Topic 6. Muscle tissue

Control questions

1. General characteristic muscle tissue.
2. Classification of the muscle tissues.
3. General characteristic of smooth muscle tissue.
4. Structure of smooth myocyte.
5. Mechanism of contraction of smooth muscle cells.
6. Histogenesis of smooth muscle tissue.
7. Regeneration and innervation of smooth muscle tissue.
8. General characteristic of skeletal muscle tissue.
9. Structure of the muscle fibers.
10. Contractile apparatus of muscle fiber. Structure of myofibril, sarcomere.
11. Mechanism of muscle fiber contraction.
12. Histogenesis, innervation and regeneration of skeletal muscle tissue.
13. Structure of muscle as an organ.
14. General characteristic of cardiac muscle tissue.
15. Types of cardiac muscle cells.
16. Typical cardiac muscle cells: structure and function.
17. Secretory cardiac muscle cells: structure and function.
18. Counductin system of the heart. Characteristic of its cells.
19. Histogenesis, innervation and regeneration of cardiac muscle tissue.

Question 1. General characteristic muscle tissue.

Muscle tissue is responsible for movement of the body and its parts and for changes in the size and shape of internal organs. This tissue is characterized by aggregates of specialized, elongated cells or fibers arranged in parallel array that have the primary role of contraction.

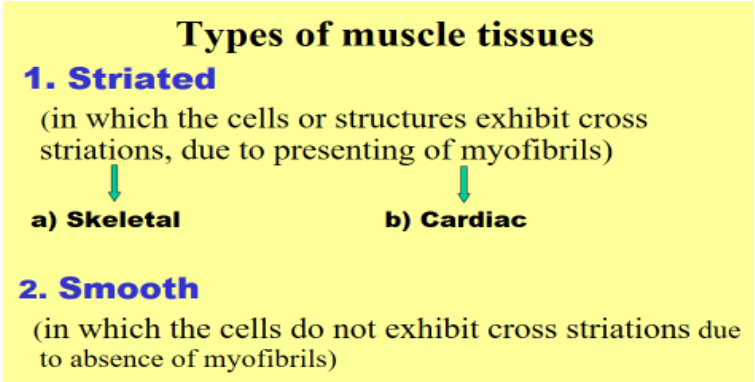
Two types of myofilaments are associated with cell contraction. They are more thine actin filaments consisting of contractile protein actin and more thick myosin filaments consisting of contractile protein myosin [13].

Cytoplasm of muscle cells or fibers is called sarcoplasm, outer covering of muscle cells or fibers is called sarcolemma [4].

In sarcoplasm of muscle cells, there are all general organelles of cell, but more developing are mitochondria and smooth endoplasmic reticulum.

In muscle cells, the smooth endoplasmic reticulum is called sarcoplasmic reticulum. It provides accumulation and realization of calcium necessary for contraction. Mitochondria produce ATP necessary for contraction also [3].

Question 2. Classification of the muscle tissues.



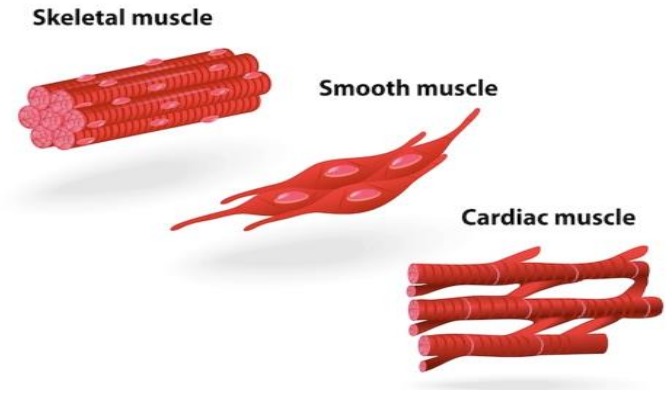


Figure 6.1. Diagram of muscle types.

Question 3. General characteristic of smooth muscle tissue

Smooth muscle tissue arises from mesenchyme.

Smooth muscle tissue is found in the walls of internal organs, ducts of glands and in walls of the most vessels.

Structural and functional unit of smooth muscle tissue is named smooth muscle cells or smooth myocyte.

Question 4. Structure of smooth muscle cells.

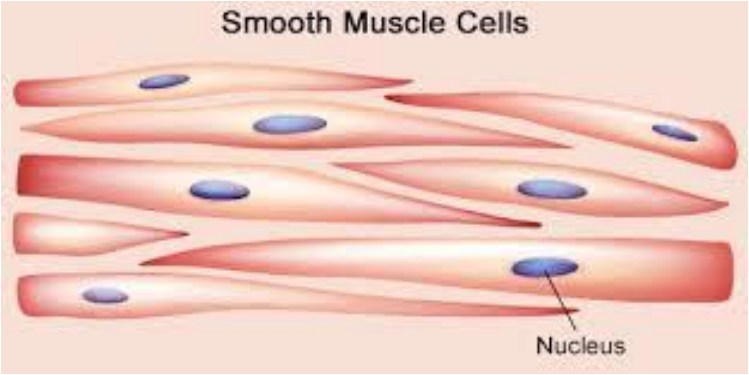


Figure 6.2. Diagram of smooth muscle cells.

Smooth muscle cells are long spindle shaped cells, having a broad central part and tapering ends. In routin H&E preparations the smooth muscle cell sarcoplasm is stained oxyphilically with eosin, because contains high concentrations of actin and myosin contractile proteins [13].

The band like nucleus is located in the center part of the smooth muscle cell. At nuclear pole, the sarcoplasm of the smooth muscle cell contains mitochondria, a Golgi complex, endoplasmic reticulum, free ribosomes [9].

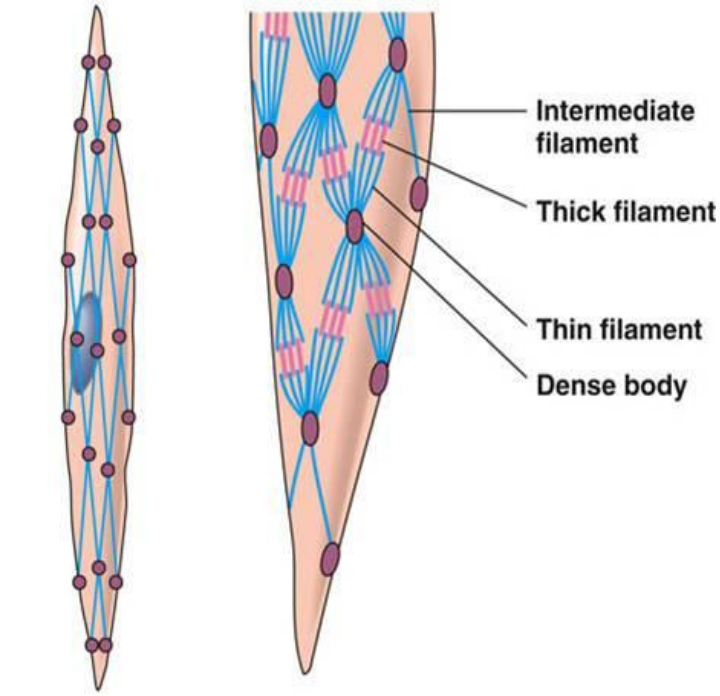


Figure 6.3. Diagram of a contractile apparatus in smooth muscle cell.

Smooth muscle cells possess a contractile apparatus presenting by thin actin and thick myosin filaments and a cytoskeleton presenting mainly by intermediate filaments.

The bundles of thin actin filaments crisscross through the cell, forming a three-dimensional anastomosing network. They are attached to the irregular electron-dense bodies, presenting in sarcoplasm of smooth muscle cell. There are 2 type of dense bodies – membrane-associated and cytoplasmic. Dense bodies contain a protein α-actin. Actin filaments are anchored to the dense bodies by only one end. Increasing of the Ca level initiates formation of myosin filaments, which are polymerized between free ends of actin myofilaments. The intermediate filaments that are attached to dense bodies also consist of proteins called desmin and vimentin [13].

Thus, the dense bodies anchors both thin filaments and intermediate filaments either directly or indirectly to the sarcolemma of smooth muscle cells.

Sarcolemma of muscle cells and fibers consists of two layers:

1) Internal lamina or plasma membrane;
2) External lamina or basal lamina [13].

Each smooth muscle cell is surrounded with elements of loose connective tissue. Mainly they are delicate fibers (collagen, reticular, elastic) that hold the cells together. Loose connective tissue matrix is secretory product of both fibroblasts and smooth muscle cells.

Question 5. Mechanism of contraction of smooth muscle cells.

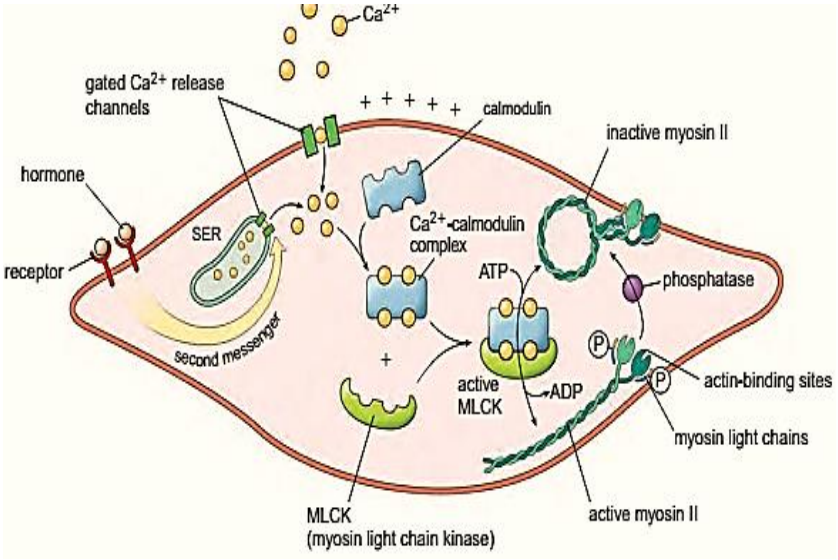


Figure 6.4. Diagram of smooth muscle cells contraction [13].

Smooth muscle is specialized for slow, prolonged contraction.

Smooth muscle cells contract by a sliding filaments mechanism similar to that in striated muscles, but the contraction of smooth muscle cells does not act through a troponin-tropomyosin complex on the thin myofilaments.

Calcium ions control the contraction in smooth muscle cells. An increase in the Ca^{2+} level concentration within the smooth muscle cell is achieved either by initial depolarization of the cell membrane or hormonal stimulation of cell surface receptors. But sarcoplasmic reticulum is rudimentary in smooth muscle cells and mainly Ca^{2+} enter to the cells from intercellular substances by pinocytosis to produce large numbers of pinocytotic vesicles associated with the sarcolemma called caveolae [13].

In smooth muscle, an increase in calcium concentration, the calcium binds to protein called calmodulin to form calcium-calmodulin complex. Then this complex binds to an enzyme called myosin light chain kinase (MLCK) to phosphorylate one of the two regulatory light chains of the myosin molecules. When the light chain is phosphorylated, the actin-binding site of the myosin head is activated and attached to actine [13].

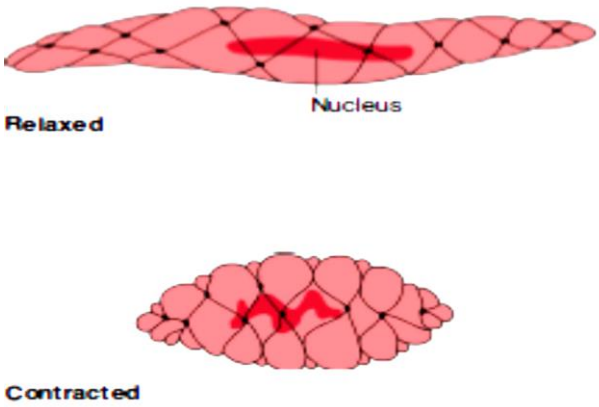


Figure 6.5. Diagram of relaxed and contracted smooth muscle cells [5].

When smooth muscle cell contracts, the borders of the cell become scalloped and the nucleus becomes folded.

Question 6. Histogenesis of smooth muscle tissue

The cells of smooth muscle are derived from the mesenchyme.

Question 7. Regeneration and innervation of smooth muscle tissue.

Smooth muscle cells are capable to mitotic divisions to maintain or increase their number. They may respond to injury by undergoing mitosis.

The smooth muscle of the stomach and colon regularly replicates and may even slowly thicken (hypertrophy) during life [13].

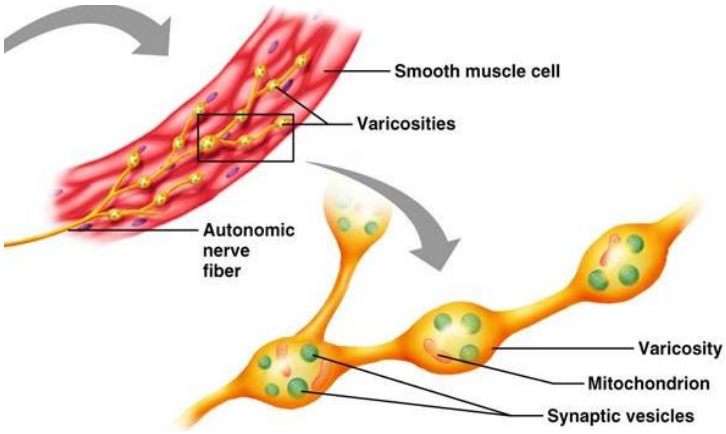


Figure 6.6. Diagram of smooth muscle tissue innervation.

Smooth muscle tissue is innervated by the autonomic nervous system. Motor neurons axons terminate forms dilatations (varicosities) containing synaptic vesicles with neurotransmitters [9].

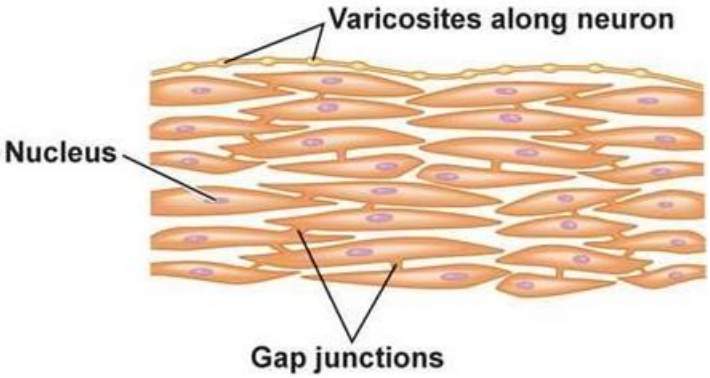
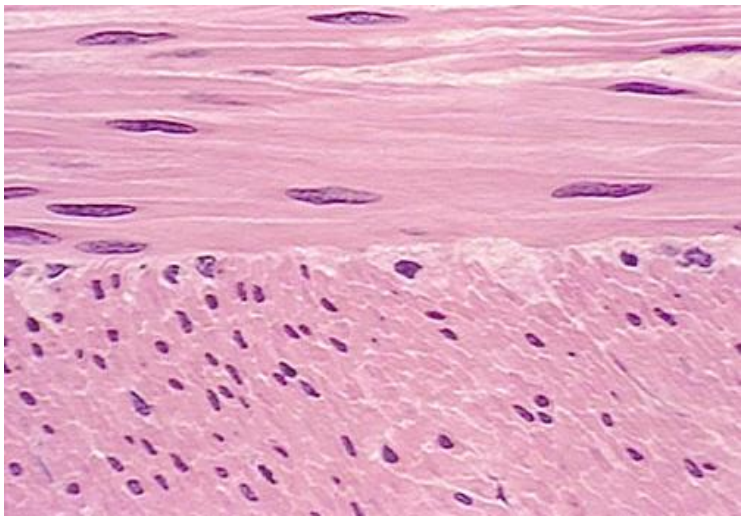


Figure 6.7. Diagram of gap junctions between smooth muscle cells.

Single axon of autonomic nervous system motor neuron innervates a bundle of smooth muscle cells usually including 8 to 10 cells. Gap junctions between adjacent smooth muscle cells allow the transmission of excitation signals from cell to cell and coordinate activity within a smooth muscle bundle [13].

Smooth muscle tissue (slide)

Stain: hematoxylin-eosin



Transverse section

Longitudinal section

Figure 6.8. Photomicrograph of smooth muscle tissue.

Question 8. General characteristic of skeletal muscle tissue.

Skeletal muscle is usually attached to the bones of skeleton and is specialized to execute rapid voluntary movements in response to signals from the central nervous system [3].

Structural and functional unit of skeletal muscle tissue is called muscle fiber or symplast, which is multinucleated syncytium [13].

This type of muscle tissue belongs to the striated because muscle fibers contain striated myofibrils.

Question 9. Structure of the muscle fibers.

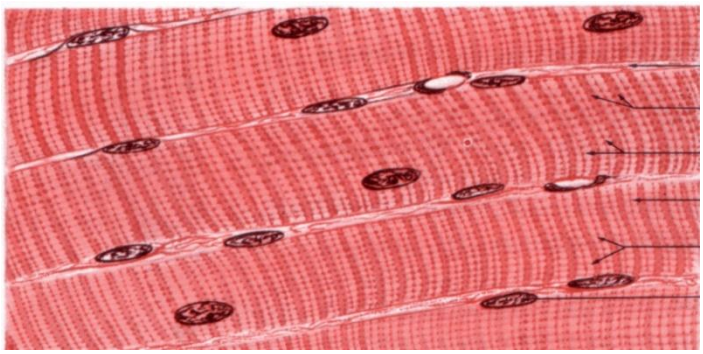


Figure 6.9. Diagram of muscle fibers.

Muscle fiber is long, cylindrical structure. Each muscle fiber is really a symplast or syncytium with hundreds of nuclei along its length. Nuclei are elongated and lie just beneath sarcolemma, covering the muscle fibers outside. The thick sarcolemma consists of external lamina and internal lamina. External lamina is similar to the basal lamina of epithelium and internal lamina is usual plasma membrane of the cell [3].

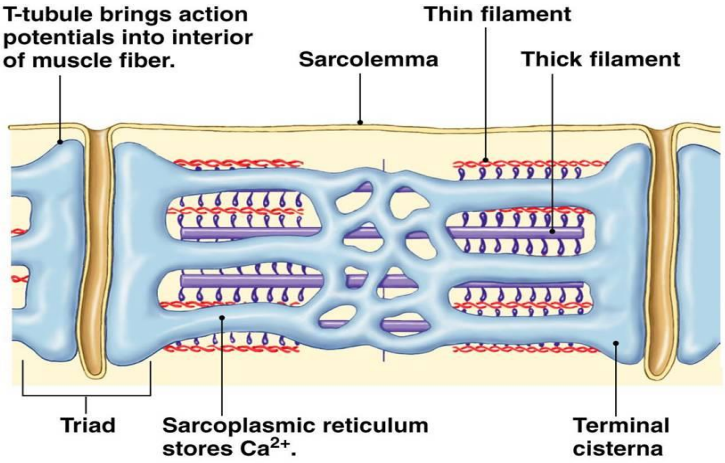


Figure 6.10. Diagram of muscle triad.

The sarcoplasm of muscle fiber contains all general organelles and inclusions (myoglobin, glycogen) and is filled with numerous longitudinal dispose striated myofibrils. More developing general organelles of muscle fibers are mitochondria and sarcoplasmic reticulum.

The sarcoplasmic reticulum is arranged as series of networks around the myofibrils. One network of sarcoplasmic reticulum surrounds the A band, and the adjacent network surrounds the I band. Where the two these networks meet, at the junction between A and I bands, the sarcoplasmic reticulum forms a ring like channel called the terminal cisterna of sarcoplasmic reticulum. Sarcoplasmic reticulum serve as reservoirs for Ca2+.

The transverse tubular system (T system) consists of numerous tubular invaginations of the muscle fiber plasma membrane called T tubules. T tubules penetrate to all levels of the muscle fiber and are located between adjacent terminal cisternae of sarcoplasmic reticulum at the A–I junctions. One T tubule communicates with two terminal cisternae of sarcoplasmic reticulum to produce a structure called a **muscle triad** [3].

Also located around the myofibrils in association with the sarcoplasmic reticulum are large numbers of mitochondria and glycogen granules, both of which are involved in providing the energy necessary for the reactions involved in contraction.

Question 10. Contractile apparatus of muscle fiber. Structure of myofibril, sarcomere.

Contractile apparatus of muscle fiber is represented by numerous longitudinal dispose **striated myofibrils.** They belong to the special organelles.

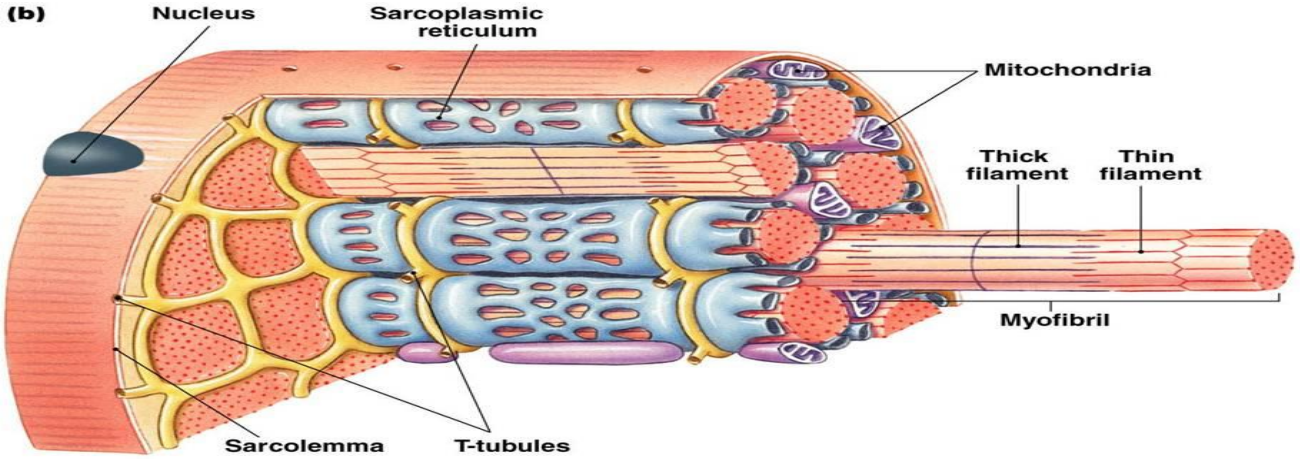


Figure 6.10. Diagram of the organization of striated muscle fiber.

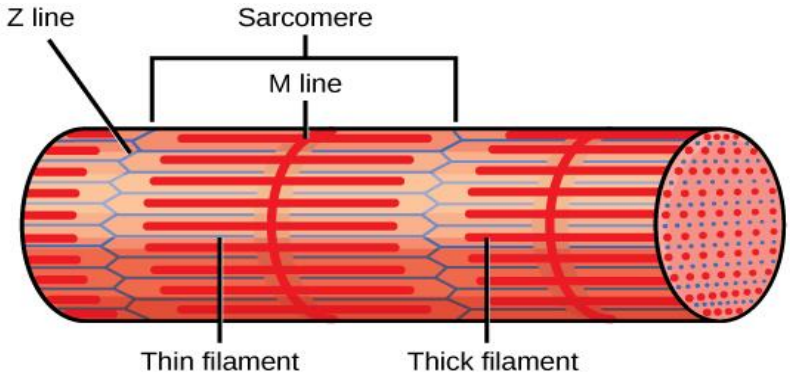


Figure 6.11. Diagram of myofibril.

Each myofibril is composed of the bundles of myofilarnents: thin actin filaments and thick myosin filaments.

The bundles of myofilaments are arranged into groups so that cross-striation appears in myofibrils. The transverse striations of the myofibrils are seen as alternate dark and light bands. The dark ones are called A-bands (anisotropic). The light ones are called I-bands (isotropic). A thin dark *Z* -line lies in the middle part of each I-band. The M-band is a line in the middle part of each A-band. A lighter band called the H-band traverses the center of A-band.

The segment of the myofibril between two Z lines is called a **sarcomere.** Sarcomere is the functional unit of the myofibril.

Thin, actin filaments attach to the Z-line and extend into the A-band. Thick myosin filaments are anchored at the M-band and they are placed between thin actin filaments. The H-band represents the part of the A-band into which actin filaments do not extend [13].

Therefore, the I-band consists of only actin filaments. The A-band consists of both actin and myosin filaments and here the thick and thin filaments interact for contraction. Each thick filament is surrounded by six thin filaments. This is one of the essential structural features of the sliding filament mechanism of contraction.

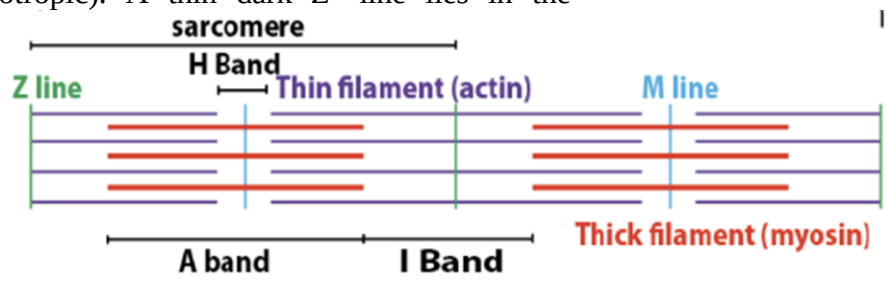


Figure 6.12. Diagram of myofibril.

Ultrastructure of myofibril

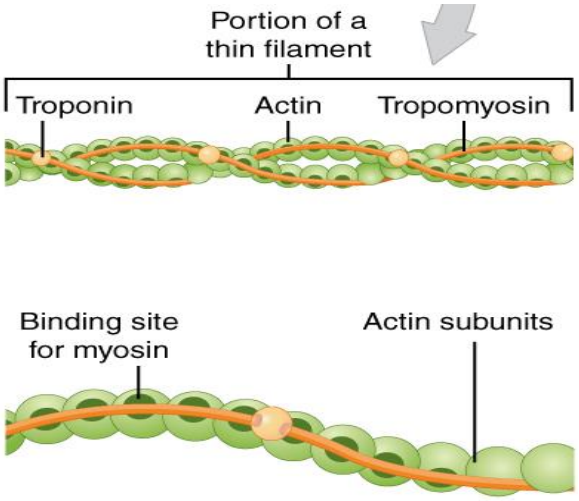


Figure 6.13. Diagram of actin filament.

An actin filament is composed of two subfilaments that are twisted round each other. Each actin subfilament is a chain of globular (rounded) actin molecules. So, actin filaments look like beads on a string. The actin filaments also contain regulatory proteins tropomyosin, and troponin [13].

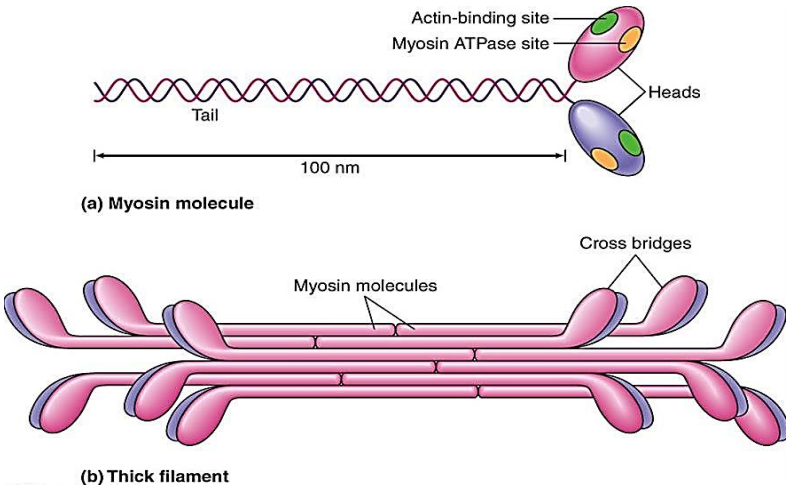


Figure 6.14. Diagram of myosin filament.

Myosin filament is made up of a large number of myosin molecules. Each myosin molecule is composed of two units. Each unit has 2 parts – a head and a tail. The tails are coiled over each other.

The myosin molecules aggregate tail to tail to produce a bundle. Heads project outwards from the bundle. Globular head has two specific binding sites, one for ATP and one for actin.

In a resting muscle, myosin cannot associate with actin, because the binding sites of actin molecules for myosin heads are blocked by the troponin-tropomyosin complex [13].

Question 11. Mechanism of muscle fiber contraction.

The contraction of a skeletal muscle fiber is initiated when a nerve impulse traveling along the axon of a motor neuron arrives at the motor end plate. Skeletal muscle contracts after releasing of neurotransmitter acetylcholine from the presynaptic part (terminal button) of motor end plate. Acetylcholine causes Na+ channels to open in the sarcolemma of muscle fiber. After Na^+ enters the muscle fiber causing general depolarization of sarcolemma. Then depolarization spreads over the plasma membrane of the muscle fiber and continues via membranes of the T tubules to reach the sarcoplasmic reticulum. After Ca^{2+} is rapidly released from the sarcoplasmic reticulum into the sarcoplasm and then binds to the troponin of the actin filaments. It allows the actin molecules and myosin heads to interact to produce the cross-bridges [13].

The movement of many cross-bridges causes the actin filament to "slide" along the length of the myosin filaments. The process is repeated many times during a single contraction. As a result, actin filaments are more and more slide into the cleft between the myosin filaments. For this the length of H-bands, sarcomeres of myofibril and the muscle as a whole become sorter [13].

The energy for the bending of the myosin heads is provided by adenosine triphosphate (ATP). ATP is involved not only in the process of contraction, but also in relaxation.

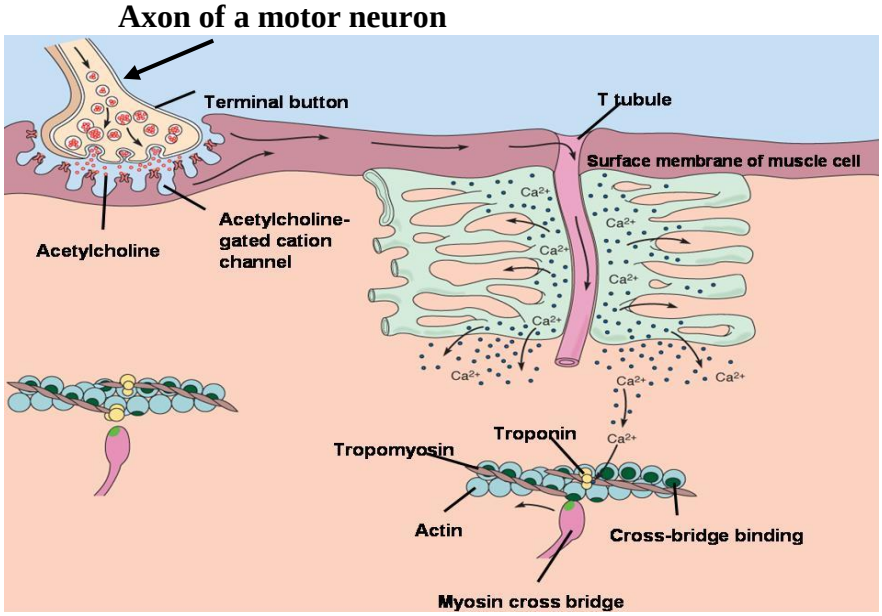


Figure 6.15. Diagram of mechanism of muscle fiber contraction.

Question 12. Histogenesis, innervation and regeneration of skeletal muscle tissue.

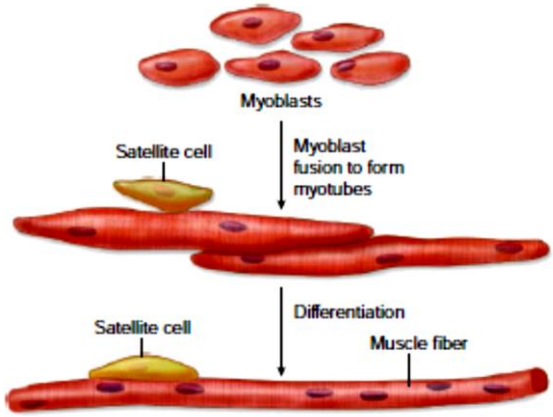


Figure 6.16. Diagram of muscle fibers development [9].

Striated muscles arise from intermediate part of mesoderma somites called myotome.

Mononucleated mesodermal cells called promyoblasts migrate to definitive site of muscle production, accumulate here, show high mitotic activity and differentiate into the cells called myoblasts. Myoblasts are spindle-shaped cells with a single nucleus. They synthesize myofilaments.

Myoblasts have tend to fuse with each other to form structures called myotubes, in which the nuclei have peripheral location. Fusion of myotubes with each other leads to the establishment of a multinucleated symplast [9].

Regeneration of skeletal muscle tissue

Some myoblasts do not fuse and remain mononucleated cells to produce satellite or myosatellite cells. Satellite cells are interposed between external lamina and internal lamina of the sarcolemma along muscle fiber. They are small cells with scant cytoplasm. Satellite cells are stem cells important for repairing. They have capacity to proliferate and produce new muscle fibers following muscle injury [9].

.

Innervation of the skeletal muscle fibers

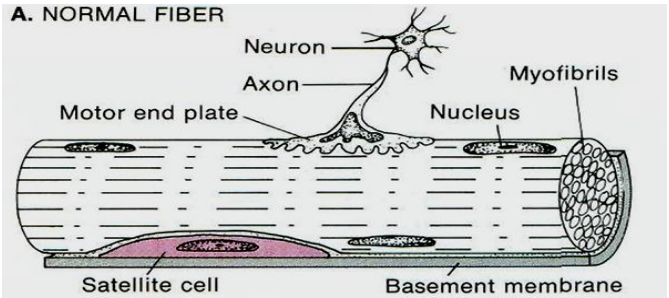


Figure 6.17. Diagram of muscle fibers innervation.

Skeletal muscle fibers are richly innervated by motor neurons of the spinal cord or brainstem (central nervous system organs). The axons of the neurons branch near the skeletal muscle fibers, giving rise to twigs or terminal branches (button) that end on every muscle fiber as **motor end plates (MEP)** [13].

MEP there is on every skeletal muscle fiber. A single neuron has capacity to innervate several to hundred or more muscle fibers. The axon ending on surface of the muscle fiber is a typical presynaptic structure containing numerous mitochondria and membrane limited synaptic vesicles with neurotransmitter acetylcholine. The postsynaptic part of the motor end plate is represented by sarcolemma, containing the specific cholinergic receptors for acetylcholine. The cleft lying between presynaptic and postsynaptic parts known as synaptic cleft [13].

Question 13. Structure of muscle as an organ.

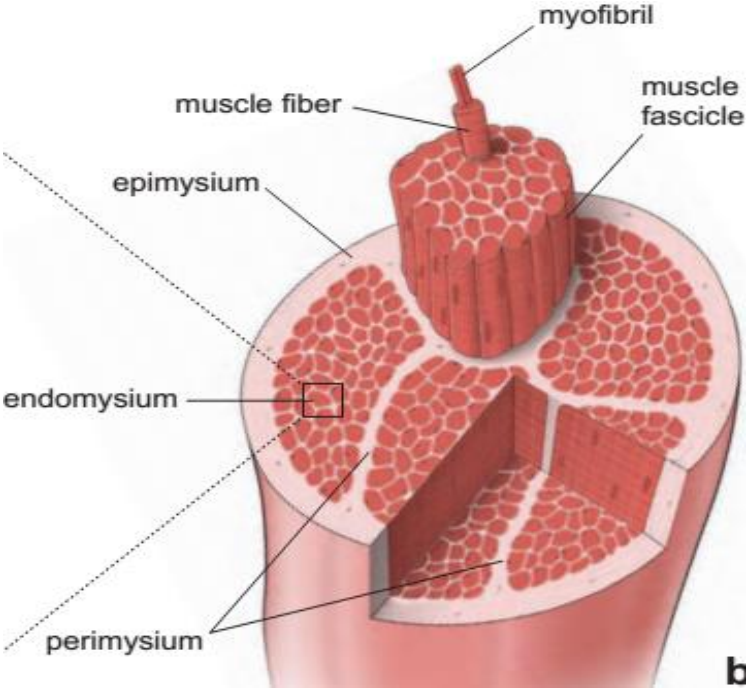


Figure 6.18. Diagram of general organization of skeletal muscle [13].

In skeletal muscle, the striated muscle fibers held together by connective tissue. The connective tissue associated with muscle is named according to its relationship with the muscle fibers. According to this relationship, the connective tissue subdivided into endomysium, perimysium and epimysium.

Endomysium is a delicate layer of loose connective tissue mainly consisting of reticular fibers that immediately surround the individual muscle fibers.

Perimysium is a thicker loose connective tissue layer that surrounds a group of muscle fibers to form a bundle or fascicle. Fascicles tend to work together to perform a specific function.

Epimysium is the sheath of dense connective tissue that surrounds a collection of fascicles that constitute the muscle.

At the end of the muscle, the connective tissue continues as a tendon that attaches the muscle, usually to bone [13].

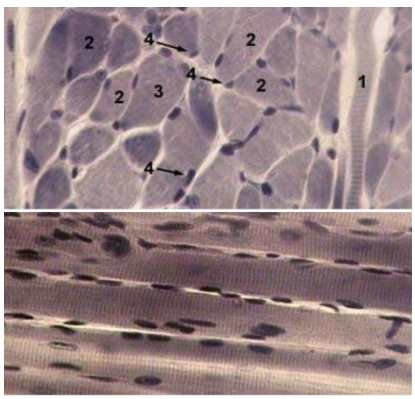
.

Skeletal muscle (slide)

Stain: iron hematoxylin

Using this illustration you must perform the exercise 5 of album (topic "Muscle tissue")

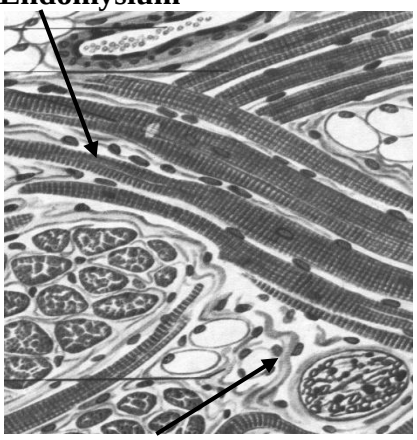
Transverse section



Longitudinal section

Figure 6.19. Photomicrograph of skeletal muscle tissue.

Endomysium



Perimysium

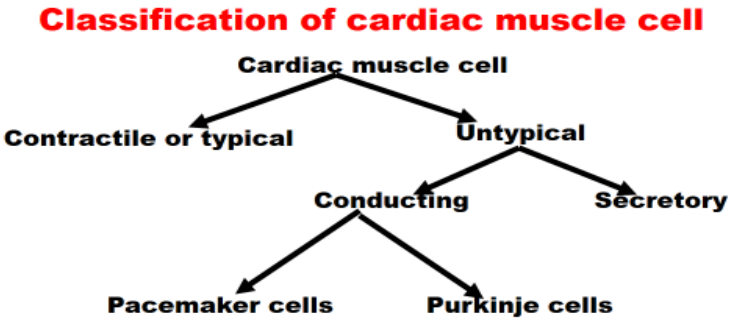
Figure 6.20. Diagram of skeletal muscle tissue [15].

Question 14. General characteristic of cardiac muscle tissue.

Cardiac muscle tissue makes up the myocardium of heart and is responsible for pumping blood throughout the body. Structural and functional unit of cardiac muscle tissue is a cell called cardiac muscle cell or cardiac myocyte.

Cardiac muscle has the same types and arrangement of contractile filaments as skeletal muscle to produce striated myofibrils. Therefore, cardiac muscle tissue belongs to the striated type of muscles.

Question 15. Types of cardiac muscle cells.



Question 16. Typical cardiac muscle cells: structure and function.

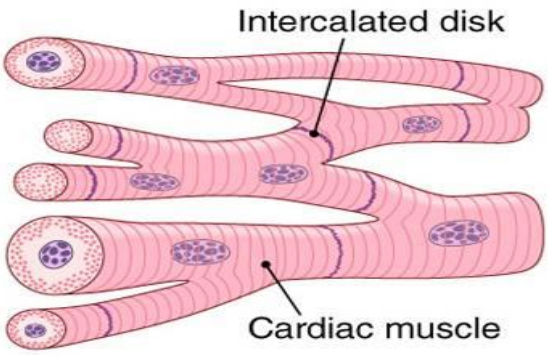


Figure 6.21. Diagram of cardiac muscle cells.

Typical cardiac muscle cells are contractile cells. They are elongated and branched, containing one or two nuclei in the center of the cell.

Typical cardiac muscle cells are joined to one another as arrays, forming branching and anastomosing cardiac muscle fibers (functional syncyte), which provide synchronic work of the myocardium.

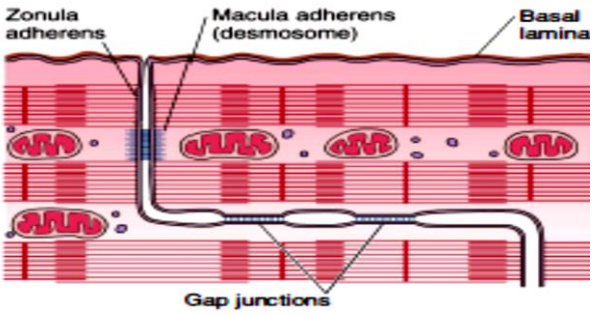


Figure 6.22. Diagram of intercalated disc [5].

The structure of typical cardiac muscle cells is similar to that of skeletal muscle fibers, but there are some differences between them. They are:

1) Myofibrils in cardiac muscle cells are relatively small and have capacity to form anastomoses;
2) Larger diameter T-tubules in cardiac muscle cells are associated with only one sarcoplasmic reticulum cisterna, forming muscle diad;
3) Cardiac muscle cells contain numerous mitochondria;
4) Cardiac muscle cells and their branches are joined end to end by specialized membrane junctions, called intercalated disks;
5) Sarcolemma there is not in place of the intercalated disks. Only plasma membrane is present here [13].

The intercalated disc represents the attachment site between cardiac muscle cells. It include intercellular junctions:

1) Fascia (zonula) adherens for attachment of myofibril actin filaments to the plasma membrane;
2) Desmosomes for mechanical attachment between cells;
3) Gap junctions for passing the electrical signals from cell to cell [5].

Question 17. Secretory cardiac muscle cells: structure and function.

Some cardiac muscle cells are called secretory cardiac muscle cells because they synthesize two types polypeptide hormones. These hormones are called atrial natriuretic factor (ANF) and brain natriuretic factor (BNF). Both hormones are diuretics and inhibit renin secretion in the kidney and aldosterone secretion in the adrenal gland. Both hormones also stimulate relaxation of vascular smooth muscle.

In heart, the secretory cardiac muscle cells mainly place in myocardium of atriums [13].

Question 18. Conducting system of the heart. Characteristic of its cells.

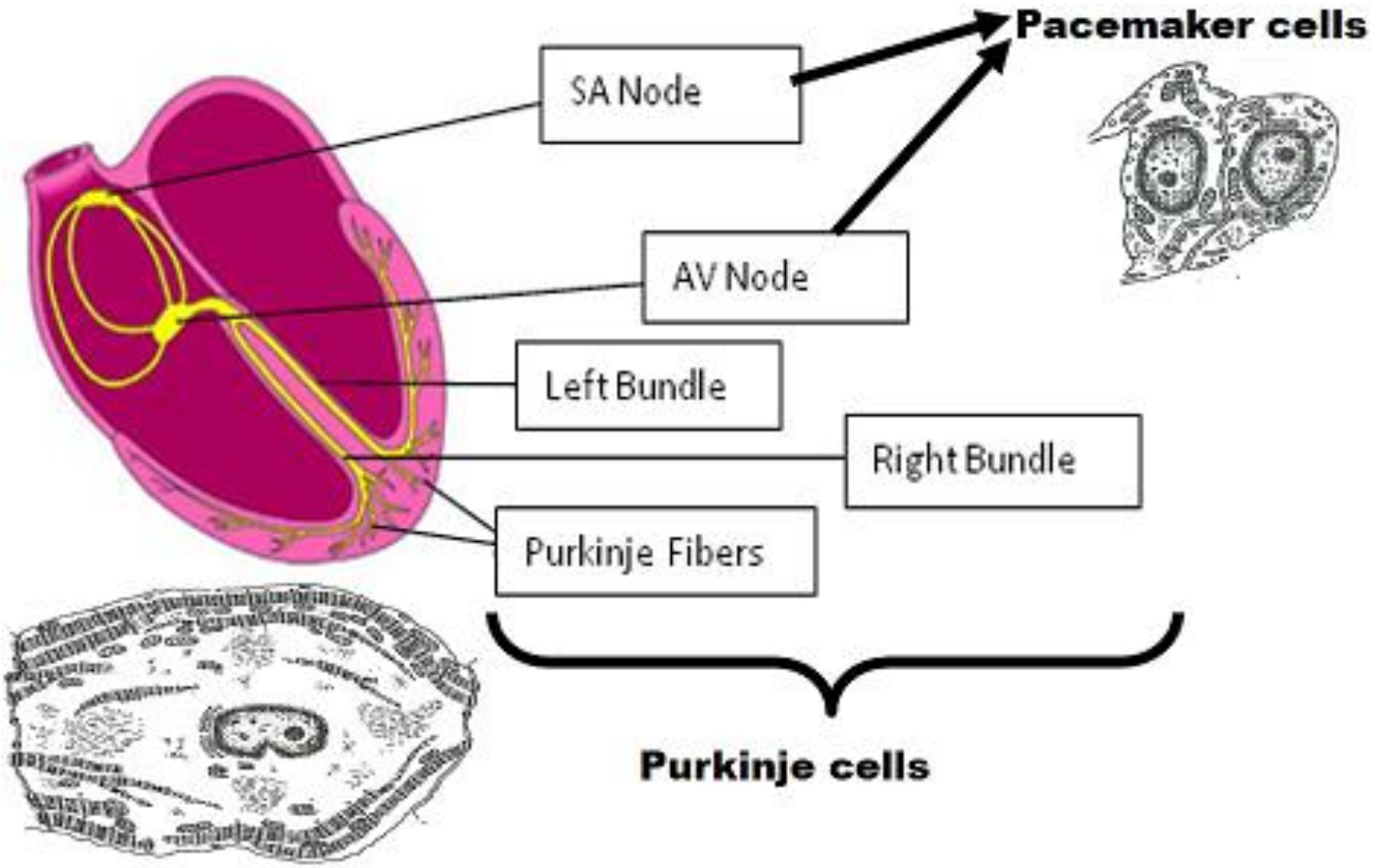


Figure 6.23. Diagram of conducting system of the heart.

The rate скорость and force of contraction are modulated by the autonomic nervous system. Specialized nodal cells known as pacemaker cells (P-cells) initiate the impulse for contraction. After, a signal passes through the heart by way of modified cardiac muscle cells called Purkinje cells.

Pacemaker cells are located in the sinoatrial node, which situates close to the entrance of the superior vena cava into the right atrium. They are small irregular shape cells with fewer myofibrils, lying in different directions.

The pacemaker rate of the sinoatrial node is about 60 to 90 beats per minute. The sinoatrial node initiates an impulse that spreads along the cardiac muscle fibers of the atria and along internodal conducting tract.

The impulse is then picked up to the atrioventricular node, lying in the mediam wall of the right atrium. This node consist of specialized cardiac muscle cells that are similar to those of the sinoatrial node.

Then the impulse carried to the ventricles by the atrioventricular bundle of His, which divides into right and left bundle branches and then into subendothelial branches, commonly called Purkinje fibers.

Atrioventricular bundle of His, bundle branches and Purkinje fibers are composed of specialized cardiac muscle cells called Purkinje cells.

Purkinje cells are large cells with round shaped 1 or 2 centrally placed nuclei, an abundance of glycogen, and few peripherally disposed myofibrils. These cells are united longitudinally by intercalated discs. Both P-cells and Purkinje cells specialize in conduction of impulse to the typical cardiac muscle. cells. Purkinje cells conduct the impulse to the typical cardiac muscle of ventricles [13].

Question 19. Histogenesis, innervation and regeneration of cardiac muscle tissue.

Cardiac muscle tissue arises from the visceral layer of mesodermal splanchnotome.

Autonomic sympathetic and parasympathetic nervous system innervates the heart to increase or decrease the rhythm of heart contraction.

A localized injury to cardiac muscle tissue that results in the death of cells is repaired by replacement with fibrous connective tissue, because mature cardiac muscle cells have not capacity to mitosis. Consequently, cardiac function is lost at the site of injury [13].

Cardiac muscle (slide)

Stain: iron hematoxylin

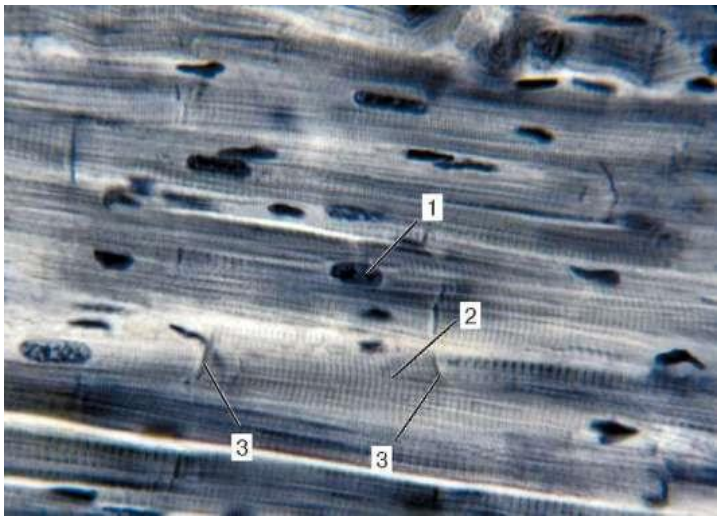


Figure 6.24. Photomicrograph of cardiac muscle tissue.

Using this illustration you must perform the exercise 10 of album (topic "Muscle tissue")

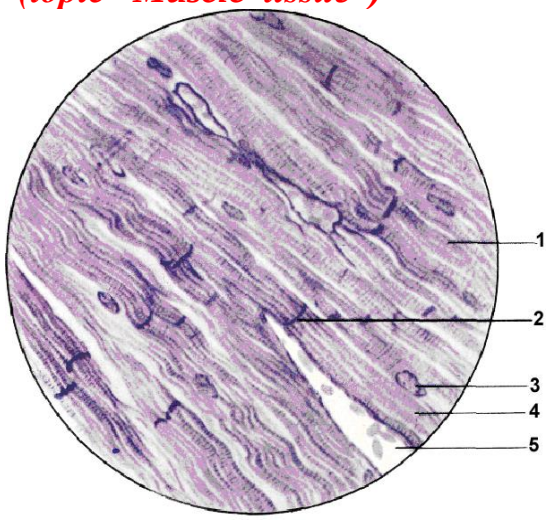


Figure 6.20. Diagram of cardiac muscle tissue [17].

1. Cardiac myocytes
2. Intercalated disk
3. Nucleus
4. Myofibrils
5. LCT with blood vessels