natural posture, and in case of violation, restores it, initiates all types of physical activity (physical work, physical education, sports, any movement of the body).

**2. Regulation of the work of internal organs is carried out by means of the autonomic nervous system and endocrine glands:** a) at rest - ensuring homeostasis (constancy of the internal environment of the body); b) during work - adaptive regulation of the activity of internal organs according to the needs of the body and maintenance of homeostasis.

**3. Providing consciousness and all types of mental activity.** Mental activity is an ideal, subjectively conscious activity of the body, carried out with the help of neurophysiological processes. Higher nervous activity is a set of neurophysiological processes that provide consciousness, subconscious processing of information and purposeful behavior of the organism in the environment. Mental activity is carried out with the help of higher nervous activity. Lower nervous activity is a set of neurophysiological processes that ensure the implementation of unconditioned reflexes.

**4. The formation of the interaction of the body with the environment** is realized, for example, through the reaction of avoidance or getting rid of unpleasant stimuli (protective reactions of the body), regulation of the intensity of metabolism when the temperature of the environment changes. Changes in the internal environment of the body perceived subjectively in the form of sensations also induce the body to one or another purposeful motor activity.

Any activity of the central nervous system itself is ultimately realized with the help of the functioning of individual cells − neurons.

**(Slide 6)** The Neuron. **Video.**

**(Slide 7)** Neurons are highly specialized for the processing and transmission of cellular signals. Given the diversity of functions performed by neurons in different parts of the nervous system, there is, as expected, a wide variety in the shape, size, and electrochemical properties of neurons. For instance, the soma of a neuron can vary in size from 4 to 100 micrometers in diameter.

**The soma (cell body)** is the central part of the neuron. It contains the nucleus of the cell and therefore is where most protein synthesis occurs. The nucleus ranges from 3 to 18 micrometers in diameter. **The dendrites** of a neuron are cellular extensions with many branches, and metaphorically this overall shape and structure are referred to as **a dendritic tree**. This is where the majority of input to the neuron occurs. The axon is a finer, cable-like projection which can extend tens, hundreds, or even tens of thousands of times the diameter of the soma in length. The axon carries nerve signals away from the soma (and also carry some types of information back to it). Many neurons have only one axon, but this axon may - and usually will - undergo extensive branching, enabling communication with many target cells. The part of the axon where it emerges from the soma is called the 'axon hillock'. Besides being an anatomical structure, the axon hillock is also the part of the neuron that has the greatest density of voltage-dependent sodium channels. This makes it the most easily-excited part of the neuron and the spike initiation zone for the axon: in neurological terms, it has the greatest hyperpolarized action potential threshold.

**(Slide 8)** Glia, also called glial cells or neuroglia, are non-neuronal cells in the central nervous system (brain and spinal cord) and the peripheral nervous system that do not produce electrical impulses. They maintain homeostasis, form myelin, and provide support and protection for neurons. In the central nervous system, glial cells include oligodendrocytes, astrocytes, ependymal cells, and microglia, and in the peripheral nervous system glial cells include Schwann cells and satellite cells. They have four main functions: (1) to surround neurons and hold them in place; (2) to supply nutrients and oxygen to neurons; (3) to insulate one neuron from another; (4) to destroy pathogens and remove dead neurons. They also play a role in neurotransmission and synaptic connections, and in physiological processes like breathing. While glia were thought to outnumber neurons by a ratio of 10:1, recent studies using newer methods and reappraisal of historical quantitative evidence suggests an overall ratio of less than 1:1, with substantial variation between different brain tissues.

**(Slide 9)** Types of neurons.

**Sensory neurons** are the nerve cells that are activated by sensory input from the environment - for example, when you touch a hot surface with your fingertips, the sensory neurons will be the ones firing and sending off signals to the rest of the nervous system about the information they have received. **Most sensory neurons are pseudounipolar which means they only have one axon which is split into two branches.**

**Motor neurons** of the spinal cord are part of the central nervous system (CNS) and connect to muscles, glands and organs throughout the body. These neurons transmit impulses from the spinal cord to skeletal and smooth muscles (such as those in your stomach), and so directly control all of our muscle movements. **Motor neurons have the most common type of ‘body plan’ for a nerve cell - they are multipolar, each with one axon and several dendrites.**

As the name suggests, **interneurons** are the ones in between - they connect spinal motor and sensory neurons. As well as transferring signals between sensory and motor neurons, interneurons can also communicate with each other, forming circuits of various complexity. **They are multipolar, just like motor neurons.**

**(Slide 10)** Neurons connect to each other using synapses. Synapses are essential to the transmission of nervous impulses from one neuron to another.

**(Slide 11)** Synapse types by interfaces.

**(Slide 12)** All synapses are also divided into chemical and electrical. The structure of the chemical synapse is fully consistent with the structure of the neuromuscular synapse. An electrical synapse is a mechanical and electrically conductive link between two neighboring neurons that is formed at a narrow gap between the pre- and postsynaptic neurons known as a gap junction. At gap junctions, such cells approach within about 3.8 nm of each other, a much shorter distance than the 20- to 40-nanometer distance that separates cells at chemical synapse. In many animals, electrical synapse-based systems co-exist with chemical synapses. Compared to chemical synapses, electrical synapses conduct nerve impulses faster.

**(Slide 13)** Types of excitatory neurotransmitters. Neurotransmitters are chemical messengers that transmit a signal from a neuron across the synapse to a target cell, which can be a different neuron, muscle cell, or gland cell.

**Acetylcholine** is an excitatory, small-molecule neurotransmitter involved in synaptic transmission at neuromuscular junctions controlling the vagus nerve and cardiac muscle fibers, as well as in the skeletal and visceral motor systems and various sites within the central nervous system.

**Glutamate** is a small, amino acid neurotransmitter, and is the primary excitatory neurotransmitter at almost all synapses in the central nervous system.

**The catecholamines**, which include **Adrenalin, Noradrenalin, and Dopamine**, are excitatory biogenic amine neuromodulators that are derived from the amino acid tyrosine and serve as excitatory neurotransmitters at various locations in the central nervous system as well as the peripheral nervous system.

**Serotonin** is an excitatory neurotransmitter that regulates sleep and wakefulness and is found in neurons of the raphe region of the pons and upper brain stem, which extend into the forebrain.

**(Slide 14)** Synapses are also classified as excitatory and inhibitory. An excitatory synapse is a synapse in which an action potential in a presynaptic neuron increases the probability of an action potential occurring in a postsynaptic cell. An inhibitory postsynaptic potential (IPSP) is a kind of synaptic potential that makes a postsynaptic neuron less likely to generate an action potential.

**(Slide 15)** All nervous processes are realized through reflexes. A reflex is the body's response to irritation emanating from the external or internal environment which is realized with the help of the nervous system. Each reflex is carried out using a **reflex arc**. Each reflex arc consists of an afferent (sensitive) link that begins with the receptor apparatus, and an efferent (motor), ending with a working organ (effector). Quite often, there are one or two interneurons between the two indicated links.

**(Slide 16)** Knee reflex structure. **Video**

**(Slide 17)** How to do knee and ankle reflexes. **Video**

**(Slide 18)** There are different classifications of reflexes.

1. **Classification by heredit**y. According to this criterion reflexes are divided into inborn (species) reflexes and acquired (learned, individual) reflexes. The latter group was called “conditioned” reflexes by acad. I. Pavlov.

2. Classification by the biological significance (food reflexes, drinking reflexes, defense reflexes, etc.).

3. Classification by localization of the nerve center of the reflex in the CNS.

By this criterion reflexes are divided into reflexes of the spinal cord (spinal reflexes), of medulla oblongata (bulbar reflexes), of mesencephalon (mesencephalic) reflexes, etc.

4. According to what part of the nervous system is the effector of a reflex, reflexes are classified into somatic and autonomic.

5. By time required for realization of a reflex, there are distinguished fast (phasic) and slow (tonic) reflexes.

6. By effector organs reflexes are divided into motor, secretory, cardiac, vascular and others.

7. By relation to a stimulus reflexes are classified into positive and negative. Positive reflexes attract an individual to a stimulus. Negative reflexes drive an individual away from a stimulus, or prevent an individual from approaching it.

**(Slide 19) A nerve center** is a complex of neurons represented at different levels of the CNS and interrelated to control a specific physiological function.

**(Slide 20)** Properties of Nerve Centers.

**1. Unidirectional propagation of excitation.** This property is due to existence of numerous synaptic contacts that propagate excitation only one way.

**2. Central delay in propagation of excitation.** This property is also attributed to existence of numerous synapses in nerve centers.

**(Slide 21 and 22) 3. Ability of nerve centers to summate excitation.** There exist two probable variants of summation of excitation: temporal, or successive, summation (summation in time) and spatial summation (summation in space).

**(Slide 23) 4. High sensitivity to chemical compounds.** This property is based on the similarity between chemical structures of certain chemical compounds and neurotransmitters. Therefore, these compounds may change the state of postsynaptic membranes of neurons in the nerve center.

**(Slide 24) 5. Existence of posttetanic potentiation in nerve centers.** This is increased efficacy of conduction of excitation through a nerve center due to the effect of previous excitation. This effect can be explained by potentiation of excitation at synapses due to accumulation of calcium ions in presynaptic terminals.

**(Slide 25) 6. Aftereffect (after-action) in nerve centers.** This phenomenon can be explained by existence of collaterals in nerve centers that form the so called “neuronal traps”.

**(Slide 26) 7. Ability of nerve centers to transform rhythm of transmission of excitation.** This feature is also due to a large number of synapses in nerve centers and to physiological peculiarities of some nerve cells.

**(Slide 27)** 8. High fatigability of nerve centers. This feature is due to a large number of chemical synapses in nerve centers that are highly fatigable.

**9. Low lability of nerve centers.** This property also owes to a large amount of chemical synapses in nerve centers characterized by low lability.

**10. High sensitivity to oxygen deficit.** Nerve tissues mostly rely on aerobic processes for production of energy, therefore they are sensitive to lack of oxygen. Most sensitive to oxygen deficit are cortical nerve centers.

**11. High plasticity of nerve centers.** This is an ability of nerve centers to change their specialization to compensate for the lost functions of injured nerve centers.

**(Slide 28) Coordination in the nervous system** implies coordination between excitatory and inhibitory processes in the nerve centers involved in a specific reflex. As follows from the above definition, inhibition plays a role in coordination mechanisms.

**Principles of Coordination**

**(Slide 29) 1. Principle of reciprocal innervation.** This principle emphasizes significance of reciprocal interrelations in mechanisms of coordination of the activity of nerve centers.

**(Slide 30) 2. Principle of the common final pathway.** This principle emphasizes the minority of effector cells in the CNS in comparison with other cells. For example, efferent cells make only 3% of all neurons in the spinal cord. Therefore, nerve cells continuously compete for the final, or effector, pathway.

**(Slide 31) 3. Principle of dominant.** This principle was first described in the works of Russian physiologist A. Ukhtomsky in the 1923. It reflects the fact that at any given moment there exist some dominating nerve centers in the CNS that perform the most important for the moment physiological function. Dominant nerve centers may be formed both on the basis of reflexes and under action of humoral factors. They have a number of properties that provide their dominating position in the CNS: increased excitability, increased ability to summate excitation, evident ability to inhibit other nerve centers, and inertness of excitation.

**(Slide 32) 4. Principle of feedback.** It demonstrates significance of feedback mechanisms in the coordinated activity of nerve centers (P. Anokhin, N. Bernstein and others).

**(Slide 33) 5. Principle of temporary connections.** This principle demonstrates significance of connections between the nerve centers established in the ontogenesis, for their coordinated activity. An example of enrichment of coordination mechanism with temporary connections is the act of walking in humans that is established in children by 1.5-2 years of age on the basis of the inborn “step” reflex. A step reflex is a mechanism of coordinated activity of nerve centers supplying antagonistic muscles – flexors and extensors.

**(Slide 34)** The processes of coordination of reflex processes in the central nervous system are performed with the obligatory participation of inhibition processes.

Inhibition is an active independent nervous process that manifests itself externally in the suppression or weakening of the excitation process and is characterized by a certain intensity and duration.

**(Slide 35)** Depending on the mechanism, inhibition may be hyperpolarizational and depolarizational, or primary and secondary.

**Presynaptic inhibition** is a special case of synaptic inhibitory processes, manifested in the suppression of neuron activity as a result of a decrease in the effectiveness of the action of excitatory synapses even at the presynaptic link by inhibition of the mediator release process by excitatory nerve endings.

**Postsynaptic inhibition** is a nervous process caused by the action on the postsynaptic membrane of specific inhibitory mediators (glycine, GABA), secreted by specialized presynaptic nerve endings. The mediator released by them changes the properties of the postsynaptic membrane, which causes suppression of the cell's ability to generate excitation.

**Pessimal inhibition** develops in excitatory synapses as a result of strong depolarization of the postsynaptic membrane under the influence of the frequent arrival of nerve impulses, which does not correspond to the lability of synapses.

**Induction inhibition** develops in neurons after the end of excitation as a result of strong trace membrane hyperpolarization (postsynaptic).

**(Slide 36)** Spinal Cord Structure and Function. **Video**

**(Slide 37)** The spinal cord plays a vital role in various aspects of the body’s functioning:

1. Carrying signals from the brain: The spinal cord receives signals from the brain that control movement and autonomic functions.

2. Carrying information to the brain: The spinal cord nerves also transmit messages to the brain from the body, such as sensations of touch, pressure, and pain.

3. Reflex responses: The spinal cord may also act independently of the brain in conducting motor reflexes. One example is the patellar reflex, which causes a person’s knee to involuntarily jerk when tapped in a certain spot.

These functions of the spinal cord transmit the nerve impulses for movement, sensation, pressure, temperature, pain, and more.

**(Slide 38)** The Brainstem. **Video**

**(Slide 39)** The medulla oblongata connects the higher levels of the brain to the spinal cord, and is responsible for several functions of the autonomous nervous system which include:

The control of ventilation via signals from the carotid and aortic bodies. Respiration is regulated by groups of chemoreceptors. These sensors detect changes in the acidity of the blood; if, for example, the blood becomes too acidic, the medulla oblongata sends electrical signals to intercostal and phrenical muscle tissue to increase their contraction rate and increase oxygenation of the blood. The ventral respiratory group and the dorsal respiratory group are neurons involved in this regulation. The pre-Bötzinger complex is a cluster of interneurons involved in the respiratory function of the medulla.

Cardiovascular center – sympathetic, parasympathetic nervous system.

Vasomotor center – baroreceptors.

Reflex centers of vomiting, coughing, sneezing, and swallowing. These reflexes which include the pharyngeal reflex, the swallowing reflex (also known as the palatal reflex), and the masseter reflex can be termed, bulbar reflexes.

**(Slide 40)** There are three main functions of the brainstem:

1. The brainstem plays a role in conduction. That is, all information relayed from the body to the cerebrum and cerebellum and vice versa must traverse the brainstem. The ascending pathways coming from the body to the brain are the sensory pathways and include the spinothalamic tract for pain and temperature sensation and the dorsal column-medial lemniscus pathway (DCML) including the gracile fasciculus and the cuneate fasciculus for touch, proprioception, and pressure sensation. The facial sensations have similar pathways and will travel in the spinothalamic tract and the DCML. Descending tracts are the axons of upper motor neurons destined to synapse on lower motor neurons in the ventral horn and posterior horn. In addition, there are upper motor neurons that originate in the brainstem's vestibular, red, tectal, and reticular nuclei, which also descend and synapse in the spinal cord.

2. The cranial nerves III-XII emerge from the brainstem. These cranial nerves supply the face, head, and viscera. (The first two pairs of cranial nerves arise from the cerebrum).

3. The brainstem has integrative functions being involved in cardiovascular system control, respiratory control, pain sensitivity control, alertness, awareness, and consciousness. Thus, brainstem damage is a very serious and often life-threatening problem.

**(Slide 41)** Muscle tone (residual muscle tension or tonus) is the continuous and passive partial contraction of the muscles, or the muscle's resistance to passive stretch during resting state.

Muscle tone has a reflex nature. This is proved by atonia which develops in muscles supplied from the respective segment of the spinal cord after cutting its dorsal or ventral roots.

The muscle tone is controlled in the spinal cord by two complementary mechanisms.

The first mechanism is associated with continuous action of gravitation forces on skeletal muscles causing their stretch and increase in length. This activates the receptor part of intrafusal fibers with the resultant excitation of α2-motor neurons and of red (slow) muscle fibers innervated by them. A high level of muscle tone leads to a considerable shortening of muscles, to decrease in the activity of receptor parts of intrafusal fibers, and to reduction of muscle tone.

The second mechanism is associated with γ-motor neurons supplying peripheral parts of the intrafusal fibers. Excitation of γ-motor neurons leads to contraction of contractile elements of the intrafusal fibers, to stretch of the central capsule, activation of receptors, excitation of α2-motor neurons with the resultant increase in muscle tone. This mechanism is called “γ-regulation of muscle tone”. γ-Motor neurons are controlled by supraspinal suprasegmental formations (reticular formations of the brainstem, red nucleus, basal ganglia, cerebellum, cerebral cortex).

**Thank you for attention**