SAMARKAND STATE
MEDICAL UNIVERSITY

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# FUNCTIONAL ANATOMY OF HUMAN SKELETAL MUSCLES

TEXTBOOK

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# Functional anatomy of human skeletal muscles

*(Textbook)*

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The textbook is intended for first-year students at medical universities who are deeply engaged in the discipline "Normal Human Anatomy". The manual is a supplement to the main educational literature

**Annotation**

This manual is intended for students of higher medical educational institutions of medical, pediatric and professional (medical) orientation, since the functional anatomy of the skeletal muscles of the system in teaching medical biological sciences remains an urgent problem of fundamental science. The guide is intended to provide the necessary knowledge and skills to illuminate the functional anatomy of the skeletal muscle system. The manual contains materials necessary to improve the implementation of educational programs in the training of qualified specialists. The manual is illustrated by diagrams, tables.

This tutorial will help make the process of teaching and teaching the functional anatomy of the skeletal muscle system among life sciences more effective, useful and interesting for both faculty and students.

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# PREFACE

When studying the anatomy of the human musculoskeletal system, one of the most complex and important topics is "Anatomy of Skeletal Muscles". Students' understanding of its fundamental and applied aspects makes it possible to combine previously studied topics on the anatomy of the skeleton and its connections.

Think about what you do every day – talking, walking, sitting, standing, running – all of these activities require the movement of certain skeletal muscles. Skeletal muscles are involved even during sleep. The diaphragm is skeletal muscle that needs to contract and relax so that you can breathe day and night.

The focus of this manual is on the organization of skeletal muscle. The naming system of skeletal muscle will be explained; in some cases, a muscle is called by its shape, and in others by its location or attachment to the skeleton. If you understand the meaning of a muscle's name, it will help you remember its location and/or what it does. In this tutorial, we will describe the general anatomy of the muscular system and consider the functional relationship between the muscles and bones of the body. We want to emphasize that it will not be able to replace the main educational literature, such as atlases and textbooks.

We hope that it will not only facilitate the study of human anatomy by students but will also contribute to the development of their professional medical competencies and skills: to understand the structural features of the musculoskeletal system, to determine its individual elements, features of their relief and location, and also to correctly describe their name, using modern terms.

We hope that this book will be useful not only to first-year students, on whom it is focused to a greater extent, but also to senior students, residents and doctors.

# GENERAL FUNCTIONAL ANATOMY OF THE MUSCULAR SYSTEM

**After completing this chapter, you will be able to:**

1 Describe the structural and functional differences in skeletal, cardiac, and smooth muscle tissue

2 Describe the structure and function of skeletal muscle fibers

3 Explain the processes associated with the onset of muscle contraction and relaxation

4 Explain how the nervous system can regulate force generation in skeletal muscle

5 Describe the types of skeletal muscle fibers

6 Explain the link between exercise and muscle function

7 Understand the structure and function of smooth muscle tissue

8 Explain the process of development and regeneration of muscle tissue

When most people think of muscles, they think of muscles that are visible under the skin, especially on the limbs. These are skeletal muscles, so named because most of them drive the skeleton. But there are two more types of muscles in the body that perform completely different tasks. The heart muscle, located in the heart, is responsible for pumping blood through the circulatory system. Smooth muscles are responsible for various involuntary movements, for example, for making hair stand on end from cold or fear, or for moving food through the digestive system. In this chapter, we will look at the structure and function of these three types of muscles.

## OVERVIEW OF MUSCLE TISSUE

Muscle is one of the four main types of body tissues (along with epithelial, nerve, and connective tissues), and there are three types of muscle tissue in the body: skeletal muscle, heart muscle, and smooth muscle (Fig. 1). All three muscle tissues share some common properties; they all have a quality called excitability because their plasma membranes can change their electrical state (from polarized to depolarized) and send an electrical wave, called an action potential, along the entire length of the membrane.

Although the nervous system can to some extent affect the excitability of the heart and smooth muscles, the skeletal muscles are completely dependent on the signals coming from it. On the other hand, both heart muscle and smooth muscles can respond to other stimuli, such as hormones and local stimuli.

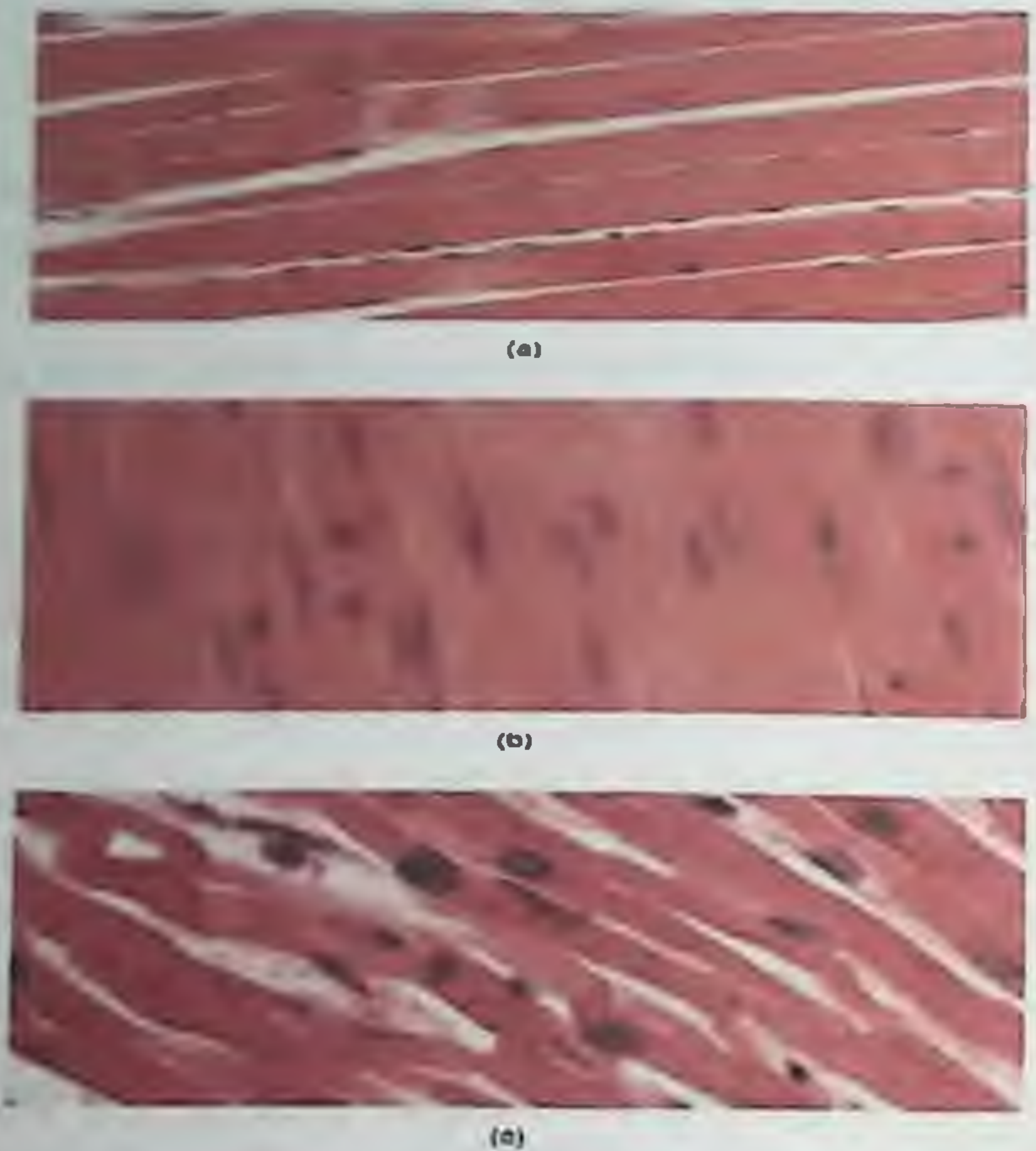


**Figure. 1** *Three types of muscle tissue: The body contains three types of muscle tissue: (a) skeletal muscle, (b) smooth muscle, and (c) heart muscle.*

A unique property common to all three types of muscle tissue is contractility, that is, the ability of cells to contract (change their linear characteristics) and generate strength. Although muscle tissue can shorten when contracted, it also has extensibility, or the ability to lengthen and extend beyond the resting length of cells. After stretching, the elasticity of the muscle allows it to return to its original length.

All muscles begin a mechanical process of contraction (shortening) when a protein called actin is stretched by a protein called myosin, with differences in the microscopic organization of these contractile proteins existing between the three types of muscle tissue. In skeletal and cardiac muscles in the cytoplasm of individual muscle cells, the proteins actin and myosin are located very often, which creates an alternating light and dark striped pattern, creating a kind of striping. These bands are visible in a light microscope at high magnification (see Figure 2, A).

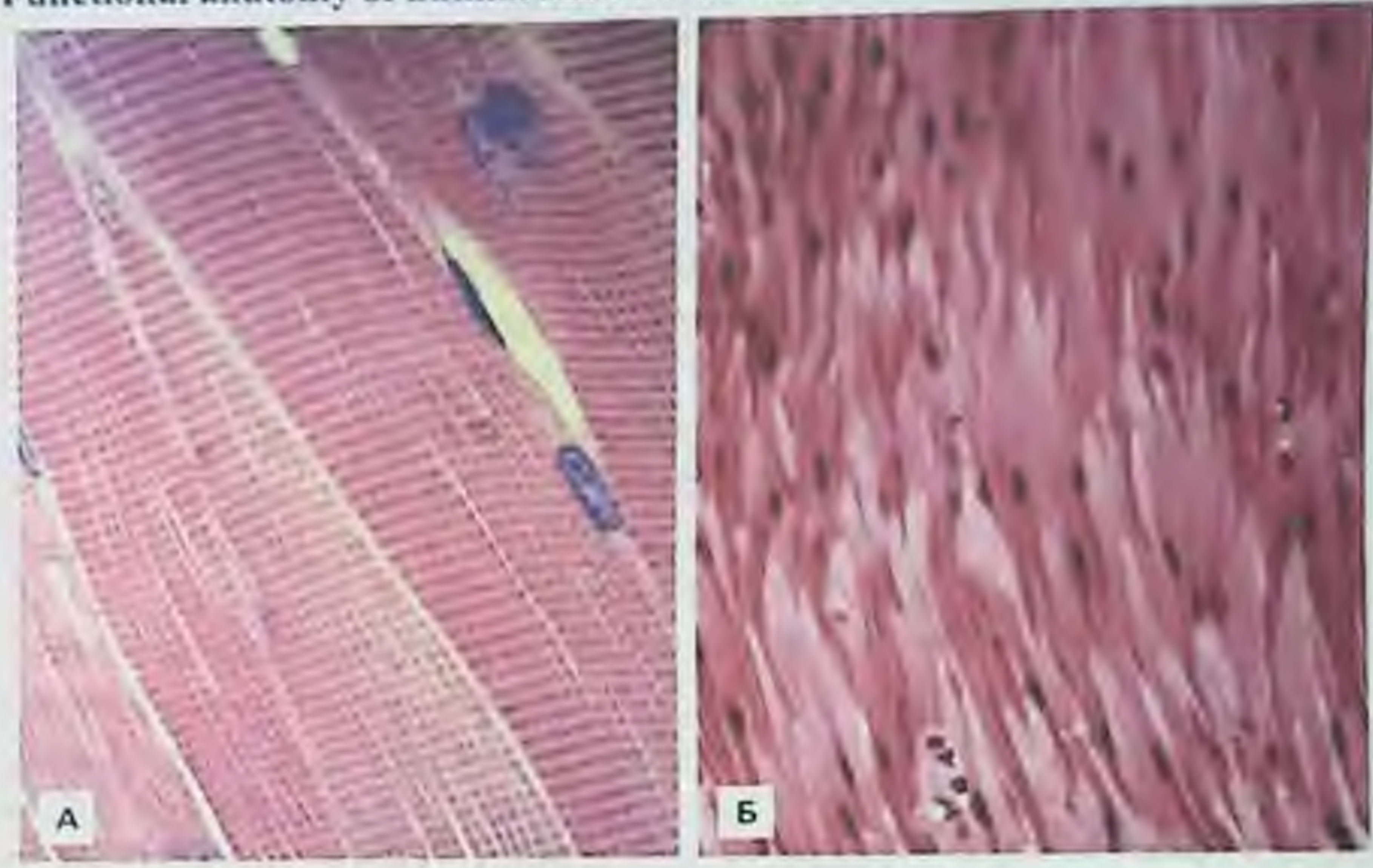


Figure 2. *Striated (A) smooth (B) muscle under a microscope. The presence of a pronounced striped pattern of skeletal muscles is well visualized.*

Smooth muscle (so named for the absence of stripes) does not have such a striped pattern, since contractile proteins are not so regularly located in it (see Fig. 2, B). Skeletal muscle cells (also called muscle fibers) are unique in that they are multinucleated, and the nuclei are located on the periphery of the cell under the cell's plasma membrane (in muscle, it is called sarcolemma).

During early development, embryonic myoblasts, each with its own nucleus, fuse with hundreds of other myoblasts to form long, multinucleated skeletal muscle fibers. Heart muscle cells usually have one nucleus located in the center of the cell, but the cells are physically and electrically connected to each other so that contraction signals travel through the cells and the entire heart contracts as a unit. Smooth muscle cells contain a single nucleus and can exist as electrically connected units contracting together as a unit, or as multi-component smooth muscle where the cells are not electrically connected.

## MUSCLE FUNCTION

The most well-known feature of skeletal muscle is its ability to contract and provide movement. It should be understood that skeletal muscles act not only to produce movement, but also to stop movement, for example, resist gravity to maintain posture. To maintain an upright body position or balance in any position, small, constant movements of skeletal muscles are necessary.

Muscles also prevent excessive movement of bones and joints, maintaining the stability of the skeleton and preventing damage or deformation of the skeletal structure. Skeletal muscles are located throughout the body at the openings of the internal pathways (sphincters: upper esophageal, urethra and passage). Thanks to these muscles, functions such as swallowing, urination, and defecation are under voluntary control. Skeletal muscle also protects internal organs (especially the abdominal and pelvic organs) by acting as an external barrier or shield against external injuries and maintaining organ weight.

Skeletal muscle contributes to the maintenance of homeostasis in the body, producing heat. Muscle contraction requires energy, and heat is released when ATP is broken down. This heat is very noticeable during physical exertion, when the constant movement of the muscles causes an increase in body temperature, as well as in severe cold, when trembling causes erratic muscle contractions to produce heat.

The heart muscle is located only in the heart and performs the function of creating a force and pressure gradient for the movement of blood throughout the body.

Smooth muscle in the walls of the arteries is an essential component that regulates blood pressure and blood flow in the circulatory system. Smooth muscles of the skin, internal organs, and internal passageways are also needed to move food lumps and intestinal contents through the digestive tract.

***Chapter Overview***

Muscles are built from a kind of tissue that provides active movement of the body in space or materials inside the body. There are three types of muscle tissue: skeletal muscle, heart muscle, and smooth muscle. Most of the skeletal muscles of the body produce movement by acting on the skeleton. The heart muscle is located in the wall of the heart and pumps blood through the circulatory system. Smooth muscles are found in the skin, where they are associated with hair follicles; they are also found in the walls of internal organs, blood vessels, and internal passageways, where they help move materials.

***Self-Assessment Questions***

1. Why is elasticity an important quality of muscle tissue?
2. What are the main functions of skeletal muscle?

***Glossary***

*The heart muscle* is a striated muscle located in the heart; it is under the control of cardio stimulating cells, which contract as a whole, pumping blood through the circulatory system. The heart muscle is under involuntary control.

*contractility* - the ability to contract (contract) with force

*elasticity* - the ability to stretch and restore its original length

*excitability* - the ability to be subjected to neural stimulation

*extensibility* - the ability to lengthen (stretch)

*skeletal muscle* – a multinucleated muscle that requires a signal from the central nervous system for its contraction; most skeletal muscle refers to voluntary muscles that are connected to the bones and perform movement

*smooth muscle* -, mononuclear muscle, helps to move the contents of internal organs, is not regulated by the cerebral cortex, refers to involuntary muscles.

***Answers to questions***

1. Allows the muscle to return to its original length during relaxation after contraction.

2. Provide skeletal movement, maintain posture and body position, support soft tissues, surround the openings of the digestive, urinary and other tracts, and maintain body temperature.

## SKELETAL MUSCLES

**After completing this chapter, you will be able to**:

Describe the layers of connective tissue surrounding skeletal muscle

Define muscle fiber, myofibril and sarcomere

List the main sarcomeric proteins involved in muscle contraction

Determine the areas of the sarcomere and whether they change during contraction

Explain the process of muscle contraction with the help of filaments

Each skeletal muscle is an organ made up of various integrated tissues. These tissues include skeletal muscle fibers, blood vessels, nerve fibers, and connective tissue. Each skeletal muscle has three layers of connective tissue that surround it, provide muscle structure, and distribute muscle fibers within the muscle (Fig. 3).


**Figure 3.** *Three layers of connective tissue: Groups of muscle fibers called bundles are covered with perimysium. Muscle fibers are coated with endomysium.*

Each muscle is covered with a sheath of dense fibrous connective tissue called an epimysium, which allows the muscle to contract and move with great force while maintaining its structural integrity. The epimysium also separates the muscle from other tissues and organs in this area, allowing it to move on its own.

Inside each skeletal muscle, muscle fibers are organized into bundles called bundles, surrounded by a middle layer of connective tissue called perimysium. Such a bundle organization is characteristic of the muscles of the limbs; it allows the nervous system to induce a certain muscle movement by activating many muscle fibers inside the muscle bundle. Inside each bundle, each individual muscle fiber is encased in a thin connective tissue layer of collagen and reticular fibers called endomysium. Endomysium surrounds the extracellular matrix of cells and plays a role in the transfer of force produced by muscle fibers to tendons.

In skeletal muscle, which works with tendons to pull bones, collagen in three layers of connective tissue is intertwined with tendon collagen. At the other end of the tendon, it fuses with the periosteum covering the bone. The tension that occurs during the contraction of muscle fibers is transmitted through the connective tissue layers to the tendon, and then to the periosteum, in order to, acting on the bone, perform the movement of the skeleton. Elsewhere, muscle layers may fuse with a broad, tendon-like leaf called an aponeurosis, or with fascia, the connective tissue between skin and bones. An example of an aponeurosis is a wide layer of connective tissue in the lower back into which the muscles of latissimus dorsi fuse.

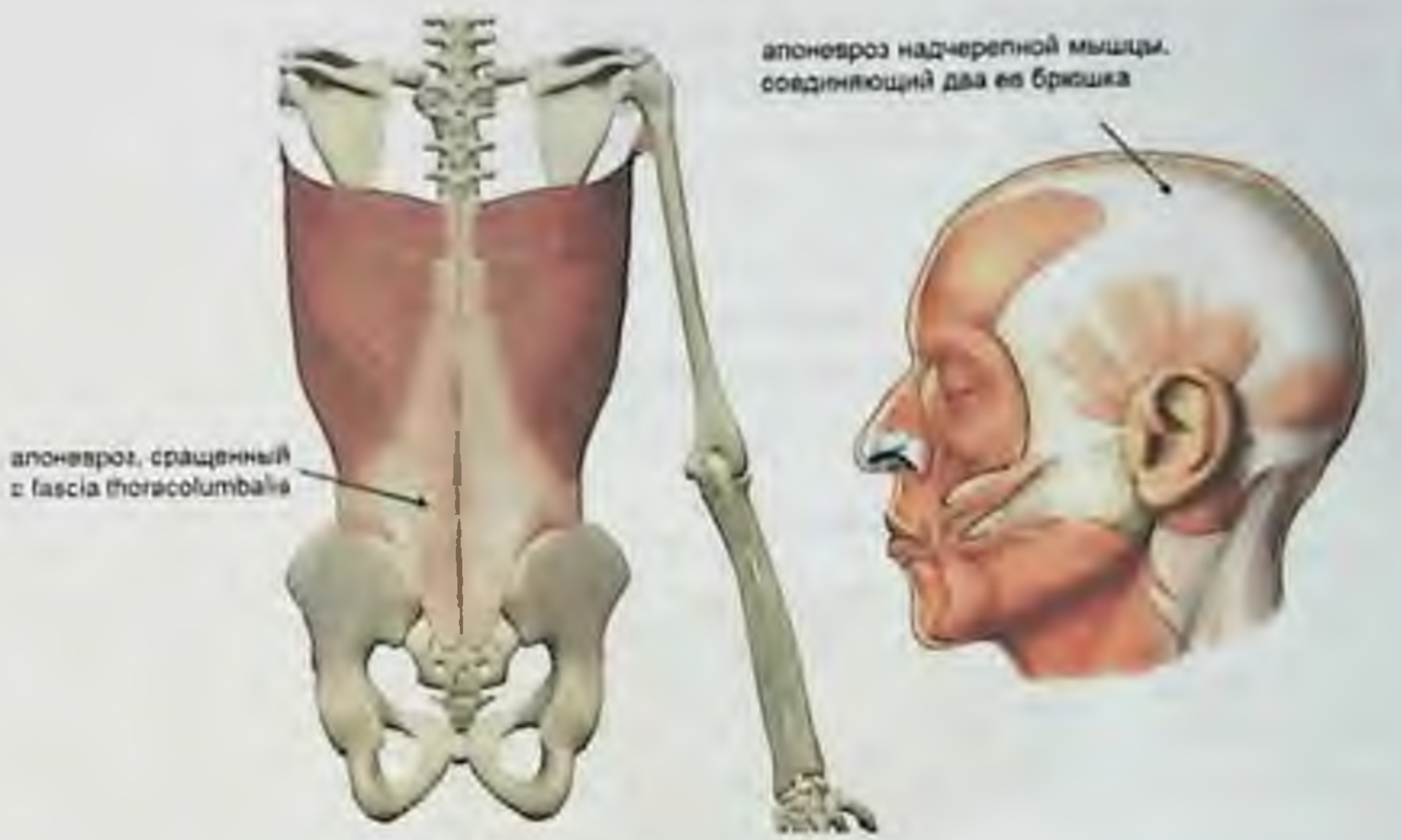



**Fig.4.** *Location of tendon aponeurosis of the latissimus muscle of the back and supracranial muscle (explanation - in the text)*

Each skeletal muscle is also richly supplied with blood vessels for nutrition, oxygen delivery, and waste removal. In addition, each muscle fiber of skeletal muscle is supplied by an axon process of a somatic motor neuron, which signals the fiber to contract. Unlike heart and smooth muscle, the only way skeletal muscle functionally contracts is through a signal from the central nervous system.

**Skeletal muscle fibers**

Since skeletal muscle cells are long and cylindrical, they are called muscle fibers (or myofibrils). Skeletal muscle fibers can be quite large compared to other cells, their diameter can reach 100 μm, and length - up to 30 cm, for example, in tailor muscle, m. The presence of a large number of nuclei allows the production of large numbers of proteins and enzymes necessary to maintain the normal function of these large cells. In addition to the nuclei, skeletal muscle fibers also contain cellular organelles found in other cells, such as mitochondria and endoplasmic reticulum.

However, in muscle fibers, some of these structures are specialized. A specialized smooth endoplasmic reticulum called the sarcoplasmic reticulum (CP) accumulates, releases, and retrieves calcium ions (Ca++).

The plasma membrane of muscle fibers is called sarcolemma (from the Greek sarco, meaning "flesh"), and the cytoplasm is called sarcoplasm (Fig. 5). Inside the muscle fiber, proteins are organized into structures called myofibrils, which stretch along the entire length of the cell and contain series-connected sarcomeres. Since the diameter of myofibrils is only about 1.2 μm, hundreds to thousands (each with thousands of sarcomeres) can be found in a single muscle fiber. The sarcomere is the smallest functional unit of skeletal muscle fiber and is a highly organized structure of contractile, regulatory, and structural proteins. It is the shortening of these individual sarcomeres that leads to the contraction of individual skeletal muscle fibers (and eventually the entire muscle).

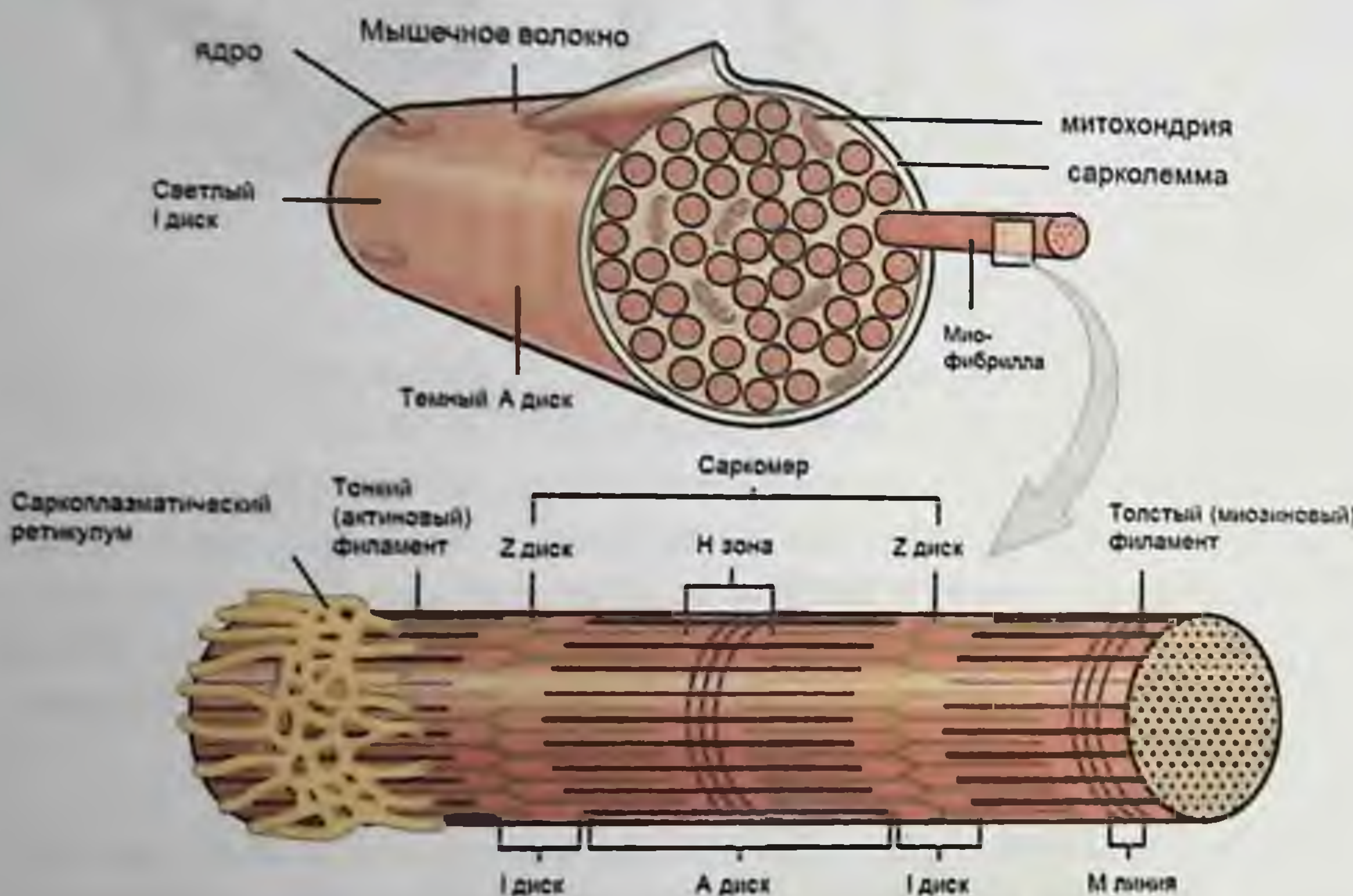



**Figure 5.** *Muscle fiber: The skeletal muscle fiber is surrounded by a plasma membrane called the sarcolemma, which contains sarcoplasm, the cytoplasm of muscle cells. The muscle fiber is made up of many myofibrils that contain sarcomeres with light and dark areas giving the cell a striped appearance.*

**Sarcomere**

A sarcomere is defined as a region of myofibril located between two cytoskeletal structures called Z-discs (also called Z-lines). The striped appearance of skeletal muscle fibers is due to the arrangement of thick and thin myofilaments inside each sarcomere. The dark band A consists of thick filaments containing myosin that run through the center of the sarcomere, extending to the Z-discs. Thick filaments are fixed in the middle of the sarcomere (M-line) by the protein myomesin. The lighter regions of the I band contain thin actin filaments fixed to the Z-disks by the protein α-actinin. Thin filaments extend into band A towards line M and overlap with areas of thick filaments. Band A is dark due to thicker filaments of myosin, as well as due to overlap with actin filaments. The H zone in the middle of band A is slightly lighter because the thin filaments do not extend to this area.

Since the sarcomere is defined by Z-disks, one sarcomere contains one dark band A with half a lighter band I at each end (Fig. 5). During contraction, the myofilaments themselves do not change length, but actually slide over each other, so the distance between the Z-discs is reduced. The length of band A does not change (the thick filament of myosin remains a constant length), but the areas of zone H and band I are reduced. These areas are areas where the filaments do not overlap, and as the overlap of the filaments increases during contraction, these areas do not overlap.

**Components of myofilaments**

The thin filaments consist of two filamentous actin chains (F-actin) consisting of individual actin proteins (Figure 10.2.3). These thin filaments are fixed to the Z-disc and extend to the center of the sarcomere. Inside the filament, each globular monomer of actin (G-actin) contains a myosin binding site and is also bound to regulatory proteins, troponin, and tropomyosin. The troponin protein complex consists of three polypeptides. Troponin I (TnI) binds to actin, troponin T (TnT) binds to tropomyosin, and troponin C (TnC) binds to calcium ions. Troponin and tropomyosin move along the actin filaments and control when actin binding sites are open to bind to myosin.

Thick myofilaments are composed of myosin protein complexes, which consist of six proteins: two heavy chains of myosin and four molecules of light chains. Heavy chains consist of a tail section, a flexible articulated part, and a globular head that contains an actin binding site and a binding site for the high-energy ATP molecule. Light chains play a regulatory role in the hinge area, but the head of a heavy chain interacts with actin and is the most important factor for creating force. Hundreds of myosin proteins are located in each thick filament: the tails are directed to the M-line, and the heads to the Z-disks.

Other structural proteins are related to the sarcomere but do not play a direct role in active force production. Titine, which is the largest known protein, helps align the thick filament and adds an elastic element to the sarcomere. Titin is fixed on the M-line, runs along the entire length of the myosin and extends to the Z-disk. Thin filaments also have a stabilizing protein called nebulin, which extends along the entire length of the thick filaments.

**Sliding model of filaments of contraction**

The arrangement and interaction between thin and thick threads allows the sarcomeres to be shortened, which creates muscle strength. At the signal of a motor neuron, skeletal muscle fiber contracts as thin filaments stretch and slide past thick filaments inside the sarcomeres of the muscle fiber. It is important to note that when the sarcomere is shortened, the individual proteins and filaments do not change length, but simply slide next to each other. This process is known as the filament sliding model (Fig. 6).

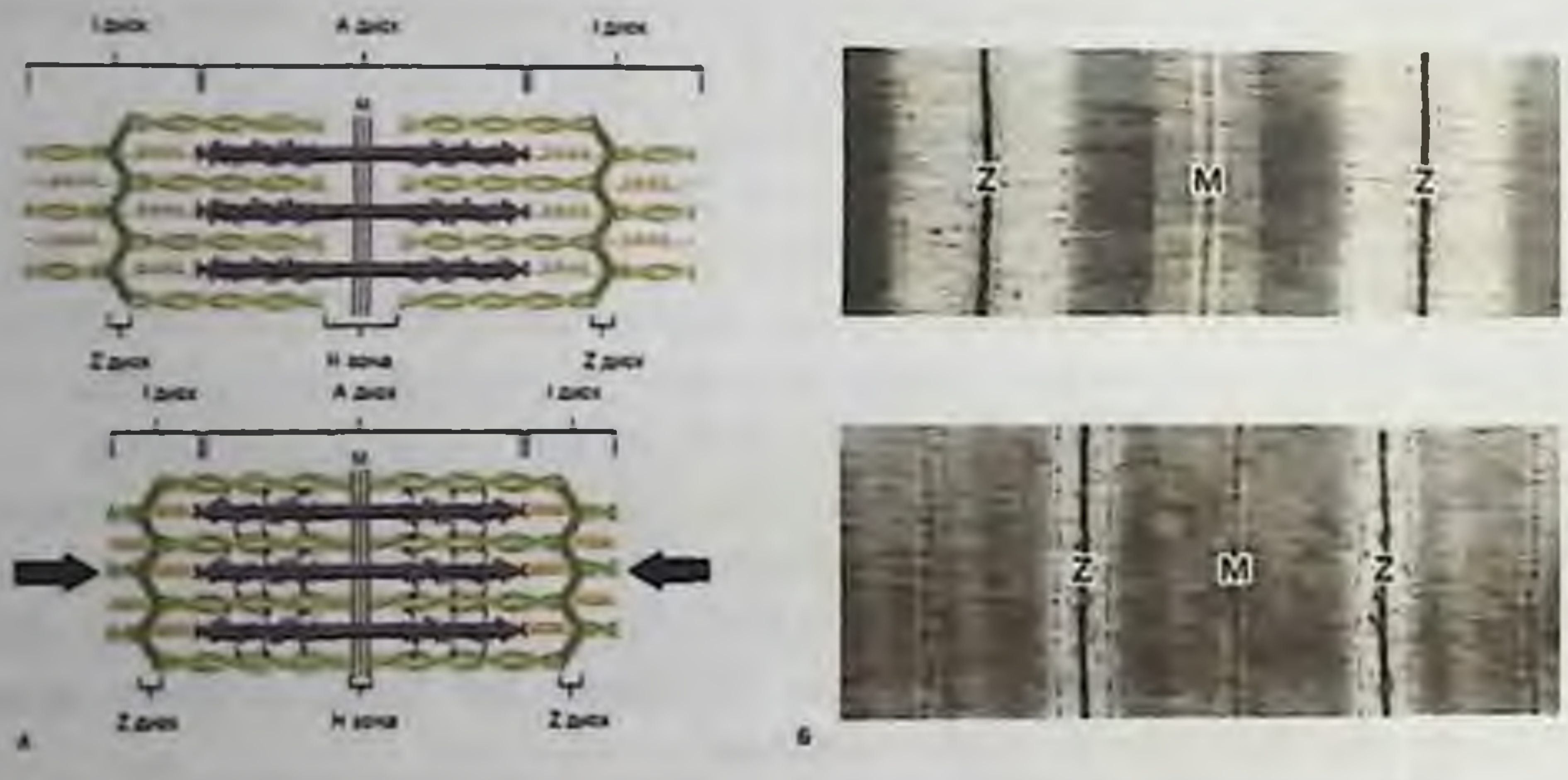



**Figure 6.** - *Filament sliding model. A – scheme; B - Microphotography: When the sarcomere shrinks, the Z disks shift closer together and Disk I become smaller. Disk A remains the same width. When fully reduced, thin and thick threads overlap.*

The process of filament sliding during contraction can only occur when myosin-binding sites on the actin filaments open as a result of a series of steps that begin with the entry of Ca++ into the sarcoplasm. Tropomyosin is wound on chains of actin filaments and closes the myosin-binding sites to prevent actin from binding to myosin. The troponin-tropomyosin complex uses the binding of calcium ions to TnC to regulate the moment when the heads of myosin form cross-bridges with actin filaments. The formation of transverse bridges and the expansion of filaments occur in the presence of calcium, and the signaling process leading to the release of calcium and muscle contraction is known as the conjugation of excitation and contraction.

***Chapter Overview***

Skeletal muscle contains connective tissue, blood vessels, and nerves. There are three layers of connective tissue: epimysium, perimysium, and endomysia. Skeletal muscle fibers are organized into groups called bundles. Blood vessels and nerves enter the connective tissue surrounding the fiber bundles and branch out in the cells. Muscles are attached to the bones directly or through tendons or aponeurosis. Skeletal muscles maintain posture, stabilize bones and joints, control internal movements and generate heat.

Skeletal muscle fibers are long, multinucleated cells. Cell membrane - sarcolemma; the cytoplasm of the cell is sarcoplasm. The sarcoplasmic reticulum is a type of endoplasmic reticulum. Muscle fibers consist of myofibrils, which consist of series-connected sarcomeres. Striping of skeletal muscles is created due to the organization of actin and myosin filaments, which leads to the appearance of a banded pattern of myofibrils. These actin and myosin filaments slide over each other, causing the sarcomeres to shorten, and the cells produce strength.

***Questions for self-control***

1. What happens to skeletal muscle if the epimysium is destroyed?
2. Describe how tendons promote body movement.
3. What causes the striped appearance of skeletal muscle tissue?

***Glossary***

*acetylcholine* is a neurotransmitter that binds in the end plate of the motor apparatus and causes depolarization

*Actin* is the protein that makes up most of the thin myofilaments in the sarcomere of muscle fiber.

*action potential* - a change in the tension of the cell membrane in response to a stimulus, which leads to the transmission of an electrical signal, characteristic only of neurons and muscle fibers.

*aponeurosis* is a broad, tendon-like leaflet of connective tissue that attaches skeletal muscle to another skeletal muscle or to bone.

*depolarize* – reduce the voltage difference between the inner and outer sides of the cell's plasma membrane (muscle fiber sarcolemma), making the inside less negative than at rest.

*endomysium* – loose and well-moistened connective tissue covering every muscle fiber in skeletal muscle

*epimysium* – the outer layer of connective tissue around skeletal muscle

excitation and contraction link – a sequence of events from the motor neuron signal to the skeletal muscle fiber to the contraction of the fiber's sarcomeres.

*bundle* - a bundle of muscle fibers inside skeletal muscle

motor terminal plate - sarcolemma of a muscle fiber in a neuromuscular junction containing receptors for the neurotransmitter acetylcholine

*myofibril* is a long, cylindrical organelle running parallel inside a muscle fiber and containing sarcomeres

*myosin* is a protein that makes up most of the thick cylindrical myofilament in the sarcomere of muscle fiber

*neuromuscular junction* is a synapse between the terminal of the axon of a motor neuron and a section of the membrane of a muscle fiber with receptors for acetylcholine secreted by the terminal.

*Neurotransmitter* is a signaling chemical secreted by nerve terminals that binds to receptors on target cells and activates them.

*perimysium* – connective tissue that binds skeletal muscle fibers into bundles within skeletal muscle

Sarcomeres, a longitudinally repetitive functional unit of skeletal muscle containing all the contractile and related proteins involved in contraction

*sarcolemma* - plasma membrane of skeletal muscle fiber

*sarcoplasm* - cytoplasm of a muscle cell

*sarcoplasmic reticulum* – specialized smooth endoplasmic reticulum that accumulates, releases and extracts $Ca^{++}$

*synaptic cleft* - the space between the nerve (axon) terminal and the motor terminal plate

*T-tubule* - projection of sarcolemma into the inside of the cell

*thick filament* - thick filaments of myosin and their numerous heads protruding from the center of the sarcomere in the direction of the Z-disks, but not completely *thin filament* - thin filaments of actin and its troponin-tropomyosin complex, protruding from the Z-disks to the center of the sarcomere

*triad* - a group of one T-tube and two terminal tanks

- *troponin* - a regulatory protein that binds to actin, tropomyosin, and calcium

- *tropomyosin* - a regulatory protein that closes myosin-binding sites to prevent actin from binding to myosin

Voltage-coupled sodium channels are membrane proteins that open sodium channels in response to a sufficient change in voltage, initiating and transmitting an action potential as Na+ enters through the channel.

***Answers to questions***

Muscles can lose their integrity during powerful movements, which will lead to their damage.

When a muscle contracts, the force of movement is transmitted through the tendon, which pulls on the bone, producing skeletal movement.

Dark A-bands and light I-bands are repeated along the myofibrils, and the alignment of myofibrils in the cell leads to the fact that the entire cell looks striped.

## EXCITATION, CONTRACTION AND RELAXATION OF MUSCLE FIBERS

**By the end of this section, you should be able to:**

Describe the connection between motor neurons and muscles

Explain the mechanism of neurotransmitter signal transmission that generates a postsynaptic electrical signal

Explain the process of pairing excitation and muscle contraction

Explain how muscle contraction and relaxation relate to calcium processing in the sarcoplasmic reticulum

**Neuromuscular junction**

The process of muscle contraction begins at the junction of the terminal of the motor neuron with the muscle fiber - the neuromuscular junction (NMJ). Every skeletal muscle fiber in every skeletal muscle is innervated by a motor neuron in the NMJ. Excitation signals from a motor neuron are the only way to functionally activate muscle fibers for contraction.

**Excitation and inhibition relationship**

All living cells have membrane potentials, or electrical gradients, on their membranes based on the distribution of positively and negatively charged ions. The inner part of the membrane usually has a voltage of -60 to -90 mV with respect to the outside. Neurons and muscle cells can use their membrane potentials to generate and conduct electrical signals, controlling the movement of charged ions across the membrane to create an electric current. This movement of ions is controlled by selectively opening and closing specialized proteins in the membrane called ion channels. Although the currents created by the ions passing through these channel proteins are very small, they form the basis of both neural signaling and muscle contraction.

Both neurons and skeletal muscle cells are electrically excitable, that is, they are able to generate action potentials. An action potential is a special type of electrical signal that can propagate along the cell membrane as a wave. This allows you to quickly and accurately transmit the signal over long distances.

In skeletal muscle, the release of calcium to initiate cross-bridge formation and contraction is associated with an excitatory signal of action potentials from a motor neuron. Thus, the process of communication of excitation and contraction begins with a signal from the nervous system in the neuromuscular junction and ends with the release of calcium for muscle contraction.

The motor neurons that instruct skeletal muscle fibers to contract are located in the spinal cord (Fig. 7), with a smaller number located in the brainstem to activate the skeletal muscles of the face, head, and neck. These neurons have long processes called axons, which are designed to transmit action potentials over long distances — in this case, from the spinal cord to the muscle itself (which can be up to a meter away). The axons of several neurons join together to form nerves, similar to wires connected in a cable.

Signaling begins when the action potential of a neuron travels through the axon of a motor neuron and then through individual branches to end at the neuromuscular junction. The neuromuscular terminal of the axon releases a chemical mediator, or neurotransmitter, called acetylcholine. Acetylcholine molecules diffuse into a space called the synaptic cleft and bind to acetylcholine receptors located in the motor terminal plate of the sarcolemma on the other side of the synapse. Once the mediator binds, a channel in its corresponding receptor opens, and positively charged ions can pass into the muscle fiber, causing it to depolarize, which means that the membrane potential of the muscle fiber becomes less negative (closer to zero).


**Figure 7.** *Diagram of the somatic three neuronal arc.*

As the muscle membrane depolarizes, another set of ion channels called voltage-specific sodium channels open. Sodium ions enter the muscle fiber, and the action potential quickly spreads (or "shoots") along the entire membrane, initiating an excitation-contraction bond.

In the world of excitable membranes, everything happens very quickly (just think about how quickly you can snap your fingers as soon as you decide to do so). Immediately after depolarization of the membrane, it repolarizes, restoring the negative membrane potential. Meanwhile, acetylcholine in the synaptic cleft is broken down by the enzyme acetylcholinesterase so that acetylcholine cannot re-bind to the receptor and reopen its channel, which would cause unwanted prolonged muscle excitation and contraction.

The propagation of the action potential along the sarcolemma is part of the excitation-contraction connection and must be associated with the release of calcium ions for reduction. High concentrations of calcium in skeletal muscle are stored in a specialized type of smooth endoplasmic reticulum organelle called the sarcoplasmic reticulum. The latter surrounds the myofibrils, ensuring the storage and release of calcium directly at the sites of the overlap of actin and myosin.

The excitation of the muscle membrane is associated with the release of calcium by the sarcoplasmic reticulum through intussusceptions in the sarcolemma, called T-tubules ("T" stands for transverse ). Since the diameter of the muscle fiber can reach 100 μm, the T-tubule complex with terminal cisterns of the sarcoplasmic reticulum located on either side of it is called the triad (Fig. 8).

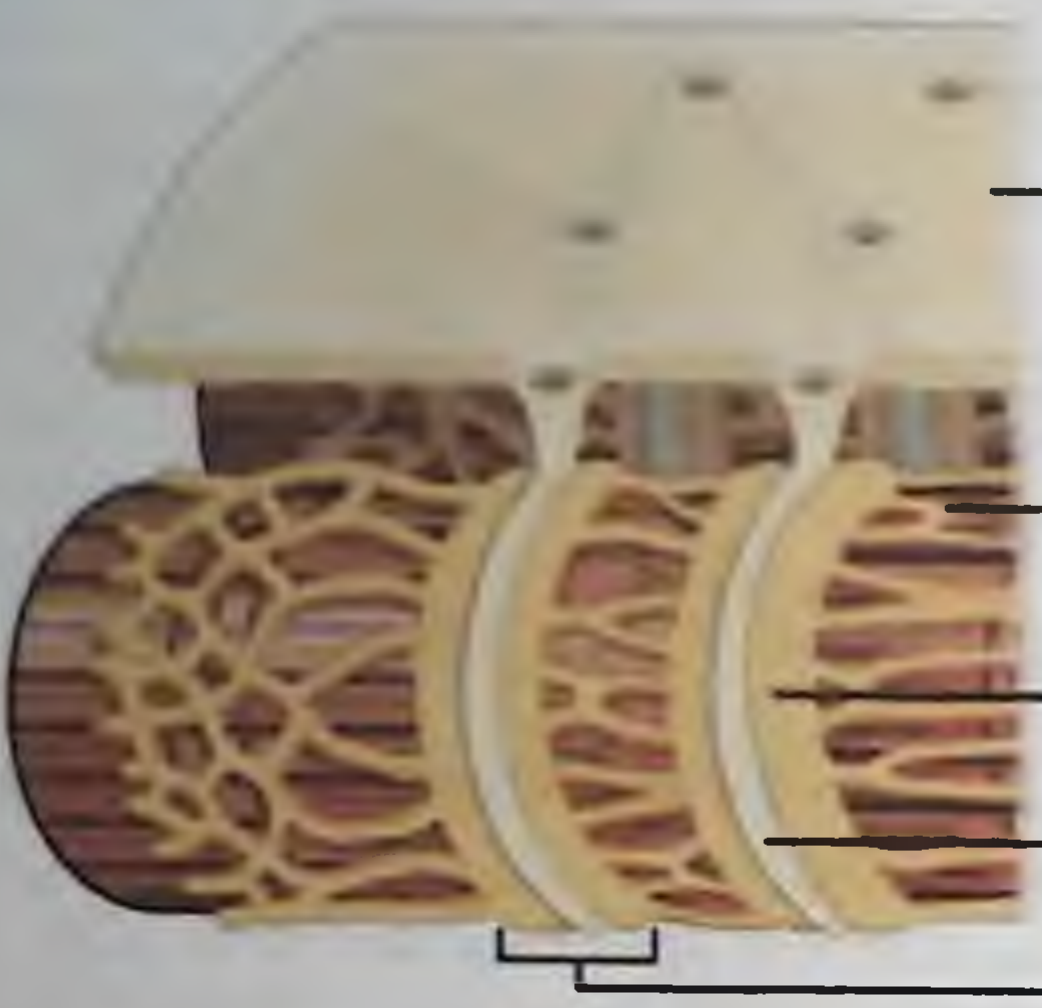



**Figure 8.** *T-tube: Narrow T-tubes provide conduction of electrical impulses. The sarcoplasmic reticulum (CP) functions to regulate intracellular calcium levels. Two terminal tanks CP and one T-tube make up a triad - a "troika" of membranes, on both sides of which there are CP, and between them - a T-tube.*

The voltage-sensitive dihydropyridine receptors (DHPR) on the sarcolemma are mechanically linked to calcium channels in the adjacent CP membrane called rianadine receptors (RyR). Through DHPR, the action potential in the sarcolemma triggers the discovery of RyR, allowing Ca++ to diffuse from the sarcoplasmic reticulum to the sarcoplasm. It is the entry of Ca++ into the sarcoplasm that initiates the reduction and shortening of sarcomeres.

**Contraction and relaxation**

The sequence of events leading to the contraction of an individual muscle fiber begins with a signal – the neurotransmitter acetylcholine – from the motor neuron innervating that fiber. The local membrane of the fiber is depolarized as positively charged sodium (Na+) ions penetrate it, causing an action potential that spreads to the rest of the membrane, including the T tubules. This causes the release of calcium ions (Ca++) from storage in the sarcoplasmic reticulum (CP). Ca++ then initiates a contraction that is supported by ATP. As long as Ca++ ions remain in the sarcoplasm to bind to troponin, which keeps actin-binding regions "unprotected," and as long as ATP is available to drive cycles of transverse bridges and pull actin filaments with myosin, the muscle fiber will continue to contract to an anatomical limit.

Muscle contraction usually stops when signals from the motor neuron end, which repolarizes the sarcolemma and T tubules and closes the calcium channels in the sarcoplasmic reticulum. The Ca++ ions are then pumped back into the reticulum, which causes tropomyosin to close the binding sites on the actin again.

Recall that each head of myosin has a site that binds to actin and a site that binds to ATP. Myosin cannot free itself from actin until ATP also binds to it, and the hydrolysis of ATP to adenosine diphosphate (ADP) and inorganic phosphate (Pi) releases the energy needed by the myosin head to reposition or re-fix.

Cross-bridge formation occurs when the head of myosin attaches to actin, while adenosine diphosphate (ADP) and inorganic phosphate are still bound to myosin. Pi is then released, causing the myosin to form a stronger attachment to the actin, after which the head of the myosin moves towards the M-line, dragging the actin with it. As the actin is pulled, the filaments move about 10 nm towards the M-line. This movement is called a force strike, since at this stage the movement of a thin filament occurs. In the absence of ATP, the head of the myosin does not detach from the actin.

Binding of ATP leads to the detachment of the head of myosin from actin. The ATP is then converted to ADP and Pi by myosin's INHERENT ATPase activity. The energy released by ATP hydrolysis changes the angle of inclination of the myosin head, turning it into a broken position. The myosin head is now in a position for further movement.

When the head of myosin is rotated, myosin is in a high-energy configuration. This energy is expended as the myosin head moves during a forceful strike, and at the end of a forceful stroke, the myosin head is in a low-energy position. After a forceful strike, the ADF is released, but the formed transverse bridge remains in place, and the actin and myosin are connected to each other. As long as ATP is available, it easily attaches to myosin, the cross-bridge cycle can repeat, and muscle contraction can continue.

Note that each thick filament, consisting of about 300 myosin molecules, has several myosin heads, and many cross-bridges are constantly formed and ruptured during muscle contraction. Multiply that by all the sarcomeres in one myofibril, all the myofibrils in one muscle fiber, and all the muscle fibers in one skeletal muscle, and you can see why it takes so much energy (ATP) to keep skeletal muscle working. In fact, it is the loss of ATP that leads to the cadaveric stiffening seen shortly after a person's death. Since further production of ATP is not possible, the heads of myosin cannot detach from the binding sites of actin, so the transverse bridges remain in place, causing stiffness of skeletal muscle.

**Sources of ATP**

ATP provides energy for muscle contraction. In addition to its direct role in the cycle of transverse bridges, ATP also provides energy for Ca++ active transport pumps in the sarcoplasmic reticulum. Muscle contraction does not occur without enough ATP. The amount of ATP stored in the muscles is very small, it is enough only for a few seconds of contraction. Therefore, ATP must quickly recover and replace as it breaks down to ensure sustainable reduction. There are three mechanisms by which ATP can be restored: creatine phosphate metabolism, anaerobic glycolysis, fermentation, and aerobic respiration.

Creatine phosphate is a molecule that can store energy in its phosphate bonds. In the resting muscle, excess ATP transfers its energy to creatine, forming ADP and creatine phosphate. This acts as an energy reserve that can be used to quickly create more ATP. When the muscle begins to contract and needs energy, creatine phosphate transfers its phosphate back to ATP, forming ATP and creatine. This reaction is catalyzed by the enzyme creatine kinase and occurs very quickly; thus, ATP derived from creatine phosphate provides energy for the first few seconds of muscle contraction. However, creatine phosphate can provide energy for only about 15 seconds, after which it is necessary to use another source of energy.

As the ATP produced by creatine phosphate is depleted, muscles turn to glycolysis as a source of ATP. Glycolysis is an anaerobic (oxygen-independent) process that breaks down glucose (sugar) to produce ATP; however, glycolysis cannot generate ATP as quickly as creatine phosphate. Thus, the transition to glycolysis leads to a decrease in the rate of ATP entry into the muscles. The sugar used in glycolysis can be obtained from blood glucose or by the metabolism of glycogen, which is stored in the muscles. When one molecule of glucose is broken down, two ATP and two molecules of pyruvic acid are formed, which can be used in aerobic respiration or at low oxygen levels converted to lactic acid.

If oxygen is available, pyruvic acid is used in aerobic respiration. However, if oxygen is not available, pyruvic acid is converted to lactic acid, which can contribute to muscle fatigue. This conversion allows the coenzyme nicotinamide-adenine dinucleotide (NAD+) to be recycled from the nicotine-amidadenine dinucleotide (NADH), which is necessary for the continuation of glycolysis. This happens during strenuous workouts, when a large amount of energy is required, but oxygen cannot be delivered to the muscles in sufficient quantities. Glycolysis alone may not last very long (about 1 minute of muscle activity), but it is useful for relieving short bursts of high-intensity work. This is because glycolysis does not use glucose very efficiently, producing a net increase in two ATP per glucose molecule and the final product is lactic acid, which, when accumulated, can contribute to muscle fatigue.

Aerobic respiration is the breakdown of glucose or other nutrients in the presence of oxygen (O2) to form carbon dioxide, water, and ATP. Approximately 95% of the ATP needed for resting or moderately active muscles is provided by aerobic respiration, which occurs in the mitochondria. As starting materials for aerobic respiration, glucose circulating in the bloodstream, pyruvic acid and fatty acids are used. Aerobic respiration is much more effective than anaerobic glycolysis: about 36 molecules of ATP are produced per molecule of glucose against four during glycolysis. However, aerobic respiration cannot be maintained without a constant supply of O2 to skeletal muscle and proceeds much more slowly. To compensate, muscles store small amounts of excess oxygen in proteins called myoglobin, which allows muscles to contract more efficiently and get less tired. Aerobic training also increases the efficiency of the circulatory system, so that oxygen can flow into the muscles for a longer time.

Muscle fatigue occurs when a muscle can no longer contract in response to nervous system signals. The exact causes of muscle fatigue are not fully known, although certain factors have been correlated with the decrease in muscle contraction that occurs with fatigue. ATP is necessary for normal muscle contraction, and as ATP stores decrease, muscle function may decrease. This may be a more significant factor in short-term, intense muscle work rather than sustained low-intensity effort. The accumulation of lactic acid can reduce intracellular pH, which affects the activity of enzymes and proteins. An imbalance in Na+ and K+ levels due to membrane depolarization can disrupt the outflow of Ca++ from the sarcoplasmic reticulum. Prolonged physical exertion can damage the reticulum and sarcolemma, which will lead to a violation of the regulation of Ca ++.

Intense muscle activity results in oxygen debt, which is the amount of oxygen needed to compensate for the ATP produced without oxygen during muscle contraction. Oxygen is needed to restore ATP and creatine phosphate levels, convert lactic acid to pyruvic acid, and in the liver to convert lactic acid to glucose or glycogen. Other systems used during exercise also need oxygen, and all of these processes combine to lead to an increase in the breathing rate that occurs after exercise. Until the oxygen debt is repaid, oxygen consumption remains elevated even after the exercise is stopped.

**Skeletal Muscle Relaxation**

The relaxation of skeletal muscle fibers and, ultimately, skeletal muscle begins with a motor neuron that stops releasing its chemical neurotransmitter, acetylcholine, into a synapse at the neuromuscular junction. The muscle fiber is repolarized, which closes the gate in the sarcoplasmic reticulum through which Ca++ was released. Pumps under the action of ATP move Ca ++ from the sarcoplasm back to the reticulum. This leads to the "re-adaptation" of the actin binding sites on the thin filaments. Without the ability to form cross-bridges between thin and thick filaments, the muscle fiber loses tension and relaxes.

**Muscle strength**

The number of skeletal muscle fibers in a given muscle is genetically determined and does not change. Muscle strength is directly related to the number of myofibrils and sarcomeres in each fiber. Factors such as hormones and stress (and artificial anabolic steroids) acting on muscles can increase the production of sarcomeres and myofibrils in muscle fibers, this change is called hypertrophy, which leads to an increase in the mass and volume of skeletal muscle. Similarly, reducing the use of skeletal muscle leads to atrophy when the number of sarcomeres and myofibrils disappears (but not the number of muscle fibers). Usually, atrophied muscles are visible on the limb in the cast after the plaster is removed, and in some diseases, such as polio, the muscles atrophy.

***Chapter Overview***

The sarcomere is the smallest contractile part of the muscle. Myofibrils consist of thick and thin threads. Thick filaments are made up of myosin protein, and thin filaments are made up of actin protein. Troponin and tropomyosin are regulatory proteins.

Muscle contraction is described by a model of sliding strands of contraction. Acetylcholine is a neurotransmitter that binds in the neuromuscular junction, causing depolarization, and an action potential runs along the sarcolemma, triggering the release of calcium from CP. Actin sites are exposed after Ca++ enters the sarcoplasm from the CP repository to activate the troponin-tropomyosin complex, causing tropomyosin to shift away from the sites. The cross bridges of myosin heads docked with actin-binding sites are followed by a "force blow" - the sliding of thin filaments on thick filaments. Force strikes are carried out under the action of ATP. Eventually, sarcomeres, myofibrils, and muscle fibers shorten, producing movement.

***Questions for self-control***

1. How would the absence of T tubules in skeletal muscle fibers affect muscle contractions?

2. What are the opposite roles of voltage sodium channels and voltage potassium channels?

3. How would the complete depletion of ATP in the muscle fiber affect muscle contractions?

***Glossary***

*aerobic respiration* – production of ATP in the presence of oxygen

*ATPase* is an enzyme that hydrolyzes ATP to ADP

*creatine phosphate* is the main high-energy molecule for storing phosphates in muscles. In rested muscles, creatine phosphate is the predominant form; its maximum concentration is five times higher than that of ATP; used to store ATP energy and transfer it to the muscles

*glycolysis* - anaerobic breakdown of glucose to ATP

*lactic acid* - a product of anaerobic glycolysis

*oxygen debt* – the amount of oxygen needed to compensate for ATP produced without oxygen during muscle contraction

force strike - the action of myosin pulling actin inward (to the M line)

*pyruvic acid is a* glycolysis product that can be used in aerobic respiration or converted to lactic acid

***Answers to questions***

1. Without T tubules, the conduction of the action potential into the inside of the cell would be much slower, causing delays between nerve stimulation and muscle contraction, resulting in slower and weaker contractions.

2. The opening of sodium channels with voltage and the inflow of Na+ transmit the action potential after sufficient depolarization of the membrane. Delaying the opening of potassium channels allows K+ to exit the cell to repolarize the membrane.

3. Without ATP, myosin heads cannot detach from actin-binding sites. All "stuck" cross bridges lead to muscle rigidity. In a living person, this can cause a condition similar to "writer's seizures." In a recently deceased person, this leads to cadaveric stiffening.

## CONTROL OF THE NERVOUS SYSTEM OVER MUSCLE TENSION

**By the end of this section, you should be able to:**

Explain concentric, isotonic, and eccentric contractions

Define the motor unit and explain how activation of the motor unit affects the generation of force

Describe the dependence of length on tension in muscle fiber

Describe the three phases of muscle contraction

To define the concepts of "summation of waves", "tetanus".

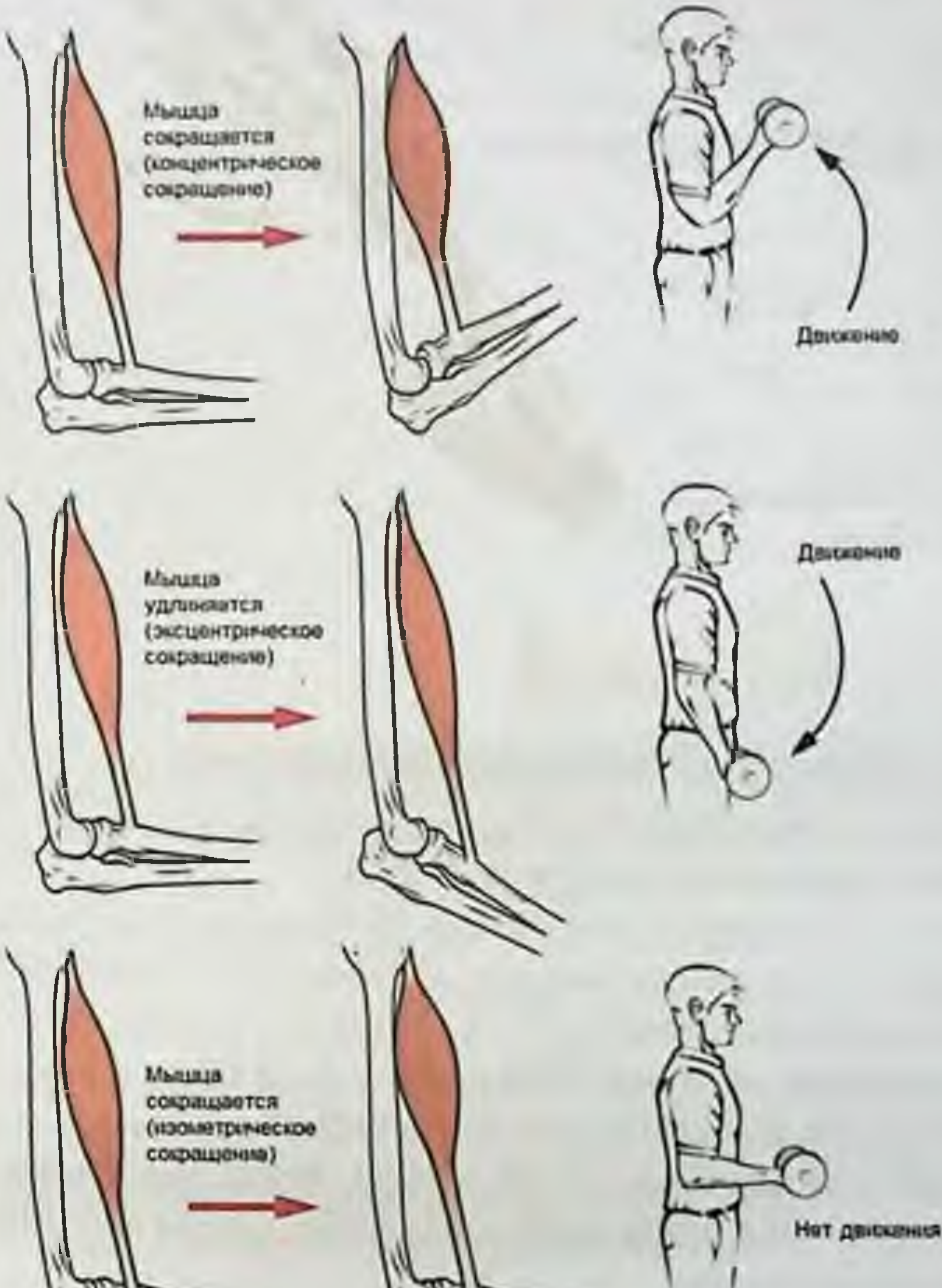
To move an object called a load, the muscle fibers of skeletal muscle must contract. The force that occurs when a muscle contract is called muscle tension. Muscle tension can also occur when a muscle contracts against a load that does not move, resulting in two main types of skeletal muscle contractions: isotonic and isometric (Fig. 9).

In isotonic contraction, when the tension in the muscle remains relatively constant, the weight moves as the length of the muscle changes. With concentric contraction, the muscle shortens to move the load. An example of such a contraction is the contraction of the biceps muscle of the shoulder when the kettlebell rises up towards the body. Eccentric contraction occurs when muscle tension decreases, and muscle lengthens. This type of contraction is observed with a slow and controlled lowering of the same weight in the arm using the biceps muscle of the shoulder.

Isometric contraction occurs when a muscle produces tension without changing the length of the muscle. Isometric contraction involves shortening the sarcomeres and increasing muscle tension but does not result in the movement of the load, since the force produced cannot overcome the resistance exerted by the load.

For example, if you try to lift a kettlebell that is too heavy, the sarcomeres will be activated and shortened to a certain point, the muscle tension will constantly increase, but the position of the kettlebell will not change. In everyday life, isometric contractions are actively used to maintain posture and maintain a stable position of bones and joints.

Most of the body's actions are the result of a combination of isotonic and isometric contractions working together to produce a wide range of results. This muscular activity is under the control of the nervous system. The most important aspect of the control of the nervous system over skeletal muscles is the role of motor units.




**Picture 8.** *Types of muscle contractions.*

**Neuromotor units**

As mentioned earlier, the contraction of skeletal muscle fibers is triggered by a signal from a motor neuron. Each muscle fiber is innervated by only one motor neuron, but a single motor neuron can innervate multiple muscle fibers.


**Figure 9.** *Scheme of organization of the motor unit*

The neuromotor (motor) unit is understood as one motor neuron and all the muscle fibers innervated by it (Fig. 9).

The size of the motor unit dictates its function. A small motor unit consisting of a motor neuron and just a few muscle fibers allow for very fine motor control of the muscle. For example, the external muscles of the eye have thousands of muscle fibers, every 5-10 fibers are provided by one motor neuron; this allows precise control of eye movements so that both eyes can quickly focus on the subject. Small motor units are also involved in numerous subtle movements of the fingers and thumb when grasping, writing text, etc.

Large motor units engage in simple, or "gross," movements, such as moving parts of the body against gravity. The large motor units of the muscles of the thigh or back, where a single motor neuron provides thousands of muscle fibers in the muscle, are representatives of this type of activity.

Most muscles in the human body have a mixture of small and large motor units, which gives the nervous system a wide range of muscle control. The smaller motor units in the muscle have motor neurons that are more excitable. The initial activation of these small motor units results in a relatively small degree of tension created in the muscle. When more force is required, larger motor units are used to create more stress. This process of attracting additional motor units to create more tension is called recruiting. It allows a muscle, such as the biceps muscle of the shoulder, to lift the feather with minimal effort, while lifting a heavy weight requires much more effort.

If necessary, the maximum number of motor units in a muscle can be activated simultaneously, creating the maximum contraction force for a given muscle, but this cannot last very long due to the need for energy to maintain the contraction. To prevent complete muscle fatigue, motor units usually do not work at the same time, but on the contrary, some motor units rest, while others work, which allows muscles to contract longer. Thus, the nervous system uses recruitment as a mechanism for the effective use of skeletal muscle.

**Sarcomere's length range**

As mentioned earlier, when the skeletal muscle fiber contracts, the heads of myosin attach to the actin, forming cross-bridges, after which thin threads slide along the thick threads when the heads pull actin, and this leads to a shortening of the sarcomere, creating a tension of muscle contraction. Transverse bridges can only form where thin and thick filaments overlap; thus, the length of the sarcomere directly affects the force that occurs when it is contracted. This is called a length-tension relationship.

The ideal length of the sarcomere to create maximum stress is 80 to 120 percent of its rest length, with 100 percent being a state where the medial edges of thin filaments are at the level of the most medial myosin heads of thick filaments. This length maximizes the overlap of actin binding sites and myosin heads.

If the sarcomere is stretched beyond the ideal length (more than 120 percent), the thick and thin filaments do not completely overlap, resulting in a decrease in stress. If the muscle is stretched to such an extent that thick and thin threads do not overlap at all, cross-bridges do not form, and tension does not occur. Such stretching usually does not occur because the auxiliary proteins and connective tissue resist extreme stretching.

If the sarcomere shortens by more than 80%, the overlap zone decreases, and thin threads extend beyond the last head of myosin. Eventually, the thin threads have nowhere to go, and the tension force decreases.

**Frequency of motor neuron stimulation**

A single action potential from a motor neuron causes a single contraction of muscle fibers innervated by a motor neuron. A single muscle contraction can last from a few milliseconds to 100 milliseconds, depending on the type of muscle fiber. The tension created by a single muscle contraction can be measured using a myogram, a method that measures the amount of tension created by a muscle over time.

In muscle contraction, three phases are distinguished. The first phase is the latent period, during which the action potential propagates through the sarcolemma and Ca++ ions are released from the sarcoplasmic reticulum. This is the phase during which excitation and contraction are related, but contraction has not yet occurred. The contraction phase occurs as the muscle creates more and more tension; Ca++ ions in sarcoplasm bind to troponin, tropomyosin shifts from the binding sites to actin, cross-bridges are formed, and sarcomeres are actively shortened. The last phase is the relaxation phase, when tension is reduced as Ca++ ions are pumped out of the sarcoplasm back into the sarcoplasmic reticulum, returning the muscle fibers to a dormant state.

Although a person may feel the "twitching" of skeletal muscle, one twitch does not produce "useful" activity in a living organism. Instead, muscle contraction capable of producing work requires a rapid series of action potentials sent to the muscle fibers. By changing the rate at which a motor neuron sends out action potentials, it is possible to change the amount of tension created by innervated muscle fibers; this is called a graduated muscular response.

The gradient muscle response works as follows: if you stimulate the fibers while the previous twitching is still ongoing, the second twitch will be stronger. Such a response is called wave summation because the effects of the excitation-contraction connection are summed up, or added, when motor neurons give signals sequentially. At the molecular level, summation occurs because the second stimulus triggers the release of more Ca++ ions, which become available to activate more cross bridges, while the muscle is still contracting from the first stimulus. Summation leads to a greater reduction in the motor unit.

If the frequency of signals from motor neurons increases, the summation and subsequent tension of the muscle in the motor unit continues to increase until it reaches a peak point. The voltage at this point is about three to four times greater than the voltage in a single contraction, a condition called an incomplete tetanus. During incomplete tetanus, the muscle goes through rapid contraction cycles, followed by a short relaxation phase. If the frequency of stimuli is so high that the relaxation phase disappears completely, the contractions become continuous, which is called a full (smooth) tetanus.

During full tetanus, the concentration of Ca++ ions in the sarcoplasm allows almost all sarcomeres to form cross-bridges and shorten, so that contraction can continue continuously (until the muscle is tired and can no longer produce tension).

**The Staircase Effect (Bowditch Stairs)**

When skeletal muscle is dormant for a long period of time and then stimulated to contract, all other things being equal, the initial contractions create about half the strength of subsequent contractions. The tension in the muscle increases gradually, which for some looks like a ladder. This increase in tension is a condition in which muscle contractions become more effective. It is also known as the "ladder effect". It is believed that this effect occurs due to the increased concentration of Ca ++ in the sarcoplasm as a result of the constant flow of signals from the motor neuron. It can only be maintained if there is a sufficient amount of ATP.

**Muscle tone**

Skeletal muscle is rarely completely relaxed, or sluggish. Even if the muscle does not produce movement, it contracts by a small amount to preserve its contractile proteins and create muscle tone. The tension created by muscle tone allows the muscles to constantly stabilize the joints and maintain posture.

Muscle tone is provided by a complex interaction between the nervous system and skeletal muscles, which leads to the activation of several motor units simultaneously, most likely in a cyclic mode. Thus, the muscles never get tired completely, since some motor units are in a state of recovery, while others actively generate tension.

**Muscle disorders: Hypotension**

The absence of low-level contractions that lead to muscle tone is called hypotension or atrophy and can result from damage to parts of the central nervous system (CNS), such as the cerebellum, or loss of skeletal muscle innervation, as in polio. Hypotonic muscles have a sluggish appearance and demonstrate functional disorders, for example, weak reflexes. Conversely, excessive muscle tone is called hypertension and is accompanied by hyperreflexia (excessive reflex reactions), often resulting from damage to the upper motor neurons in the CNS. Hypertension can be manifested by muscle rigidity (as in Parkinson's disease) or spasticity - a phase change in muscle tone, in which the limb "snaps" after passive stretching (as in some strokes).

***Chapter Overview***

The number of transverse bridges formed between actin and myosin determines the amount of tension created by the muscle. The length of the sarcomere is optimal when the overlap zone between thin and thick threads is the largest. Muscles that stretch or contract too much do not produce the maximum amount of energy. The motor unit is formed by a motor neuron and all muscle fibers that are innervated by this same motor neuron. A single contraction is called a cramp. Muscle twitching has a latent period, a contraction phase, and a relaxation phase. A graduated muscular response allows you to vary muscle tension. Summation occurs when successive stimuli are added together to cause a stronger muscle contraction. Tetanus is a fusion of abbreviations to produce a continuous reduction. Increasing the number of motor neurons involved increases the number of activated motor units in the muscle, which is called recruitment. Muscle tone is a constant low-level contraction that provides posture and stability.

***Questions for self-control***

1. Why does the motor unit of the eye have few muscle fibers compared to the motor unit of the leg?
2. What factors affect the amount of tension created in an individual muscle fiber?

***Glossary***

*concentric contraction* – muscle contraction in which the muscle is shortened to move the load

*contraction* phase – convulsive contraction phase when the stress increases

*eccentric contraction* – a muscle contraction in which the muscle lengthens as the tension decreases

*hypertension* - abnormally high muscle tone

*hypotension* - abnormally low muscle tone caused by the absence of low-level contractions *isometric contraction* – muscle contraction that occurs without changing the length of the muscle

*isotonic contraction* - muscle contraction, in which there is a change in the length of the muscle

*latent period* – the time during which the cramp does not lead to muscle contraction

*motor unit – motor* neuron and a group of muscle fibers that it innervates

*muscle tension* - the force that occurs when a muscle contracts; tension occurs with isotonic and isometric contractions

*muscle tone* – a low level of muscle contraction that occurs when a muscle does not produce movement

*myogram* - recording of electrical signals obtained as a result of recording muscle contractions

*recruiting* - increasing the number of motor units involved in the reduction

*relaxation phase* – the period after muscle contraction when tension decreases

*tetanus* - continuous fused contraction

muscle contraction – a single contraction caused by a single action potential

*wave summation* – adding sequential neural stimuli to produce a stronger contraction

***Answers to questions***

1. The eyes require subtle movements and a high degree of control, which is possible due to the smaller number of muscle fibers associated with the neuron.

2. The length, size, and types of muscle fibers, as well as the frequency of neural stimulation, contribute to the amount of tension created in an individual muscle fiber.

## TYPES OF MUSCLE FIBERS

By the end of this section, you should be able to:

Distinguish between slow oxidative fibers, fast oxidative fibers, and fast glycolytic fibers.

Skeletal muscle fibers can be classified according to two criteria: 1) how quickly the fibers contract compared to others, and 2) how the fibers repair ATP. Using these criteria, three main types of skeletal muscle fibers can be distinguished (Table 1). Slow oxidative (SO) fibers contract relatively slowly and use aerobic respiration (oxygen and glucose) to produce ATP. Fast oxidative (FO) fibers contract relatively quickly and use predominantly aerobic respiration to produce ATP. Finally, fast glycolytic (FG) fibers have relatively rapid contractions and mainly use anaerobic glycolysis. Most skeletal muscle in the human body contains all three types, albeit in different proportions.

The rate of contraction depends on how quickly the myosin ATPase hydrolyzes the ATP to create a cross-bridge. Fast fibers hydrolyze ATP about twice as fast as slow fibers, resulting in a much faster cyclic movement of the transverse bridges (which pull thin filaments faster toward the center of the sarcomere).

The main metabolic pathway used by muscle fiber determines which type the fiber is oxidizing or glycolytic. If the fiber primarily produces ATP through aerobic pathways, then it is classified as oxidative. More ATP can be produced during each metabolic cycle, making the fiber more resistant to fatigue. Glycolytic fibers mainly create ATP through anaerobic glycolysis, which produces less ATP per cycle. As a result, glycolytic fibers tire faster.

Slow oxidative fibers have structural elements that maximize their ability to generate ATP through aerobic metabolism. These fibers contain much more mitochondria than glycolytic fibers because aerobic metabolism, which uses oxygen ($O_2$) in the metabolic pathway, occurs in the mitochondria. This allows slow oxidative fibers to shrink longer due to the large amount of ATP they can produce, but they have a relatively small diameter and therefore do not produce much stress.

In addition to the increased number of mitochondria, the slow oxidative fibers are abundantly supplied with blood capillaries for the intake of $O_2$ from the bloodstream. They also possess myoglobin, a molecule that binds $O_2$, similar to hemoglobin in red blood cells. Myoglobin retains some of the necessary $O_2$ in the fibers themselves and is partly responsible for the dark red color of the oxidative fibers.

The ability of slow oxidative fibers to function for a long time without fatigue makes them useful for maintaining posture, isometric contractions, and stabilizing bones and joints. Because they do not create high voltage, they are not used for powerful, fast movements that require a lot of energy and the rapid cycling of crossbridge.

**Table 1. Types of muscle fibers and their brief characteristics**

| Characteristic | Type I | IA type | IVB type |
|---|---|---|---|
| Name of muscle fibers | Red, slow, fatigue-resistant, oxidizing | Intermediate, fast, fatigue-resistant, redox-glycolytic | White, fast, fast-fatigued, glycolytic, anaerobic |
| Motor neuron size | small | Big | Big |
| Myosin ATPase Activity | Low | High | High |
| Sarcoplasmic reticulum | Poorly developed | Average development | Well developed |
| Capillary density | High | High | Low |
| Amount of myoglobin | A lot | Middle | Little |
| Number of mitochondria | A lot | Middle | Little |
| Mitochondrial size | Very large | Average | Small |
| Activity of mitochondrial enzymes | Big | Big | Low |
| Fatigue resistance | High | Middle | Very low |
| Glycogen stores | Low | Big | Big |
| Glycolytic ability | Low | Big | Big |
| Speed of reduction | Low | High | High |
| Cross-sectional area of the muscle fiber | Small | Big | Big |
| Maximum Power | Small | Big | Very large |

Fast glycolytic fibers primarily use anaerobic glycolysis as a source of ATP. They have a large diameter and contain a large amount of glycogen, which is used in glycolysis to rapidly produce ATP. Due to their reliance on anaerobic metabolism, these fibers lack a significant number of mitochondria, a limited number of capillaries, and a significant amount of myoglobin, resulting in white muscles containing large amounts of these fibers.

Fast glycolytic fibers get tired quickly, allowing them to be used only for a short time. However, during these short periods, the fibers are capable of producing rapid, force contractions associated with fast, powerful movements.

Fast oxidative fibers are sometimes called intermediate fibers because they have characteristics intermediate between slow oxidative fibers and fast glycolytic fibers. These fibers produce ATP relatively quickly and can therefore produce relatively large voltages, but because they are oxidizing, they do not tire quickly. Fast oxidative fibers are used primarily for movements, such as walking, which require more energy than postural control but less energy than explosive movement.

***Chapter Overview.***

There are three types of muscle fibers: slow oxidative (SO), fast oxidative (FO), and fast glycolytic (FG). Slow oxidative fibers use aerobic metabolism to produce low-power reductions for a long time and slowly tire out. Fast oxidative fibers use aerobic metabolism to produce ATP but produce contractions with greater stress than slow oxidative fibers. Fast glycolytic fibers use anaerobic metabolism to produce powerful, high-stress contractions, but quickly get tired.

***Questions for self-control***

1. Why do muscle cells use creatine phosphate instead of glycolysis to provide ATP during the first few seconds of muscle contraction?

2. Is aerobic respiration more or less effective than glycolysis? Explain your answer.

***Glossary***

*fast glycolytic fiber* - muscle fiber, which mainly uses anaerobic glycolysis

*fast oxidative fiber* - intermediate muscle fiber located between slow oxidative and fast glycolytic fibers

*slow oxidative fiber* - muscle fiber, using mainly aerobic respiration

***Answers to questions***

1. Creatine phosphate is used because creatine phosphate and ADP are very quickly converted to ATP by the action of creatine kinase. Glycolysis cannot generate ATP as quickly as creatine phosphate.

2. Aerobic respiration is much more efficient than anaerobic glycolysis, giving 36 ATP per glucose molecule, as opposed to the two ATPs produced by glycolysis.

## EXERCISE AND MUSCLE WORK

By the end of this section, you should be able to:

Describe muscular hypertrophy and muscular atrophy

Explain how endurance and resistance exercise affect muscles

Explain how performance-enhancing substances affect muscles.

Physical training can change the appearance of skeletal muscle and lead to changes in muscle performance. Conversely, lack of training can lead to a decrease in muscle mass and performance. Although muscle cells can change in size, new cells rarely form as muscles grow. Instead, structural proteins are added to the muscle fiber in a process called muscle hypertrophy, which leads to an increase in the diameter of the fiber. The reverse process, when structural proteins are lost and muscle mass decreases, is called muscle atrophy.

**Endurance exercises**

Slow fibers are predominantly used in endurance exercises that require limited effort but involve a large number of repetitions. Aerobic metabolism, used by slow oxidative fibers, allows them to maintain contractions for a long time. Endurance training changes these slow fibers, making them even more efficient by forming more mitochondria and synthesizing more myoglobin, resulting in increased ATP production by increasing the rate of aerobic metabolism.

Exercise can cause the formation of more extensive capillary networks around the fibers — a process called angiogenesis — to supply the fibers with oxygen and remove metabolic waste. So that these capillary networks can supply the deep parts of the muscle, muscle mass is not greatly increased to save a smaller area for the diffusion of nutrients and gases.

The proportion of slow oxidative muscle fibers in a muscle determines the muscle's fitness for endurance and may benefit those involved in endurance exercise. Postural muscles (holding the body in a certain posture) have a large number of slow oxidative fibers as they are constantly contracting to keep the body upright. Endurance athletes benefit greatly from the fact that muscles contain more slow oxidative fibers compared to fast oxidative fibers. Studies show that genetics plays an important role in determining the overall ratio of slow oxidative and fast glycolytic fibers in muscles, and repetitive workouts have the greatest impact on fast oxidative fibers.

**Resistance exercises**

Resistance exercises, unlike endurance exercises, focus on fast glycolytic fibers because they focus on short, powerful movements that are not repeated for a long time. The high rate of ATP hydrolysis and cross-bridge formation in fast glycolytic fibers is responsible for such powerful muscle contractions. Thus, muscles used for strength training often have a higher ratio of fast glycolytic fibers compared to slow oxidative fibers. Resistance exercises affect the muscles, increasing the formation of myofibrils, thereby increasing the diameter of muscle fibers. Since the increase in muscle mass occurs due to the addition of structural proteins, athletes seeking to build muscle mass often consume large amounts of protein.

In addition to increasing the diameter of muscle fibers, resistance training also promotes the development of connective tissue, increasing overall muscle mass. The increase in connective tissue helps to hold the muscles as they produce increasingly powerful contractions. Tendons also become stronger, which prevents them from being damaged as the force produced by the muscles is transferred to the tendons that attach the muscles to the bones.

For effective strength training, it is necessary to constantly increase the intensity of the exercises. For example, constant weightlifting without increasing the weight of the load does not lead to an increase in muscle size. To get better results, it is necessary that the weights lifted become heavier, which complicates the task of the muscles to move the load. The muscles then adapt to the heavier load, and an even heavier load must be used to achieve even greater muscle mass.

With the wrong approach, resistance training can lead to injuries to muscles, tendons or bones. These injuries can occur if the load is too heavy, if the muscles are not given enough time to recover between workouts, or if the joints do not align properly during exercise. Cellular damage to muscle fibers that occurs after intense physical exertion includes damage to the sarcolemma and myofibrils. This muscle damage contributes to the feeling of soreness after intense training, but the muscles gain mass as the damage recovers and additional structural proteins are added to replace the damaged ones.

*Chapter Overview*

Muscle hypertrophy is an increase in muscle mass through the addition of structural proteins. The opposite of muscle hypertrophy is muscle atrophy – loss of muscle mass due to the breakdown of structural proteins. Endurance exercise causes an increase in the number of cellular mitochondria, myoglobin, and capillary networks in the slow oxidative fibers. Endurance athletes benefit from a high proportion of slow oxidative fibers compared to other types of fibers. Resistance training leads to muscle hypertrophy, primarily due to fast glycolytic fibers. In muscles that develop strength, the density of fast glycolytic fibers is higher than that of slow oxidative fibers. Some athletes use performance-enhancing substances to improve muscle performance. Age-related muscle atrophy is called sarcopenia and occurs as muscle fibers die and are replaced by connective and adipose tissue.

*Questions for self-control*

1. What changes occur at the cellular level in response to endurance training?

2. What changes occur at the cellular level in response to resistance training?

*Glossary*

*angiogenesis* - the formation of a network of blood capillaries

atrophy – loss of structural proteins from muscle fibers

*hypertrophy* – adding structural proteins to muscle fibers

*sarcopenia* - age-related muscle atrophy

*Answers to questions*

1. Endurance training alters slow fibers, making them more efficient by producing more mitochondria to enable more aerobic metabolism and more ATP production. Endurance exercise can also increase the amount of myoglobin in the cell and the formation of more extensive capillary networks around the fiber.

2. Resistance exercise affects the muscles, causing the formation of more actin and myosin, increasing the structure of muscle fibers.

## DEVELOPMENT AND REGENERATION OF MUSCLE TISSUE

**By the end of this section, you should be able to:**

Describe the function of satellite cells

Define fibrosis

Explain which muscle has the greatest ability to regenerate.

Most of the body's muscle tissue arises from the embryonic mesoderm. Paraxial mesodermal cells adjacent to the neural tube form blocks of cells called somites. Skeletal muscles, with the exception of the muscles of the head and limbs, develop from mesodermal somites, whereas skeletal muscles of the head and limbs develop from the common mesoderm (Fig. 10). Somites give rise to myoblasts. A myoblast is a stem cell that forms muscles that migrates to different regions of the body and then fuses to form a syncytium, or myotube. Because the myotube is formed from many different myoblast cells, it contains many nuclei but has a continuous cytoplasm. That is why skeletal muscle cells are multinucleated, since the nucleus of each myoblast involved in the formation of the myotube remains intact in a mature skeletal muscle cell. However, the cells of the heart and smooth muscles are not multinucleated since the myoblasts that form their cells do not fuse.

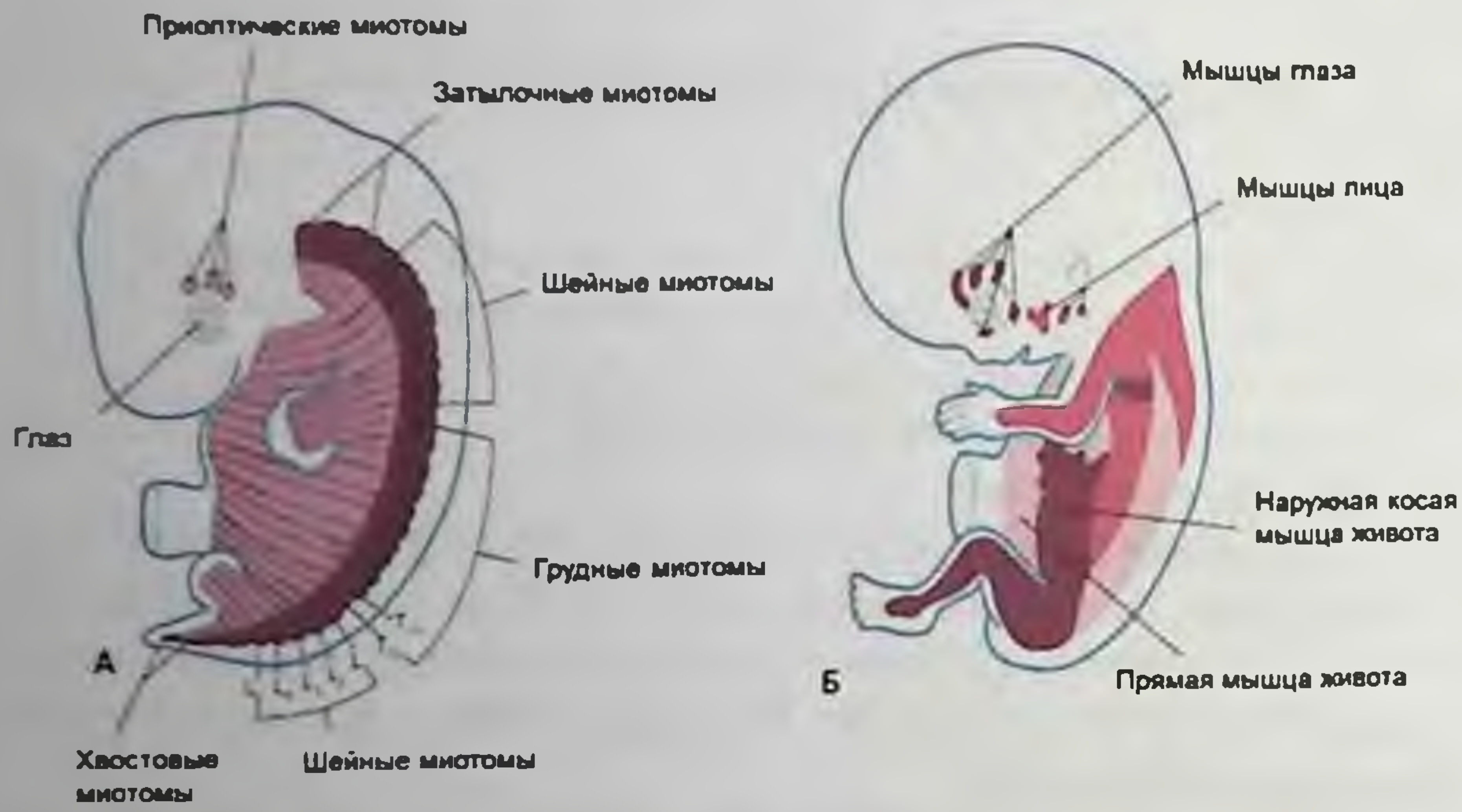



**Figure 10.** *Developing muscular system. A , Figure of a 6-week-old embryo shows areas of myotomes in somites that give rise to skeletal muscle. B - a drawing of an 8-week-old embryo, shows the developing muscles of the trunk and limbs.*

In the early stages of development, gap transitions develop in the cardiac and single-component smooth muscle. In skeletal muscle, ACh receptors are initially present on most of the surface of myoblasts, but innervation of the spinal nerves triggers the release of growth factors that stimulate the formation of motor end plates and NMJ. When neurons become active, the electrical signals sent through the muscle affect the distribution of slow and fast fibers in the muscle.

Although the number of muscle cells is established during development, satellite cells help repair skeletal muscle cells. Satellite cells are similar to myoblasts in that they are a type of stem cell; however, satellite cells integrate into muscle cells and promote protein synthesis necessary for repair and growth. These cells are located outside the sarcolemma and are stimulated to grow and fuse with muscle cells by growth factors that are secreted by muscle fibers during certain forms of stress. Satellite cells can regenerate muscle fibers to a very limited extent, but they mostly help repair damage in living cells. If the cell is damaged to a greater extent than can be repaired by satellite cells, the muscle fibers are replaced by scar tissue in a process called fibrosis. Because scar tissue cannot contract, muscles that have sustained significant damage lose strength and cannot produce as much energy and endurance as they did before the injury.

Smooth muscle tissue can be repaired from a type of stem cell called pericytes, which are found in some small blood vessels. Pericytes allow smooth muscle cells to regenerate and repair much faster than skeletal and cardiac muscle tissue. Like skeletal muscle tissue, heart muscle does not recover to a large extent. Dead cardiac muscle tissue is replaced by scar tissue that cannot contract. As scar tissue accumulates, the heart loses its ability to pump air due to the loss of contractile power. However, a small regeneration can occur thanks to stem cells found in the blood, which sometimes enter the heart tissue.

***Chapter Overview***

Muscle tissue arises from the embryonic mesoderm. Somites give rise to myoblasts and merge to form a myotube. The nucleus of each myoblast remains intact in a mature skeletal muscle cell, resulting in the formation of a mature multinucleated cell. Satellite cells help repair skeletal muscle cells. Smooth muscle tissue can be repaired from stem cells called pericytes, while dead cardiac muscle tissue is replaced by scar tissue. As a result of aging, muscle mass decreases and is replaced by non-contractile (non-contracting) connective and adipose tissue.

***Questions for self-control***

1. Why can't muscles that have been severely damaged produce as much energy as they could before the damage?

2. What type(s) of muscle (skeletal, smooth, or cardiac) can regenerate new muscle cells/fibers? Explain your answer.

***Glossary***

*fibrosis* - replacement of muscle fibers with scar tissue

*myoblast* - muscle-forming stem cell

*myotube* - fusion of many myoblast cells

*pericyte* - stem cell that regenerates smooth muscle cells

*satellite cell* - stem cell that promotes the restoration of muscle cells

*somites* - blocks of cells of the paraxial mesoderm

***Answers to questions***

1. If the damage exceeds what satellite cells can repair, the damaged tissue is replaced with scar tissue that cannot contract.

2. Smooth muscle tissue can regenerate from stem cells called pericytes, which are found in some small blood vessels. They allow smooth muscle cells to regenerate and repair much faster than skeletal and cardiac muscle tissue.

## THE CONCEPT OF MUSCLES - AGONISTS, MUSCLES - ANTAGONISTS AND MUSCLES - SYNERGISTS

**Interaction of skeletal muscles in the body**

The movable end of the muscle that attaches to the bone that is being pulled is called the insertion of the muscle, and the end of the muscle attached to the immobile (stabilized) bone is called the beginning.

Although several muscles may be involved in the action, the main muscle performing the main movement is called the agonist. Flexion of the forearm is carried out by the biceps muscle of the shoulder (m. biceps brachii), and the extension of the forearm is carried out by the triceps muscle of the shoulder (m. triceps brachii). If we consider the flexion of the forearm as the main movement, then the agonist muscle will be the biceps muscle of the shoulder (it carries out this movement), and the antagonist muscle will be the triceps muscle of the shoulder (Fig. 10). It is responsible for extension. It should be noted, however, that there can be a lot of agonist muscles. The agonist muscles in this case are all the muscles that are responsible for flexing the forearm. These are muscles: biceps muscle of the shoulder, humerus, humerus. These muscles are both synergistic muscles (responsible for the same function) and agonists (responsible for basic movement).

Consider the extension of the tibia. The muscle-agonist will be the quadriceps muscle of the thigh (it carries out this movement). And the antagonist muscles will be the hip flexor muscles: biceps femoris muscle, semi-tendon, semi-membranous, tailoring, thin, popliteal, calf and plantar. (fig. ). Thus, a muscle whose action is opposite to the action of the main movement is called an antagonist. Antagonists play two important roles in muscle function: (1) they support the position of the body or limbs, for example, by holding the arm outstretched or standing up straight; and (2) they control rapid movement, as in a shadow box without hitting or being able to test limb movement.


**Picture 10.** *Agonists and synergists: The biceps muscle of the shoulder flexes the arm at the shoulder joint. The brachial radius muscle, located on the forearm, and the brachial muscle, located under the biceps muscle of the shoulder at the top of it, are synergists that help in this movement.*

There are also muscles that are not involved in the movement of the skeleton, for example, facial muscles. The beginning of the facial muscles is in the skin, so certain individual muscles contract to form any kind of emotional reaction: smile or frown, say a sound or a word, raise eyebrows. Skeletal muscles are also found in the tongue, external urinary and sphincters, which provide volitional regulation of urination and defecation, respectively.

**Features of the functional anatomy of antagonist muscles**

Why do we need muscles - antagonists? Everything is quite simple, and the answer lies in the function of skeletal muscles: they set in motion (with rare exceptions) individual bones of our skeleton. The movement is carried out on the principle of levers, that is, the muscles during their contraction are only able to pull the bone but cannot push it. As a consequence, in order for the bone base to perform actions in opposite directions (flexion and extension, for example), you need the presence of two muscles located on different sides in relation to the joint that they drive. In this case, one of the muscles will be responsible for flexion in the joint, and the other for extension. In 1925, the German scientist R. Wagner showed on experimental data that when performing movement, muscle antagonists do not always work in turn. Depending on the conditions of the external force field, the ratio of the phases of activity of the antagonist muscles changes. The complete coincidence of muscle activity with movement is observed only with movements against frictional forces. When working against the forces of inertia, the agonist muscle is active only during the first phase of the movement. Then it continues by inertia with the increasing activity of the antagonist muscle, which inhibits movement. In addition, the activity of the antagonist muscles depends on the pace of movement. If the movement is performed at a slow pace, the activity of the antagonist muscles corresponds to the phases of movement for which they are responsible: when flexing, the flexors show activity, when extending, the extensors. If you significantly increase the pace of movement, then the antagonists will act as a kind of brake: for example, at the end of the flexion phase, the extensor muscle can be activated.

There are cases when the same muscles can act as both antagonists and synergists in relation to each other. When the forearm is flexed, the round pronator muscle is a synergist of the biceps muscle of the shoulder, and when the forearm is rotated, these muscles become antagonists: the round pronator performs pronation of the forearm, and the biceps muscle performs supination.

***Chapter Overview***

Human skeletal muscles have a number of functions, among which locomotor is the main one. In their work, skeletal muscles are grouped into peculiar clusters for participation in the act of movement. Thus, three muscle groups are distinguished: agonists, antagonists and synergists. No physical action is performed in isolation by a single muscle. Several muscles always take part in the work. If several muscles are involved in the movement and they perform an action together (for example. flexion), then they are called synergistic muscles. Muscles involved in the opposite action are called antagonists.

***Questions for self-control***

1. Why are the muscles that perform multidirectional work located on different sides of the bone or joint that they set in motion?

2. Under what condition can the antagonist muscles work together?

***Glossary***

*Agonists* are skeletal muscles that perform the main work in a certain movement.

*Antagonists* are muscles that counteract agonists.

*Synergists* - these muscles act as assistants to agonists in movement, taking part of the load on themselves, or are stabilizers (fixators) of the position.

*Pronator* – muscle that performs rotation inward (to the body)

*Supinator* - the muscle that performs rotation to the outside (from the body)

***Answers to questions***

This position of the muscles is necessary for the ability to make opposite movements in the joint, since the muscles during their contraction cannot push the bone, but only pull.

The joint work of the muscles of antagonists is possible when working against frictional forces, or at a fast pace of movements.

## THE ORGANIZATION OF MUSCLE BUNDLES AND THEIR ROLE IN MUSCLE STRENGTH

**Features of the organization of muscle bundles**

Skeletal muscle is enclosed in a connective tissue sheath on three levels. Each muscle fiber (cell) is covered with endomysium, and the entire muscle is covered with epimysium. When a group of muscle fibers "binds" into a single unit within the entire muscle, it is called a bundle. The bundles are covered with a layer of connective tissue called perimysium (see Figure 11). The arrangement of the bundles correlates with the force created by the muscle and affects the range of motion of the muscle. Skeletal muscle can be classified by the arrangement of the bundles in several ways. Below are the most common options for arranging the beams.

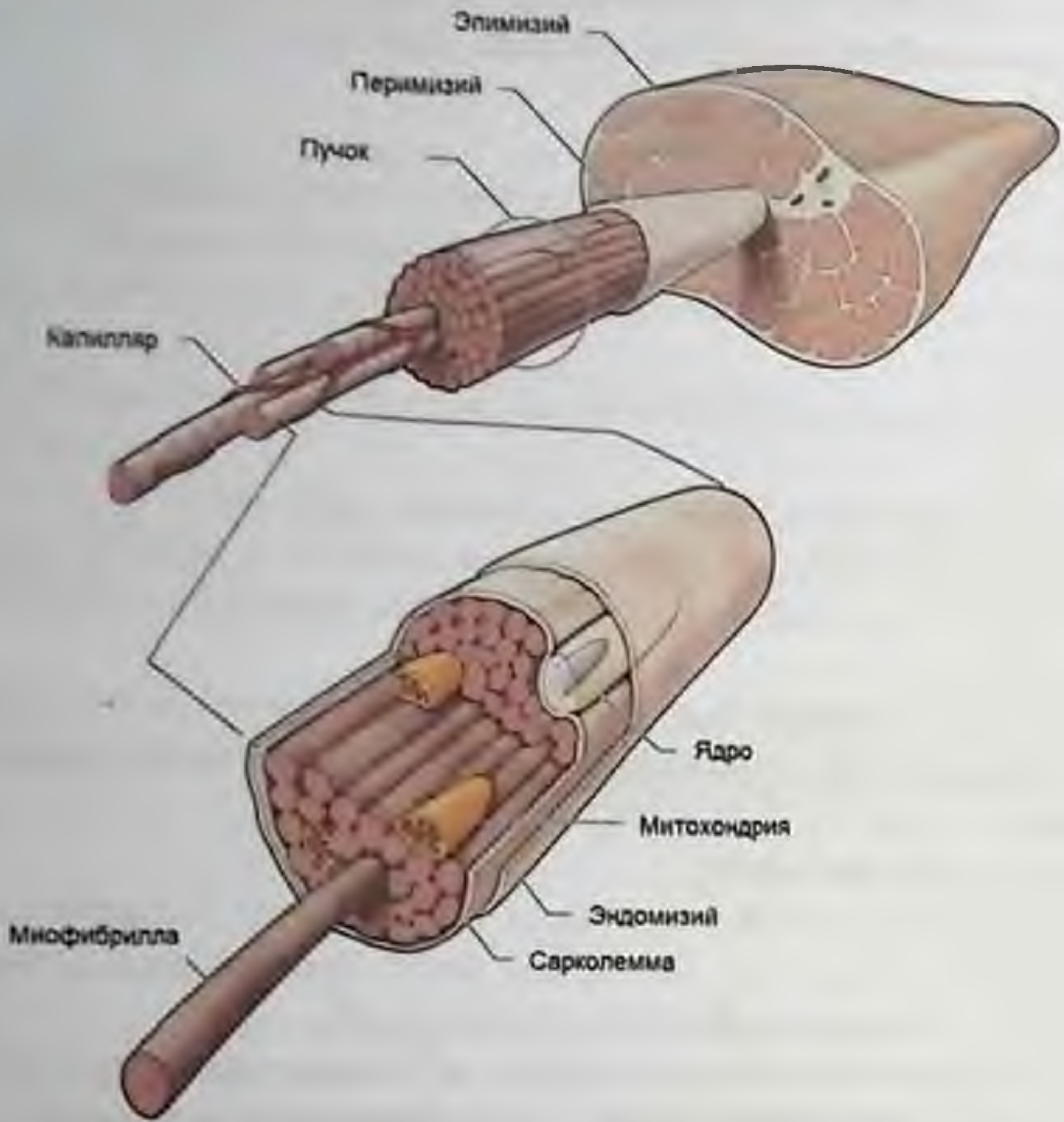



**Figure 11.** *Connective tissue membranes of muscle bundles*

Parallel muscles have bundles arranged in the same direction as the long axis of the muscle (Fig. 12). Most skeletal muscles in the body have this type of organization. Some parallel muscles are flat sheets that expand at the ends to create wide attachments, such as sartorius. Other parallel muscles have a large central area called the muscular abdomen tapering to tendons at each end. This arrangement is called fusiform, as in the biceps muscle of the shoulder

Circular muscles are also called sphincters (see Figure 12). When they relax, the concentrically arranged bundles of sphincter muscle fibers increase the size of the hole, and when they contract, the size of the hole decreases to the closing point. The circular muscle of Orbicularis oris is a circular muscle that runs around the mouth. When it contracts, the mouth opening becomes smaller, as, for example, when squeezing the lips to whistle.

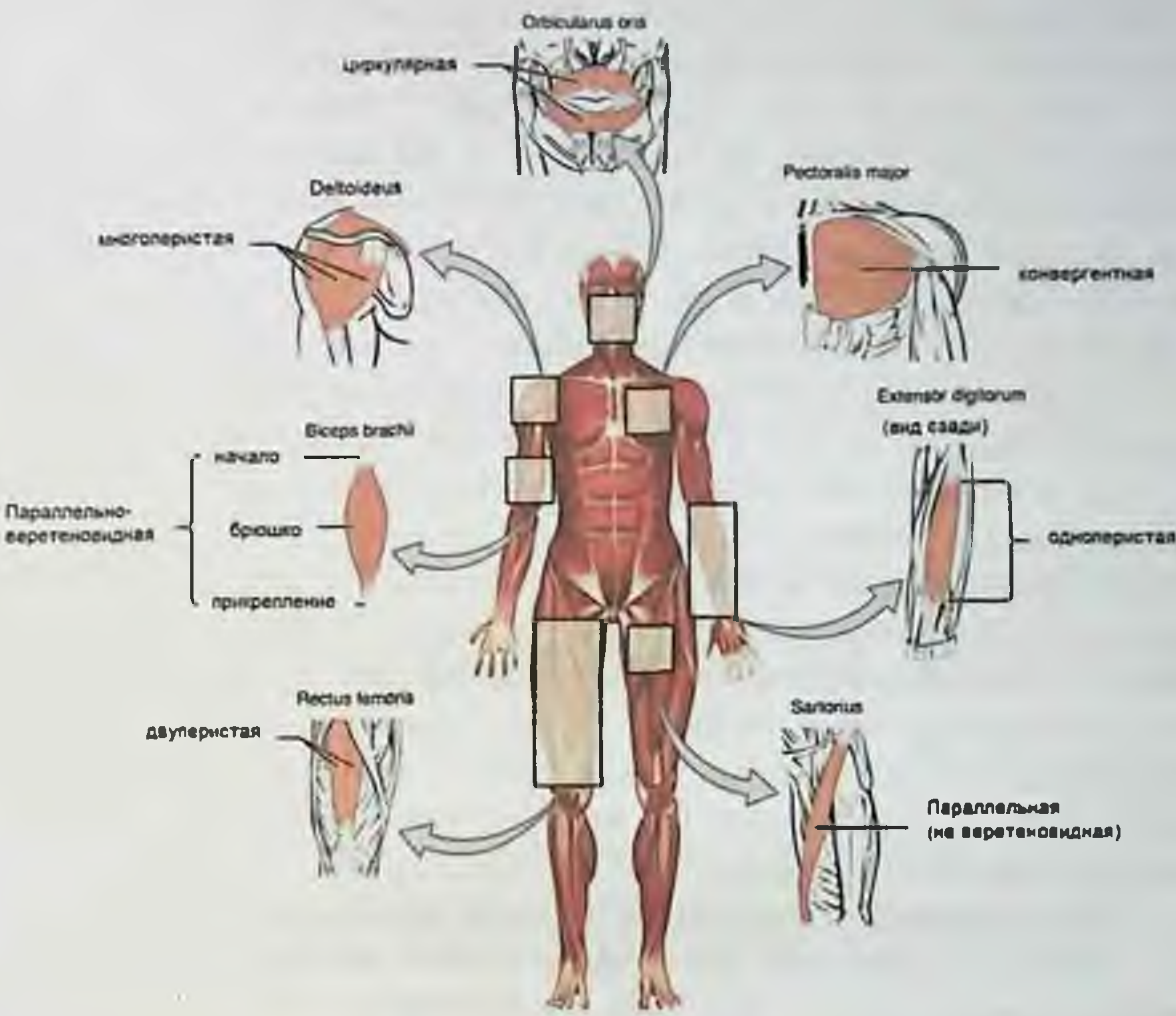



**Figure 12.** *Muscle variants by fiber arrangement: The skeletal muscles of the body usually have seven different shapes.*

Another example is the circular eye muscle, one of which surrounds each eye. Consider, for example, the names of two circular muscles (orbicularis oris and orbicularis oculi), where part of the first name of both muscles is the same. The first part of the word orbicularis, orb (orb = "round"), refers to a circular or circular structure; it can also make you think about the orbit, for example, about the path of the Moon around the Earth. The word oris ("oral") refers to the oral cavity, or mouth. The word oculi ("eye") refers to the eye.

When a muscle has a widespread over a large area, and the bundles converge to one common attachment point, the muscle is called convergent. The site of attachment of the convergent muscle can be a tendon, aponeurosis (flat, wide tendon) or brine (a very thin tendon). A large muscle on the chest, pectoralis major, is an example of a convergent muscle because it converges on the intertubercular sulcus and the large tubercle of the humerus through the tendon (see Figure 12).

Cirrus muscles, mm. pennaty, (penna - "feathers") fuse with a tendon that runs through the central part of the muscle along its entire length, which resembles a feather, and the muscle bundles are arranged like feathers. Because of this design, the muscle fibers in the oblique muscles can only stretch at an angle, and as a result, the contracting oblique muscles cannot move their tendons very far. However, since the knee muscle usually holds more muscle fibers, it can produce a relatively greater voltage for its size. There are three subtypes of knee muscles.

In a single-pinnate muscle, the bundles are located on one side of the tendon. The extensor of the fingers of the forearm is an example of a single-pinnate muscle. In the biceps muscle, such as the rectus femoris muscle, the bundles are arranged on either side of the tendon, like a single feather. Multidimensional muscles have bundles located on several tendons tapering to a common tendon, similar to several feathers converging to a central point. A common example is the deltoid muscle of the shoulder, which covers the shoulder but has a single tendon that is inserted into the deltoid tubercle of the humerus.

**Lever system of interaction between muscles and bones**

Skeletal muscle does not work on its own. Muscles are arranged in pairs depending on their functions. For muscles attached to the bones of the skeleton, the joint determines the strength, speed, and amplitude of movement. These characteristics depend on each other and can explain the overall organization of the muscular and skeletal systems.

The skeleton and muscles work together to move the body. Have you ever used the back of a hammer to pull a nail out of wood? The handle acts as a lever, and the hammer head acts as a fulcrum, a fixed point to which force is applied when you pull or press the handle. The force applied to this system is pulling or pressing on the handle to extract the nail, which is a load, or "resistance" to the movement of the handle in the system. Our musculoskeletal system works in a similar way: the bones are rigid levers, and the articular endings of the bones, enclosed in the synovial joints, act as support points. A load is a liftable object or any resistance to movement (your head is a weight when you lift it), and an effort, or applied force, occurs when skeletal muscle contracts.

***Chapter Overview***

Skeletal muscle has a beginning and an end. The end of the muscle that attaches to the bone being pulled is called the tail, and the end of the muscle attached to the immobile, or stabilized, bone is called cooking. Between them is the abdomen, represented by muscle tissue. The muscle that is primarily responsible for movement is called the primary mover, and the muscles that help in this action are called synergists. The synergist that makes the insertion site more stable is called a retainer. A muscle whose action is opposite to that of the primary propulsion is called an antagonist. The strength created by skeletal muscle depends on several factors. One is the arrangement of bundles in skeletal muscle. The bundles can be parallel, circular, convergent, oblique, spindle or triangular. Each location has its own range of motion and ability to do the job.

***Questions for self-control***

1. What effect does the location of the bundles have on the action of the muscle?

2. How muscle bundles set the joints in motion. Describe how the muscles around the joints of the body are arranged.

3. Explain how the synergist helps the agonist by being a fixative.

***Glossary***

*abduction* - deviation from the midline in the sagittal plane

*abdomen* - voluminous central body of the muscle

*biceps* - a muscle that has bundles located on either side of the tendon

*circular* - (also sphincter) bundles, concentrically arranged around the opening

*bundle* - muscle fibers united by perimysium into a single whole

*fixative* – synergist that helps the agonist by preventing or reducing movement in the other joint, thereby stabilizing the onset of the agonist

*flexion* – movement that reduces the angle in the joint

*spindle* - *a* muscle whose bundles have a spindle shape and create large abdomens

*tail* – the end of skeletal muscle (tendon) that is attached to the structure (usually bone) moved by muscle contraction

*multiple heads muscle* - *multiple heads muscle*, inside which the tendon branches

*onset* – an element of skeletal muscle (tendon) that attaches to another structure (usually bone) in a fixed position

*parallel* - bundles that stretch in the same direction as the long axis of the muscle *unipennate* - the knee muscle, in which the bundles are located on one side of the tendon

***Answers to questions***

1. The location of the bundles determines what movement the muscle can make. For example, circular muscles act as sphincters, closing holes.

2. Muscles work in pairs to facilitate the movement of bones around the joints. Agonists are the primary driving forces, while antagonists resist or resist the movements of the agonists. Synergists help agonists, and fixators stabilize the muscular onset.

3. Agonists are the primary driving forces, while antagonists resist or resist the movements of the agonists. Synergists help agonists, and fixators stabilize the beginning of the muscle.

## EXPLANATION OF THE CRITERIA USED TO NAME SKELETAL MUSCLE

To understand the vocabulary of anatomy and physiology, it is very important to take the time to study the Latin and Greek roots of words. When you understand the names of the muscles, it will help you remember where they are located and what they do (Fig. 13).

Anatomists give names to skeletal muscle according to a number of criteria, each of which describes the muscle in a certain way. These include the name of a muscle by its shape, size, fiber direction, location, number of origins, or action.

The names of some muscles reflect their shape. For example, the deltoid muscle is a large triangular muscle that covers the shoulder. It is so named because the Greek letter delta is a triangle.

The anatomical location of skeletal muscle or its association with a particular bone often determines its name. For example, the frontal muscle is located at the apex of the frontal bone of the skull. Another example is the muscles of the arm, the name of which includes the term brachii (arm).

For gluteal muscles, size influences the names: gluteus maximus (largest), gluteus medius (medium), and gluteus minimus (smallest). Another example is the pectoral muscles, including the large or small muscles.

Names are often used to denote length - brevis (short), longus (long).

Some muscle names denote their position relative to the midline: lateralis (outward from the midline) and medialis (towards the midline).

Often used to describe the muscle direction of muscle fibers and bundles. For example, for all abdominal muscles, the direction of the fibers is indicated: straight (vertically arranged fibers), oblique (at an angle) and transverse (horizontal) abdominal muscles.

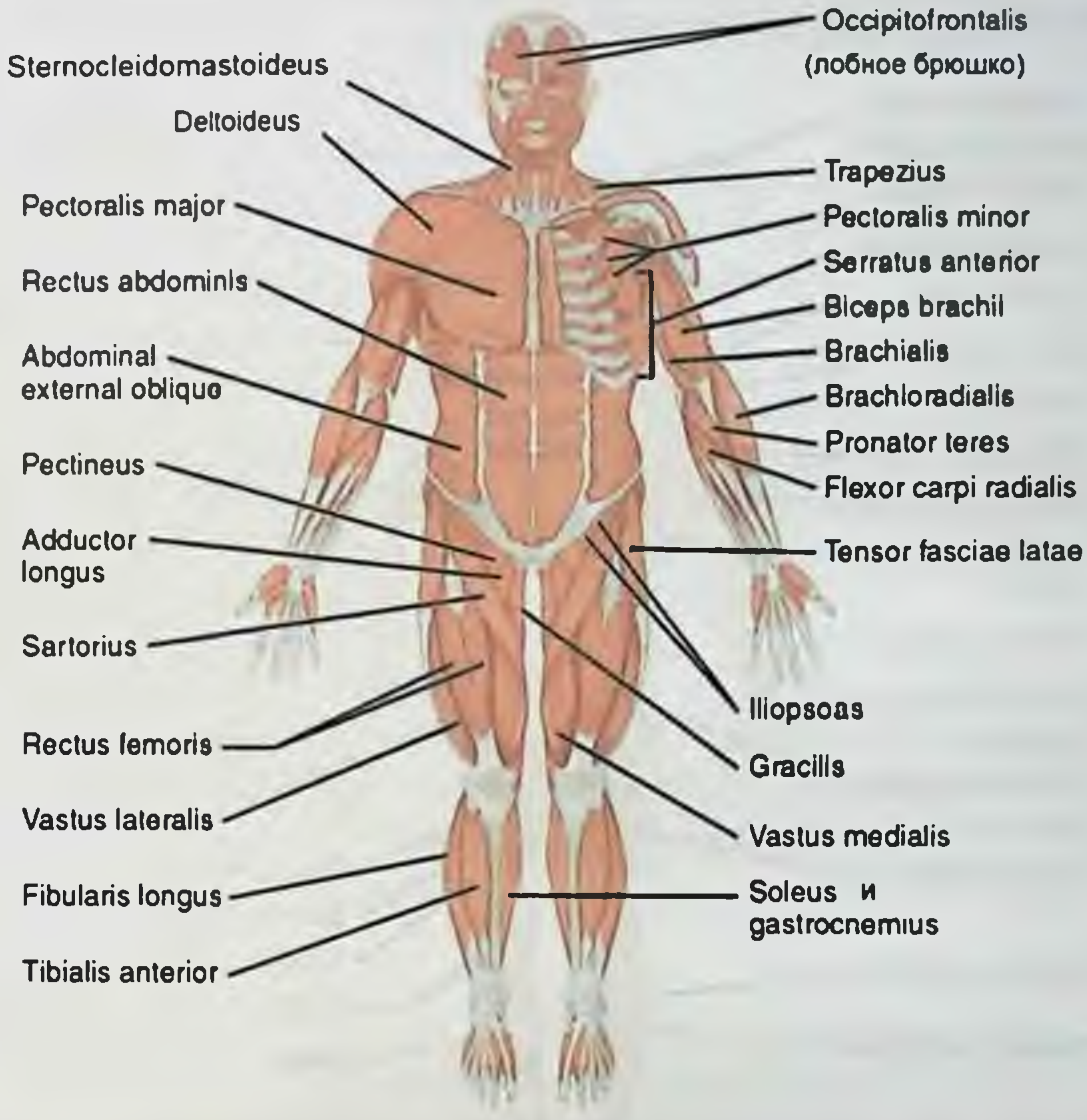



**Figure 13.** *Muscles of the front surface of the human body. Large superficial (left) and deep (right) muscles of the anterior surface of the body are represented.*

Some names indicate the number of muscles in the group. For example, a quadriceps is a group of four muscles located on the anterior (anterior) surface of the thigh.

Other muscle names may contain information about how many origins a particular muscle has, such as biceps brachii. The prefix bi indicates that the muscle has two beginnings, and tri has three beginnings.

The place of attachment of the muscle can also be indicated in its name. When the name of a muscle is based on its attachment, the place of its attachment is always indicated first. For example, the sternocleidomastoid muscle of the neck has a double origin - from the sternum (sterno) and clavicle (cleido) and attaches to the mastoid process of the temporal bone (mastoideus).


**Figure 14.** *Review of the large muscles of the back of the human body: superficial muscles (those that are on the surface) are shown on the right side of the body, and deep muscles (those that are under the superficial muscles) are shown on the left half of the body. For the legs, the superficial muscles are shown in the foreground, and both the superficial and deep muscles are visible in the background.*

The last sign by which you can call a muscle is its action. When muscles are named for the movement they produce, words for action can be found in their name. For example, flexors - flexores (decreasing the angle in the joint), extensors - extensores (increasing the angle in the joint), abductors - abductores (moving the bone from the midline) or adductors - adductores (moving the bone to the midline), rotators - rotatores.

***Chapter Overview***

Muscle names are based on many characteristics. The location of the muscle in the body is of great importance. Some muscles are named depending on their size and location, such as the gluteal muscles. Other muscle names may indicate a location in the body or bones to which a muscle is associated, such as the anterior tibial muscle. Some muscles have a characteristic shape; for example, the direction of muscle fibers is used to describe the muscles of the midline of the body. The beginning and / or insertion may also be signs used to name the muscle; examples include the biceps muscle of the shoulder, the triceps muscle of the shoulder, and the greater pectoral muscle.

***Questions for self-control***

1. Describe the various criteria that contribute to the naming of skeletal muscle.

***Glossary***

*abductor* - moves the bone away from the midline
*adductor* - moves the bone to the midline
*bi* - two
*brevis* - short
*extensor* - the muscle that increases the angle in the joint
*flexor* - muscle that reduces the angle in the joint
*lateral* - outward
*longus*- long
*maximus* - the largest
*medialis* – located closer to the inside
*medius* - medium
*minimus* - smallest
*oblique* – located obliquely
*rectus* - direct

***Answers***

In anatomy and physiology, many words have Latin or Greek roots. The parts, or roots, of words give us clues about the function, shape, action, or location of a muscle.

## SYSTEMIC REVIEW OF MUSCLE ANATOMY

Skeletal muscles are divided into axial (muscles of the trunk and head) and appendicular (muscles of the arms and legs). This system reflects the bones of the skeletal system, which are also arranged in a similar way. Some of the axial muscles may seem vague as they pass into the appendicular skeleton. The first group of axial muscles you will consider includes the muscles of the head and neck, then you will consider the muscles of the spinal column and finally the oblique and rectus muscles.

## MUSCLES OF THE HEAD, NECK, AND BACK

**Facial muscles**

Mimic muscles. These muscles originate from the surface of the skull or fascia (connective tissue) of the face. A distinctive feature of this muscle group is that in the places of attachment, their fibers are intertwined with the connective tissue and dermis of the skin. Because muscles are attached to the skin rather than bone, when they contract, the skin shifts to create our facial expressions (Fig. 15).

M. orbicularis oris, the circular muscle that moves the lips, and m. orbicularis oculi, the circular muscle that covers the eye. The occipitofrontalis muscle lifts the scalp and eyebrows. The muscle has a frontal abdomen and an occipital abdomen (near the occipital bone at the back of the skull). In other words, there is a muscle on the forehead (frontal) and on the back of the head (occipital). These two abdomens are connected by a wide tendon called supracranial aponeurosis, or a Gal helmet (galea, "apple"). Doctors who originally studied human anatomy believed that the skull looked like an apple.

M. buccinator, the buccal muscle, sets our cheek in motion. This muscle allows you to whistle, blow and suck, and also promotes chewing. There are several small facial muscles, one of which is the corrugator supercilia muscle, the wrinkling eyebrow that drives the eyebrows. Place your finger on your eyebrows at the bridge of your nose. Raise your eyebrows as if you are surprised and lower your eyebrows as if you are frowning. With these movements, you can feel the action of the eyebrow arch corrugator supercilia. Muscle, the lowering eyebrow, m. depressor supercilia, comes from the medial edge of the frontal abdomen of the occipital-frontal muscle and attaches to the skin of the back of the nose; often absent. The muscle of the proud, m. procerus, begins from the root of the nose and the aponeurosis of the nasal muscle, m. nasalis, attaches to the skin of the glabella, connecting with the frontal abdomen of the occipital-frontal muscle.

To study all the facial muscles in more detail, you will have to refer to an anatomy textbook.

Often students make the mistake of considering the facial muscles to be the only representatives of the facial muscles. That's not the case at all. After all, there are still muscles of the eyeball, ear, tongue, palate. Next, we'll touch a little bit on individual groups.


**Fig.15.** *Facial muscles, front view*

1 - tendon helmet; 2 - frontal abdomen of the occipital-frontal muscle; 3 - the muscle that wrinkles the eyebrow; 4 - the muscle that raises the upper lip; 5 - the muscle that raises the corner of the mouth; 6 - masticatory muscle; 7 - buccal muscle; 8, 12 - the muscle that lowers the corner of the mouth; 9 - chin muscle; 10 - the muscle that lowers the lower lip; 11 - circular muscle of the mouth; 13 - the muscle of laughter; 14 - large zygomatic muscle; 15 - small zygomatic muscle; 16 - circular eye muscle; 17 - medial age bundle; 18 - muscle of the proud

**Muscles that drive the eyeball**

The movement of the eyeball is controlled by the extraocular (extraocular, external) muscles of the eye, which originate from the bones of the orbit and exit to the outer surface of the sclera, the white membrane of the eye. These muscles are located inside the eye socket and are not visible on the visible part of the eyeball (Fig. 16). If you've ever been to a doctor who has lifted a finger and asked you to follow it up, down, and both, he's checking to see how coherent your eye muscles are.

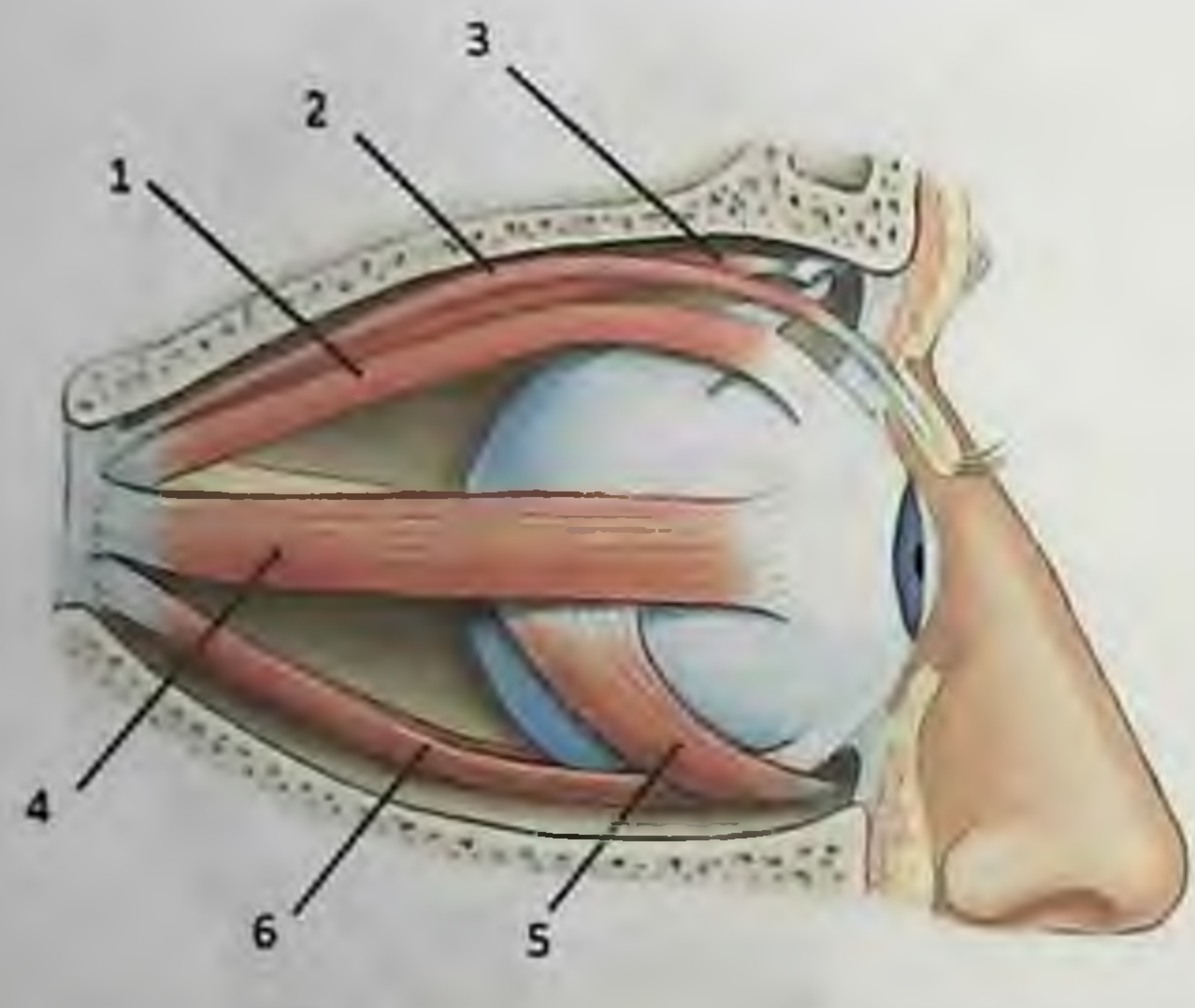



**Figure 16.** *Muscles of the eyeball (oculomotor muscles), side view: 1 - upper rectus muscle; 2 - the muscle that raises the upper eyelid; 3 - upper oblique muscle; 4 - lateral rectus muscle; 5 - lower oblique muscle; 6 - lower rectus muscle*

To move the eye, six muscles are attached to it. These muscles originate in the eye socket (orbit) and work to move the eye up, down, from side to side and rotate the eye.

The rectus upper muscle is a muscle that attaches to the top of the eye. It moves the eye up. The inferior rectus muscle is a muscle that attaches to the lower part of the eye. It moves the eye down. The medial rectus muscle is a muscle that attaches to the side of the eye near the nose. It moves the eye inward towards the nose. The lateral rectus muscle is a muscle that attaches to the lateral side of the eye near the temple. It moves the eye outward.

The oblique upper muscle is the muscle that exits the back of the orbit. It passes through a small block (trochlea) in orbit near the nose and then attaches to the top of the eye. The upper oblique muscle turns the eye inward around the long axis of the eye (from front to back). The upper oblique also moves the eye down.

The inferior oblique muscle is a muscle that originates in the front of the orbit near the nose. It then moves in orbit outward and backward before attaching to the bottom of the eyeball. It turns the eye outward along the long axis of the eye (from front to back). The lower oblique also moves the eye upwards.

In the thickness of the temporal bone of the skull are two muscles attached to the auditory ossicles. They regulate the movements of the bones and protect them from excessive vibrations during a strong sound. The muscle that strains the eardrum (m. tensor tympani) is located in the semi-channel of the same name. The tendon of this muscle is attached to the initial part of the hammer handle. The stirrup muscle (m. stapedius), starting inside the pyramidal elevation, attaches to the posterior leg of the stirrup, near its head. Contractions of the stirrup muscle regulate the pressure of the base of the stirrup on the window of the pre-movement.

**Masticatory muscles**

The muscles involved in chewing must be able to exert enough pressure to bite through and then chew food before swallowing. Masticatory muscle, m. masseter, is the main masticatory muscle because it raises the lower jaw to close the mouth, and it is aided by the temporal muscle, which extends the lower jaw. You can feel the movement of the temporal muscle by placing your fingers on the temple while chewing. The medial pterygoid and lateral pterygoid muscles help chew and move food in the mouth by moving the lower jaw laterally and medially to grind food between the molars.

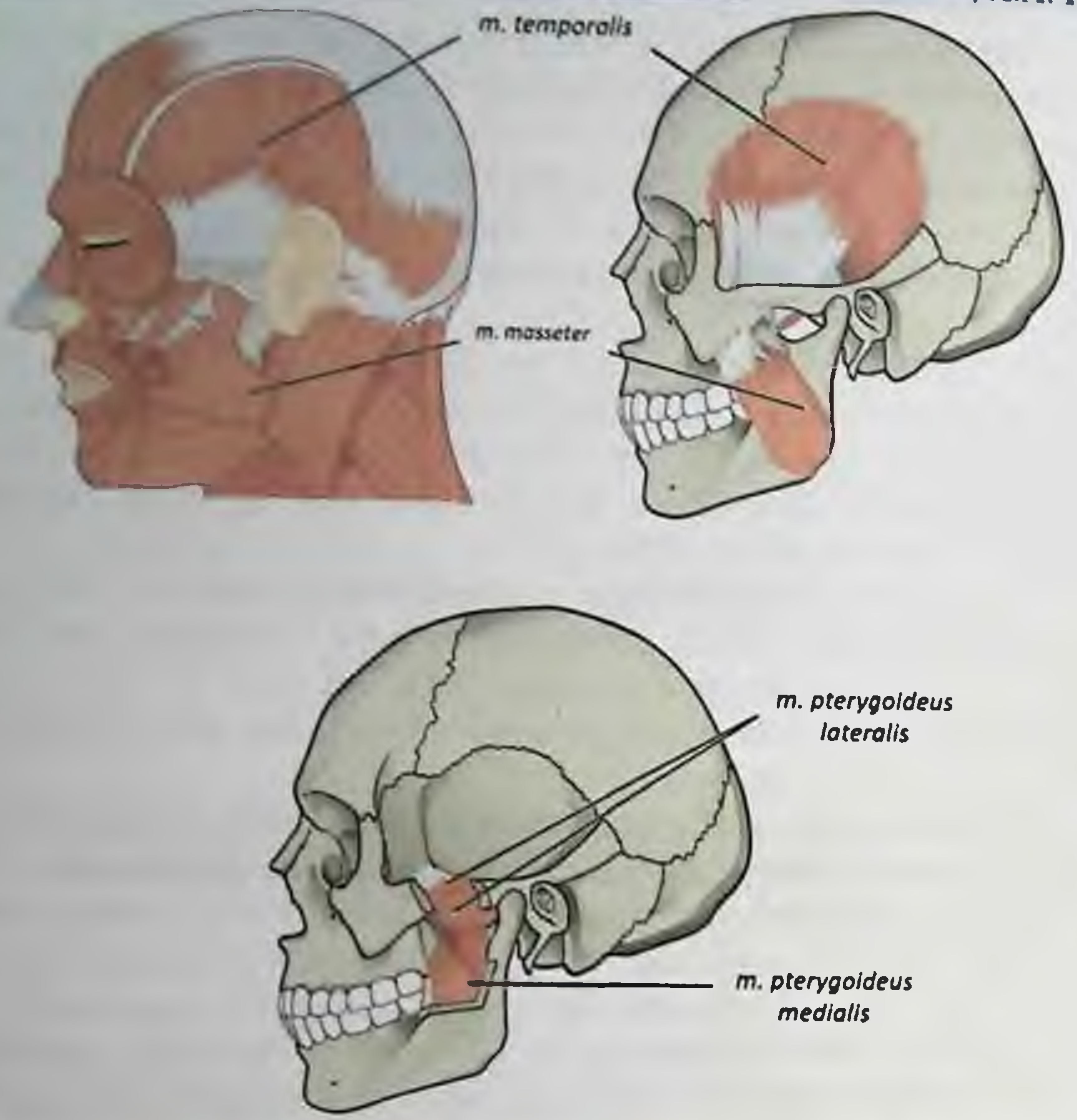



**Figure 17.** *Masticatory, temporal, and pterygoid muscles*

**Muscles that move the tongue**

While tongue is certainly important for tasting food, it is also essential for chewing, swallowing, and speaking (Fig. 18). Due to its mobility, the language facilitates the pronunciation of complex speech patterns and sounds.

The muscles of the tongue can be external (skeletal) or internal (own). The skeletal muscles of the tongue connect the tongue to the bones of the skeleton, and the internal muscles of the tongue are located inside. External muscles move the entire tongue in different directions, and the internal muscles allow the tongue to change its shape (for example, twisting the tongue into a loop or flattening it).

All skeletal muscles of the tongue include the root of the word glossus (glossus = "tongue"), and the names of the muscles come from where they originated. Genioglossus (genio, "chin") originates on the lower jaw and allows the tongue to move down and forward. Styloglossus originates on the awl process of the temporal bone (processus styloideus) and provides upward and backward movement of the tongue. Palatoglossus originates on the soft palate (palatum) and raises the back of the tongue, while hyoglossus originates on the hyoid bone (os hyoideum) and moves the tongue down, flattening it.

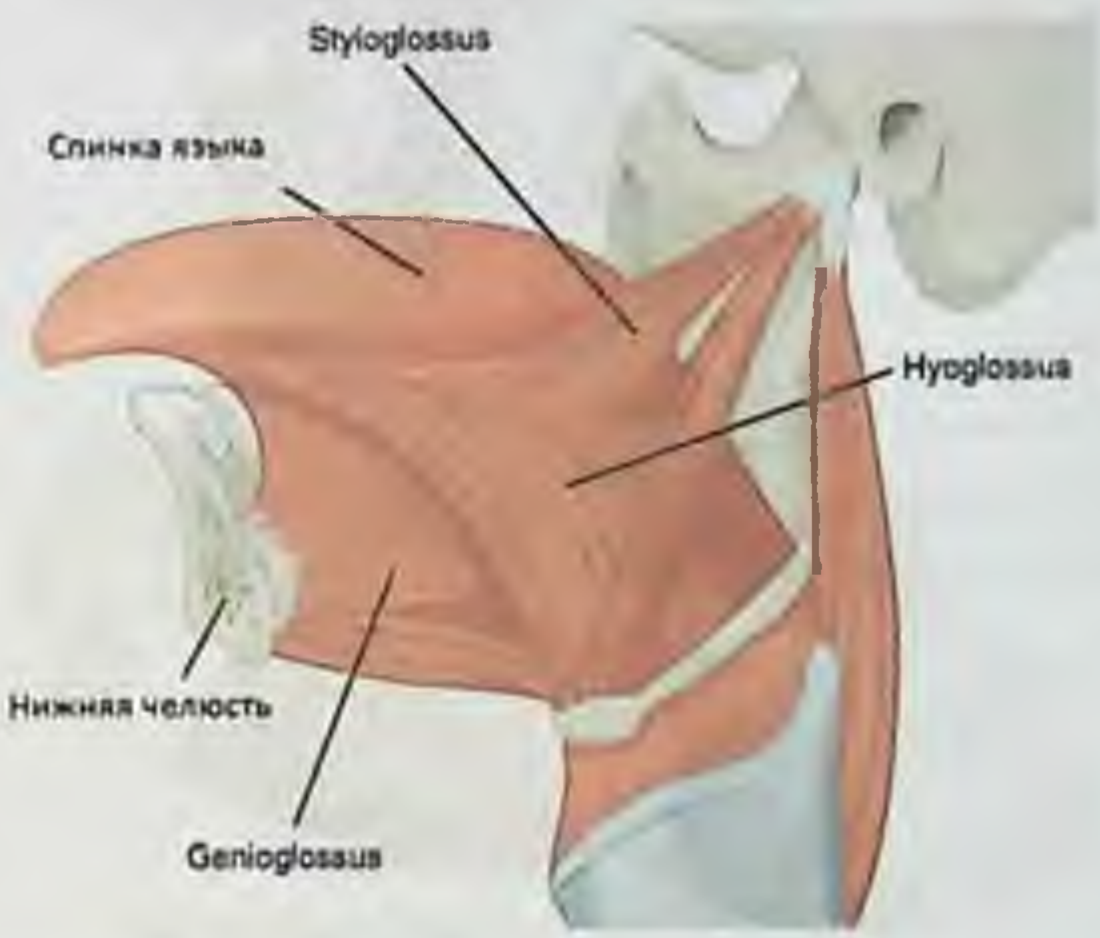



**Figure 18.** *Skeletal muscles of the tongue*

**Muscles of the anterior neck**

The muscles of the front of the neck help with swallowing and speech, controlling the position of the larynx (vocal apparatus) and the hyoid bone - a horseshoe-shaped bone that serves as the basis for the muscles that provide tongue movements. The muscles of the anterior surface of the neck are classified according to their position relative to the hyoid bone (Fig. 19). The supralingual muscles are above it, and the sublingual muscles are below.

*The supralingual muscles* raise the hyoid bone, the floor of the mouth, and the larynx during swallowing. These include the digastric muscle, which has an anterior and posterior abdomen that raises the hyoid bone and larynx when swallowing; it also lowers the lower jaw. M. stylohyoideus moves the hyoid bone back, raising the larynx, and the maxillofacial muscle, m. mylohyoideus, raises it and helps press the tongue against the palate. Chin-hyoid muscle, m. geniohyoideus, lowers the lower jaw, raises, and pulls the hyoid bone anteriorly.

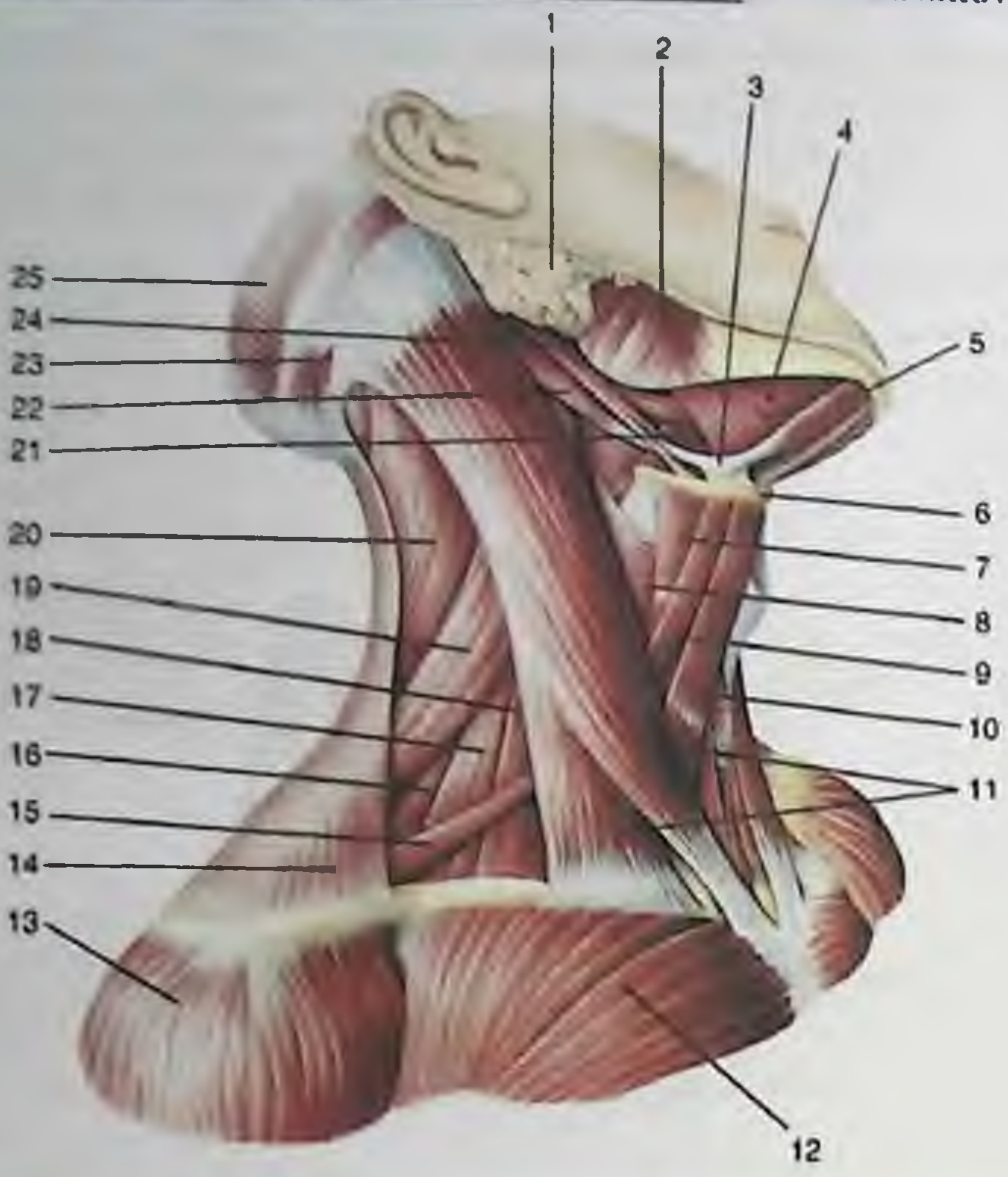



**Figure 19.** *Muscles of the neck, view on the right. Explanation:*

*1 - parotid salivary gland; 2 - masticatory muscle; 3 - tendon of the digastric muscle; 4 - maxillo-sublingual muscle; 5 - anterior abdomen of the digastric muscle; 6 - hyoid bone; 7 - thyroid sublingual muscle; 8 - lower pharyngeal constrictor; 9 - upper abdomen of the scapulo-sublingual muscle; 10 - sternum-sublingual muscle; 11 - heads of the sternocleidomastoid muscle; 12 - large pectoral muscle; 13 - deltoid muscle; 14 - trapezius muscle; 15 - lower abdomen of the scapulo-sublingual muscle; 16 - posterior ladder muscle; 17 - middle ladder muscle; 18 - anterior ladder muscle; 19 - the muscle that lifts the scapula; 20 - belt muscle of the head; 21 - sublingual-lingual muscle; 22 - posterior abdomen of the digastric muscle; 23 - transverse neck muscle; 24 - awl-sublingual muscle; 25 - occipital abdomen of the occipital-frontal muscle*

*The sublingual muscles* lower the hyoid bone and move the larynx. The scapulo-sublingual muscle, m. omohyoideus, which has an upper and lower abdomen, lowers the hyoid bone together with the sternocleidomastoid muscle. The thyroid muscle, m. thyrohyoideus, also raises the thyroid cartilage of the larynx, while the sternoclavicular muscle, m. sternothyroideus, lowers it.


**Figure 20.** *Internal (medial, M) and external (lateral, L) neck triangles*

**Muscles that drive the head**

The head is balanced, moved and rotated with the help of the muscles of the neck. When these muscles act unilaterally, the head turns. When they contract bilaterally, the head tilts or rises. The main muscle that tilts the head to the side and rotates is the sternocleidomastoideus, m. sternocleidomastoideus. If both muscles contract, the head is tilted forward. Therefore, this muscle is called the nodding muscle. Place your fingers on both sides of the neck and turn your head left and right. You will feel that the movement is coming from there. This muscle divides the neck into medial and lateral triangles (Fig. 20, 21).

Finally, the ladder muscles work together to flex, laterally flex, and rotate the head. They also promote a deep breath. The ladder muscles include the anterior muscle, the middle muscle (the longest, intermediate muscle between the anterior and posterior muscles), and the posterior muscle (the smallest).

**Muscles of the back of the neck and back**

In anatomy, the neck is called only the front part of the biological neck, the back part refers to the upper region of the back. The posterior muscles of the neck are mainly associated with head movements, for example, the cervical part of the spine is extended. The muscles of the back stabilize and move the spinal column and are grouped depending on the length and direction of the bundles.

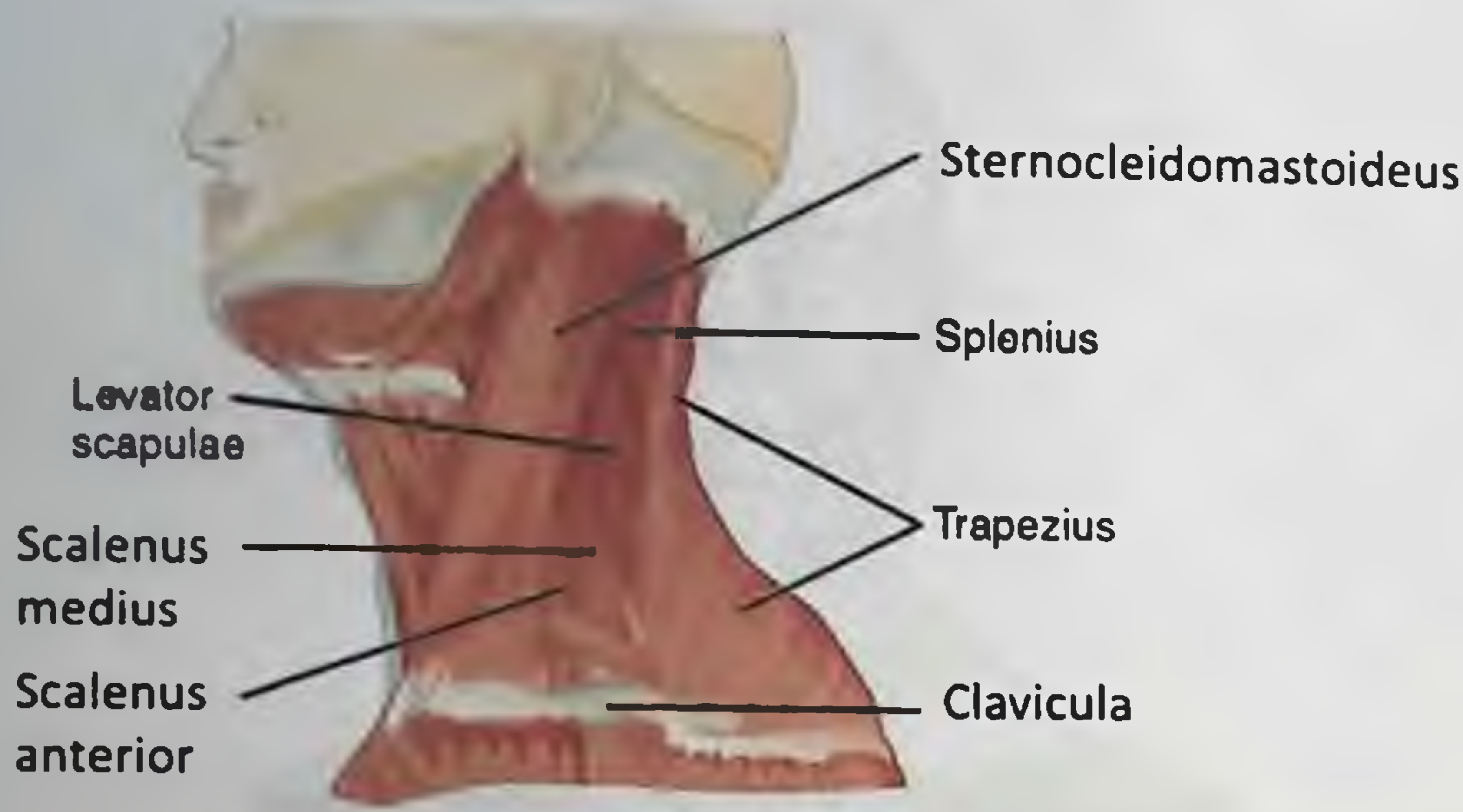



**Figure 21.** *Neck and back muscles on the side*

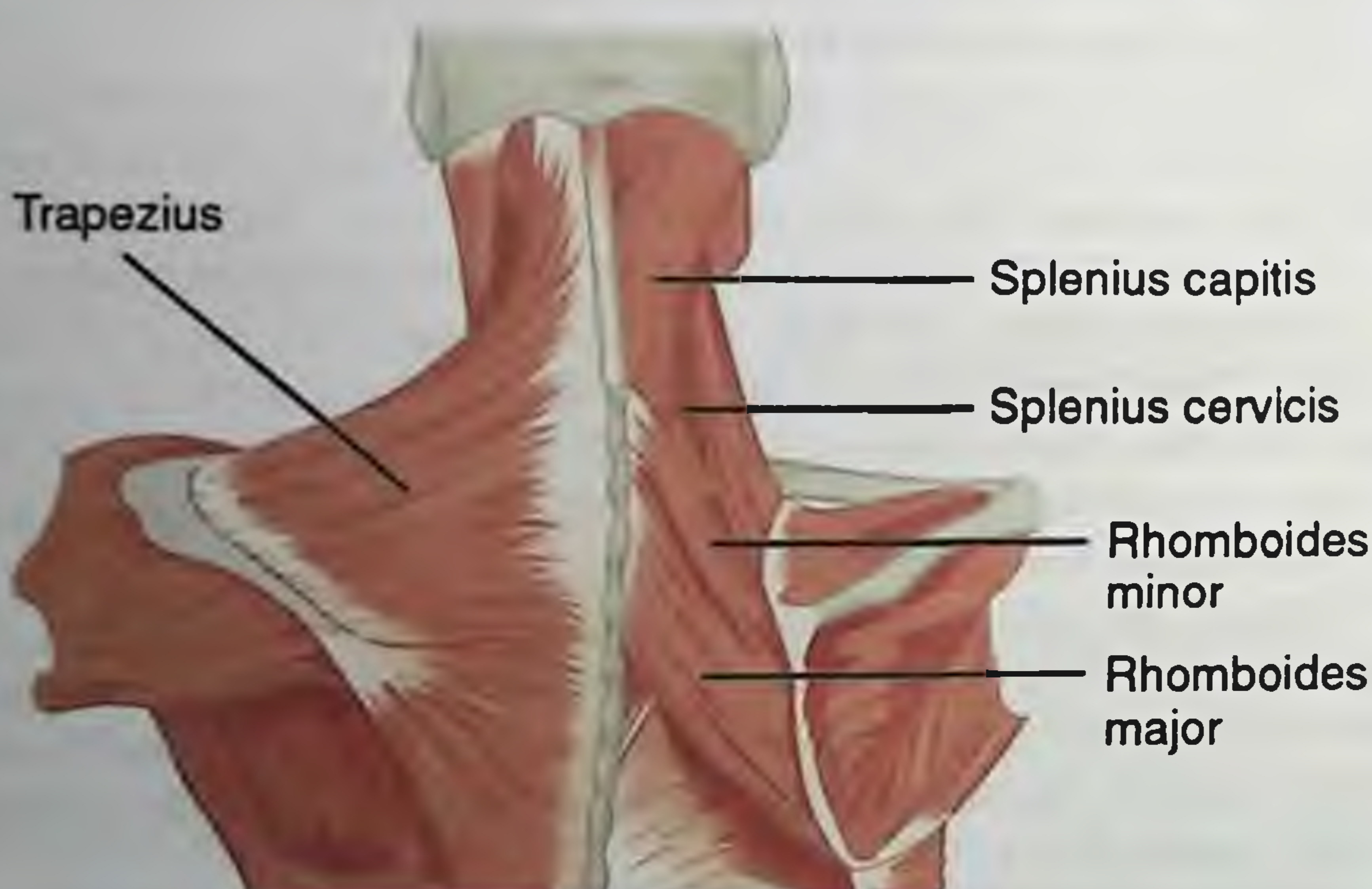



**Figure 22.** *Muscles of the back of the neck and back*

The strap muscles of the head, m. splenius capitis, and neck, m. splenius cervicis, originate in the midline and go laterally and higher to the sites of attachment: to the mastoid process of the temporal bone and to the occipital bone. From the sides and back of the neck, splenius capitis attaches in the head area, and splenius cervicis ends in the cervical region, attaching to the posterior tubercles of the transverse processes of the two or three upper cervical vertebrae (Fig. 22). These muscles can extend the cervical spine and head and rotate it.

The muscle that straightens the spine (m. erector spinae) is the most powerful of the autochthonous muscles of the back, which is located along the entire length of the spine from the sacrum to the base of the skull (Fig. 23). Its fibers make up most of the muscle mass of the back and is the main extensor of the spinal column. It controls the extension, lateral flexion and rotation of the spinal column, and also supports lumbar flexion. Starting from the level of the I-II lumbar vertebrae, the muscle that straightens the spine is divided into 3 tracts: lateral, intermediate and medial. The lateral tract is called the ilio-costal muscle, the intermediate - the longest muscle, the medial - the spinous muscle. So, erector spinae include the group iliocostalis (located laterally), the group longissimus (located intermediately) and the group spinalis (located medially).

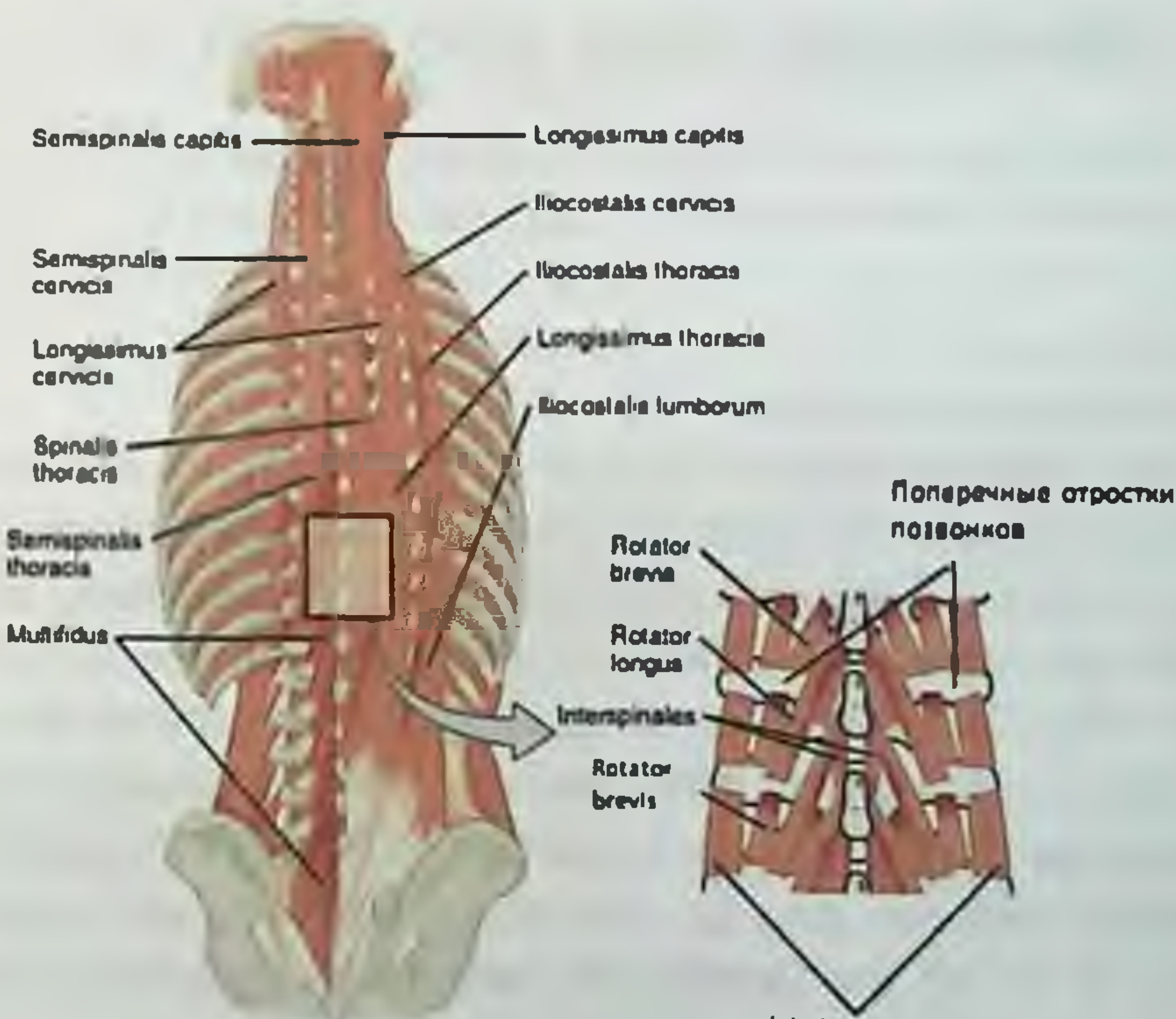



**Figure 23.** *Deep back muscles*

The group of iliac muscles includes the cervical iliac muscle associated with the cervical region; the pectoral iliac muscle associated with the thoracic region; and the lumbar iliac muscle associated with the lumbar region. The three muscles of the longissimus group are longissimus capitis, associated with the head area; longissimus cervicis associated with the cervical region; and longissimus thoracis, associated with the thoracic region. The third group, the spinal muscle group, includes the dorsal muscle of the head (spinalis capitis), the cervical muscle (spinalis cervicis), and the pectoral muscle (spinalis thoracis).

Transverse muscles go from the transverse processes to the spinous processes of the vertebrae. Like erector spinae muscles, the semi-spinous muscles of this group are named after the areas of the body with which they are connected. Semi spinous muscles include the semi-spinous muscle of the head, the semi-membranous neck muscle and the semi-membranous pectoral muscle. The multidimensional muscle of the lumbar spine helps to extend and bend the spinal column to the side.

Important in stabilizing the spinal column is the segmental muscle group, which includes the interspinous and intertransverse muscles. These muscles connect the spinous and transverse processes of each subsequent vertebra.

## ABDOMINAL WALL AND CHEST MUSCLES

Balancing on two legs and walking upright is a difficult task. The muscles of the spinal column, chest and abdominal wall extend, flex and stabilize various parts of the trunk. The deep muscles of the body help maintain posture and also provide stability when moving the limbs.

**Abdominal muscles**

The abdominal wall consists of four pairs of muscles: the rectus abdominis muscle, the external oblique abdominal muscles, the internal oblique abdominal muscles, and the transverse abdominal muscle.

On the anterolateral wall of the abdomen are three flat skeletal muscles (Fig. 24). The outer obliques, located closest to the surface, their fibers extend downward and medially, in the direction that our four fingers in the pockets of our trousers would have. Perpendicular to it is the internal oblique muscle, extending upwards and medially, in the direction in which the thumbs are usually located, when the remaining fingers are in the pocket of the trousers.

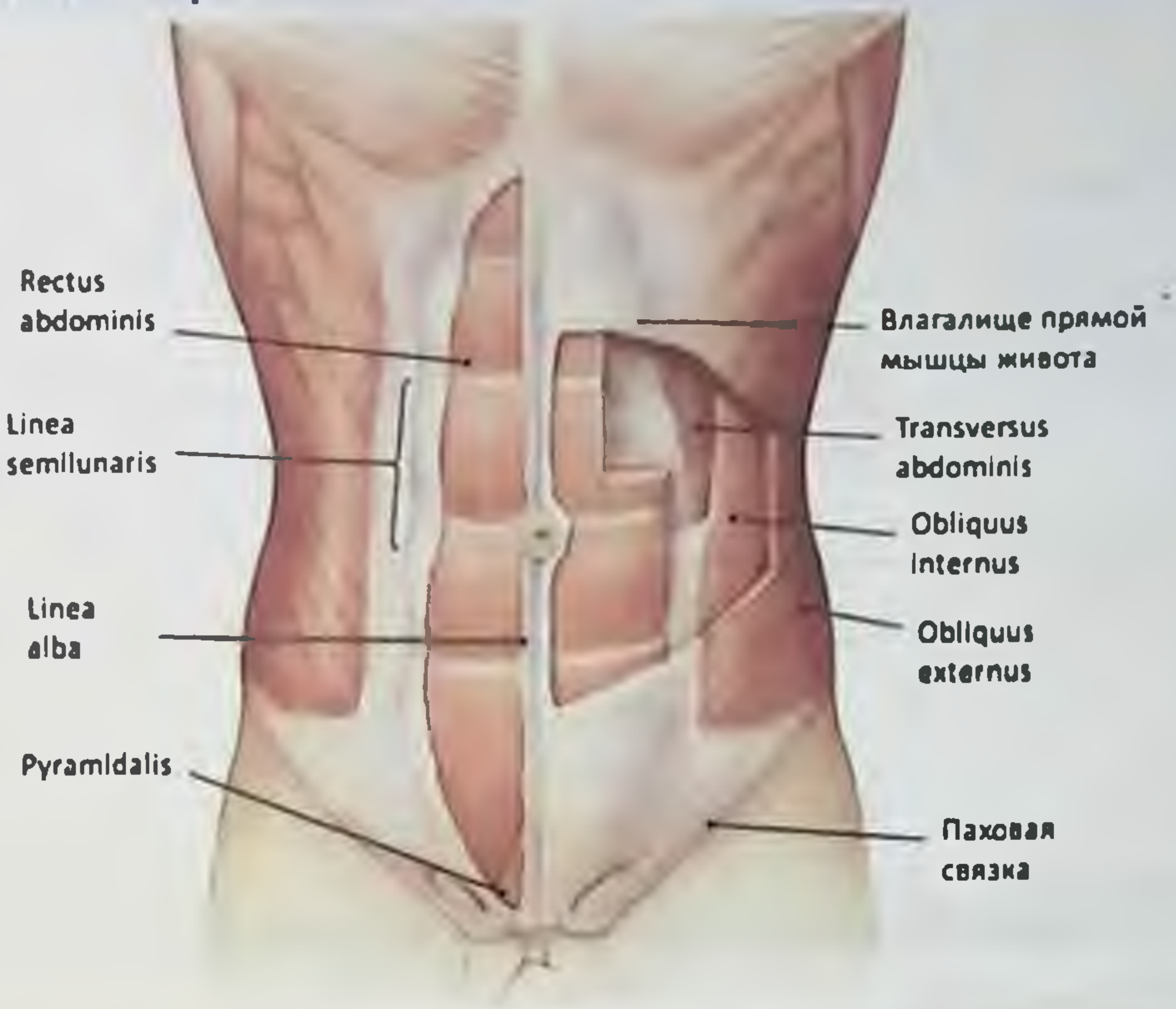



**Figure 24.** *Muscles of the anterolateral wall of the abdomen*

Deepest of all lies the transverse abdominal muscle, it is located across the abdomen, like a belt. This arrangement of three layers of muscles in different directions allows you to perform various movements and turns of the trunk. The three layers of muscle also help protect the internal organs of the abdomen in an area where there are no bones.

The white line of the abdomen, linea alba, is a white fibrous strip along the midline of the abdomen, consisting of the aponeurosis fibers of the three pairs of flat muscles surrounding the two rectus abdominis muscles that originate on the public ridge and symphysis and extend along the entire length of the anterior wall of the abdomen, ending at the ribs. Each muscle is separated by three transverse bands of collagen fibers called tendon bridges. which creates the appearance of "press cubes"?

The posterior abdominal wall is formed by the lumbar vertebrae, parts of the iliac bones of the thigh, the large lumbar and iliac muscles, and the quadratic muscle of the lower back (Fig. 25). This part plays a key role in stabilizing the rest of the body and maintaining posture.


**Figure 25.** *Muscles of the posterior wall of the abdomen*

## Chest muscles

The muscles of the chest are involved in the act of breathing, changing the volume of the chest cavity. When inhaling, the chest rises, increasing the volume of the chest cavity. When exhaling, the chest descends, reducing the volume of the chest cavity. The muscles of the chest are usually divided into two groups. The first is own: mm. intercostales externi et interni, subcostales, transversus thoracis.

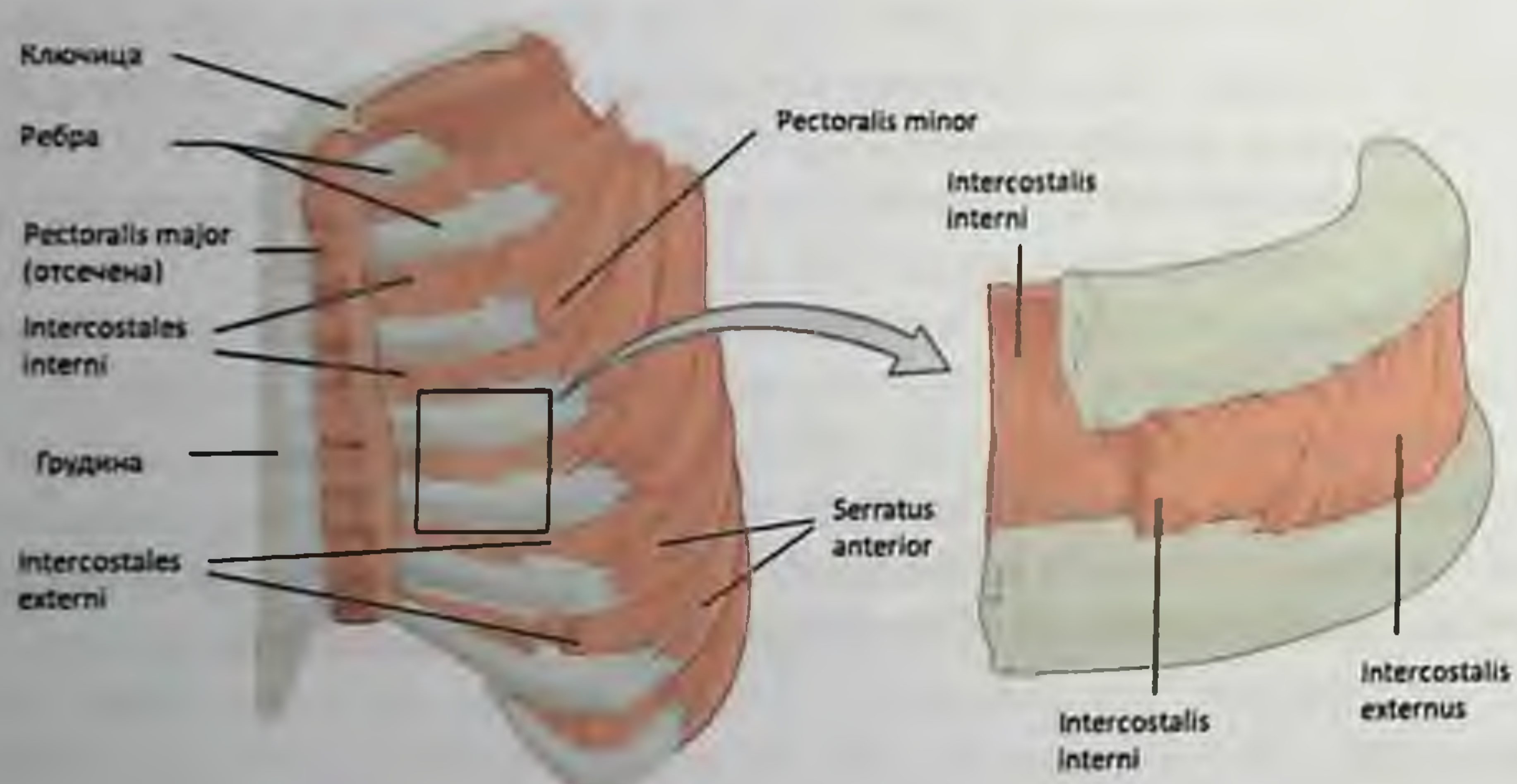



**Figure 26.** *Chest muscles*

The muscles of the second group begin on the bones of the chest and attach to the bones of the shoulder girdle and upper limb, located superficially. These include m. pectoralis major, m. pectoralis minor, m. subclavius, m. serratus anterior.

It is also customary to include the diaphragm (diaphragm), which, although laid on the neck, but descends into the chest and is a respiratory muscle.

**Intercostal muscles**

There are three muscle groups called intercostal muscles that encompass each of the intercostal spaces. The main role of the intercostal muscles is to aid breathing by changing the size of the chest (Fig. 26). Eleven pairs of external intercostal muscles promote inhalation, because when contracted, they raise the chest, expanding it. In turn, eleven pairs of internal intercostal muscles, located directly below the outer ones, are used for exhalation, as they attract the ribs to each other, compressing the chest.

**Diaphragm**

The change in the volume of the chest cavity during breathing occurs due to the alternating contraction and relaxation of the diaphragm (Fig. 27). It separates the thoracic and abdominal cavities and at rest has a domed shape. The upper surface of the diaphragm is convex, creating a raised bottom of the chest cavity. The lower surface is concave, forming a curved roof of the abdominal cavity.

During defecation, urination and even childbirth, the diaphragm and abdominal muscles interact. During breath holding, the diaphragm and abdominal muscles contract, increasing the pressure on the peritoneal cavity. When the abdominal muscles contract, the pressure cannot push the diaphragm up, so the pressure on the intestinal tract (which happens during the act of defecation), the urinary tract (urination) or the reproductive tract (childbirth) increases.

The lower surface of the cardiac bag (pericardium) and the lower surfaces of the serous membrane of the lungs (parietal pleura) merge with the tendon center of the diaphragm. On the sides of it are parts of the skeletal muscles of the diaphragm, which grow into the tendon and have a number of origins, including the sword-shaped process of the sternum in front, the lower six ribs and their cartilage on the side, as well as the lumbar vertebrae and the 12th rib in the back.


Figure 27. *Aperture (bottom view)*

The diaphragm has three openings for communication between the thoracic and abdominal cavity. The inferior vena cava passes through an opening in the tendon center, and the esophagus and vagus nerves pass through the esophageal cleft between the legs in the lumbar part of the diaphragm. The aorta, the thoracic duct pass through the aortic cleft - posterior from the esophageal.

**Pelvic floor and perineal muscles**

The pelvic floor (also called the pelvic diaphragm) is the muscular leaflet that defines the lower part of the pelvic cavity. The pelvic floor extends in the anteroposterior direction from the pubis to the tailbone and consists of the muscle that raises the anus and the coccygeal muscle. Its openings include the and urethra, as well as the vagina in women.

M. levator ani, the muscle that lifts the anus, consists of two skeletal muscles, the pubic-coccygeal and ilio-coccygeal muscles (Fig. 28). Levator ani is considered the most important muscle of the pelvic floor because it supports the pelvic entrails. It resists the pressure that occurs when the abdominal muscles contract to put pressure on the colon to facilitate defecation and on the uterus to facilitate childbirth (with the assistance of the coccygeal muscle, which pulls the tailbone forward). This muscle also creates the musculoskeletal sphincters of the urethra and anus. M. coccygeus, the coccygeal muscle, complements the muscular layer of the pelvic diaphragm in the posterior region. Starting from spina ischiadica and from the pelvic surface of lig. sacrospinale, it walks, fan-shaped expanding, medially and attaches to the lateral edge of the coccyx and the apex of the sacrum. The superficial muscles of the pelvic diaphragm include one - the external (voluntary) compressor of the anus, m. sphincter ani externus. The muscle is located under the skin around the anus outward from the involuntary internal sphincter (m. sphincter ani internus) formed by the muscular membrane of the rectal wall.

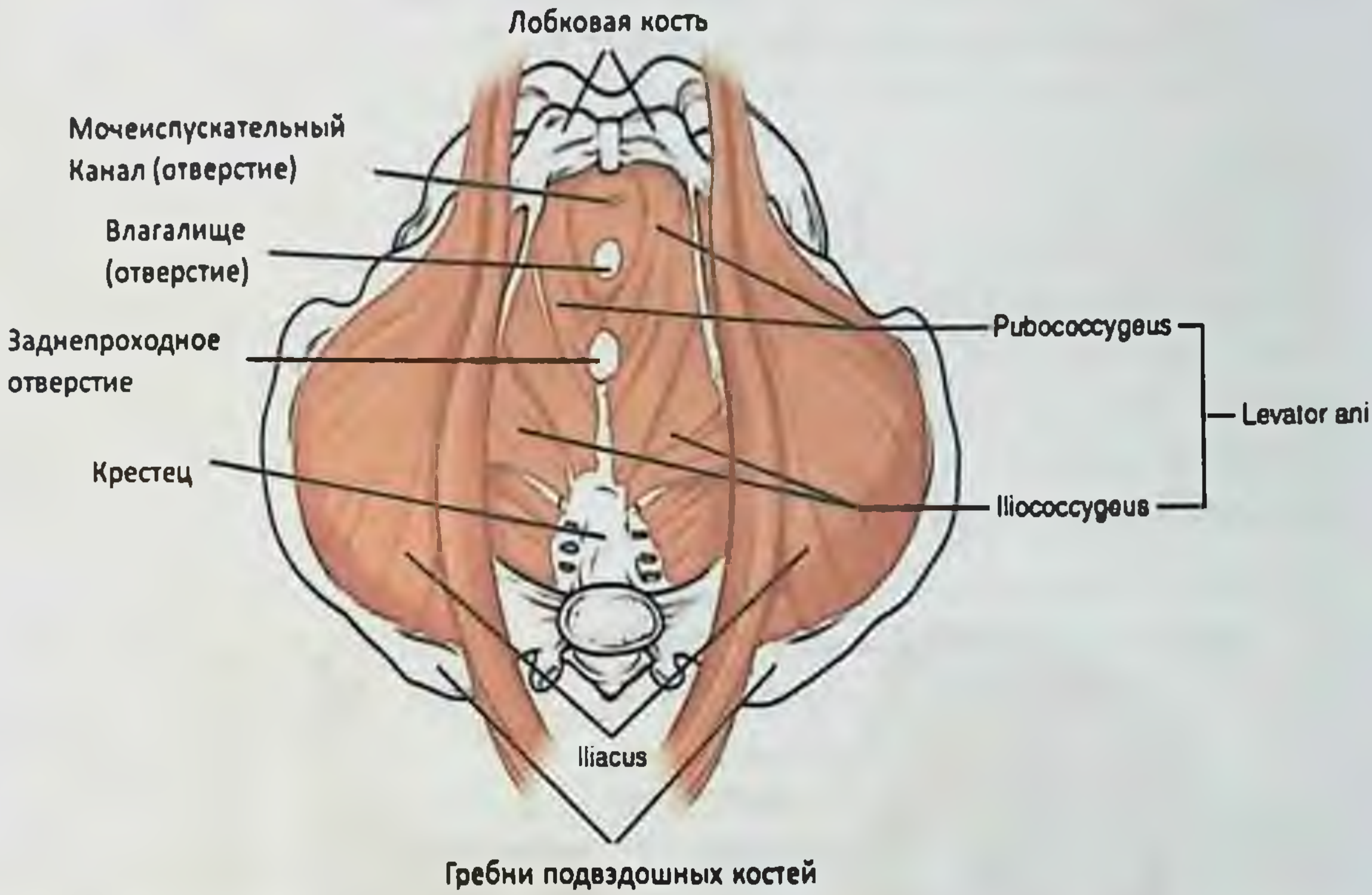



**Figure 28.** *Pelvic floor muscles*

The perineum is the diamond-shaped space between the pubic symphysis (anteriorly), tailbone (posteriorly), and sciatic tubercles (flank), lying just below the pelvic diaphragm (levator ani and ischiococcygeus). The perineum is divided in the transverse direction into triangles: the anterior - genitourinary triangle, which includes the external genitalia, and the posterior - triangle, containing the anus. The perineum is also divided into superficial and deep layers with some muscles common to men and women. Women also have urethral compressors and a urethrovaginal sphincter (sphincter urethrovaginalis) that serve to close the vagina. In men, the deep transverse muscle of the perineum plays a role in the act of ejaculation.

# MUSCLES OF THE SHOULDER GIRDLE AND FREE UPPER LIMB

The muscles of the upper arm and free upper limb can be divided into four groups: the muscles that stabilize and position the upper limb girdle, the muscles that move the shoulder, the muscles that move the forearm, and the muscles that move the wrist, hand, and fingers.

**Muscles supporting the shoulder girdle**

The shoulder girdle is represented by the lateral ends of the clavicle and scapula, as well as the proximal end of the humerus and the muscles covering these three bones to stabilize the shoulder joint. The muscles that provide the position of the shoulder girdle are located either on the front or back of the chest (Fig. 29). The anterior muscles include the subclavian, small thoracic and anterior dentate muscles. The posterior muscles include the trapezius, large and small rhomboid muscles. When the rhomboid muscles contract, the scapula shifts medially, which can pull the shoulder and upper limb back.

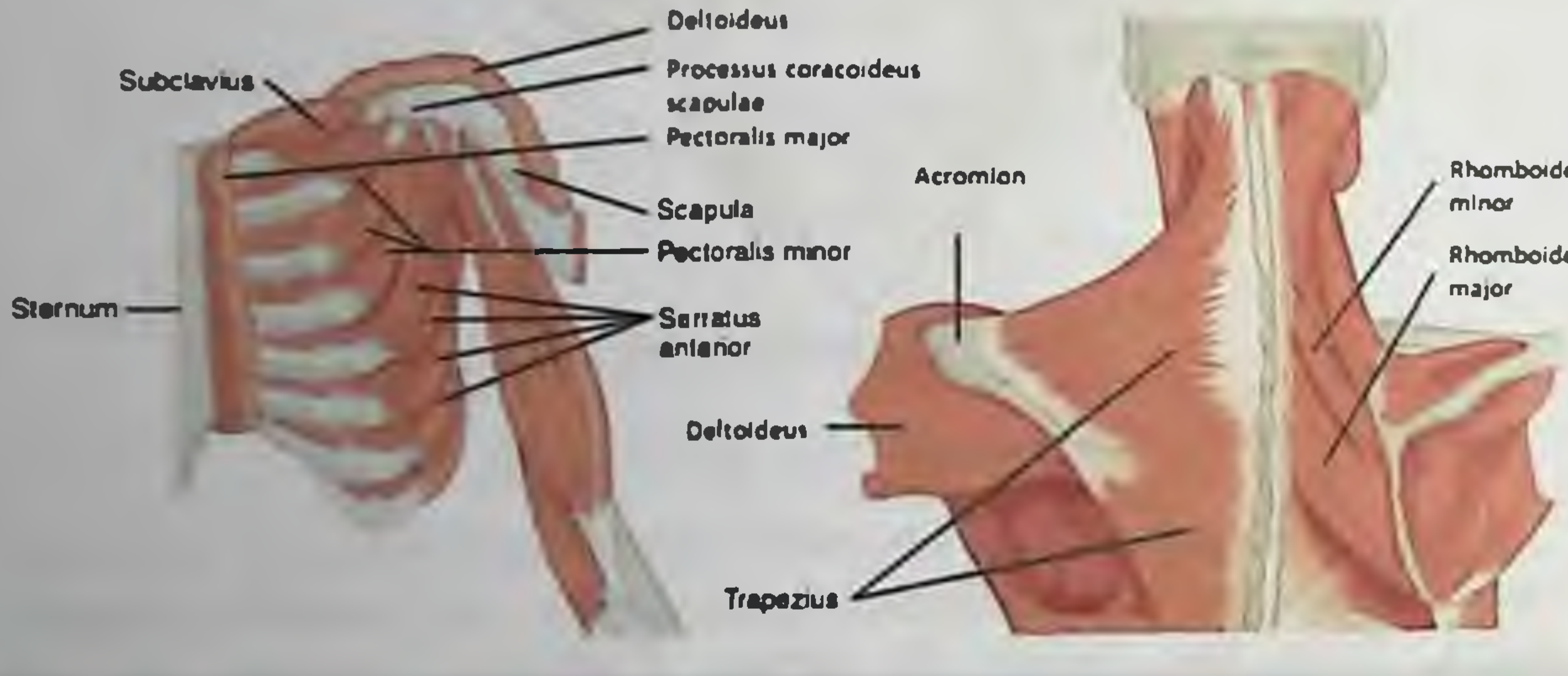



**Figure 29.** *Muscles of the shoulder girdle*

**Muscles that drive the shoulder joint**

Like the muscles that provide the position of the shoulder girdle, the muscles that move the shoulder joint and move the humerus of the upper limb include the axial and scapular muscles (Fig. 29). The two axial muscles are the large pectoral muscle and the latissimus dorsi muscles. The large pectoral muscle is thick and fan-shaped, covering most of the upper part of the front of the chest. The broad, triangular latissimus dorsi is located on the lower back and has several onset points, including the lumbosacral fascia attached to the lower 6 thoracic vertebrae, the lower 3 ribs, the iliac crest, and the lower corner of the scapula.

The rest of the muscles originate on the scapula and help move the shoulder. The deltoid muscle is the main abductor (leading it to the body) of the shoulder, but also promotes flexion and medial rotation, as well as extension and lateral rotation. The subscapular muscle originates in the subscapular fossa and rotates the arm inward. The suprascapular (originating in the suprascapular fossa of the scapula) and subscapular (originating in the subscapular fossa) lead the shoulder and rotate the arm in the lateral direction, respectively. Thick and flat large round muscle, m. teres major, located below the small round muscle, it extends the shoulder in the shoulder joint, pierces it, brings the raised arm to the torso. With the upper limb fixed, it pulls the lower corner of the scapula outward and shifts it forward. The small round muscle turns (supinates) the shoulder outward - the synergist of the subscapular muscle and the scapular part of the deltoid muscle; pulls the capsule of the shoulder joint, preventing infringement of the capsule. Movement in the shoulder joint also provides and the beak-brachial muscle, m. coracobrachialis, belonging to the anterior muscle group of the shoulder. The beak-humerus muscle flexes the shoulder at the shoulder joint and leads it to the trunk, turns the shoulder outwards, with a fixed shoulder pulls the scapula forward and downward.

The tendons subscapularis, supraspinatus, infraspinatus, and teres minor connect the scapula to the humerus to form a rotator cuff (rotator), a circle of tendons around the shoulder joint. Although the shoulder joint provides greater freedom of movement due to a shallow glenoid cavity, it is extremely vulnerable to dislocation downwards. The muscles and tendons of the rotator cuff provide stability to the joint.

**Muscles that drive the elbow joint**

The forearm, consisting of the radius and ulna, has four main types of movement in the hinge of the elbow: flexion, extension, pronation, and supination. When the forearm is facing the front, it is supinated. When the forearm is pointed backwards, it is pierced. The flexors of the forearm include the biceps muscle of the shoulder, the shoulder muscle, and the brachia-radial muscle (Fig. 30). The extensors are the triceps muscle of the shoulder and the octal muscle, m. anconeus. Pronators are the round pronator, pronator teres and square pronator, the pronator quadratus, and the supinator, m. supinator, rotates the forearm anteriorly (Fig. 31).

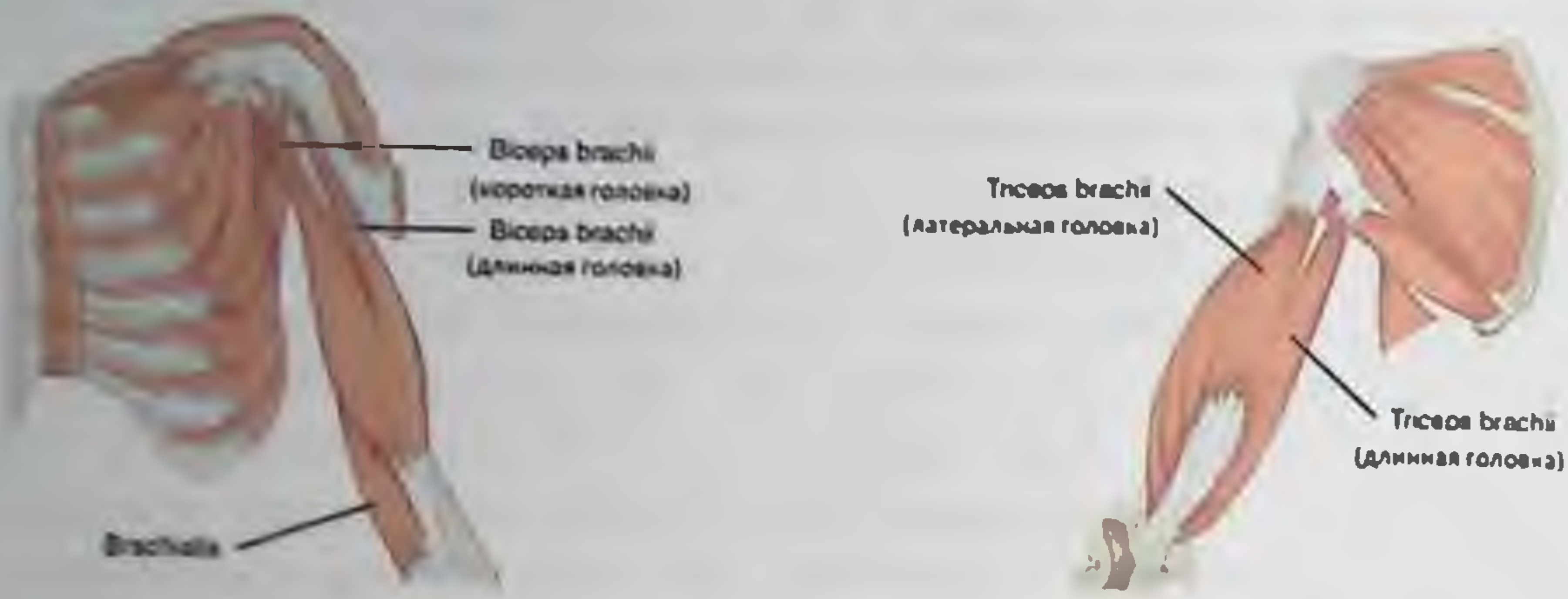



**Figure 30.** *Anterior (left) and posterior (right) shoulder muscle groups*

The biceps muscle of the shoulder, the shoulder muscle and the brachia-radial muscle flex the forearm. The biceps shoulder muscle crosses the shoulder and elbow joints to flex the forearm and is also involved in supination of the forearm in the radial ulnar joints and flexion of the arm in the shoulder joint. Being deeper biceps brachii, the humerus muscle is its synergist in flexing the forearm. Finally, the brachioradialis muscle can flex the forearm quickly or slowly lift a load (Fig. 30).


**Figure 31.** *Superficial muscles of the left forearm in front (left) and behind (right)*

**Muscles that drive the wrist, hand and fingers**

Movements of the wrist, hand and fingers are provided by two muscle groups. The forearm is the site of the beginning of the outer muscles of the hand. The palm is the source of the inner muscles of the hand.

**Extra-articular muscles of the hand**

The muscles of the anterior part of the forearm (the anterior part of the flexors of the forearm) originate on the humerus and are attached to various parts of the hand. They make up the bulk of the forearm. From lateral to medial, the superficial anterior forearm includes the radius flexor (flexor carpi radialis), the long palmar flexor (palmaris longus), the ulnar flexor (flexor carpi ulnaris), and the superficial flexor (flexor digitorum superficialis). The superficial flexor bends the hand as well as the fingers in the joint area of the phalanges, which allows you to perform rapid movements with the fingers, for example, when typing or playing a musical instrument (see Figures 31, 32). The deep muscles of the anterior group produce flexion of the fingers into a fist. These are the long flexor of the fingers (flexor pollicis longus) and the deep flexor of the fingers (flexor digitorum profundus).

The superficial muscles of the posterior group of the forearm originate on the humerus. These are the long radial extensor of the wrist (extensor carpi radialis longus), the short radial extensor of the wrist (extensor carpi radialis brevis), the extensor of the fingers of the hand (extensor digitorum), the extensor of the little finger (extensor digiti minimi) and the elbow extensor of the wrist (extensor carpi ulnaris).

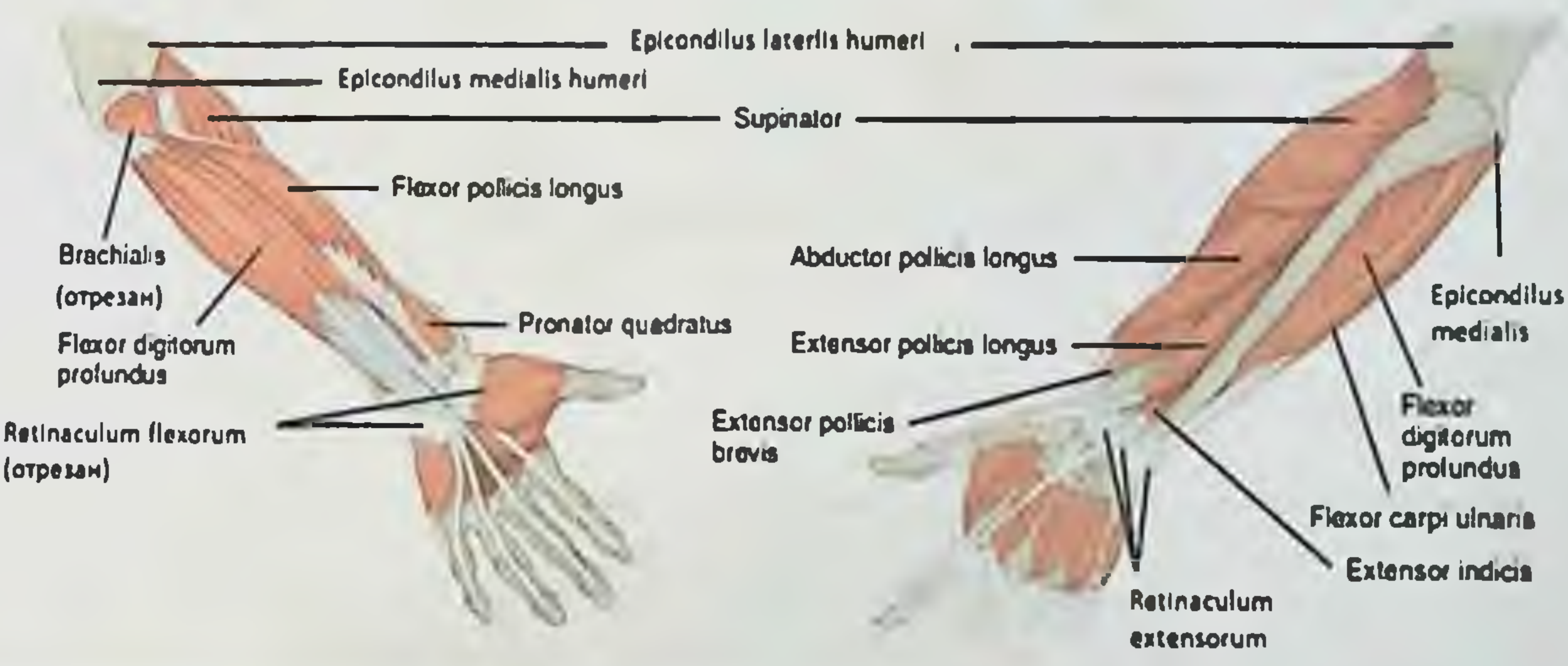
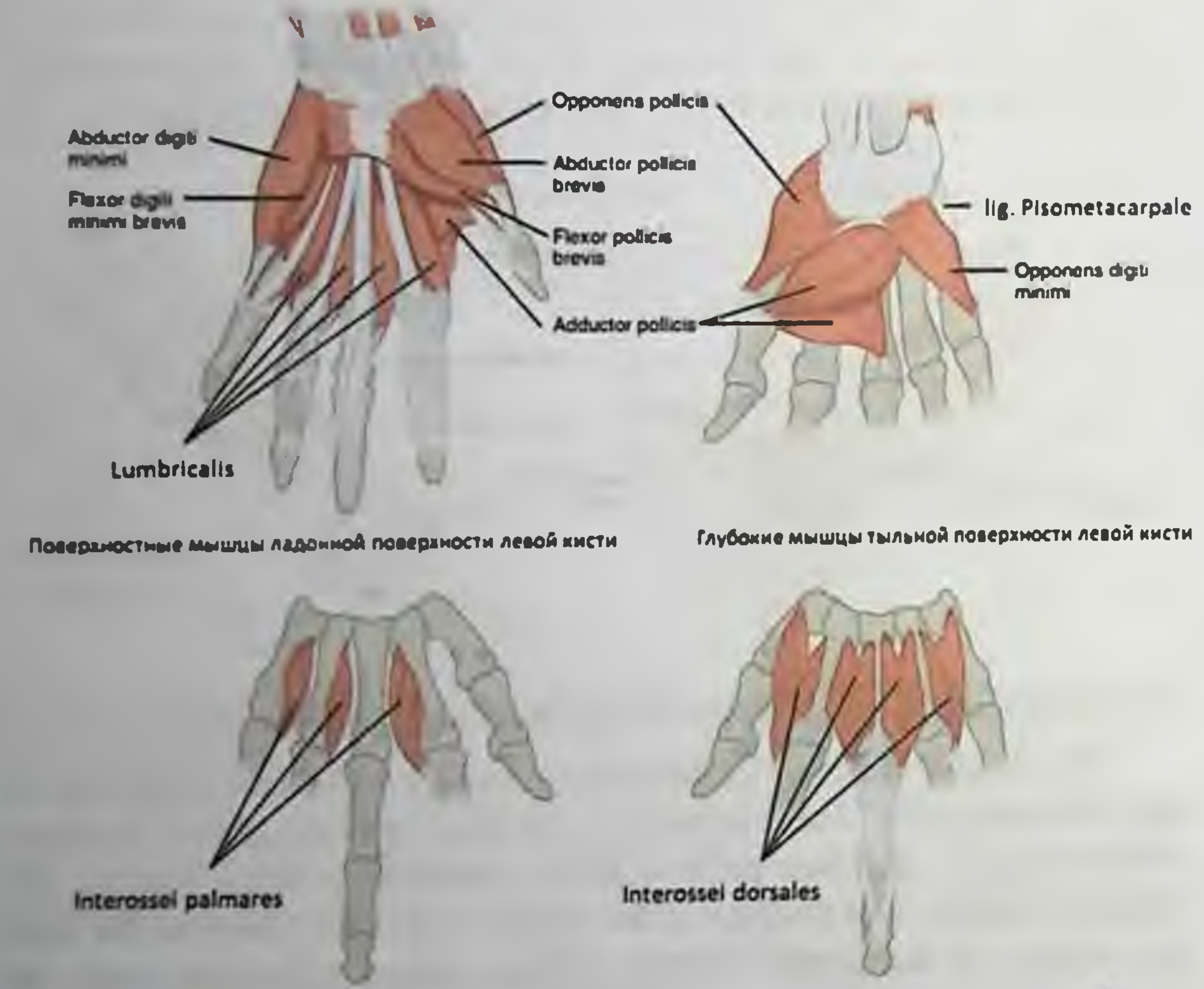



**Figure 32.** *Deep forearm muscles front (left) and back (right)*

The deep muscles of the posterior group of the forearm originate on the radius and ulna. These include m. abductor pollicis brevis, abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus, and extensor indicis. The tendons of the forearm muscles attach to the wrist and extend to the hand. Fibrous ribbons called retinacula cover the tendons at the wrist. The flexor retainer extends across the front of the wrist and the extensor retainer extends along the posterior (Fig. 32).

**Muscles of the hand**

The muscles of the hand both arise and are attached inside it (Fig. 33). These muscles allow the fingers to make precise movements when performing activities such as typing or writing. These muscles are divided into three groups. Thumb elevation muscles (thenar): the short, thumb abductor, the short flexor of the thumb, the muscle leading the thumb, and the muscle opposing the thumb. They are on the radial side of the palm. The elevations of the little finger (hypothenar) are also four muscles: the short palmar muscle, the muscle that draws the little finger, the short flexor of the little finger, and the muscle opposing the little finger. The middle muscle group of the hand, located between these two elevations, includes four worm-like muscles, as well as three palmar and four dorsal interosseous muscles.




Межкостные мышцы ладонной поверхности левой кисти    Межкостные мышцы тыльной поверхности левой кисти

Figure 33. *Muscles of the hand*

# MUSCLES OF THE PELVIC GIRDLE AND FREE LOWER LIMB

The muscles of the lower body provide position and stabilization of the pelvic girdle, which serves as the basis for the lower extremities. Compared to the pelvic girdle, there is much more movement in the shoulder girdle than in the pelvic girdle. The movement of the pelvic girdle is very limited due to its connection to the sacrum at the base of the axial skeleton and because the deep acetabulum provides a stable point of articulation with the femoral head. The lack of range of motion of the pelvic girdle allows it to stabilize and support the body. The center of gravity of the body is in the pelvic area. If the center of gravity did not remain stationary, it would be difficult to stand. Therefore, if the muscles of the legs lack range of motion and versatility, they compensate for this with size and strength, contributing to body stabilization, posture and movement.

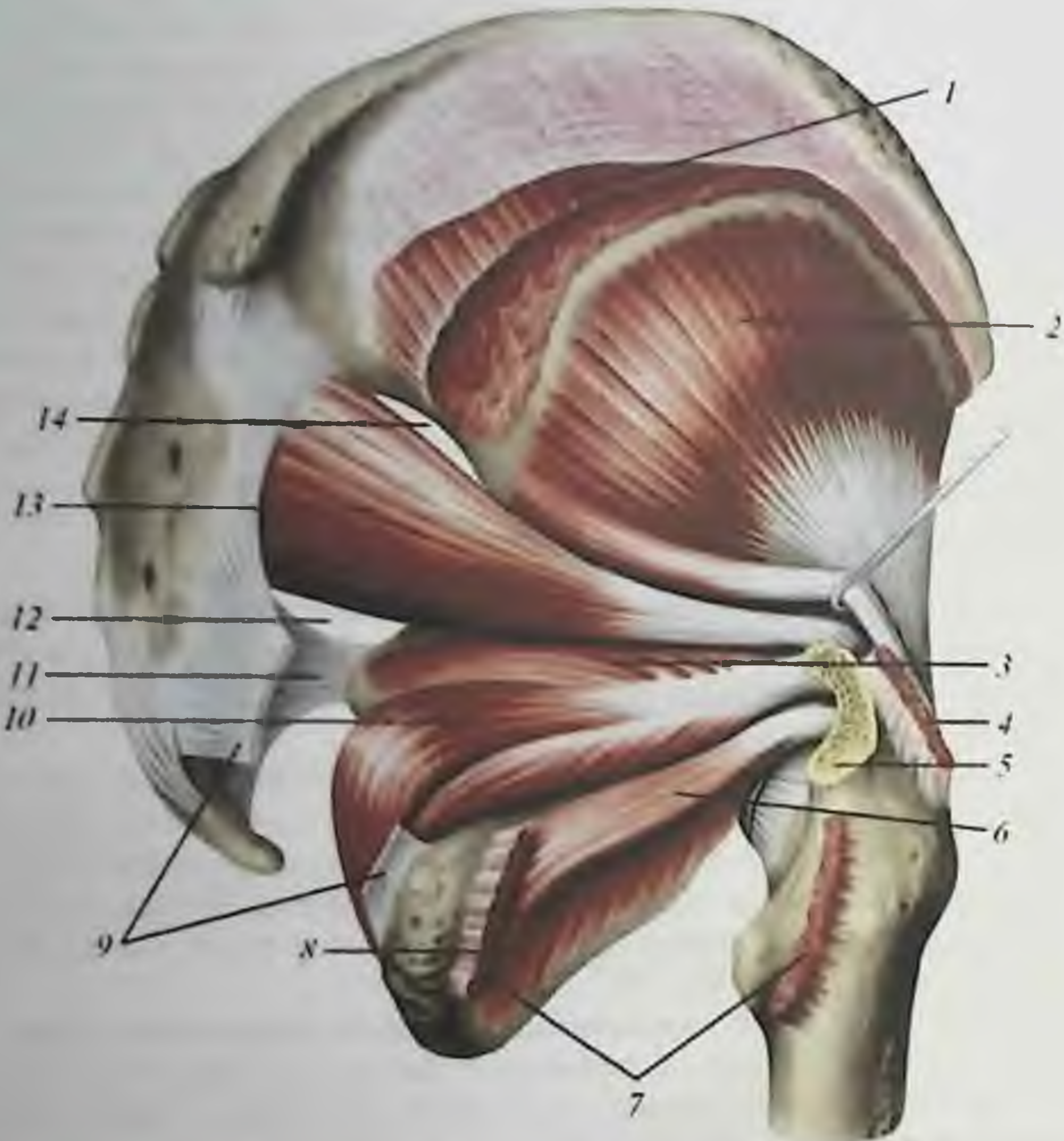
**Muscles of the gluteal region, which move the hip joint**

Most of the muscles that attach to the hip (femur) and set it in motion originate in the pelvic girdle. The main flexors of the thigh are the greater lumbar muscle, psoas major and iliac muscle, iliacus, which make up the iliopsoas group.

One of the largest and most powerful muscles in the body are the gluteal muscles or gluteal muscle group. The gluteus maximus muscle, one of the main extensors of the thigh in the thigh area, is the largest; deeper than the gluteus maximus muscle is the gluteus medius muscle, and deeper than the gluteus medius is the gluteus minor muscle, the smallest of these three (Fig. 34).

The muscle that strains the broad fascia of the thigh is a thick, square muscle in the upper part of the lateral surface of the thigh. It acts as a synergist of the middle gluteus muscle and the ilio-lumbar muscle when flexing and extending the thigh. It also helps stabilize the lateral side of the knee by tightening the ilio-tibial tract. Deep from gluteus maximus are piriformis, obturator internus, obturator externus, superior gemellus, inferior gemellus, and quadratus femoris.

The deep fascia divides the thigh into medial, anterior and posterior sections. The muscles of the medial thigh, responsible for bringing the femur to the hip joint, are a group of adducors that drive the hip. The muscles of the medial group include the thin, comb, large, long and short adductor muscles of the thigh. These muscles, which drive the hip, are very developed in humans due to upright walking. Muscles are located on the medial side of the thigh throughout its length.




**Rice. 34.** *Deep (external) pelvic muscles. The large and middle gluteal and quadratic muscles of the thigh are removed*

*Explanation: 1 - gluteus medius (cut off); 2 - gluteus minor muscle; 3 - upper twin muscle; 4 - gluteus medius muscle (cut off); 5 - large spit (sawn); 6 - lower twin muscle; 7 - square thigh muscle (cut off); 8 - external locking muscle; 9 - sacro-tubercle ligament (partially removed); 10 - internal locking muscle; 11 - sacro-spinous ligament;12 - hypoglossal; 13 - piriformis muscle; 14 - tombstone hole*

They begin on the bones of the pelvis (pubic and sciatic) near the locking hole, which these muscles cover in front. Under the initial section of the adductor muscles is the external locking muscle. More superficially in the group of adductor muscles lie the comb and thin muscles, deeper is the long adductor muscle, and even deeper - the large and short adductor muscles. The muscles of the medial group attach for almost the entire length of the femur, from the small trochanter to the medial epicondyle of the thigh.

**Thigh muscles that drive the femur, tibia and fibula**

The muscles of the anterior thigh bend the thigh and extend the leg. In this section is a group of quadriceps femoris muscles consisting of four muscles that extend the leg and stabilize the knee. In this section, the rectus femoris muscle is on the anterior side of the thigh, the lateral thigh muscle is on the lateral side of the thigh, the medial thigh muscle is on the medial side of the thigh, and the intermediate thigh muscle is between the lateral and medial thigh muscles and deep from the rectus femoris muscle (Fig. 35). All four muscles are united by the tendon of the quadriceps muscle (patellar tendon), which is attached to the patella and continues under it in the form of a patellar ligament. The patellar ligament attaches to the tuberosity of the tibia.

In addition to the quadriceps femoris muscle, the tailor muscle is a ribbon muscle that stretches from the anterior superior ilium to the medial side of the proximal tibia. This multifunctional muscle flexes the leg at the knee and also flexes, extends and laterally rotates the hip at the hip joint. This muscle allows us to sit with our legs crossed.

The posterior thigh includes muscles that flex the leg and extend the hip. The three long muscles on the back of the thigh are a group of muscles that bend the knee. This is the biceps femoris muscle, semi-tendon and semi-membranous. The tendons of these muscles form the upper boundary of the popliteal fossa, the rhomboid space at the back of the knee (Fig. 36).

**Muscles that drive the feet and toes**

Like the muscles of the thigh, the muscles of the lower leg are divided by deep fascia into sections, there are three of them: anterior, lateral and posterior.

All the muscles of the anterior tibia contribute to the flexion of the tibia: the anterior tibia muscle, the long and thick muscle on the lateral surface of the tibia, the long extensor of the thumb located deep below it, and the long extensor of the fingers located laterally (Fig. 37). The third fibula muscle (fibularis tertius), a small muscle that originates on the anterior surface of the fibula, is associated with the long extensor and sometimes fuses with it but is not present in all people. Thick bands of connective tissue, called the upper extensor retainer (ankle transverse ligament) and the lower extensor retainer, hold the tendons of these muscles in place during dorsiflexia.

The lateral part of the leg includes two muscles that contribute to the plantar flexion of the foot, raising its lateral edge: the long fibula muscle (peroneus longus) and the fibula muscle (peroneus brevis). All the superficial muscles of the posterior leg attach to the heel tendon (Achilles tendon), a strong tendon that attaches to the heel bone of the ankle area, and they all contribute to plantar flexion. The muscles of this department are large and strong and support a person in an upright position.

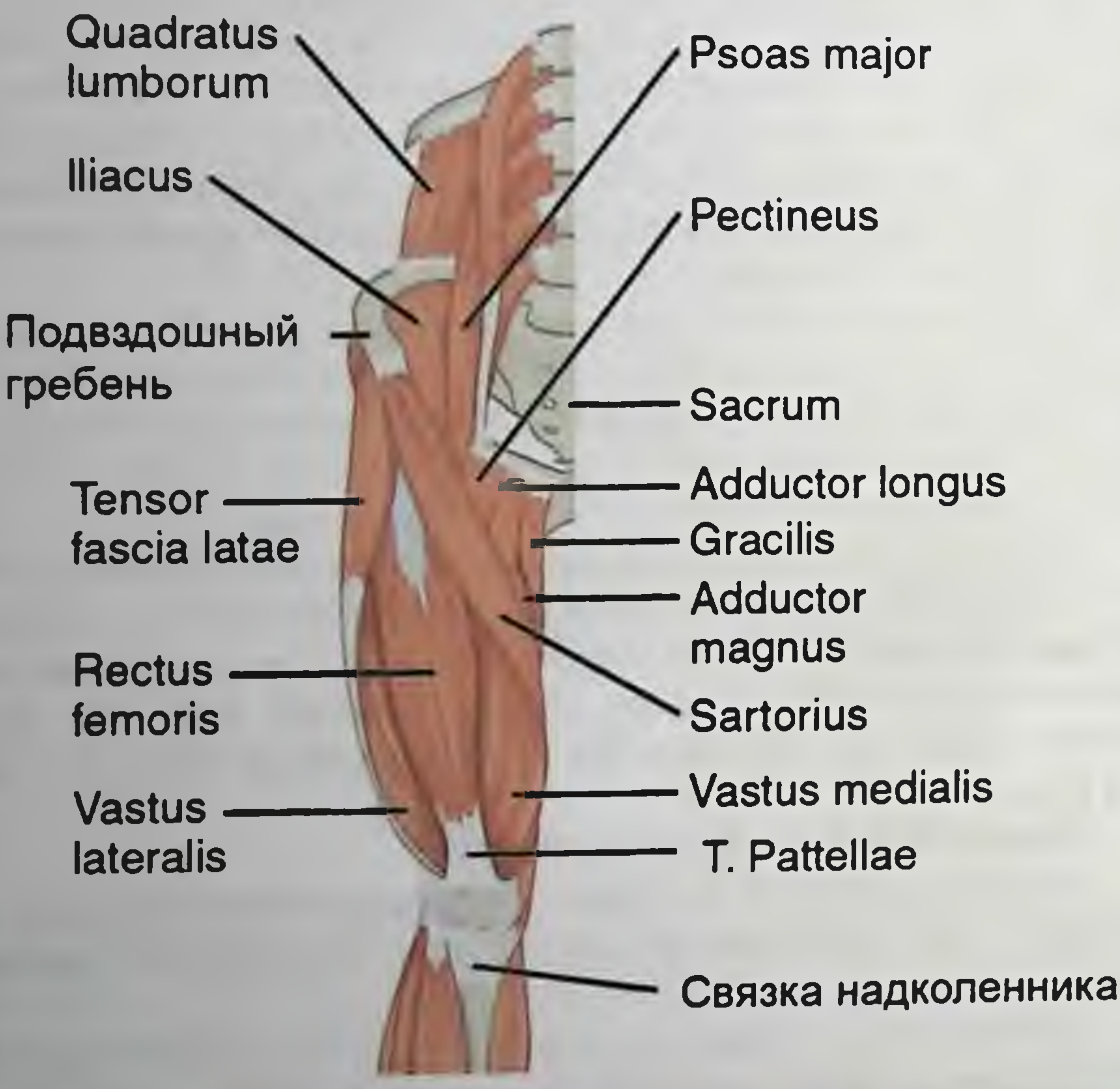



**Figure 35.** *Superficial thigh muscles (front view)*

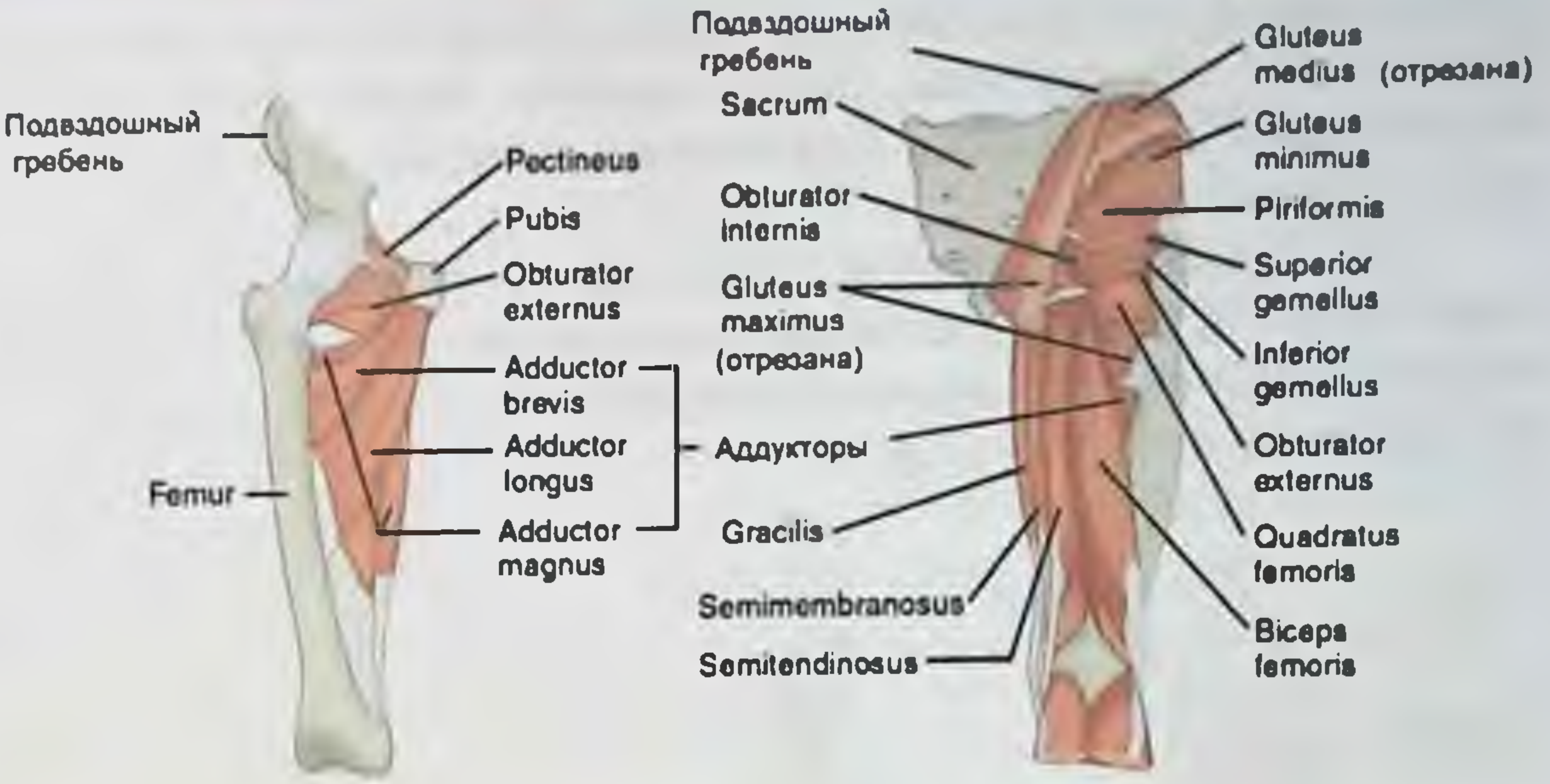



**Figure 36.** *Deep thigh muscles in front (left), pelvic muscles and posterior thigh muscle group (right)*


**Figure 37.** *Muscles of the right lower leg*

The most superficial and noticeable muscle of the lower leg is the calf. Deep to this muscle is a broad flat soleus muscle. Between them obliquely passes the plantar muscle; some people may have these two muscles, whereas the absence of the plantar muscle is observed in about seven percent of autopsies. The plantar tendon is a desirable replacement for the broad fascia of the thigh in the treatment of hernias, tendon transplantation and ligament repair. There are also four deep muscles in the posterior leg: popliteus, flexor digitorum longus, flexor hallucis longus, and tibialis posterior – all of which contribute to plantar flexion or foot inversion.

The foot also has internal muscles that originate on the foot and attach to its bones (similar to the inner muscles of the hand). These muscles mainly provide support to the foot and its arch, as well as promote the movement of the toes (Fig. 38).

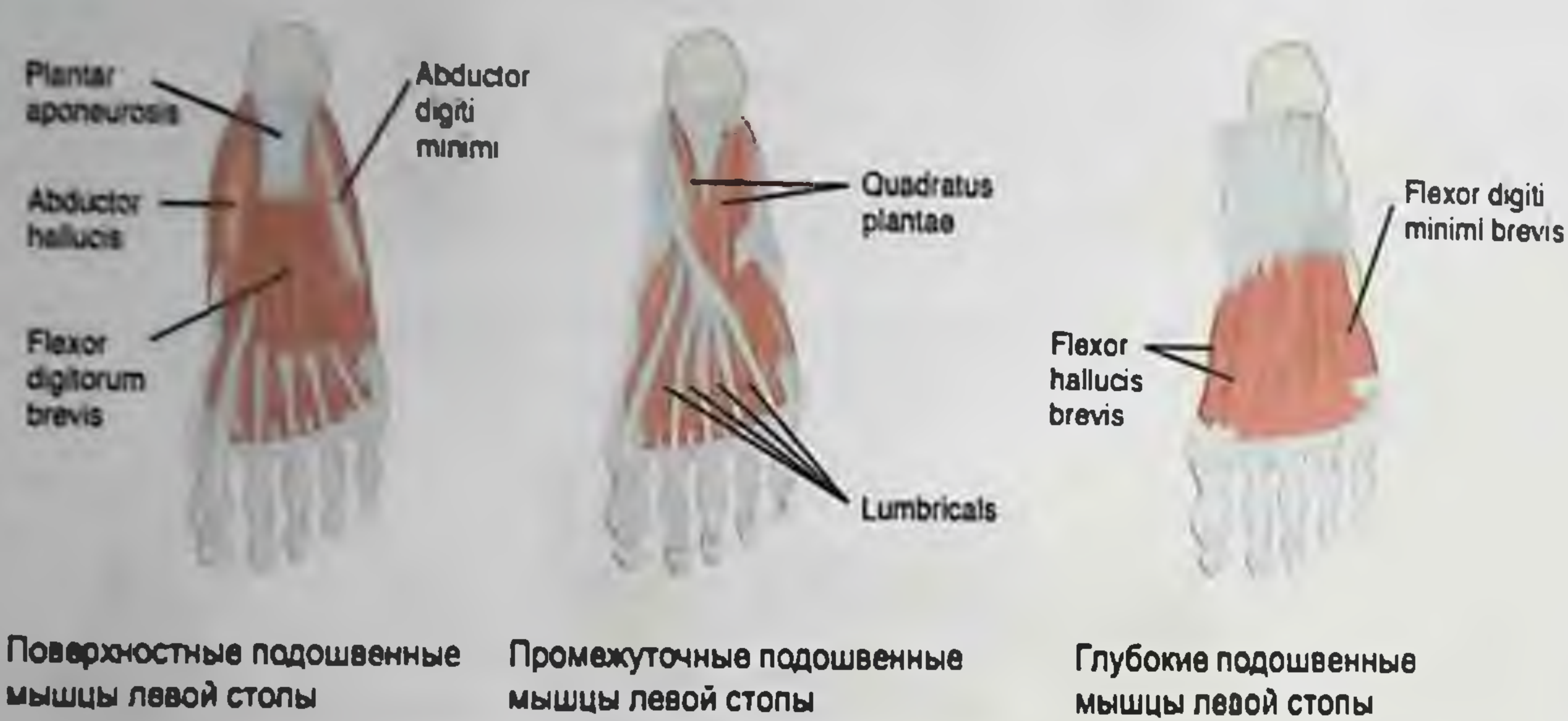



**Figure 38.** *Foot muscles*

The main support of the longitudinal arch of the foot is a deep fascia called the plantar aponeurosis, which runs from the heel bone to the toes (inflammation of this tissue is the cause of "plantar fasciitis", which can affect runners. The internal muscles of the foot include the tarsal extensor on the dorsal side and the plantar group, consisting of four layers.

***Self-Assessment Questions***

1. Explain the difference between axial and appendicular muscles.
2. Describe the muscles of the front of the neck.
3. Why are facial muscles different from normal skeletal muscles?
4. Which muscles form hamstrings? How do they function together?
5. Which muscles form the quadriceps muscle? How do they function together?
6. Describe the location of the bundles in the abdominal wall muscles. How do they relate to each other?
7. What are the similarities and differences between the diaphragm and the pelvic diaphragm?

8. Which muscle tendons form the rotator cuff? Why is the rotator cuff important?

9. List the common muscle groups of the shoulder girdle and upper extremities, as well as their subgroups.

***Answers to questions***

1. Axial muscles arise on the axial skeleton (the bones of the head, neck and the main body), while appendicular muscles arise on the bones that make up the limbs of the body.

2. The muscles of the front of the neck are positioned to facilitate swallowing and speech. They act on the hyoid bone: the supralingual muscles pull upwards, and the sublingual muscles pull down.

3. Most skeletal muscles provide movement due to the impact on the skeleton. Facial muscles are distinguished by the fact that they create movements and facial expressions, stretching the skin, without the participation of bones.

3. Abdominal wall muscles are the internal and external oblique muscles located diagonally, the rectus abdominis muscle running straight along the midline of the body, and the transverse abdominal muscle wrapping around the trunk.

4. Both diaphragms are thin sheets of skeletal muscle that horizontally cover areas of the trunk. The diaphragm separating the thoracic and abdominal cavities is the main muscle of breathing. The pelvic diaphragm, consisting of two paired muscles, the coccygeal muscle and the levator ani, forms the pelvic floor at the lower end of the trunk.

5. Tendons infraspinatus, supraspinatus, teres minor and subscapularis form the rotator cuff, which is the basis for stabilization and movement of the arms and shoulders.

5. The muscles that form the muscles of the shoulder girdle and upper extremities include the muscles that provide the position of the pelvic girdle, the muscles that provide the movement of the humerus, the muscles that provide the movement of the forearm, and the muscles that provide movement of the wrists, hands and fingers.

6. Biceps femoris muscle, semi-membranous muscle and semi-tendon muscle form the hamstring. They bend the leg at the knee joint.

7. Rectus femoris muscle, medial thigh muscle, lateral thigh muscle and intermediate thigh muscle form quadriceps muscle. The quadriceps muscle extends the leg at the knee joint.

## Situational tasks

Task No1

The patient as a result of the injury does not open the eye.

Question: Which muscle function is impaired?

Interview to solve the problem: Facial muscles (facial muscles): features of their development, structure, topography, functions, classification, blood supply.

Answer to question: Circular eye muscle.

Task No. 2

The patient complains of pain in the temporal region when opening the mouth and chewing.

Q: List the masticatory muscles.

Interview to solve the problem: Masticatory muscles: features of development; topography, structure, functions, blood supply.

Answer to the question: Masticatory muscle, temporal muscle, medial and lateral pterygoid muscles.

Task No. 3

During the examination of the victim, the wound to the front of the neck was

it is noted that the zone of the sleep triangle is affected.

Question: "What structures limit the sleepy triangle?"

Interview to solve the problem: Neck muscles: classification, structure, functions, blood supply, innervation. Areas and triangles of the neck. Fascia and cellular spaces of the neck.

Answer to the question: In front and above - the posterior abdomen of the digastric muscle; posteriorly - the anterior edge of the sternocleidomastoid muscle; in front and below - the upper abdomen of the scapulo-sublingual muscle.

Task No. 4

With the fracture of the ribs with the displacement of their fragments, the external and internal intercostal muscles were damaged.

Question: What muscle group do they belong to?

Interview to solve the problem: Muscles and fascia of the chest: classification, structure, functions, blood supply.

Answer to the question: To your own chest muscles.

Task No. 5

The patient had a diaphragmatic hernia.

Question: Specify the weak points of the diaphragm.

Interview to solve the problem: Diaphragm: topography, parts, structure, functions, blood supply.

Answer to the question: Lumbosition-costal and sternal-costal triangles.

Task No. 6

With an increase in intra-abdominal pressure, the patient revealed a hernia in the region of the anterior abdominal wall.

Question: List the weak points of the anterior abdominal wall.

Interview to solve the problem: Anatomy of the abdominal muscles: classification, topography, structure, functions, blood supply, innervation. The vagina of the rectus abdominis muscle. White

the line of the abdomen.

Answer to the question: White line of the abdomen, umbilical ring, lateral and medial inguinal fossa.

Task No. 7

The patient had an inguinal hernia.

Question: Name the contents of the inguinal canal in men and women.

Interview to solve the problem: Inguinal canal; its walls, the outer and inner rings of the inguinal canal.

Answer to the question: In men - the spermatic cord, in women - a round ligament of the uterus.

Task No. 8

The patient has a stretching of the superficial muscles of the back.

Question: List the superficial muscles of the back.

Interview to solve the problem: Back muscles: classification, topography, structure, functions, blood supply.

Answer to the question: Trapezius, latissimus, large and small rhomboid muscles; the muscle that lifts the scapula; upper and lower posterior dentate muscles.

Task No. 9

The patient needs surgical intervention in the region of the posterior wall of the axillary fossa.

Question: What holes are there in the back wall of the axillary fossa?

Interview to solve the problem: Axillary fossa: borders, walls, holes, topography, contents.

Answer to question: Three-sided and four-sided holes.

Task No. 10

With traumatic injury to the shoulder area, the tendon of the muscle attached to the crest of the small tubercle of the humerus was affected.

Q: Name that muscle.

Interview to solve the problem: Muscles of the shoulder girdle: classification, topography, structure, functions, blood supply.

Answer to the question: The latissimus muscle of the back.

Task No. 11

The patient has a weak development of the biceps muscle of the shoulder.

Question: Specify the functions of this muscle.

Interview to solve the problem: Shoulder muscles: classification, topography, structure, functions, blood supply.

Answer to the question: Flexes and supinates the forearm at the elbow joint, flexes the shoulder at the shoulder joint

Task No. 12

As a result of the injury, the patient's deltoid muscle was damaged.

Question: Specify the places of onset and attachment of the deltoid muscle and its functions.

Interview to solve the problem: Muscles of the shoulder girdle: topography, structure, functions, blood supply.

Answer to question: The deltoid muscle begins from the acromial end of the clavicle, the acromion and the scapula, attaches to the deltoid tuberosity of the humerus.

Functions: flexion, extension, removal of the upper limb in the shoulder joint to a horizontal level, as well as its pronation and supination.

Task No. 13

The patient was taken to the surgical department with a deep cut wound to the palmar surface of the left hand.

Question: Which tendons of the forearm muscles are damaged?

Problem Solving Interview: Forearm Muscles and Fascia: Classification,

topography, structure, functions, blood supply.

Answer to the question: Deep and superficial flexors of the fingers, long flexor of the thumb, long palmar muscle.

Task No. 14

A patient with a hand injury had a fracture of the scaphoid bone.

Question: Which of the three parts of the bones of the hand does the injured bone belong to?

Interview to solve the problem: Hand: bones, joints, muscles; their functions, blood supply.

Answer to the question: To the bones of the proximal row of the wrist.

Task No. 15

The patient was taken to the trauma department with a deep cut wound to the palm of the hand.

Question: List the muscle groups of the hand that may have been damaged.

Interview to solve the problem: Muscles of the hand: structure, functions, blood supply.

Answer to the question: Muscles of elevation of the thumb, muscles of elevation of the small finger, middle group of muscles of the hand.

Task No. 16

As a result of improper performance of intramuscular injection, the patient developed an abscess (purulent inflammation) in the gluteal region.

Question: Name the muscle involved in the inflammatory process.

Interview to solve the problem: Pelvic muscles: classification, topography, structure, functions, blood supply.

Answer to question: Gluteus maximus muscle.

Task No. 17

The result of damage to the femoral nerve was a violation of the functions of the muscles of the anterior group of the thigh.

Question: List the muscles in this group.

Interview to solve the problem: Thigh muscles: classification, structure, functions, blood supply.

Answer to question: Quadriceps thigh muscle, tailor's muscle

Task No. 18

As a result of inflammation of the locking nerve, there was a violation of the function of the muscles of the medial group of the thigh.

Question: List the muscles in this group.

Interview to solve the problem: Thigh muscles: classification, topography, structure, functions, blood supply.

Answer to the question: Thin, comb, leading (large, short, long).

Task No. 19

The surgeon needs to perform an operation in the popliteal fossa.

Question: What structures of the lower limb limit the popliteal fossa and project into it?

Interview to solve the problem: Name the important topographic and anatomical formations of the lower limb, their boundaries and contents.

Answer to question: The popliteal fossa is bounded on top by the tendons of the semitensive and semi-membranous muscles (medially), the tendon of the biceps femoris muscle (laterally) and below by the heads of the calf muscle. Contains the tibial nerve, popliteal artery and vein, lymphatic vessels and nodes.

Task No. 20

A patient was taken to the trauma center with an injury to the tendon of the right triceps muscle of the lower leg.

Question: What will be the manifestation of a violation of the function of this muscle?

Interview to solve the problem: Muscles, fascia of the lower leg and foot: topography, structure, functions, blood supply.

Answer to the question: Difficulty flexing the right foot; with a fixed foot - tipping the body anteriorly in the right ankle joint.

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