Muscle and Muscle Tissue

Functions

Through contractions, muscles perform four functions.

1. Movement or motion - Skeletal muscles provide movements of the body by muscle contraction, such as walking, and running. Cardiac muscle contraction maintains the beating of the heart. Smooth muscle contraction in the intestines, urinary bladder, and blood vessels moves substances through the body.

2. Maintenance of posture - Skeletal muscles contract and make small adjustments almost continuously to hold the body in stationary positions, such as sitting or standing.

3. Stabilize joints - Skeletal muscles add stability to joints that have poor reinforcement and articular surfaces that do not fit well, such as in the shoulder and knee joints.

4. Heat production - Skeletal muscle constitutes 40% of body mass. Contractions produce heat and are important in maintaining normal body temperature.

Functional Characteristics of Muscles

Muscle tissue has four characteristics that play a role in maintaining homeostasis.

1. excitability - The ability to receive and respond to stimuli. Stimuli initiate nerve impulses which are interpreted by the brain and spinal cord and transmitted back to the muscles, causing them to respond.

2. contractility - The ability to shorten and thicken, or contract, when a sufficient stimulus is received. This characteristic distinguishes muscle tissue from other types of tissue.

3. extensibility - The ability to stretch or extend.

4. elasticity - The ability of muscle to return to its original shape after contraction or extension.
Types of Muscles

Muscle tissues differ in their location, structure, and in the way they are stimulated to contract. All muscle tissue is composed of muscle fibers which are really muscle cells.

There are three types of muscles:

1. **Skeletal muscle**
   Skeletal muscle is found attached to and covering bones. They are classified as skeletal, striated, voluntary muscles. The muscle fibers are multinucleated (contain many nuclei), have band-like striations, and contraction is by conscious control.

2. **Cardiac muscle**
   Cardiac muscle is located in the walls of the heart and is classified as cardiac, striated, involuntary muscle. The muscle fibers are branched, contain a single nucleus, have band-like striations, and are not under conscious control. They have thicker striations, called intercalated discs, where one muscle fiber joins the next fiber.

3. **Smooth muscle**
   Smooth muscle is located in the walls of hollow visceral (internal) organs such as the intestines, stomach, urinary bladder, respiratory passages, and blood vessels. They are classified as visceral, nonstriated, involuntary muscles. The muscle fibers contain a single nucleus, no striations, and are not under conscious control.

**Naming of Skeletal Muscles**

1. **location** - the body region or bone with which the muscle is associated.
   Examples: temporalis, abdominus, femoris, tibialis

2. **shape**
   Examples: deltoid (triangular), trapezius (trapezoid), rhomboideus (rhomboid), splenius (bandage), serratus (serrated)
3. **size**
   Examples: maximus (largest)
   minimus (smallest)
   longus (long)
   brevis (short)
   vastus (great)
   major (larger)
   minor (smaller)

4. **direction of the muscle fibers**
   Examples: rectus (straight or parallel to the midline)
   transversus (perpendicular to the midline)
   oblique (diagonal to the midline)

5. **origin and insertion** - The **origin** is where the muscle attaches to the less movable or immovable bone. **Insertion** is where the muscle attaches to the movable bone.
   Examples: sternomastoid (origin is the sternum and mastoid is the mastoid process of the skull)

6. **number of origins**
   Examples: biceps (two origins)
   triceps (three origins)

7. **action**
   Examples: flexor (flexes)
   extensor (extensors)
   adductor (moves toward the midline)
   abductor (moves away from the midline)

**Functional Groups of Skeletal Muscles**

There are four functional groups of skeletal muscles:

1. **prime mover or agonists** - They are responsible for most of the movement and they cause the desired action.

2. **antagonists** - They oppose or reverse the movement of the agonist and prevent it from overextending.

3. **synergists** - They are muscles that contract and assist the same movement of the agonist and reduce undesired or unnecessary movements.

4. **fixators** - They are synergistic muscles that immobilize a bone or the origin of a muscle.
Structure of Skeletal Muscle

Muscles and groups of muscles are separated from one another by a sheet of dense connective tissue called fascia.

Skeletal muscle is surrounded by a dense fibrous connective tissue called epimysium. Extending inward from the epimysium is collagenous tissue called perimysium which separates the muscle tissue into small compartments. The compartments contain bundles of muscle fibers called fascicles. The arrangement of fascicles determines the shape, function, power, and range of motion of the muscle. Each muscle fiber in a fascicle is surrounded by a thin layer of connective tissue called endomysium.

All three types of connective tissue (epimysium, perimysium, endomysium) of the muscle extend beyond the muscle as tendons which attach the muscle to the periosteum of the bone.

A muscle fiber is a muscle cell which consists of a plasma membrane called the sarcolemma which surrounds the fiber. Within the fiber is the sarcoplasm (cytoplasm) which contains the nuclei, mitochondria, and other organelles.

Within the sarcoplasm is a network of membranous channels called the sarcoplasmic reticulum. The sarcoplasmic reticulum contains sac-like structures called terminal cisternae. Calcium is transported by the sarcoplasmic reticulum and stored in the terminal cisternae. Running transversely through the fiber from the sarcolemma are membranous channels called transverse tubules or T-tubules.

Numerous threadlike myofibrils run the length of the fiber and contain two types of myofilaments composed of contractile proteins:

1. **Thick myofilaments** - composed of the protein myosin. It is a rod-shaped molecule with two round heads at one end called cross bridges.

2. **Thin myofilaments** - composed of the protein actin. It consists of a double-stranded coil. The molecule also contains regulatory proteins called tropomyosin and troponin.

The myofilaments do not extend the length of the muscle fiber. They are contained in small contractile compartments or units called sarcomeres. Sarcomeres are separated from each other by narrow zones of dense material called Z lines.

The arrangement of thick and thin myofilaments produces the characteristic light and dark striations in the fiber.

In a relaxed muscle, each sarcomere contains an area where thick and thin myofilaments overlap to form a dark, dense band called the A band. In the middle of the A band is a narrow area of thick myofilaments called the H zone.

In the center of the H zone is the M line which is a series of fine threads that connect the middle of adjacent thick myofilaments.

The light-colored, less dense area of the sarcomere is composed of only thin myofilaments and is called the I band. The Z line runs down the middle of the I band.
Skeletal Muscle Contraction

A skeletal muscle fiber contracts when a stimulus causes an electrical current, or action potential along the sarcolemma. Muscle cells are stimulated by motor neurons of the nervous system. A neuron consists of a cell body which contains a nucleus, a long thread-like extension called the axon, and several small extensions known as dendrites. Neurons are found in the brain and spinal cord and the axons extend into the muscle cells. The axon enters the skeletal muscle and branches into fine endings which come into close contact with the sarcolemma. The portion of the muscle cell directly below the termination of the axon is the motor end plate. The area of contact between the motor end plate (neuron) and the sarcolemma (muscle fiber) is called the neuromuscular junction.

When a nerve impulse reaches the terminal branches of the nerve fiber, small vesicles in the branches called synaptic vesicles, release a chemical neurotransmitter known as acetylcholine (ACh). The ACh transmits the nerve impulse from the neuron, across the neuromuscular junction, to the motor end plate, initiating contraction.

A muscle fiber usually has a single motor end plate, but the nerve fibers of the motor neurons are highly branched, which results in one nerve fiber connected to many muscle fibers. When the nerve fiber transmits the impulse, all of the muscle fibers to which it is connected are stimulated to contract simultaneously. A motor neuron and the muscle fibers to which it connects is called a motor unit. Muscle fibers of a motor unit will contract to their fullest extent or not at all when stimulated - all-or-none principle.

Muscles are always in a slightly contracted state and ready to respond to stimuli (muscle tone).

Contraction and Relaxation of a Skeletal Muscle Fiber - Sliding Filament Theory

1. A nerve impulse causes synaptic vesicles in the motor axon terminals to release acetylcholine.

2. Acetylcholine diffuses across the neuromuscular junction and initiates an impulse that spreads from the motor end plate over the surface of the sarcolemma.

3. The impulse enters the T-tubules and sarcoplasmic reticulum and stimulates the release of calcium from storage in the terminal cisternae into the sarcoplasm.

4. Calcium ions activate myosin of the thick myofilaments, which breaks down ATP to ADP. Calcium ions also bind the tropomyosin-troponin complex to permit the complex to split from the thin myofilaments.
5. The cross bridges of the myosin molecules of the thick myofilaments connect with free receptor sites on the actin of the thin myofilaments, using energy from the breakdown of ATP.

6. The myosin cross bridges move like oars of a boat along the surface of the thin myofilaments, and the thick and thin myofilaments slide past one another.

7. The thin myofilaments slide inward toward the H zone, the Z lines are drawn closer together and the sarcomeres shorten. The lengths of the thick and thin myofilaments do not change.

8. As the sarcomeres shorten, the myofibrils shorten, and the muscle fibers contract, resulting in the contraction of the muscle.

9. Acetylcholine is inactivated by acetylcholinesterase (enzyme), thus inhibiting nerve impulse conduction from the axon terminals to the motor end plate.

10. Once the nerve impulse is inhibited, calcium ions are actively transported back into the sarcoplasmic reticulum by a transport protein, using energy from the breakdown of ATP.

11. The low calcium ion concentration in the sarcoplasm stops the enzyme activity of myosin. The myosin cross bridges separate from the thin myofilaments and ADP is resynthesized to ATP. ATP binds to the myosin cross bridges, and the tropomyosin-troponin complex is reattached to the actin of the thin myofilaments.

12. The thick and thin myofilaments return to their relaxed position, the sarcomeres return to their resting lengths, the myofibrils lengthen, the muscle fibers relax, and the muscle relaxes.

Smooth Muscle Fibers

Smooth muscle fibers are small, spindle-shaped cells with a centrally located nucleus. They contain actin and myosin myofilaments, but they are very thin and randomly arranged so that no striations or sarcomeres are present. T-tubules are absent. Smooth muscle fibers are surrounded by a fine connective tissue called endomysium. The fibers may be arranged singly, in small fascicles, or organized into sheets.
There are two types of smooth muscle:

1. **Visceral or single-unit smooth muscle** - the most common type. They are composed of sheets of spindle-shaped cells in close contact with one another and found in the walls of hollow visceral organs such as the stomach, intestines, urinary bladder, and uterus.
   The fibers are capable of stimulating each other, and when one fiber is stimulated, the impulse moving over the surface may excite adjacent fibers, which, in turn, stimulate others. The muscles also display **rhythmicity** - a pattern of repeated contractions.

2. **Multi-unit smooth muscle** - The muscle fibers are less well organized and occur as separate fibers rather than in sheets. They are found in the irises of the eyes and in the walls of blood vessels.
   The muscle consists of muscle fibers that are structurally independent of each other, richly supplied with nerve endings, and motor units are formed with a number of muscle fibers.

**Smooth Muscle Contraction**

Smooth muscle contraction resembles skeletal muscle contraction in that they both involve reactions of actin and myosin, they are triggered by nerve impulses along the sarcolemma and the release of calcium ions, and they use energy from ATP molecules.

They differ in that smooth muscles are affected by two neurotransmitters, acetylcholine and norepinephrine which stimulate contractions in some muscles and inhibit contractions in others. Smooth muscles are also affected by a number of hormones, which stimulate contractions in some cases and alter the amount of response to neurotransmitters in others.

Smooth muscle is slower to contract and slower to relax than skeletal muscle, but smooth muscle can maintain a forceful contraction for a longer time with ATP. Smooth muscle fibers can change length without changing tautness and can stretch, allowing organs to expand and hold fluid and other substances.

An action potential is generated by the binding of neurotransmitters to sarcolemma membrane receptors. Calcium ions are released by the sarcoplasmic reticulum and interact with regulatory molecules that are part of the thick myofilaments and myosin is activated. The effect of a specific neurotransmitter on a muscle fiber depends on the type of receptor molecule (stimulatory or inhibitory) on the sarcolemma. The thin myofilaments lack the troponin complex and are always ready to contract.
Some smooth muscles respond to neural and chemical stimuli. Chemical factors cause muscle contraction and relaxation without an action potential and inhibit or stimulate the release of calcium ions into the sarcoplasm. The chemical factors include hormones, lack of oxygen, low pH, and excess carbon dioxide. The direct response of smooth muscle to chemical stimuli allows activity according to local tissue needs.

Cardiac Muscle Contraction

Thick and thin myofilaments are arranged the same as they are in skeletal muscle with the same bands, zones, and lines. Cardiac muscle is stimulated by specialized conducting tissues within the heart. The branching cardiac muscle fibers form a network and the networks are located in the walls of the chambers of the heart. When a single fiber of the network is stimulated, all the fibers of the network are stimulated and it contracts as a unit. Each fiber in a network is separated from the next fiber by an irregular transverse thickening of the sarcolemma called an intercalated disc. These discs strengthen the cardiac muscle and aid in impulse conduction. Cardiac muscle contracts and relaxes rapidly, continuously, and rhythmically.