Muscular System

Slide 2

This chapter will focus on muscle cells and tissues. Muscle tissue has several functions:

Movement: Muscles work as pulleys on bones to help create changes in body position. Muscles also move internal contents and function in communication.

Stability: Muscles are used to help maintain body position and posture and prevent unwanted movement.

Control of body openings and passages: Muscles in the mouth, iris of the eye and sphincters of the digestive system help to with control of substances entering and exiting the body and help keep internal materials moving properly.

Heat production: Muscles use ATP and produce heat as a by-product. Heat is used to maintain body temperature and facilitate enzyme activity.

Glycemic control: Muscles can store and release sugar to help maintain homeostasis with blood levels

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All types of muscle cells display the following characteristics:

Excitablity: the potential to respond to an electrical or chemical stimulus and also to stretching

Conductivity: the ability to carry electrical signals after a local stimulus has occurred

Contractility: the ability to shorten after being stimulated

Extensibility: the ability to be stretched longer than their normal length between contractions without rupturing

Elasticity: ability to return to their original shape after being stretched

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The three specific types of muscle tissue in the body will be discussed in later slides. Skeletal muscles exist in a number of different shapes. Shape is determined by the orientation of the muscle cells. Muscle strength is determined by muscle size and shape and by the direction the cells contract. Here are the common skeletal muscle shapes:

Fusiform muscles are wide in the middle and tapered end

Parallel muscles are uniform in width and have parallel cells, they are elongated straps, can span long distances, shorten more than other types and produce less forces due to fewer cell

Triangular muscles are fan-shaped, broad at one end and narrow at the other, and are relatively strong due to a large number of cells

Pennate muscles are feather shaped and generate the most force due to the arrangement of the muscles cell

Circular muscles are round and often control movement through openings and passageways

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Muscle Compartments are groups of functionally related muscles enclosed in connective tissue.

Muscles and Muscle Compartments attach to bone. The gap between the muscle and bone is spanned by tendons.

Muscles work on bones in a manner similar to the way pulleys work on levers to produce work. When a specific muscle is contracting, one end in usually stationary or anchored. This end is called the origin. The end of the muscle that attaches to the mobile bone is referred to as the insertion. For instance, your textbook gives the example of the biceps brachii. The origin for the biceps brachii is on the scapula and the insertion is on the radius. When the muscle contracts, it acts on the radius and causes flexion of the elbow.

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A muscle action is the effect produced by muscle. Muscles do not work on bones in isolation. When muscles act, they play various roles. During a specific action, there is a prime mover, a synergist, a fixator and an antagonist.

The prime mover produces the primary force for the action. The synergist(s) aids the prime mover. The muscle that stabilizes a part of the body that the moving muscle is attached to is known as the fixator.

During a specific muscle action, other muscles are often used to counteract the prime mover. The muscle that works in opposition is called the antagonist. The overall outcome is that the prime mover's action is more controlled due to less excess movement and decreased speed. In other words, antagonists work as a check and balance for the prime movers. The antagonist keeps the prime mover from moving too far and fast and causing injuries and they also help stabilize the joint.

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Each specific skeletal muscle has a specific structural organization. A muscle, itself, is actually considered a complete organ. Different layers of connective tissue divide a complete muscle into smaller components. Starting with a complete muscle and working to the level of the cell (macroscopic to microscopic), the tissues and compartments are as follows:

The fascia is the connective tissue that separates a muscle from other muscles or other organs or tissues, such as skin.

The epimysium is the connective tissue that that surrounds an individual muscle

Within the muscle, the perimysium is the connective tissue that surrounds and defines fascicles. Fascicles are bundles of muscles cells (fibers)

Lastly, within a fascicle, individual muscle cells are separated by layers of endomysium.

As you'll continue to discover, prefixes and suffixes are very useful in helping to learn and identify structures and functions. The prefixes epi-, peri-, endo will be used in other chapters, as well. The prefix epi- means outer or surface. The prefix endo- refers to inner or inside. The prefix peri- usually translates to around.

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Skeletal muscle cells, also known as muscle fibers, contain many of the same features as other cells. Some of the skeletal muscle cell components have specific names.

The cell membrane of a muscle cell is also known as the sarcolemma. It has the same phospholipid construction as most cells and also contains special receptors that function in excitation.

Transverse Tubules, or t-tubules, are infoldings from the sarcolemma that penetrate from one side of the cell to the other. They are important in the conduction of impulses.

The cytoplasm (cytosol and organelles) in a muscle cell are referred to as the sarcoplasm. Within the sarcoplasm of the cell, there are several substances and organelles and are important for normal cellular function.

A muscle fiber contains many molecules of glycogen. Glycogen is a polysaccharide made of glucose. The glucose contained in the glycogen molecules can be used by the cell to produce ATP. The sarcoplasm also contains many molecules of myoglobin. Myoglobin is a protein that can bind to and store oxygen within the muscle fiber. When needed, the oxygen can be used to help produce ATP.

The smooth endoplasmic reticulum of a muscle fiber is specifically known as the sarcoplasmic reticulum. It forms an extensive network within the sarcoplasm. Special sacs from the sarcoplasmic reticulum called terminal cisternae store and release the calcium ions that are essential for contraction.

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Within the sarcoplasm, the most prominent organelles are known as myofibrils. Myofibrils are long tube-like bundles of proteins. Within the myofibrils are several types of myofilaments. Myofilaments are long chains of parallel proteins and are responsible for muscle contraction. There are three types of myofilaments.

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Thick filaments are composed of bundles of contractile proteins called myosin. Each myosin protein has a head and a tail portion. Myosin heads extend from the thick filaments and use ATP to attach to and pull on thin filaments.

Thin filaments consist of two intertwined contractile proteins called actin and two additional regulatory proteins, troponin and tropomyosin. Each actin protein has a binding sites for myosin heads. The two regulatory proteins found in thin filaments help to ensure that muscle contraction remains under control. Tropomyosin molecules are proteins that cover the myosin binding sites on actin when the muscle is resting. The second regulatory protein is called Troponin. Troponin is positioned along tropomyosin. They work together to either allow or prevent contraction. Troponin has binding sites for calcium ions. When calcium binds to troponin, the tropomyosin molecule shifts position and exposes the myosin binding sites on actin. Without calcium, myosin and actin cannot interact.

The third and final myofilaments are known as elastic filaments. Elastic filaments contain spring-like proteins called titin. Elastic filament anchor thick filaments in place and prevent them from overstretching. They also recoil after contraction to help the proteins return to their original positions within the myofibril.

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Finally, within the myofibrils of the sarcoplasm, the functional units of muscle contraction are found. Each myofibril is divided by Z discs into smaller units called sarcomeres. A sarcomere is the collection of thick, thin and elastic filaments found between two adjacent Z discs.

Within a sarcomere, thin filaments are anchored to the proteins in a Z disc and extend towards the center of the sarcomere. Because each sarcomere contains to Z discs, there are two sets of thin filaments. Thick filaments are found in the center of the sarcomere. They are held in place by elastic filaments that are anchored to the Z discs.

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Please review all of the skeletal muscle cell structures. As we move on and discuss physiology, it will be crucial to have a full understanding of the cellular anatomy.

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In order for muscle fibers to contract, they must be stimulated. Skeletal muscle cells receive stimulatory signals from special nervous system cells called motor neurons. Motor neurons are cells that carry information from the brain or spinal cord to specific muscle fibers. Signals from the motor neurons may ultimately cause muscle cells to contract. Individual motor neurons have multiple branches at their distal ends that allow them to each stimulate multiple skeletal muscle cells.

Within a single skeletal muscle, there are many functional arrangements of motor neurons and the cells that they control. A motor unit is comprised of a motor neuron and all the muscle cells that receive

information from its branches. Some motor neurons have more branches than others which means that different motor units may contain different numbers of muscle cells. Within a muscle, motor units are either entirely active or completely resting. In order for a muscle to do more work, it must incorporate more motor units. The motor units that are functioning, at any given time, are completely active…all the cells in the motor unit are working. The motor units that are not being incorporated into an action will remain completely resting…none of the muscle cells will be stimulated to contract.

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All neurons communicate with other cells at regions called synapses. Neurons release chemical messengers called neurotransmitters to signal their target cells at a synapse.

The branches from the motor neuron of a motor unit communicate with the muscle cells in the motor at specific synapses called neuromuscular junctions. There are separate neuromuscular junctions for each muscle cell.

A neuromuscular junction has several components. Each branch from the motor neuron has an enlarged terminal end known as the synaptic knob. The synaptic knob contains synaptic vesicles. Synaptic vesicles are small sacs that contain neurotransmitters. Neurotransmitters are the chemical messengers that used by neurons to communicate with other cells. The specific neurotransmitters found in the vesicles of the synaptic knob are molecules of acetylcholine. Acetylcholine (Ach) molecules are used by the motor neuron to stimulate the skeletal muscle cells at a specific neuromuscular junction.

The synaptic cleft is the physical space between the synaptic knob and the muscle cell.

Across the synaptic cleft from the synaptic knob, the sarcolemma of the muscle cell at a neuromuscular junction possesses proteins receptors for acetylcholine. These receptors are able to recognize and bind to ACh that is released from synaptic vesicles.

Additionally, in the synaptic cleft there are molecules of Acetylcholinesterase (AChE). AChE is an enzyme that breaks down ACh.

When the neuromuscular junction is active AChE degrades ACh and limits the stimulation of the muscle cell.

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Please review all of the components of the neuromuscular junction. As we move on and discuss muscle behavior, it will be crucial to have a full understanding of the neuromuscular junction components.

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When a motor unit becomes active, there are several specific steps involved that ultimately result in the contraction of the muscle cell and its ultimate return to its original resting state. In order, the steps are excitation, excitation-contraction coupling, contraction and relaxation.

As you move forward and start to study muscle behavior, please make sure you are familiar with muscle fiber anatomy and the composition of the neuromuscular junction.

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There are several steps in the process of Excitation.

1. A nerve impulse is sent down the motor neuron and arrives at the synaptic knob. This causes extracellular calcium ions to move by facilitated diffusion into the synaptic knob.

2. The entry of calcium causes synaptic vesicles in the synaptic knob to release ACh into the synaptic cleft

3. Molecules of ACh diffuse across the synaptic cleft and bind to receptors on the sarcolemma of the muscle cell.

4. The binding of ACh generates electrical signals on the sarcolemma. The signals spread out on the sarcolemma in all directions.

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When ACh molecules bind to protein receptors on the sarcolemma, a muscle impulse Is generated. Remember that all muscle cells are excitable and conductive.

From the receptors, the impulses spread across the sarcolemma and then down into the cell through transverse tubules.

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After the sarcolemma is stimulated, there are several steps involved in Excitation-Contraction Coupling.

1. Electrical signals travel from the cell surface down into the sarcoplasm through transverse tubules

2. Impulses in the transverse tubules cause the terminal cisternae of the sarcoplasmic reticulum to release stored calcium

3. Released calcium ions diffuse through the sarcoplasm and bind to troponin molecules on thin filaments

4. The binding of calcium to troponin causes tropomyosin to shift away from the myosin binding sites on actin

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Please refer to this diagram and track the steps. This illustration is also found in your text.

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After the myosin binding sites on actin are exposed, the contractile proteins in the myofilaments are able to interact. There are several steps that result in the shortening of the sarcomere.

The Sliding Filament Theory explains how the sarcomeres of the myofibril shorten. The theory states that the myofilaments, themselves, don't actually shorten but rather they slide past each other pulling the Z discs closer together.

1.Myosin heads use the enzyme Adenosinetriphosphotase (ATPase) to break down ATP and release energy

2. Myosin heads use energy to extend to actin and attach to the binding sites on actin (cross-bridge)

3. Myosin heads pull opposing thin filaments to the center of the sarcomere (power stroke)

4. Additional ATP binds to myosin and they release the original cross-bridge.

5. ATPase breaks down the new ATP and the process repeats until the sarcomere shortens completely

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After a muscle is done being used, it returns to its original resting length. The process is known as relaxation.

There are several steps involved in relaxation.

1. Nerve impulse stops.

2. ACh ceases to be released from synaptic vesicles.

3. In the cleft, the previously released ACh is broken down by Acetylcholinesterase

4. The sarcolemma is no longer stimulated and calcium ceases to be released from terminal cisternae.

5. Active transport pumps return calcium from the sarcoplasm back into the sarcoplasmic reticulum.

6. Calcium leaves the binding sites on troponin and tropomyosin returns to its original position

7. When myosin can no longer bind to actin, the myofilaments slide back into their original position and the sarcomere returns to its normal length

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Muscles cells rely on ATP to provide the energy needed for contraction and relaxation. Although there are a number of factors that influence the availability of ATP, oxygen and glucose levels are among the most important.

Glycolysis is the process of producing ATP starting with glucose. During the first step of the process, glucose is broken down by enzymes into pyruvic acid. A small amount of ATP is produced during this process. Depending upon the local environment in a cell, the pyruvic acid produced during the breakdown of glucose has two potential fates:

If oxygen is unavailable or limited, pyruvic acid gets converted immediately into lactic acid. This process is known as anaerobic fermentation. This process results in the production of a limited amount of ATP.

If sufficient oxygen is available, pyruvic acid can get converted into a much greater amount of ATP. Additionally, carbon dioxide and water are produced. This series of chemical reactions is known aerobic respiration.

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The ATP need for contraction and relaxation of skeletal muscle comes from several potential sources. The sources of ATP vary depending upon the magnitude and duration of the muscle actions.

The immediate ATP that is consumed during the first few seconds comes from aerobic respiration and then the phosphagen system. The myoglobin stored in the sarcoplasm provided the oxygen need to convert glucose, and then pyruvic acids, into ATP. Due to the fact that myoglobin is limited, these reactions are brief in duration.

After this initial ATP is consumed, another source is needed in order to all the muscles to continue to work. For a few additional seconds after the myoglobin-facilitated ATP is depleted, ATP can be produced by adding phosphate groups back onto molecules of ADP. The phosphagen system, named because phosphate molecules are used to recycle ADP instead of producing new ATP from glucose. Two potential enzymes function in the phosphagen system.

An enzyme called myokinase works by removing a phosphate group from a molecule of ADP. This reaction liberates a phosphate and also results in converting ADP into adenosine monophosphate (AMP). The removed phosphate is then added to another molecule ADP to produce a usable molecule of ATP.

The other enzyme in the phosphagen system is creatine kinase. Creatine kinase functions by removing a phosphate group from a molecule of creatine phosphate (a common molecule in the body) and

attaching the liberated phosphate onto a molecule of ADP to create ATP. Although the phosphagen system is extremely important, it only produces enough ATP to allow for a few additional seconds worth of muscle activity.

If muscles are called upon for more than a few seconds, the body switches to a short term source for ATP. The glycogen-lactic acid system uses glucose in the blood or stored glycogen from other tissues and converts it quickly into pyruvic acid and then into lactic acid (anaerobic fermentation). This produces a limited amount of additional ATP per glucose consumed but it also has the affect of producing lactic acid.

The most sustainable long term source for ATP is aerobic respiration. In the presence if oxygen, pyruvic acid from glucose can be converted into a significant amount of ATP. In order for aerobic respiration to be sustained, the body must have sufficient supplies of oxygen and glucose.

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This illustration depicts the two primary enzymes phosphagen system.

In the top example, the enzyme myokinase is shown removing a phosphate group from a molecule of ADP and transferring it to another ADP to create a new molecule of ATP

In the bottom illustration, the enzyme creatine kinase is shown removing a phosphate group from a molecule of creatine phosphate and transferring it to a molecule of ADP to create a new molecule of ATP.

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Here is a summary of the potential sources for ATP and how they change due to overall oxygen demand.

Initially, ATP is provided by aerobic respiration using oxygen from myoglobin

After a few seconds, the phosphagen system kicks in and several enzymes borrow phosphate groups to help create new ATP from ADP.

If additional work is required, cells start to use glucose. Glucose is first broken down into pyruvic acid. If insufficient oxygen is available, pyruvic acid is converted to lactic acid.

The most sustainable source for oxygen is aerobic respiration. In order for this to occur, the body must respond to make sufficient glucose and oxygen available!

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There are three primary types of muscle tissue in the body (recall the tissue identification in lab). Each tissue has specific corresponding cells.

The three types of muscle tissue are skeletal, cardiac and smooth.

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Skeletal muscle tissue is found in all of the muscles that are anchored to the bones of the skeletal system. The motor neurons that control skeletal muscle cell arise from the voluntary portions of the central nervous system. This type of muscle is under conscious control.

The arrangement of myofilaments in myofibrils is visible under a microscope. The overlapping proteins result in alternating light and dark bands. Due to the alternating bands, skeletal muscle tissue is often referred to as striated.

Unlike the two other types of muscle cells, each cell has more than one nucleus. The high concentration of myofilament and the need to maintain the protein content within the cells demand that the cells are multinucleate.

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Cardiac muscle cells are found exclusively in the heart. Although cardiac muscle cells must be simulated in order to contract, their control is considered to be involuntary… the motor neurons that can influence their functions do not arise from the portions of the central nervous system that are voluntary.

Like skeletal muscle, they have myofibril and myofilaments that are organized in a striated fashion. Adjacent cardiac muscle cells are connected by intercalated discs. These connections allow impulses to spread from one cell to another.

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Smooth muscle tissue is found in many organs and tissues. For example, smooth muscle is found in the walls of many blood vessels and also in the wall of the digestive tract. All smooth muscle is involuntary.

Smooth muscle cells contain actin and myosin but they are not arranged in sarcomeres with alternating bands. Under a microscope, smooth muscle has a non-striated appearance.