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MUSCULAR SYSTEM

The muscular system is responsible for the movement of the human body. Attached to the bones of the skeletal system are about 700 named muscles that make up roughly half of a person's body weight. Each of these muscles is a discrete organ constructed of skeletal muscle tissue, blood vessels, tendons, and nerves. Muscle tissue is also found inside of the heart, digestive organs, and blood vessels. In these organs, muscles serve to move substances throughout the body.

Muscular System Anatomy

Muscle Types

There are three types of muscle tissue: Visceral, cardiac, and skeletal.

Visceral Muscle: Visceral muscle is found inside of organs like the stomach, intestines, and blood vessels. The weakest of all muscle tissues, visceral muscle makes organs contract to move substances through the organ. Because visceral muscle is controlled by the unconscious part of the brain, it is known as involuntary muscle—it cannot be directly controlled by the conscious mind. The term "smooth muscle" is often used to describe visceral muscle because it has a very smooth, uniform appearance when viewed under a microscope. This smooth appearance starkly contrasts with the banded appearance of cardiac and skeletal muscles.

Cardiac Muscle: Found only in the heart, cardiac muscle is responsible for pumping blood throughout the body. Cardiac muscle tissue cannot be controlled consciously, so it is an involuntary muscle. While hormones and signals from the brain adjust the rate of contraction, cardiac muscle stimulates itself to contract. The natural pacemaker of the heart is made of cardiac muscle tissue that stimulates other cardiac muscle cells to contract. Because of its self-stimulation, cardiac muscle is considered to be autorhythmic or intrinsically controlled.

The cells of cardiac muscle tissue are striated—that is, they appear to have light and dark stripes when viewed under a light microscope. The arrangement of protein fibers inside of the cells causes these light and dark bands. Striations indicate that a muscle cell is very strong, unlike visceral muscles.

The cells of cardiac muscle are branched X or Y shaped cells tightly connected together by special junctions called intercalated disks. Intercalated disks are made up of fingerlike projections from two neighboring cells that interlock and provide a strong bond between the cells. The branched structure and intercalated disks allow the muscle cells to resist high blood pressures and the strain of pumping blood throughout a lifetime. These features also help to spread electrochemical signals quickly from cell to cell so that the heart can beat as a unit.

Skeletal Muscle: Skeletal muscle is the only voluntary muscle tissue in the human body—it is controlled consciously. Every physical action that a person consciously performs (e.g. speaking, walking, or writing) requires skeletal muscle. The function of skeletal muscle is to contract to move parts of the body closer to the bone that the muscle is attached to. Most skeletal muscles are attached to two bones across a joint, so the muscle serves to move parts of those bones closer to each other.

Skeletal muscle cells form when many smaller progenitor cells lump themselves together to form long, straight, multinucleated fibers. Striated just like cardiac muscle, these skeletal muscle fibers are very strong. Skeletal muscle derives its name from the fact that these muscles always connect to the skeleton in at least one place.

Gross Anatomy of a Skeletal Muscle

Most skeletal muscles are attached to two bones through tendons. Tendons are tough bands of dense regular connective tissue whose strong collagen fibers firmly attach muscles to bones. Tendons are under extreme stress when muscles pull on them, so they are very strong and are woven into the coverings of both muscles and bones.

Muscles move by shortening their length, pulling on tendons, and moving bones closer to each other. One of the bones is pulled towards the other bone, which remains stationary. The place on the stationary bone that is connected via tendons to the muscle is called the origin. The place on the moving bone that is connected to the muscle via tendons is called the insertion. The belly of the muscle is the fleshy part of the muscle in between the tendons that does the actual contraction.

Names of Skeletal Muscles

Skeletal muscles are named based on many different factors, including their location, origin and insertion, number of origins, shape, size, direction, and function.

Location: Many muscles derive their names from their anatomical region. The rectus abdominis and transverse abdominis, for example, are found in the abdominal region. Some muscles, like the tibialis anterior, are named after the part of the bone (the anterior portion of the tibia) that they are attached to. Other muscles use a hybrid of these two, like the brachioradialis, which is named after a region (brachial) and a bone (radius).

Origin and Insertion: Some muscles are named based upon their connection to a stationary bone (origin) and a moving bone (insertion). These muscles become very easy to identify once you know the names of the bones that they are attached to. Examples of this type of muscle include the sternocleidomastoid (connecting the sternum and clavicle to the mastoid process of the skull) and the occipitofrontalis (connecting the occipital bone to the frontal bone).

Number of Origins: Some muscles connect to more than one bone or to more than one place on a bone, and therefore have more than one origin. A muscle with two origins is called a biceps. A muscle with three origins is a triceps muscle. Finally, a muscle with four origins is a quadriceps muscle.

Shape, Size, and Direction. We also classify muscles by their shapes. For example, the deltoids have a delta or triangular shape. The serratus muscles feature a serrated or saw-like shape. The rhomboid major is a rhombus or diamond shape. The size of the muscle can be used to distinguish between two muscles found in the same region. The gluteal region contains three muscles differentiated by size—the gluteus maximums (large), gluteus medius (medium), and gluteus minimus (smallest). Finally, the direction in which the muscle fibers run can be used to identify a muscle. In the abdominal region, there are several sets of wide, flat muscles. The muscles whose fibers run straight up and down are the rectus abdominis, the ones running transversely (left to right) are the transverse abdominis, and the ones running at an angle are the obliques.

Function: Muscles are sometimes classified by the type of function that they perform. Most of the muscles of the forearms are named based on their function because they are located in the same region and have similar shapes and sizes. For example, the flexor group of the forearm flexes the wrist and the fingers. The supinator is a muscle that supinates the wrist by rolling it over to face palm up. In the leg, there are muscles called adductors whose role is to adduct (pull together) the legs.

Groups Action in Skeletal Muscle

Skeletal muscles rarely work by themselves to achieve movements in the body. More often they work in groups to produce precise movements. The muscle that produces any particular movement of the body is known as an agonist or prime mover. The agonist always pairs with an antagonist muscle that produces the opposite effect on the same bones. For example, the biceps brachii muscle flexes the arm at the elbow. As the antagonist for this motion, the triceps brachii muscle extends the arm at the elbow. When the triceps is extending the arm, the biceps would be considered the antagonist.

In addition to the agonist/antagonist pairing, other muscles work to support the movements of the agonist. Synergists are muscles that help to stabilize a movement and reduce extraneous movements. They are usually found in regions near the agonist and often connect to the same bones. Because skeletal muscles move the insertion closer to the immobile origin, fixator muscles assist in movement by holding the origin stable. If you lift something heavy with your arms, fixators in the trunk region hold your body upright and immobile so that you maintain your balance while lifting.

Skeletal Muscle Histology

Skeletal muscle fibers differ dramatically from other tissues of the body due to their highly specialized functions. Many of the organelles that make up muscle fibers are unique to this type of cell.

The sarcolemma is the cell membrane of muscle fibers. The sarcolemma acts as a conductor for electrochemical signals that stimulate muscle cells. Connected to the sarcolemma are transverse tubules (T-tubules) that help carry these electrochemical signals into the middle of the muscle fiber. The sarcoplasmic reticulum serves as a storage facility for calcium ions (Ca2+) that are vital to muscle contraction. Mitochondria, the “power houses” of the cell, are abundant in muscle cells to break down sugars and provide energy in the form of ATP to active muscles. Most of the muscle fiber’s structure is made up of myofibrils, which are the contractile structures of the cell. Myofibrils are made up of many proteins fibers arranged into repeating subunits called sarcomeres. The sarcomere is the functional unit of muscle fibers. (See Macronutrients for more information about the roles of sugars and proteins.)

Sarcomere Structure

Sarcomeres are made of two types of protein fibers: thick filaments and thin filaments.

Thick filaments: Thick filaments are made of many bonded units of the protein myosin. Myosin is the protein that causes muscles to contract.

Thin filaments: Thin filaments are made of three proteins:

Actin: Actin forms a helical structure that makes up the bulk of the thin filament mass. Actin contains myosin-binding sites that allow myosin to connect to and move actin during muscle contraction.

Tropomyosin: Tropomyosin is a long protein fiber that wraps around actin and covers the myosin binding sites on actin.

Troponin: Bound very tightly to tropomyosin, troponin moves tropomyosin away from myosin binding sites during muscle contraction.

Muscular System Physiology

Function of Muscle Tissue

The main function of the muscular system is movement. Muscles are the only tissue in the body that has the ability to contract and therefore move the other parts of the body.

Related to the function of movement is the muscular system's second function: the maintenance of posture and body position. Muscles often contract to hold the body still or in a particular position rather than to cause movement. The muscles responsible for the body's posture have the greatest endurance of all muscles in the body—they hold up the body throughout the day without becoming tired.

Another function related to movement is the movement of substances inside the body. The cardiac and visceral muscles are primarily responsible for transporting substances like blood or food from one part of the body to another.

The final function of muscle tissue is the generation of body heat. As a result of the high metabolic rate of contracting muscle, our muscular system produces a great deal of waste heat. Many small muscle contractions within the body produce our natural body heat. When we exert ourselves more than normal, the extra muscle contractions lead to a rise in body temperature and eventually to sweating.

Skeletal Muscles as Levers

Skeletal muscles work together with bones and joints to form lever systems. The muscle acts as the effort force; the joint acts as the fulcrum; the bone that the muscle moves acts as the lever; and the object being moved acts as the load.

There are three classes of levers, but the vast majority of the levers in the body are third class levers. A third class lever is a system in which the fulcrum is at the end of the lever and the effort is between the fulcrum and the load at the other end of the lever. The third class levers in the body serve to increase the distance moved by the load compared to the distance that the muscle contracts.

The tradeoff for this increase in distance is that the force required to move the load must be greater than the mass of the load. For example, the biceps brachia of the arm pulls on the radius of the forearm, causing flexion at the elbow joint in a third class lever system. A very slight change in the length of the biceps causes a much larger movement of the forearm and hand, but the force applied by the biceps must be higher than the load moved by the muscle.

Motor Units

Nerve cells called motor neurons control the skeletal muscles. Each motor neuron controls several muscle cells in a group known as a motor unit. When a motor neuron receives a signal from the brain, it stimulates all of the muscles cells in its motor unit at the same time.

The size of motor units varies throughout the body, depending on the function of a muscle. Muscles that perform fine movements—like those of the eyes or fingers—have very few muscle fibers in each motor unit to improve the precision of the brain's control over these structures. Muscles that need a lot of strength to perform their function—like leg or arm muscles—have many muscle cells in each motor unit. One of the ways that the body can control the strength of each muscle is by determining how many motor units to activate for a given function. This explains why the same muscles that are used to pick up a pencil are also used to pick up a bowling ball.

Contraction Cycle

Muscles contract when stimulated by signals from their motor neurons. Motor neurons contact muscle cells at a point called the Neuromuscular Junction (NMJ). Motor neurons release neurotransmitter chemicals at the NMJ that bond to a special part of the sarcolemma known as the motor end plate. The motor end plate contains many ion channels that open in response to neurotransmitters and allow positive ions to enter the muscle fiber. The positive ions form an electrochemical gradient to form inside of the cell, which spreads throughout the sarcolemma and the T-tubules by opening even more ion channels.

When the positive ions reach the sarcoplasmic reticulum, Ca2+ ions are released and allowed to flow into the myofibrils. Ca2+ ions bind to troponin, which causes the troponin molecule to change shape and move nearby molecules of tropomyosin. Tropomyosin is moved away from myosin binding sites on actin molecules, allowing actin and myosin to bind together.

ATP molecules power myosin proteins in the thick filaments to bend and pull on actin molecules in the thin filaments. Myosin proteins act like oars on a boat, pulling the thin filaments closer to the center of a sarcomere. As the thin filaments are pulled together, the sarcomere shortens and contracts. Myofibrils of muscle fibers are made of many sarcomeres in a row, so that when all of the sarcomeres contract, the muscle cells shortens with a great force relative to its size.

Muscles continue contraction as long as they are stimulated by a neurotransmitter. When a motor neuron stops the release of the neurotransmitter, the process of contraction reverses itself. Calcium returns to the sarcoplasmic reticulum; troponin and tropomyosin return to their resting positions; and actin and myosin are prevented from binding. Sarcomeres return to their elongated resting state once the force of myosin pulling on actin has stopped.

Types of Muscle Contraction

The strength of a muscle's contraction can be controlled by two factors: the number of motor units involved in contraction and the amount of stimulus from the nervous system. A single nerve impulse of a motor neuron will cause a motor unit to contract briefly before relaxing. This small contraction is known as a twitch contraction. If the motor neuron provides several signals within a short period of time, the strength and duration of the muscle contraction increases. This phenomenon is known as temporal summation. If the motor neuron provides many nerve impulses in rapid succession, the muscle may enter the state of tetanus, or complete and lasting contraction. A muscle will remain in tetanus until the nerve signal rate slows or until the muscle becomes too fatigued to maintain the tetanus.

Not all muscle contractions produce movement. Isometric contractions are light contractions that increase the tension in the muscle without exerting enough force to move a body part. When people tense their bodies due to stress, they are performing an isometric contraction. Holding an object still and maintaining posture are also the result of isometric contractions. A contraction that does produce movement is an isotonic contraction. Isotonic contractions are required to develop muscle mass through weight lifting.

Muscle tone is a natural condition in which a skeletal muscle stays partially contracted at all times. Muscle tone provides a slight tension on the muscle to prevent damage to the muscle and joints from sudden movements, and also helps to maintain the body's posture. All muscles maintain some amount of muscle tone at all times, unless the muscle has been disconnected from the central nervous system due to nerve damage.

Functional Types of Skeletal Muscle Fibers

Skeletal muscle fibers can be divided into two types based on how they produce and use energy: Type I and Type II.

Type I fibers are very slow and deliberate in their contractions. They are very resistant to fatigue because they use aerobic respiration to produce energy from sugar. We find Type I fibers in muscles throughout the body for stamina and posture. Near the spine and neck regions, very high concentrations of Type I fibers hold the body up throughout the day.

Type II fibers are broken down into two subgroups: Type II A and Type II B.

Type II A fibers are faster and stronger than Type I fibers, but do not have as much endurance. Type II A fibers are found throughout the body, but especially in the legs where they work to support your body throughout a long day of walking and standing.

Type II B fibers are even faster and stronger than Type II A, but have even less endurance. Type II B fibers are also much lighter in color than Type I and Type II A due to their lack of myoglobin, an oxygen-storing pigment. We find Type II B fibers throughout the body, but particularly in the upper body where they give speed and strength to the arms and chest at the expense of stamina.

Muscle Metabolism and Fatigue

Muscles get their energy from different sources depending on the situation that the muscle is working in. Muscles use aerobic respiration when we call on them to produce a low to moderate level of force. Aerobic respiration requires oxygen to produce about 36-38 ATP molecules from a molecule of glucose. Aerobic respiration is very efficient, and can continue as long as a muscle receives adequate amounts of oxygen and glucose to keep contracting. When we use muscles to produce a high level of force, they become so tightly contracted that oxygen carrying blood cannot enter the muscle. This condition causes the muscle to create energy using lactic acid fermentation, a form of anaerobic respiration. Anaerobic respiration is much less efficient than aerobic respiration—only 2 ATP are produced for each molecule of glucose. Muscles quickly tire as they burn through their energy reserves under anaerobic respiration.

To keep muscles working for a longer period of time, muscle fibers contain several important energy molecules. Myoglobin, a red pigment found in muscles, contains iron and stores oxygen in a manner similar to hemoglobin in the blood. The oxygen from myoglobin allows muscles to continue aerobic respiration in the absence of oxygen. Another chemical that helps to keep muscles working is creatine phosphate. Muscles use energy in the form of ATP, converting ATP to ADP to release its energy. Creatine phosphate donates its phosphate group to ADP to turn it back into ATP in order to provide extra energy to the muscle. Finally, muscle fibers contain energy-storing glycogen, a large macromolecule made of many linked glucoses. Active muscles break glucoses off of glycogen molecules to provide an internal fuel supply.

When muscles run out of energy during either aerobic or anaerobic respiration, the muscle quickly tires and loses its ability to contract. This condition is known as muscle fatigue. A fatigued muscle contains very little or no oxygen, glucose or ATP, but instead has many waste products from respiration, like lactic acid and ADP. The body must take in extra oxygen after exertion to replace the oxygen that was stored in myoglobin in the muscle fiber as well as to power the aerobic respiration that will rebuild the energy supplies inside of the cell. Oxygen debt (or recovery oxygen uptake) is the name for the extra oxygen that the body must take in to restore the muscle cells to their resting state. This explains why you feel out of breath for a few minutes after a strenuous activity—your body is trying to restore itself to its normal state.

Excess post-exercise oxygen consumption (EPOC) is described as an increase in the rate of oxygen intake, designed to erase the oxygen debt after a period of strenuous activity or exercise. In other words, it's the reason we have a hard time catching our breaths when we've just run for several minutes on the treadmill. Our bodies are given a constant supply of oxygen, but when we engage in physical activity that strains the muscles and increases the heart rate, our bodies use up that latent supply of oxygen quickly and must resort to alternate processes to keep things flowing. One of the ways we help to replace that oxygen debt is by taking deep and often shallow breaths following a brisk walk, jog or weight-lifting session. In addition to this, the body has many elements in place to assist the process of post-exercise oxygen consumption.

Recovering Oxygen Debt

Oxygen consumption must be increased in order to replace the debt caused by exercise and vigorous activity. Under normal conditions, myoglobin, a pigment in the blood, serves as a small storehouse for oxygen. Pyruvate is used to create energy in the body, and glycogen is stored up and ready for a situation that will require a burst of energy, such as exercise. When these stores of oxygen are used up, the body processes must temporarily switch gears and take a new plan of action. When myoglobin is depleted, the muscles begin to work without oxygen. This process is commonly referred to as anaerobic. Because the supply of oxygen is now limited, components such as ATP, or adenosine triphosphate help to convert pyruvate into lactic acid. Lactic acid can then be converted into glucose or glycogen for use by the body as energy, or released into carbon dioxide and water as the body is moving strenuously. Once the body's vigorous activity has slowed down or ceased, depleted storage of ATP, myoglobin and glycogen will need to be replenished. The amount of time that replenishment takes depends upon how strenuous the activity was, and how much oxygen will be necessary for complete restoration. It will take anywhere from two hours up to several days for components such as the storage of glycogen to be recovered.

Increasing Oxygen Efficiency

The amount of oxygen debt created exertion can be greatly lessened based on a number of factors. Maximum oxygen uptake is another phrase for aerobic capacity, and it's determined by things such as age, sex and weight. Females, people who are obese or overweight, and those who are older tend to have a smaller aerobic capacity, thus they may become 'out of breath' more quickly than others when exerting themselves. Changes in diet and proper muscle or weight training can decrease the amount of oxygen debt created during a workout. When this is accomplished, people experience less exhaustion while working out, weight training or even taking that walk to the mailbox!

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