Federal State Budgetary Educational Institution of Higher Education

“Professor V.F. Voino-Yasenetsky Krasnoyarsk State Medical University”,

the Russian Federation Ministry of Health

Prof. A.T. Pshonik Department of Physiology

Instructional guidelines for students (out-of-class work)

for the discipline

**"Normal physiology"**

for students in the specialty Specialty 31.05.01 – General medicine

**FOR PRACTICAL CLASS № 3**

15.09-21.09.2021

**THEME:**

**"PHYSIOLOGY OF THE MUSCULAR SYSTEM"**

**Study questions**

1. Physical and physiological properties of skeletal and masticatory muscles.
2. The modern theory of muscle contraction and relaxation. (E.M.S.)
3. Bioelectric, chemical and thermal processes in muscles. Electromyography of skeletal and masticatory muscles
4. Types and modes of muscle contractions. Single contraction and its phases.
5. Summation of contractions and tetanus. Dependence of the amplitude of contraction on the frequency of stimulation. Optimum and pessimum of contraction.
6. Strength and work of skeletal and masticatory muscles. Fatigue. Law of average loads
7. Functional characteristics of smooth muscles.
8. The concept of motor units, their classification.
9. The mechanism of transmission of excitation from the nerve to the muscle. The neuromuscular synapse.

**Student independent learning activities**

1. **Dynamometry.** See the Textbooks "Practical skills of functional physiological research", pp. 146-147.; "Practical training in physiology"; "Methods of physiological research".

**2.** **Electromyography I (**Standard and integrated EMG of the masticatory muscles) on the equipment of the Biopac Student Lab (polygraph). See the "Guide to working with the Biopac Student Lab". Lesson 1

3**.** **Electromyography and dynamometry** (Replenishment of motor units and fatigue) on the equipment of the Biopac Student Lab (polygraph). See the "Guide to working with the Biopac Student Lab". Lesson 2

4. **Performing virtual physiological experiments:**

1. Determining the latency period
2. Determination of the threshold force of irritation
3. The effect of increasing the intensity of the stimulus
4. The staircase Phenomenon
5. Summation of muscle contractions
6. Influence of the load and the initial length of the muscle on the effect of contraction
7. An Isotonic contraction

(see "Workshop on virtual physiology" and programs "Virtual physiology", section - "Physiology of skeletal muscles."

**Topics for students' scientific research**

1. Neuromuscular transmission of excitement.
2. Contracting muscle proteins.
3. Conjugation of excitation and contraction.
4. Mechanics of muscle contraction.
5. Metabolism and muscle contraction.
6. 6. Smooth muscles.

Course textbooks and manuals

Main textbooks

1. Physiology. A textbook for students of dental faculties

edited by Smirnov V. M., 2nd edition, 2016.

2. Normal physiology: a textbook for dentists,

Savchenko, Y. I., Paz, Y. S. 2007

Supplementary books

1. Workshop on normal physiology: instructional guidelines for students in the specialty Dentistry/ edited by Savchenkov Y. I. 2009
2. Savchenkov Yu. I. Methods of research of physiological functions: textbook.

Electronic resources

1. Atlas of multimedia support for lectures
2. Atlas of normal physiology. Korobkov et al. Electronic version
3. Electronic versions of all lectures and textbooks on physiology

**7. Synopsis :** Striated muscles are an active part of the musculoskeletal system. As a result of the contractile activity of these muscles, the body moves in space, the body parts move relative to each other, and the posture is maintained. In addition, muscle work produces heat.

Each muscle fiber has the following properties: **excitability**, i.e. the ability to respond to the action of a stimulus by generating AP, **conductivity -** the ability to conduct excitation along the entire fiber in both directions from the point of irritation**,** and **contractility*,*** i.e. the ability to contract or change its voltage when excited. Excitability and conductivity are functions of the surface cell membrane - sarcolemma, and contractility is a function of myofibrils located in the sarcoplasm.

**The structure of myofibrils and its changes during contraction.** Myofibrils are muscle fiber contractile apparatusIn striated muscle fibers, myofibrils are divided into correctly alternating sections (disks) that have different optical properties. Some of these areas are anisotropic, i.e. have birefringence. In normal light they appear dark, and in polarized light they appear transparent in the longitudinal direction and opaque in the transverse direction. Other areas are isotropic, and appear transparent in ordinary light. Anisotropic areas are indicated by the letter **A**, isotropic-**I**. In the middle of the disk **A** there is a light strip **H**, and in the middle of the disk **I** there is a dark strip **Z**, which is a thin transverse membrane, through the pores of which myofibrils pass. Due to the presence of such a support structure, the parallel single-digit disks of individual myofibrils inside a single fiber do not shift relative to each other during contraction.

It was found that each of the myofibrils has a diameter of about 1 micron and consists on average of 2500 protofibrils, which are elongated polymerized molecules with myosin and actin proteins. Myosin filaments (protofibrils) are twice as thick as actin filaments. Their diameter is approximately 100 angstroms. In the resting state of the muscle fiber, the filaments are located in the myofibrils in such a way that the thin long actin filaments enter their ends in the spaces between the thick and shorter myosin filaments. In this section, each thick thread is surrounded by 6 thin ones. Because of this, disks I consist only of actin filaments, and disks A also consist of myosin filaments. The light strip H is a zone free of actin filaments during the dormant period. The membrane Z, passing through the middle of the disk I, binds the actin filaments together.

Numerous cross bridges on myosin are also an important component of the ultramicroscopic structure of myofibrils. In turn, the actin filaments have so-called active centers, which are at rest covered, like a sheath, with special proteins - troponin and tropomyosin. The contraction is based on the process of sliding actin filaments relative to myosin filaments. This sliding is caused by the operation of the so-called "chemical cogwheel" ", i.e. periodically occurring cycles of changes in the state of cross bridges and their interaction with active centers on actin. ATP and CA+ions play an important role in these processes.

When the muscle fiber contracts, the actin and myosin filaments do not shorten, but begin to slide over each other: actin filaments are pushed between myosin filaments, as a result of which the length of disks I is shortened, and disks A retain their size, approaching each other. The H strip almost disappears, because the ends of the actin touch and even go behind each other.

**The role of AP in the occurrence of muscle contraction (the process of electromechanical coupling).** In skeletal muscle, under natural conditions, the initiator of muscle contraction is an action potential that propagates when excited along the surface membrane of the muscle fiber.

If the tip of the microelectrode is applied to the surface of the muscle fiber in the area of the z membrane, then when a very weak electrical stimulus is applied that causes depolarization, the I disks on both sides of the irritation site will begin to shorten. In this case, the excitation propagates deep into the fiber, along the z membrane. Irritation of other parts of the membrane does not cause this effect. Consequently, depolarization of the surface membrane in the area of disk I during the propagation of AP is the triggering mechanism of the contractile process.

Further studies have shown that an important intermediate link between membrane depolarization and the onset of muscle contraction is the penetration of free CA ++ ions into the interfibrillar space. At rest, the bulk of Ca ++ in the muscle fiber is stored in the sarcoplasmic reticulum.

In the mechanism of muscle contraction, a special role is played by the part of the reticulum that is localized in the area of the Z membrane. Electron-microscopically, the so-called triad (T-system) is revealed here, each of which consists of a thin transverse tube, centrally located in the region of the membrane Z, running across the fiber, and two lateral cisterns of the sarcoplasmic reticulum, which contain bound Ca ++. AP propagating along the surface membrane is carried deep into the fiber along the transverse tubules of the triads. Then the excitation is transmitted to the cisterns, depolarizes their membrane and it becomes permeable to CA++.

It has been experimentally established that there is a certain critical concentration of free CA++ ions at which myofibrils begin to contract. It is equal to 0,2-1,5\*106 ions per fiber. Increasing the concentration of CA++ to 5\*106 causes the maximum contraction.

The onset of muscle contraction is confined to the first third of the ascending line of the AP, when its value reaches approximately 50 mV. It is believed that it is at this depolarization value that The CA++ concentration becomes the threshold for the beginning of actin-myosin interaction.

The CA++ release process stops after the end of the AP peak . Nevertheless, the reduction continues to grow until the mechanism comes into play that ensures the return of Ca ++ to the cisterns of the reticulum. This mechanism is called the "calcium pump". To carry out its work, the energy obtained from the splitting of ATP is used.

In the interfibrillar space, Ca ++ interacts with proteins that close the active centers of actin filaments - troponin and tropomyosin, providing an opportunity for the reaction of the cross bridges of myosin and actin filaments. Thus, the sequence of events leading to contraction and then relaxation of the muscle fiber is currently drawn as follows:

***Irritation - the appearance of AP - carrying it along the cell membrane and deep into the fiber along the tubules of the T-systems -*** ***depolarization of the sarcoplasmic reticulum membrane -- release of CA++ from triads and its diffusion to myofibrils -- interaction of CA++ with troponin and release of ATP energy -- interaction (sliding) of actin and myosin filaments -- muscle contraction -- decrease in CA++ concentration in the interfibrillar space due to the operation of the CA pump --*** ***muscle relaxation.***

**The role of ATP in the mechanism of muscle contraction.** During the interaction of actin and myosin filaments in the presence of Ca ++ ions, an energy-rich compound ATP plays an important role. Myosin has the properties of the enzyme ATPase. When ATP is broken down, about 10,000 calories per mole are released. Under the influence of ATP, the mechanical properties of myosin filaments are also changed - their extensibility increases sharply. It is believed that the cleavage of ATP is the source of the energy required to slide the filaments. CA++ ions increase the ATPase activity of myosin. In addition, ATP energy is used to operate the calcium pump in the reticulum. In accordance with this, the enzymes that break down ATP are localized in these membranes, and not only in myosin.

Resynthesis of ATP, which is continuously broken down during muscle work, is carried out in two main ways. The first is the enzymatic transfer of the phosphate group from creatine phosphate (CP) to ADP. CP is found in muscle in much larger quantities than ATP, and provides its resynthesis within thousandths of a second. However, with prolonged muscle work, the reserves of CP are depleted, therefore the second path is important - slow resynthesis of ATP associated with glycolysis and oxidative processes. Oxidation of lactic and pyruvic acids formed in the muscle during its contraction is accompanied by phosphorylation of ADP and creatine, i.e. resynthesis of CP and ATP.

Disruption of ATP resynthesis by poisons that suppress glycolysis and oxidative processes leads to the complete disappearance of ATP and CP, as a result of which the calcium pump stops working. The concentration of Ca ++ in the area of myofibrils greatly increases and the muscle comes into a state of prolonged irreversible shortening - the so-called contracture.

**Heat formation during the contractile process.** According to its origin and time of development, this heat formation is divided into two phases. The first is many times shorter than the second and is called the initial heat generation. It starts from the moment of muscle excitation and continues throughout the entire contraction, including the relaxation phase. The second phase of heat formation occurs within a few minutes after relaxation, and is called delayed, or recovery heat formation. In turn, the initial heat formation can be divided into several parts - activation heat, shortening heat, relaxation heat. The heat generated in the muscles maintains the temperature of the tissues at a level that ensures the active course of physical and chemical processes in the body.

**Types of contractions.** Depending on the conditions under which the contraction occurs, there are two types of it - isotonic and isometric. Isotonic is a contraction of the muscle in which its fibers are shortened, but the tension remains the same. An example is shortening without load. Isometric is a contraction in which the muscle cannot be shortened (when its ends are fixed). In this case, the length of the muscle fibers remains unchanged, but their tension increases (lifting an unbearable load).

Natural muscle contractions in the body are never purely isotonic or isometric.

**Single contraction.** Irritation of the muscle or the motor nerve innervating it by a single stimulus causes a single contraction of the muscle. We should distinguish two main phases: the contraction phase and the relaxation phase. The contraction of the muscle fiber begins already during the ascending branch of the AP. The duration of contraction at each point of the muscle fiber is tens of times longer than the duration of AP. Therefore, a moment comes when the PD has passed along the entire fiber and ends, while the wave of contraction has covered the entire fiber and it continues to be shortened. This corresponds to the moment of maximum shortening or tension of the muscle fiber.

The contraction of each individual muscle fiber during single contractions obeys the "all or nothing" law. This means that the contraction that occurs both during threshold and above-threshold stimulation has a maximum amplitude. The magnitude of a single contraction of the entire muscle depends on the strength of irritation. With threshold stimulation, its contraction is barely noticeable; with an increase in the strength of stimulation, it grows until it reaches a certain height, after which it remains unchanged (maximum contraction). This is due to the fact that the excitability of individual muscle fibers is not the same, and therefore only a part of them is excited with weak irritation. At maximum contraction, they are all excited. The speed of the wave of muscle contraction coincides with the speed of propagation of the AP. In the biceps muscle of the shoulder, it is 3.5-5.0 m / s.

**Summation of abbreviations and tetanus.** If in an experiment a single muscle fiber or the entire muscle is affected by two rapidly following strong single stimuli, the resulting contraction will have a greater amplitude than the maximum single contraction. The contractile effects caused by the first and second stimuli seem to add up. This phenomenon is called summation of abbreviations. For summation to occur, it is necessary that the interval between stimuli have certain duration - it must be longer than the refractory period, but shorter than the entire duration of a single contraction, so that the second stimulation acts on the muscle before it has time to relax. There are two possible cases. If the second stimulus arrives when the muscle has already begun to relax, the top of the second contraction on the myographic curve will be separated from the first by a depression. If the second stimulus acts when the first contraction has not yet reached its peak, then the second contraction, as it were, merges with the first, forming together with it a single summed peak. With both full and incomplete summation, APs are not summed up. This cumulative contraction in response to rhythmic stimuli is called tetanus. Depending on the frequency of irritation, it is rough and smooth.

The reason for the summation of contractions in tetanus lies in the accumulation of Ca ++ ions in the interfibrillar space up to a concentration of 5\*106 mM / L. After reaching this value, further accumulation of Ca ++ does not lead to an increase in the tetanus amplitude.

After the termination of tetanic stimulation, the fibers do not relax completely at first, and their original length is restored only after a certain time. This phenomenon is called post-tetanic, or residual contracture. It is associated with the fact that it takes more time to remove all Ca ++ from the interfibrillar space, which got there during rhythmic stimuli and did not have time to completely retire into the cisterns of the sarcoplasmic reticulum by the operation of Ca-pumps.

If, after reaching smooth tetanus, the frequency of irritation is increased even more, then the muscle at some frequency begins to suddenly relax. This phenomenon is called pessimum. It occurs when each next impulse falls into refractoriness from the previous one.

**Motor units.** Each motor nerve fiber, which is a process of the motor cell of the anterior horns of the spinal cord (alpha-motor neuron), branches in the muscle and innervates a whole group of muscle fibers. This group is called the motor unit of the muscle. The number of muscle fibers that make up the motor unit varies widely, but their properties are the same (excitability, conductivity, etc.). Due to the fact that the speed of propagation of excitation in the nerve fibers innervating skeletal muscles is very high, the muscle fibers that make up the motor unit come to a state of excitation almost simultaneously. The electrical activity of a motor unit has the form of a stockade, in which each peak corresponds to the total action potential of many simultaneously excited muscle fibers.

The excitability of various skeletal muscle fibers and the motor units composed of them varies considerably. It is more in the so-called fast fibers and less in slow fibers. In this case, the excitability of both is lower than the excitability of the nerve fibers that innervate them. This depends on the fact that the difference between E0 and E с is greater in the muscles, which means that the rheobase is higher. AP reaches 110-130 mV, its duration is 3-6 msec. The maximum frequency of fast fibers is about 500 per sec., of most skeletal fibers - 200-250 per sec. The duration of AP in slow fibers is approximately 2 times longer, the duration of the contraction wave is 5 times longer, and the speed of its conduction is 2 times slower. In addition, fast fibers are divided, depending on the rate of contraction and lability, into phase and tonic.

Skeletal muscles in most cases are mixed: they consist of both fast and slow fibers. But within a single motor unit all the fibers are always the same. Therefore, motor units are divided into fast and slow, phase and tonic. The mixed type of muscle allows the nerve centers to use the same muscle both to perform fast, phase movements, and to maintain tonic tension.

There are, however, muscles that are predominantly composed of fast or slow motor units. These muscles are also often called fast (white) and slow (red) muscles. The duration of the contraction wave of the fastest muscle - the inner rectus muscle of the eye - is only 7.5 msec. In the slow soleus it is 75 msec. The functional significance of these differences becomes apparent when considering their responses to rhythmic stimuli. To obtain a smooth tetanus of a slow muscle, it is enough to irritate it with a frequency of 13 stimuli per second. In fast muscles, smooth tetanus occurs at a frequency of 50 stimuli per second. In tonic motor units, the duration of contraction per single stimulus can be up to 1 second.

**Summation of contractions of motor units in the whole muscle.** Unlike muscle fibers in a motor unit, which are synchronously and simultaneously excited in response to an incoming impulse, muscle fibers of different motor units in a whole muscle work asynchronously. This is explained by the fact that different motor units are innervated by different motor neurons, which send impulses with different frequencies and at different times. Despite this, the total contraction of the muscle as a whole has a continuous character under conditions of normal activity. This is because the neighboring motor unit(or units) always have time to contract before those that are already excited have time to relax. The strength of muscle contraction depends on the number of motor units involved simultaneously in the reaction, and on the frequency of excitation of each of them.

**Skeletal muscle tone.** At rest, outside of work, muscles in the body are not

completely relaxed, but retain some tension, called tone. The external expression of tone is a certain elasticity of the muscles.

Electrophysiological studies show that tone is associated with the arrival of rare nerve impulses to the muscle, which excite different muscle fibers alternately. These impulses occur in the motor neurons of the spinal cord, the activity of which, in turn, is supported by impulses coming from both higher centers and proprioreceptors (muscle spindles, etc.) located in the muscles themselves. The reflex nature of skeletal muscle tone is evidenced by the fact that the transection of the posterior roots, along which sensory impulses from the muscle spindles enter the spinal cord, leads to complete muscle relaxation.

**Work and muscle strength.** The amount of contraction (degree of shortening) of a muscle at a given intensity of irritation depends on both its morphological properties and its physiological state. Long muscles contract by a greater amount than short ones. Moderate stretching of the muscle increases its contractile effect, with strong stretching, the contracted muscles relax. If, as a result of prolonged work, muscle fatigue develops, then the amount of its contraction decreases.

To measure muscle strength, either the maximum load that it is able to lift or the maximum tension that it can develop under conditions of isometric contraction is determined.Эта сила может быть очень велика. So, it was found that a dog with the muscles of the jaw can lift a load that exceeds its body weight by 8.3 times.

A single muscle fiber can develop a tension of up to 100-200 mg. Considering that the total number of muscle fibers in the human body is approximately 15-30 million, they could develop a tension of 20-30 tons if they were all pulled in one direction at the same time.

All other things being equal, muscle strength depends on its cross section. The greater the sum of the cross-sections of all its fibers is, the greater the load that it is able to lift. This refers to the so-called physiological cross-section, when the cross-section line is perpendicular to the muscle fibers, and not the muscle as a whole. The strength of muscles with oblique fibers is greater than with straight ones, since its physiological cross-section is larger with the same geometric one. To compare the strength of different muscles, the maximum load (absolute muscle strength) that the muscle is able to lift is divided by the physiological cross-sectional area (kg / cm sq.) In this way, the specific absolute strength of the muscle is calculated. For calf muscles of a person it is equal to 5.9 kg/square centimeter, flexor of the shoulder to 8.1 kg/cm sq, triceps brachii - 16.8 kg/cm. sq.

The work of the muscles is measured by the product of the lifted load and the amount of shortening of the muscle. There is the following regularity between the load that the muscle lifts and the work it does. The external work of the muscle is zero if the muscle contracts without load. As the load increases, the work first increases, and then gradually decreases. The greatest work is done by the muscle at some average loads. Therefore, the dependence of work and power on the load is called the **rule (law) of average loads.**

Muscle work, in which the movement of load and the movement of bones in the joints occurs, is called dynamic. The work of the muscle, in which the muscle fibers develop tension, but almost do not shorten is static. Hanging on a pole is an example. Static work is more tedious than dynamic work.

**Muscle fatigue.** Fatigue is a temporary decrease in the performance

of a cell, organ, or whole organism that occurs as a result of work and disappears after rest.

If you irritate an isolated muscle with rhythmic electrical stimuli for a long time, to which a small load is suspended, the amplitude of its contractions gradually decreases until it reaches zero. The fatigue curve is registered. Along with the change in the amplitude of contractions during fatigue, the latent period of contraction increases, the period of muscle relaxation lengthens, and the threshold of irritation increases, i.e., excitability decreases. All these changes do not occur immediately after starting work, there is a certain period during which there is an increase in the amplitude of contractions and a slight increase in the excitability of the muscle. At the same time, it becomes easily stretchable. In such cases, they say that the muscle is "worked in", i.e. adapts to work in a given rhythm and strength of irritation. After a period of workability, a period of stable workability begins. With further prolonged irritation, muscle fiber fatigue occurs.

There are two main reasons for the reduced performance of a muscle isolated from the body when it is irritated for a long time. The first of them is that during contractions, metabolic products accumulate in the muscle (phosphoric acid, binding CA++, lactic acid, etc.), which have a depressing effect on the performance of the muscle. Some of these products, as well as Ca ions, diffuse from the fibers to the outside into the pericellular space and have a depressing effect on the ability of the excitable membrane to generate AP. So, if an isolated muscle, placed in a small volume of Ringer's fluid, is brought to complete fatigue, then it is enough just to change the solution that washes it in order to restore muscle contractions.

Another reason for the development of fatigue of an isolated muscle is the gradual depletion of energy reserves in it. With prolonged work, the content of glycogen in the muscle sharply decreases, as a result of which the processes of resynthesis of ATP and CP, necessary for the implementation of contraction, are disrupted.

It should be noted that in the natural conditions of the body's existence, fatigue of the motor apparatus during prolonged work develops completely differently from that in the experiment with an isolated muscle. This is due not only to the fact that in the body the muscle is continuously supplied with blood, and, therefore, receives the necessary nutrients with it and is released from metabolic products. The main difference is that in the body, excitatory impulses come to the muscle from the nerve. The neuromuscular synapse gets tired much earlier than the muscle fiber, due to the rapid depletion of the accumulated neurotransmitter reserves. This causes a blockade of the transmission of excitations from the nerve to the muscle, which protects the muscle from exhaustion caused by prolonged work. In the whole organism, the nerve centers (nerve-nervous contacts) get tired even earlier during the work.

The role of the nervous system in fatigue of the whole organism is proved by studies of fatigue in hypnosis (weight-basket), the establishment of the influence of "active rest" on fatigue, the role of the sympathetic nervous system (the Orbeli-Ginetsinsky phenomenon), etc.

**9.** Testing the initial level of knowledge

**Physiology of muscle contraction**

1. THE STRUCTURAL AND FUNCTIONAL UNIT OF A MUSCLE FIBER IS

1)actin

2) myosin

3) sarcomere\*

4) tropomyosin

5) troponin

2)WHEN THE STRIATED MUSCLE FIBER IS CONTRACTED

1. the length of myosin filaments decreases
2. actin filaments are shortened
3. actin filaments slide along the myosin \*
4. all the answers are correct

5)there is no correct answer

3) EXCITATION IS CARRIED OUT THROUGH THE NEUROMUSCULAR SYNAPSE

1. in one direction \*
2. in both directions
3. faster than along the nerve fiber
4. without synaptic delay
5. there is no correct answer

4) THE CONTRACTION OF MUSCLE AS A RESULT OF IRRITATION BY A SERIES OF SUPER THRESHOLD PULSES, EACH OF WHICH ACTS IN THE PREVIOUS RELAXATION PHASE, IS CALLED:

1. smooth tetanus
2. single contraction
3. optimal tetanus
4. rough tetanus \*
5. pessimal tetanus

5) THE STRUCTURAL UNIT OF SMOOTH MUSCLES IS

* 1. muscle fiber
  2. myofibrils
  3. muscle spindle
  4. sarcomere
  5. muscle cell \*

6) THE OPTIMUM OF FREQUENCY (STRENGTH) OF AN IRRITANT FOR MUSCLE TISSUE IS

* 1. the frequency (strength) of the stimulus, under the action of which the maximum smooth tetanus occurs \*
  2. the frequency (strength) of the stimulus, under the action of which rough tetanus occurs
  3. the frequency (strength) of the stimulus, under the action of which the minimum smooth tetanus occurs
  4. the frequency (strength) of the stimulus at which fatigue does not develop
  5. the frequency (strength) of the stimulus at which a powerful single contraction occurs

7) THE T-SYSTEM OF THE MUSCLE FIBER IS FORMED BY

* 1. the outer membrane of the muscle fiber
  2. one transverse tube and two cisterns of the sarcoplasmic reticulum\*
  3. the transverse tubules

the sarcoplasmic reticulum

8) MYOFIBRILLARY PROTEINS COMPOSE …OF ALL MUSCLE FIBER PROTEINS

* 1. 10-15 %
  2. 20-25 %
  3. 50-60 %
  4. 90-95 %

9) THE ACTIVE CENTER OF ACTIN THREADS IS A

* 1. negatively charged ADP molecule \*
  2. tropomyosin and troponin
  3. cross bridge
  4. ATPase molecule

10) MAXIMUM MUSCLE STRENGTH IS DETERMINED

1) by the absolute value of the mass of the maximum lifted load \*

2) by the mass of the maximum lifted load per unit of muscle cross-sectional area

3) by the ability to contract to the rhythm of the supplied stimuli

4) by the ability to restore your performance after rest

11) THE SECOND PHASE OF A SINGLE SKELETAL MUSCLE CONTRACTION IS CALLED

1) latent

2) the phase of shortening \*

3) the relaxation phase

4) refractory

12. CONCEPTS ABOUT PESSIMUM AND OPTIMUM OF FREQUENCY AND FORCE OF IRRITATION FOR EXCITABLE TISSUES WERE PROPOSED BY A RUSSIAN PHYSIOLOGIST

1) Vvedensky N.Ye\*

2)Pavlov I.P.

3)Ukhtomakiy A.A

4)Sechenov I.M.

5) Anokhin P.K.

12 THE ACTIVE ELEMENTS OF MYOSIN FILAMENTS ARE

* 1. a negatively charged ATP molecules
  2. tropomyosin
  3. cross bridges \*
  4. ATPase molecules

13 AT THE TOP OF THE CROSS BRIDGE IS

* 1. a negatively charged ATP molecule
  2. tropomyosin
  3. ATP-ase
  4. troponin

14 MUSCLE FATIGUE IS

* 1. contracture
  2. irreversible decline in its performance, coming after work
  3. a temporary decrease in its \*performance, which occurs after work and disappears after rest
  4. temporary increase in the strength of contractions

15. THE AMOUNT OF CALCIUM IONS RELEASED FROM THE SARCOPLASMIC RETICULUM INTO THE SARCOPLASM IS DETERMINED BY

1. the degree of depolarization of the sarcoplasmic reticulum membrane\*
2. the number of myoneural synapses on the sarcolemma
3. the size of the isotropic disk
4. the size of the anisotropic disk

16.THERE ARE ACTIVE CENTERS

1. on thick myosin filaments
2. on thin actin filaments \*
3. on myosin and actin filaments

4) on the tropomyosin

17. THE MUSCLE PERFORM MAXIMUM WORK

1. at maximum loads
2. at medium loads \*
3. at minimum loads
4. contracting without load

18 THE SPECIALIZED CONTRACTILE APPARATUS OF THE STRIATED MUSCULATURE IS

1. the plasmolemma
2. sarcoplasma
3. myofibrillae \*
4. mitochondria

5) T-system

19. THE ABILITY OF A MUSCLE TO SHORTEN OR CHANGE ITS TONE IS CALLED

1. isotonic contraction
2. isometric contraction
3. excitability
4. contractility\*
5. conductivity

20…. IONS ARE RELEASED FROM THE SARCOPLASMIC RETICULUM OF THE MUSCLE FIBER DURING CONTRACTION

1. Potassium
2. Chlorine
3. Sodium
4. Calcium\*

5) Magnesium

21 . AN ISOTONIC CONTRACTION IS A CONTRACTION IN WHICH

1. the muscle fibers are shortened and the internal tension remains constant\*
2. the length of the muscle fibers is constant, and the tension increases
3. the length of muscle fibers and tension is changed
4. all answers are correct
5. there is no correct answer

22. SKELETAL MUSCLE CONTRACTION IS MAINLY CAUSED BY … CA2 + IONS

1. extracellular IONS that enter the sarcoplasm when the muscle fiber is excited
2. intracellular IONS that enter the sarcoplasm when the muscle fiber is excited from the sarcoplasmic reticulum \*
3. intracellular IONS that enter the sarcoplasm from mitochondria
4. all answers are correct
5. there is no correct answer

23. ...ION CURRENTS TAKE PART IN THE FORMATION OF THE ACTION POTENTIALOFFF MUSCLE TISSUE

* 1. sodium and chlorine
  2. calcium and chlorine
  3. calcium and chlorine\*
  4. chlorine and potassium

24. THE STRUCTURAL UNIT OF STRIATED MUSCLES IS

1) the muscle fiber \*

2) the myofibrilla

3) the muscle spindle

4) the sarcomere

5) muscle cell

25. CONTRACTILE MUSCLE PROTEINS INCLUDE

* 1. actin, myosin \*
  2. actin, myosin, troponin
  3. actin, myosin, tropomyosin
  4. actin, tropomyosin
  5. troponin, tropomyosin

26. THE "Z" MEMBRANE OF THE MUSCLE FIBER RUNS THROUGH THE MIDDLE OF THE

* 1. muscle fiber
  2. sarcomere
  3. disk I \*
  4. disk А

27. THE SECTION OF MYOFIBRILS BETWEEN THE TWO "Z" MEMBRANES IS CALLED THE

* 1. muscle fiber
  2. protofibrils
  3. filament
  4. isotropic disk
  5. sarcomere \*

28.WITH MUSCLE CONTRACTION LENGTH OF PROTOFIBRILS

1. decreases
2. increases
3. does not change \*

depends on the load

29. THE ABSOLUTE STRENGTH OF THE MUSCLE IS DETERMINED BY THE

* 1. mass of the maximum lifted load
  2. mass of the maximum lifted load per unit cross-sectional area of the muscle \*
  3. ability to contract in the rhythm of the given stimuli
  4. ability to restore the performance after rest

30. THE PROPERTY OF SMOOTH MUSCLES THAT IS ABSENT IN SKELETAL ONES IS CALLED

1. excitability
2. conductivity
3. contractility
4. plasticity \*
5. lability

31. THE MAIN ROLE IN THE FORMATION OF THE DEPOLARIZATION PHASE OF THE SMOOTH MUSCLE CELL ACTION POTENTIAL IS PLAYED BY IONS OF:

1. sodium
2. chlorine
3. calcium \*
4. potassium I
5. magnesium

32. THE FIRST PHASE OF A SINGLE SKELETAL MUSCLE CONTRACTION IS CALLED

1. latent \*
2. shortening phase
3. relaxation phase
4. refractory

33. THE PESSIMUM OF THE FREQUENCY (STRENGTH) OF THE STIMULUS FOR MUSCLE TISSUE IS

1. the frequency (strength) of the stimulus, under the action of which the maximum smooth tetanus occurs
2. the frequency (strength) of the stimulus, under the action of which there is a rough tetanus
3. the frequency (strength) of the stimulus, which causes a minimal smooth tetanus
4. the frequency (strength) of the stimulus at which contracture develops
5. the frequency (strength) of the stimulus, under the action of which, instead of the expected increase in the response, its decrease occurs \*

34. REGULATORY PROTEINS OF MUSCLE TISSUE INCLUDE

1. actin, myosin
2. troponin, tropomyosin \*
3. troponin
4. tropomyosin
5. calmodulin

35. THERE ARE ACTIVE CENTERS

1. on thick myosin filaments
2. on thin actin filaments \*
3. on myosin and actin filaments

4) on the tropomyosin

36. MUSCLES PERFORM MAXIMUM WORK

* 1. at maximum loads
  2. at medium loads \*
  3. at minimum loads
  4. contracting without load

37. THE STRUCTURAL FORMATION THAT PROVIDES THE TRANSFER OF EXCITATION FROM THE NERVE CELL TO THE MUSCLE IS CALLED

* 1. nerve
  2. axon mound
  3. Ranvier interception
  4. nexus
  5. синапс\*

38. SET THE CORRECT SEQUENCE OF CHANGING THE MODE OF MUSCLE CONTRACTIONS WHEN THE FREQUENCY OF IRRITATION INCREASES

1. rough tetanus, smooth tetanus, single contraction
2. smooth tetanus, rough tetanus, single contraction
3. single contraction, rough tetanus, smooth tetanus \*
4. rough tetanus, single contraction, smooth tetanus
5. smooth tetanus, single contraction, rough tetanus

39. THE MEDIATOR IN SKELETAL MUSCLE SYNAPSES IS

1. epinephrine
2. norepinephrine
3. GABA
4. acetylcholine \*
5. glycine

40. SMOOTH MUSCLE CONTRACTION IS NOT REGULATED BY THE

1. sympathetic division of the autonomic nervous system
2. parasympathetic division of the autonomic nervous system
3. metasympathetic division of the autonomic nervous system
4. by the somatic nervous system \*
5. there is no correct answer

41. A CONTRACTION OF A MUSCLE IN WHICH BOTH ENDS OF IT ARE FIXED IS CALLED

1. isotonic
2. auxotonic
3. pessimal
4. isometric \*
5. optimal

42. THE SPECIALIZED CONTRACTILE APPARATUS OF THE STRIATED MUSCULATURE IS

1. the plasmolemma
2. sarcoplasma
3. myofibrillae \*
4. mitochondria

5) T-system

43. A PERSON IS CHARACTERIZED BY A … MODE OF MUSCLE CONTRACTIONS

1. sotonic
2. isometric
3. auxotonic \*
4. tetanic
5. single

44. THE AMOUNT OF CONJUNCTION OF ACTIN AND MYOSIN FILAMENTS IS

1. a value reflecting the degree of insertion of actin filaments between myosin \*
2. the value that reflects the degree of oxygen consumption by the muscles
3. the ratio of actin and myosin filaments
4. the ratio of actin filaments to the troponin complex

45. THE STRENGTH OF MUSCLE CONTRACTION DEPENDS ON THE DEGREE OF CONJUNCTION OF THIN AND THICK FILAMENTS

* 1. in direct proportion \*
  2. inversely proportional
  3. does not depend
  4. exponentially

46. MUSCLE CONTRACTION AS A RESULT OF STIMULATION BY A SERIES OF SUPER-THRESHOLD IMPULSES, EACH OF WHICH ACTS IN THE CONTRACTION PHASE OF THE PREVIOUS ONE, IS CALLED

1. a single contraction
2. rough tetanus
3. smooth tetanus \*
4. optimal tetanus
5. pessimal tetanus

47. THE MOTOR NEURON AND THE MUSCLE FIBERS INNERVATED BY IT ARE CALLED

1. the motor field of the muscle
2. the nerve center of the muscle
3. a motor unit \*
4. muscle sensory field
5. the generator of motor programs

48. THE RATIO OF ACTIN AND MYOSIN FILAMENTS TO EACH OTHER IS

* 1. 1:6
  2. 6:1\*
  3. 3:1
  4. 1:3

49 THE THIRD PHASE OF A SINGLE SKELETAL MUSCLE CONTRACTION IS CALLED

1) latent

2) the shortening phase

3) the relaxation phase \*

4) refractory

### 10. Case problems with keys

### 1. List the main physiological properties of skeletal muscles?

Correct answer: Excitability, conductivity, contractility.

1. What is called tetanus?

Correct answer: Strong and long lasting shortening of muscle that occurs in response to rhythmic stimulation is called tetanus

1. Which muscle tissue proteins play a major role in the contraction process?

Correct answer: Myosin and actin play a major role in the contraction process

1. What is fatigue?

Correct answer: A temporary decrease in the performance of a cell, organ, or whole organism that occurs as a result of work and disappears after rest is called fatigue

1. What muscle contraction is called isotonic?

Correct answer: A contraction in which the muscle fibers are shortened, but not their tension remains constant is called isotonic

1. What process results in tetanic contraction?

Correct answer: The sum of single muscle contractions leads to tetanic contractions.

1. Where is the smooth muscle located?

Correct answer: Smooth muscles are located in the internal organs and blood vessels of the skin.

1. Where does fatigue occur faster: in the muscle or in the neuromuscular junction?

Correct answer: Fatigue occurs faster in the neuromuscular junction

1. What muscle contraction is called isometric?

Correct answer: Contraction in which the length of the muscle fibers does not change, but the tension increases is called isometric.

1. Do the action potentials add up in tetanus?

Correct answer: The action potentials for tetanus do not add up

1. List the physiological properties of smooth muscles

Correct answer: Excitability, conductivity, contractility, plasticity, autonomy.

1. Interaction of what three components in the presence of which ion is necessary for muscle fiber contraction?

Correct answer: Actin, myosin, ATP, Ca++.

1. What is called smooth muscle plasticity?

Correct answer: The ability to maintain the length imparted by stretching without changing the tension is called smooth muscle plasticity.

1. What substance is the direct source of energy for muscle contraction?

Correct answer: ATP.

How does acetylcholine act on the postsynaptic membrane of the synapse?

Correct answer: Acetylcholine causes depolarization of the postsynaptic membrane by increasing the permeability of chemically excitable channels for Na and Ka.

1. List the elements of the synapse structure

Correct answer: 1 - synaptic cleft, 2 - postsynaptic membrane, 3 - presynaptic membrane.

1. What is called a single muscle contraction?

Muscle contraction in response to a single irritation is called a single muscular contraction

1. In what phase of muscle contraction should re-irritation occur in order to create a rogh tetanus?

Correct answer: To create the rogh tetanus repeated irritation should come into the relaxation phase

1. What form of contraction is characteristic of smooth muscles?

Correct answer: The tonic form of contraction is characteristic of smooth muscles

1. What phases of single muscle contraction are distinguished?

Correct answer: Latent period, shortening phase, relaxation phase.

1. To obtain which type of tetanus (smooth or serrated) is a relatively high frequency of stimulation necessary?

Correct answer: To obtain smooth tetanus a relatively high frequency of irritation is required.

1. How are smooth muscles innervated?

Correct answer: Smooth muscles are innervated by parasympathetic and sympathetic nerves

1. What does the thickening of the nerve fiber in the synapse contain?

Correct answer: Acetylcholine in the "bubbles" is contained in the thickening of the nerve fiber in the synapse

1. What is called the latency period?

Correct answer: The time from the onset of irritation to the appearance of a recorded response is called the latency period.

1. What phenomena develop in the muscle after tetanus?

Correct answer: Incomplete muscle relaxation – residual contracture.

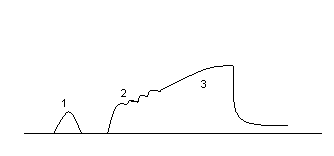
1. What is the contractile element in muscle fiber?

Correct answer: Myofibrils are a contractile element in muscle fiber

1. What is the duration of the shortening and relaxation phases of a single contraction of the frog's calf muscle?

Correct answer: about 0.05 sec.

1. Draw a single contraction,rough and smooth tetanus.

Correct answer:

1. НазоWhat are the elements of the" triad " of the conducting system of the striated muscle?

Correct answer: The system of transverse and longitudinal tubules and the sarcoplasmic reticulum.

1. What is called a motor unit?

Correct answer: A group of muscle fibers innervated by a single motor neuron

**Appendix No. 1 (for students of the Dental Faculty)**

**MUSCULATURE OF THE MAXILLO-FACIAL AREA.**

The muscles of the maxillary-facial region can be divided into:

1. masticatory;

2. mimic;

hey belong to the group of skeletal muscles and have the same physiological and physical properties and mechanisms as other skeletal muscles. The masticatory muscles belong to the power muscles, i.e. they develop mainly strength in contrast to other skeletal muscles, which develop mainly speed during contraction. The act of chewing involves the muscles that move the lower jaw relative to the upper one. The strength of the chewing pressure depends on the degree of contraction of these muscles, and, therefore, the ability of the teeth to bite off and grind the food lump to the required degree of grinding.

ABSOLUTE STRENGTH OF THE CHEWING MUSCLES.

The tension developed by the muscle at maximum contraction is called absolute muscle force. Its value is calculated by multiplying the physiological cross-sectional area of the muscle by its specific force. A muscle with a cross section of 1 cm 2 can develop, with its contraction, a force of 10 kg

Cross section m. temporalis is 8 cm 2., т. massetor is 7.5. cm. 2, т. pterugoideus mediolis is 4 cm. 2. The sum of the cross-section of the masticatory muscles that lift the lower jaw on one side of the face is 19,5 cm 2 , and on both sides is 39 cm 2 . The absolute muscle strength that lifts the lower jaw on one side is 195 kg, and for all muscles - 390 kg. - but that's in theory. In fact, the total strength will be less, i.e. the muscles go at a certain angle to each other.

CHEWING PRESSURE.

In addition to the absolute strength of the muscles that lift the lower jaw, chewing pressure is also distinguished. Chewing pressure is the force developed by the muscles under the lower jaw when acting on a certain surface. The absolute muscle strength for a given subject is characterized by a certain value. The chewing pressure with the same effort of the muscles lifting the lower jaw will be different on the molars and front teeth. This is due to the fact that the lower jaw is a lever of the second kind with the center of rotation in the joint. Along with the large value of the absolute strength of the masticatory muscles there is a small periodontal endurance of individual teeth. Therefore, with increased closing of the jaws, pain occurs in the periodontium and there is a reflex cessation of further increase in pressure, although the muscle strength has not yet been exhausted.

GNATODYNAMOMETRY.

In practice, it is important to know the effort that the muscle develops to break up a particular food. The nature of the effort depends on the place where the food is crushed, its consistency. Researcher Black created an apparatus - a gnatodynamometer.

A gnatodynamometer is an apparatus that allows you to measure the force of pressure in certain units. The determination is carried out by squeezing the cheeks of the gnatodynamometer with teeth. When closing the mouth through these plates, the teeth transmit a certain pressure to the spring, which is recorded on the scale.

According to Eckerlean: for women - 20 - 30 kg on incisors; teeth of a teenager - 40 - 60 kg. In men - on incisors 10 - 25 kg; wisdom teeth - 50 - 80 kg.

From the presented data, it can be seen that the chewing pressure is different in different parts of the dental arch and is uneven and is not the same. This phenomenon can be explained by the following reasons:

1. The presence of a second kind of lever;

2. The chewing pressure developed in any area does not exhaust the strength of the muscles, but means the limit of the tooth's endurance, age, and the degree of training of the periodontium.

It is noted that the masticatory pressure for molars = 77 kg. it is not an indicator of all muscle strength, but is the limit that the periodontal can endure. The sensation of pain stops further muscle contraction.

In experiments with the periodontal sensitivity turned off, the pressure increases almost twice.

GALVANIC PHENOMENA IN THE ORAL CAVITY.

In orthopedic dentistry, metal-based prosthesis designs are widely used - alloys of gold, platinum, special grades of stainless steel, cobalt-nichrome alloys, silver, and amalgam. The presence in the oral cavity of prostheses or fillings made of various metals or their alloys leads to the formation of galvanic elements.

There are unpleasant sensations and pathological changes in the tissue of the oral cavity are noted, and sometimes disturbances from some organs and systems of the body. Most frequent:

80% - constant burning of the oral mucosa with different localization.

70% - a metallic and sour taste appears after 3-5 months.

58% - disorders of salivation.

47% - headache.

19% - insomnia.

8% - pain in the abdomen.

3% - vomiting.

As a rule, several symptoms often cannot be defined specifically and a feeling of discomfort is expressed.

APPLICATION OF ELECTROMYOGRAPHY FOR

FUNCTIONAL RESEARCH OF MASTICATORY

MUSCLES.

Electromyography (EMG) is a method for examining the locomotor apparatus based on recording the biopotentials of skeletal muscles. EMG is used in surgical and orthopedic dentistry, orthodontics, stomatoneuralgia as a functional and diagnostic method for studying the functions of the peripheral neuromotor apparatus and evaluating the coordination of the muscles of the maxillofacial region during and in intensity, in normal and pathological conditions - in injuries and inflammatory diseases of the maxillofacial region, malocclusion, myoplastic operations, dystrophy and hypertrophy of the masticatory muscles, in cleft soft palate and other diseases. EMG is based on the registration of action potentials of muscle fibers that function as part of motor units (MU). MU consists of a motor neuron and a group of muscle fibers innervated by this motor neuron.

The number of muscle fibers innevated by a single motor neuron varies in different muscles В жевательных мышцах на один мотонейрон приходится 100 мышечных волокон, в височной – 200. In mimic muscles, MU are smaller, they include up to 20 muscle fibers. In small facial muscles, this ratio is even smaller, thus providing a high level of differentiation of muscle fiber contractions that cause a wide range of facial expressions.

At rest, the muscle does not generate action potentials, so the EMG of a relaxed muscle has the form of a pro-electric line. The action potential of an individual MU when registering with a needle electrode usually has the form of 2-3 phase oscillations with an amplitude of 100 - 3000 μV. and a duration of 8 - 10 ms. On EMG, an increase in the number of operating MU is reflected in an increase in the frequency and amplitude of vibrations as a result of temporal and spatial summation of the action potentials of MU. EMG reflects the degree of motor innervation indirectly indicates the intensity of contraction of an individual muscle and gives an accurate idea of the temporal characteristics of these processes.

There are three main types of electromyography:

1. Interference EMG (synonyms - superficial, total, global) is carried out by means of biopotential abstraction of muscles, applying electrodes to the skin, the lead area is large.

2. Local EMG -recording of individual MU activity is performed using needle electrodes.

3. Stimulating EMGs - record the electrical response of muscles to stimulation of the nerve that innervates this muscle

EQUIPMENT AND ELECTRODES.

Electromyography with a frequency range from 20 to 200 Hz. In orthopedic dentistry and orthodontics, for registration of surface EMG, it is possible to simultaneously record EMG of a larger number of muscles than on an electromyograph.

RECORDING ELECTRODES for surface EMG can be made of steel, silver, tin, brass and other metals in the form of two plates or cups with an area of 1 to 50 mm2. The distance between the two superimposed electrodes should always be 'constant' (from 10 to 20 mm. ) the most accepted distance is 15 mm. To maintain a constant distance between the electrodes for chewing muscles, they are fixed in a frame made of organic glass of fast-hardening plastic. When studying facial muscles, the electrodes are glued with a special glue to a strip of cotton fabric, which is fixed on the surface with a band-aid or elastic rubber band. For the muscles of the tongue and lips, electrodes are used in the form of a metal ring with a rubber suction cup. EMG of deep-lying muscles (for example, external and internal pterygoid) is recorded using needle electrodes. Since the EMG parameters depend significantly on the methodological conditions -the interelectrode distance, the degree of pressing of the electrodes to the skin, and the location of the electrodes-during repeated studies, the electrodes are superimposed on those points whose coordinates are marked on the face diagram in the survey map. EMG is used in therapeutic, orthopedic surgical dentistry, orthodontics and somatoneurology. NOTE: In therapeutic dentistry, an EMG is performed for paradontosis to register changes in the regulation of the force of contractions of the masticatory muscles, since these diseases cause functional and dynamic disorders of the masticatory apparatus. EMG is performed in combination with gnatodynamometric tests, which allow us to compare the intensity of muscle excitation with their power effect.

In surgical dentistry, all three methods of EMG are used for surgical interventions. Surface EMG is used for fractures of the jaws, inflammatory processes of the maxillofacial region (phlegmons, abscesses, periostitis, and osteomyelitis) during myoplastic operations for persistent paralysis of facial muscles, tongue. In case of jaw injuries, EMG is used for objective assessment of the degree of violation of the functions of the masticatory muscles, as well as for monitoring the duration of rehabilitation of patients. Fractures of the jaws lead to a significant decrease in the bioelectric activity of the masticatory muscles (especially in double fractures of the lower jaw angle) and the appearance of tonic activity at rest in the temporal muscles, which persists for a long time.

In inflammatory processes of the maxillofacial region, there is a significant decrease in bioelectric activity on the side of the lesion. The reasons for the decrease in bioelectrical activity in the masticatory muscles in these cases are obviously reflex (painful) limitation of muscle contraction and impaired conduction of nerve impulses due to tissue edema.

In myoplastic operations for persistent paralysis of the facial muscles and tongue, EMG is used to determine (before the operation) the fullness of the innervation of the transplanted muscle and the restoration of its functions after the operation. Electro-myographic communication in these cases can serve as a means of stimulating the restoration of the transplanted muscle functions.

In stomatoneurology, local EMG is used for objective detection of signs of muscle denervation and early signs of muscle reinnervation in the case of traumatic and infectious injuries to the nerves of the maxillofacial region containing motor fibers.

IN ORTHOPEDIC DENTISTRY-EMG

is used to study the bioelectric activity of the masticatory muscles in the complete absence of teeth and in the process of adaptation to complete removable dentures. Prosthetics with complete removable prostheses leads to an increase in the bioelectric activity of the masticatory muscles during chewing with the prostheses and after they are removed. In the process of adaptation to full removable prostheses, the entire chewing period is shortened by reducing the number of chewing movements and the time of one chewing movement.

IN CHILDREN'S STOMATOLOGY - interference EMG is used to control the restructuring of the coordination relationships of the temporal and masticatory muscles in the treatment of malocclusion, reveals the participation of muscles in some natural acts, for example: swallowing.

Local EMG is performed to study the bioelectric activity of the soft palate muscles in children with normal and damaged developmental abnormalities. After surgical elimination of clefts of the soft palate, EMG is used to determine the prognosis of the possibility of speech restoration and t o control during muscle training using a special set of myogymnastic exercises.

**Course textbooks and manuals**

1. Dunn, R. B. USMLE Step 1. Lecture Notes. Physiology / R. B. Dunn ; ed. D. E. Fitzovich. - [S. l.] : Kaplan, 2006. - 576 p.

2. Hall, J. E. Guyton and Hall Textbook of Medical Physiology / J. E. Hall. - 13th ed., Int. ed. - Philadelphia : Elsevier, 2016. - 1145 p.

3. Silbernagl, S. Color Atlas of Phisiology / S. Silbernagl, A. Despopoulos. - 7th ed. - Stuttgart : Thieme, 2015. - 458 p.