Anatomy and Physiology: Muscle Tissue and the Muscular System

AI-Generated Study Guide

(Based on lectures delivered by Dr. Ty C.M. Hoffman)

I. Functions of the Muscular System

- **Movement:** The primary function; muscles pull on bones, causing movement at joints.
- **Protection:** Especially in the anterior abdomen, layers of muscles act as a sheath to protect underlying viscera (organs).
- **Thermogenesis:** Production of heat. Shivering is an example of uncoordinated muscular contractions that generate heat through friction to raise body temperature and maintain homeostasis.

II. Muscle Tissue Types and Their Characteristics

There are three types of muscle tissue: skeletal, cardiac, and smooth. **Key Distinction:** Only **skeletal muscle** is part of the muscular system. Cardiac muscle is part of the circulatory system, and smooth muscle is found in multiple systems (e.g., digestive, reproductive).

A. Terminology for Muscle Cells

- Muscle cell
- Muscle fiber
- Myocyte
- Myofiber
- Myo/Mys: prefixes meaning muscle.

B. Comparison of Muscle Tissue Types

FeatureSkeletal MuscleCardiac MuscleSmooth MuscleShape/BranchingCylindrical, non-tapering,

non-branchingCylindrical, branchedSpindle-shaped, non-striatedStriationsYes (lines line up)Yes (lines do not line up)NoNucleiMulti-nucleate (cells fuse during development)Usually one, sometimes two, centrally locatedSingle, centrally locatedLengthExtremely long (can be as long as the muscle)Shorter, branchedShort, spindle-shapedContractionOnly shortens (pulls); cannot actively lengthenOnly shortens (pulls); cannot actively lengthenOnly shortens (pulls); cannot actively lengthenControlVoluntary (requires nervous system signal)Involuntary (autorhythmic, modulated by NS/ES)Involuntary (autorhythmic, low frequency)SpeedFastest (can be varied)Moderate (consistent speed of individual contraction)Slowest (gradual, can last minutes)InnervationInnervated by neuronsAutorhythmic (beats on its own)Autorhythmic (waves of contraction)LocationAttached to bonesHeartWalls of hollow organs (e.g., GI tract, uterus)III. Skeletal Muscle Hierarchy and Connective Tissues

Skeletal muscle has a hierarchical, bundled arrangement similar to a cable.

- **Whole Muscle:** The entire organ (e.g., biceps brachii).
- Covered by **Epimysium** (epi- means over/outermost).
- **Fascicle:** A bundle of muscle fibers within the whole muscle.
- Covered by **Perimysium** (peri- means around).
- **Myofiber (Muscle Cell):** An individual muscle cell.
- Covered by **Endomysium** (endo- means inside/deepest).
- **Myofibril:** An organelle within a muscle cell (myofiber). It is a bundle of protein filaments and runs the entire length of the muscle cell. **Crucially, a myofibril is NOT a cell; it is an organelle within a cell.**
- **Myofilaments:** The protein molecules that make up myofibrils.

- **Thick filaments:** Made of **myosin**.
- **Thin filaments:** Made of **actin**.

A. Tendons

- Connect muscle directly to bone.
- Composed of **dense regular connective tissue**. This tissue is very strong in one direction due to its parallel collagen fibers, suitable for pulling forces exerted by muscles.

IV. The Sarcomere: The Functional Unit of Muscle Contraction

- **Sarcomere:** The basic contractile unit of a myofibril. It is the segment between two **Z-discs**. Myofibrils are composed of many sarcomeres joined end-to-end like train cars.
- **Myofilament Arrangement within a Sarcomere:Myosin (thick filaments):** Located in the center of the sarcomere, forming the A-band and centered on the M-line.
- **Actin (thin filaments):** Anchored to the Z-discs and extend towards the center, overlapping with myosin filaments.
- **Sliding Filament Theory of Contraction:**Muscle shortening occurs as the **amount of overlap between thick and thin filaments increases**.
- Individual actin and myosin myofilaments **do NOT shorten** themselves.
- Myosin heads pull the actin filaments towards the center of the sarcomere, bringing the Z-discs closer together and shortening the sarcomere.
- The shortening of many sarcomeres simultaneously along the length of a myofibril, and thus the entire muscle, results in significant overall muscle contraction.

V. Mechanism of Skeletal Muscle Contraction (Excitation-Contraction Coupling)

Skeletal muscle contraction is initiated by a signal from a motor neuron.

A. Motor Unit

- A **motor unit** consists of **one motor neuron** and **all the skeletal muscle fibers (cells) it innervates (connects to)**.
- When a motor neuron fires, all the muscle fibers in its motor unit contract simultaneously.
- **Small motor units:** Fewer muscle fibers per neuron (e.g., fingers, for delicate movements).
- **Large motor units:** Many muscle fibers per neuron (e.g., thigh, for powerful movements).

- **Recruiting:** Causing more muscle cells to contract.

B. Action Potential and Neurotransmitter Release (Neuromuscular Junction)

1. **Nerve Impulse (Action Potential):** An electrochemical signal originates in the motor neuron (often from conscious intent). This action potential propagates down the neuron's axon and its branches to the **axon terminals**.
2. **Calcium Influx into Neuron:** When the action potential reaches the axon terminal, voltage-gated **calcium ion channels** in the neuron's membrane open. Calcium ions (Ca^{2+}) flow into the axon terminal from the extracellular fluid.
3. **Neurotransmitter Release (Exocytosis):** The influx of Ca^{2+} triggers **exocytosis** of vesicles containing **acetylcholine (ACh)**, a neurotransmitter. ACh is released into the **synaptic cleft** (the small gap between the neuron and the muscle cell).
4. **ACh Binding and Sodium Influx:** ACh diffuses across the synaptic cleft and binds to specific **ACh receptors** on the skeletal muscle cell's plasma membrane. These receptors are also **sodium ion channels**. When ACh binds, these channels open, allowing **sodium ions (Na^+)** to flow into the muscle cell.
5. **Muscle Action Potential:** The influx of positive Na^+ ions into the muscle cell causes a change in the membrane voltage, generating a new **action potential in the muscle cell**. This muscle action potential propagates along the entire length of the muscle cell.

C. Calcium Release and Cross-Bridge Formation

1. **Calcium Release in Muscle Cell:** The action potential propagating through the muscle cell causes the release of stored **calcium ions (Ca^{2+})** from the sarcoplasmic reticulum (a specialized endoplasmic reticulum) into the cytoplasm of the muscle cell.
2. **Regulatory Protein Movement:** At rest, **regulatory proteins** (e.g., tropomyosin) block the active sites on the actin (thin) filaments, preventing myosin heads from binding. When Ca^{2+} is released, it binds to these regulatory proteins, causing them to change shape and move away, **exposing the active sites** on the actin.
3. **Cross-Bridge Formation:** Once the active sites on actin are exposed, the **myosin heads** (from the thick filaments) can bind to them, forming **cross-bridges**.
4. **Power Stroke:** The myosin heads, upon binding to actin, change their angle (like a golf club head swiveling), pulling the actin filaments towards the center of the sarcomere. This "pulling" motion is called the **power stroke**.
5. **ATP for Detachment and Re-cocking:** ATP is required for the myosin head to detach from actin and re-cock for another power stroke, allowing for repeated cycles of binding and pulling as long as calcium and ATP are available.

D. Muscle Relaxation

- When the neural signal stops, ACh is removed from the synaptic cleft, and sodium channels close.
- Calcium ions are actively pumped back into the sarcoplasmic reticulum.
- The regulatory proteins move back to block the active sites on actin, preventing further cross-bridge formation.
- The muscle passively lengthens due to external forces (e.g., gravity, contraction of antagonistic muscles). Muscles can only actively pull, not push.

VI. Gross Anatomy and Major Muscle Actions

A. Muscle Attachment Points

- **Origin:** The attachment point of a muscle to a bone that remains relatively stationary during contraction.
- **Insertion:** The attachment point of a muscle to a bone that moves significantly during contraction.

B. Muscle Actions (Movements)

Most actions occur in antagonistic pairs.

- **Flexion vs. Extension:**
- **Flexion:** Decreases the angle of a joint (e.g., bending the elbow). Occurs in the sagittal plane.
- **Extension:** Increases the angle of a joint (e.g., straightening the elbow). Occurs in the sagittal plane.
- **Hyperextension:** Extension beyond the anatomical position.
- **Rotation:** Pivoting movement around an axis (e.g., shaking head "no" at the atlas-axis joint, rotating the femur).
- **Abduction vs. Adduction:**
- **Abduction:** Movement of a part **away** from the midline of the body (e.g., lifting arm out to the side). Occurs in the frontal (coronal) plane.
- **Adduction:** Movement of a part **towards** the midline of the body (e.g., bringing arm back to the side). Occurs in the frontal (coronal) plane.
- **Circumduction:** A complex movement involving sequential flexion, abduction, extension, and adduction, resulting in a cone-shaped motion (e.g., rotating the arm in a circle).
- **Dorsiflexion vs. Plantar Flexion (Foot only):**
- **Dorsiflexion:** Decreasing the angle between the top of the foot and the shin (toes closer to the body).
- **Plantar Flexion:** Increasing the angle between the top of the foot and the shin (toes farther from the body, standing on tiptoes). Both in sagittal plane.

- **Eversion vs. Inversion (Foot only):**
- **Eversion:** Sole of the foot points laterally (outward). Occurs in the frontal (coronal) plane.
- **Inversion:** Sole of the foot points medially (inward). Occurs in the frontal (coronal) plane.
- **Pronation vs. Supination (Forearm only):**
- **Pronation:** Rotation of the forearm so the palm faces posteriorly (or downward if arm is flexed) (radius and ulna cross).
- **Supination:** Rotation of the forearm so the palm faces anteriorly (or upward if arm is flexed) (radius and ulna parallel).
- **Opposition vs. Reposition (Thumb only):**
- **Opposition:** Bringing the thumb across the palm to touch the tip of any finger.
- **Reposition:** Returning the thumb to its anatomical position.

C. Specific Muscles to Know (Pronunciation and Location/Function Notes)

- **Orbicularis Oculi:** "Orb" (sphere) refers to eyeballs, "oculi" (eye). Around the eye.
- **Masseter:** Muscle of mastication (chewing). Very strong for its size. Originates on the zygomatic arch and inserts on the mandible, pulling it superiorly.
- **Sternocleidomastoid:** "Sterno" (sternum), "cleido" (clavicle), "mastoid" (mastoid process of temporal bone). Long muscle connecting sternum, clavicle, and mastoid process.
- **Deltoid:** "Deltoid" means triangular, shaped like the Greek letter Delta. Triangular muscle of the shoulder.
- **Pectoralis Major:** "Pectoralis" means of the chest/breastplate. "Major" indicates it's the larger, more superficial of the pectoralis muscles.
- **Biceps Brachii:** "Bi" (two), "ceps" (heads of origin), "brachii" (of the arm/brachium). Muscle of the arm with two heads of origin.
- **Rectus Abdominis:** "Rectus" (straight). Abdominal muscle with fibers running straight along the long axis.
- **External Oblique:** "Oblique" (at an angle/diagonal). Superficial abdominal muscle with diagonal fiber orientation (forms a 'V' with the other side).
- **Sartorius:** Longest muscle in the body. Runs diagonally across the thigh. "Sartorius" (tailor's muscle) because it allows for the cross-legged sitting position.
- **Quadriceps Femoris (Group):** "Quadri" (four), "ceps" (heads), "femoris" (of the femur). Group of four muscles on the anterior thigh responsible for knee extension.
- **Rectus Femoris:** "Rectus" (straight). Straight down the front of the thigh.
- **Vastus Lateralis:** "Vastus" (big), "Lateralis" (lateral side). Large muscle on the lateral side of the thigh.
- **Vastus Medialis:** "Vastus" (big), "Medialis" (medial side). Large muscle on the medial side of the thigh.
- **Gastrocnemius:** "Gastro" (belly). Posterior leg muscle (calf muscle) that forms a prominent belly. Connected to the calcaneal (Achilles) tendon, which attaches to the calcaneus (heel bone), causing plantar flexion.

Quiz: Muscular System

Instructions: Answer each question in 2-3 sentences.

1. List the three major functions of the muscular system.
2. Explain why cardiac muscle and smooth muscle are not considered part of the muscular system, even though they are muscle tissues.
3. Describe the key histological differences between skeletal muscle cells and cardiac muscle cells in terms of branching and nuclei.
4. Distinguish between a "myofiber" and a "myofibril."
5. Explain the "sliding filament theory" of muscle contraction. What happens to the myofilaments themselves, and what happens to the sarcomere?
6. Define a "motor unit" and explain why some motor units are "small" and others are "large."
7. Outline the sequence of events that occurs at the axon terminal of a motor neuron when an action potential arrives, leading to the release of acetylcholine.
8. Describe what happens when acetylcholine binds to receptors on the skeletal muscle cell's membrane, and what this ultimately causes in the muscle cell.
9. Explain the role of calcium ions in initiating muscle contraction within the skeletal muscle cell itself.
10. Differentiate between "flexion and extension" and "abduction and adduction" by describing the type of movement and the anatomical plane in which each typically occurs.

Answer Key

1. The three major functions of the muscular system are movement, protection (especially in the anterior abdomen for viscera), and thermogenesis (production of heat, for example, through shivering).
2. Cardiac muscle is part of the circulatory system because it forms the heart, while smooth muscle is found in multiple systems like the digestive and reproductive systems, forming linings of hollow organs. The muscular system specifically encompasses skeletal muscles and their associated tendons.
3. Skeletal muscle cells are cylindrical and unbranched, and they are multi-nucleate due to the fusion of multiple cells during development. Cardiac muscle cells are cylindrical and branched, and they typically have one or sometimes two nuclei.
4. A myofiber is another name for a muscle cell or muscle fiber, representing the entire cellular unit. A myofibril, in contrast, is an organelle located *within* a myofiber, composed of bundles of protein myofilaments.
5. The sliding filament theory states that muscles shorten because the thick (myosin) and thin (actin) myofilaments slide past each other, increasing their overlap. The individual

myofilaments themselves do not change in length; instead, the sarcomeres shorten as the Z-discs are pulled closer together.

6. A motor unit consists of one motor neuron and all the skeletal muscle fibers it innervates. Small motor units have few muscle fibers per neuron, allowing for delicate, precise movements (e.g., fingers), while large motor units have many muscle fibers per neuron, enabling powerful, less precise movements (e.g., thigh).
7. When an action potential reaches the axon terminal, voltage-gated calcium channels open, allowing calcium ions to flow into the neuron. This influx of calcium triggers the exocytosis of vesicles containing acetylcholine (ACh) into the synaptic cleft.
8. When acetylcholine binds to receptors on the skeletal muscle cell's membrane, it causes sodium ion channels to open, leading to an influx of positive sodium ions into the muscle cell. This influx changes the membrane voltage and generates a new action potential in the muscle cell.
9. Within the skeletal muscle cell, an action potential causes the release of calcium ions from the sarcoplasmic reticulum into the cytoplasm. These calcium ions then bind to regulatory proteins on the actin filaments, moving them out of the way and exposing the active sites for myosin head binding.
10. Flexion and extension involve changes in joint angle (decreasing vs. increasing) and typically occur in the sagittal plane. Abduction and adduction involve movement away from or towards the midline of the body, respectively, and typically occur in the frontal (coronal) plane.

Essay Questions (No Answers Provided)

1. Compare and contrast the three types of muscle tissue (skeletal, cardiac, and smooth) in terms of their anatomical characteristics, physiological properties (e.g., control, speed of contraction), and their roles within different organ systems.
2. Describe the hierarchical organization of a skeletal muscle, starting from the whole muscle down to the myofilaments. Explain the role of each connective tissue layer (epimysium, perimysium, endomysium) in this organization.
3. Detail the process of skeletal muscle contraction, beginning with the arrival of an action potential at the motor neuron terminal and ending with the shortening of a sarcomere. Include all key molecular events and structures involved.
4. Discuss the significance of muscle attachment points (origin and insertion) in determining muscle action. Provide examples of common muscle actions (flexion, extension, abduction, adduction) and relate them to the movement of bones at specific joints.
5. Explain the concept of a motor unit and its importance in controlling the force and precision of skeletal muscle contractions. How do differences in motor unit size contribute to the varied functions of different muscles in the body?

Glossary of Key Terms

- **Abduction:** Movement of a body part away from the midline of the body (typically in the frontal plane).
- **Acetylcholine (ACh):** A neurotransmitter released by motor neurons that signals skeletal muscle cells to contract.
- **Actin:** A protein that forms the thin myofilaments in muscle cells, with active sites for myosin binding.
- **Action Potential:** An electrochemical signal or voltage change that propagates along the membranes of excitable cells (neurons and muscle cells).
- **Adduction:** Movement of a body part toward the midline of the body (typically in the frontal plane).
- **Anatomical Position:** A standard body posture used for anatomical reference, with the body erect, feet together, arms at the sides, palms facing forward.
- **Antagonistic Pairs:** Muscles or movements that oppose each other (e.g., flexion and extension).
- **Autorhythmic:** The ability of certain tissues (like cardiac and smooth muscle) to contract on their own without external nervous system stimulation.
- **Axon Terminal:** The end portion of a neuron's axon where neurotransmitters are released to signal another cell.
- **Cardiac Muscle:** Striated, branched muscle tissue found only in the heart; involuntary and autorhythmic. Not part of the muscular system.
- **Circumduction:** A complex movement combining flexion, abduction, extension, and adduction, resulting in a cone-shaped motion.
- **Connective Tissue Membrane:** Layers of connective tissue that surround and organize muscle structures (epimysium, perimysium, endomysium).
- **Coronal Plane (Frontal Plane):** An anatomical plane that divides the body into anterior (front) and posterior (back) portions.
- **Cross-bridge:** The temporary binding of a myosin head to an active site on an actin filament during muscle contraction.
- **Deltoid:** A triangular-shaped muscle of the shoulder, named for its resemblance to the Greek letter Delta.
- **Dense Regular Connective Tissue:** A type of connective tissue with densely packed, parallel collagen fibers, providing great strength in one direction, found in tendons and ligaments.
- **Dorsiflexion:** Movement of the ankle that brings the toes closer to the anterior aspect of the shin. (Foot only)
- **Endomysium:** The deepest connective tissue layer, surrounding individual muscle cells (myofibers).
- **Epimysium:** The outermost connective tissue layer, surrounding the entire whole muscle.
- **Eversion:** Movement of the sole of the foot laterally, away from the midline. (Foot only)
- **Excitable Tissue:** Tissues (nervous and muscle) capable of producing and transmitting action potentials.
- **Exocytosis:** A type of vesicular transport that moves substances out of a cell.

- **Extension:** Movement that increases the angle of a joint, returning it to or beyond the anatomical position (typically in the sagittal plane).
- **External Oblique:** A superficial abdominal muscle with diagonal fiber orientation, contributing to the abdominal wall.
- **Fascicle:** A bundle of muscle fibers within a whole muscle, surrounded by perimysium.
- **Flexion:** Movement that decreases the angle of a joint (e.g., bending an elbow or knee) (typically in the sagittal plane).
- **Gastrocnemius:** The primary muscle of the calf, forming the "belly" of the posterior leg.
- **Gradient:** A difference in a physical quantity (e.g., pressure, concentration, charge/voltage) between two different places.
- **Homeostasis:** The body's ability to maintain a stable internal environment despite external changes.
- **Hyperextension:** Extension of a joint beyond its normal anatomical range.
- **Innervated:** Connected to a neuron of the nervous system, receiving nerve signals.
- **Insertion:** The attachment point of a muscle to the bone that moves significantly during contraction.
- **Inversion:** Movement of the sole of the foot medially, toward the midline. (Foot only)
- **Mastication:** The act of chewing.
- **Masseter:** A powerful muscle of mastication located in the cheek/jaw area.
- **Motor Neuron:** A nerve cell that transmits signals from the central nervous system to muscles, causing them to contract.
- **Motor Unit:** A single motor neuron and all the skeletal muscle fibers it innervates.
- **Multi-nucleate:** Containing more than one nucleus (characteristic of skeletal muscle cells).
- **Muscle Fiber:** Another term for a muscle cell or myofiber.
- **Muscular System:** The organ system comprising all the skeletal muscles and their associated tendons.
- **Myocyte:** Another term for a muscle cell or myofiber.
- **Myofiber:** Another term for a muscle cell or muscle fiber.
- **Myofibril:** A contractile organelle within a muscle cell, composed of many sarcomeres arranged end-to-end.
- **Myofilaments:** The protein filaments (actin and myosin) that make up myofibrils.
- **Myosin:** A protein that forms the thick myofilaments, possessing heads that bind to actin during contraction.
- **Neuromuscular Junction:** The specialized synapse between a motor neuron and a skeletal muscle fiber.
- **Neurotransmitter:** A chemical messenger released by neurons that transmits a signal across a synapse.
- **Opposition:** The movement of the thumb to touch the tip of any other finger. (Thumb only)
- **Orbicularis Oculi:** A muscle that encircles the eye, responsible for closing the eyelid and winking.
- **Origin:** The attachment point of a muscle to the bone that remains relatively stationary during contraction.

- **Perimysium:** The connective tissue layer surrounding a fascicle (a bundle of muscle fibers).
- **Plantar Flexion:** Movement of the ankle that points the toes downward, away from the shin (e.g., standing on tiptoes). (Foot only)
- **Plasma Membrane:** The outer boundary of a cell.
- **Power Stroke:** The pivoting action of the myosin head that pulls the actin filament toward the center of the sarcomere during muscle contraction.
- **Pronation:** Rotation of the forearm so the palm faces posteriorly (or downward if arm is flexed), crossing the radius and ulna. (Forearm only)
- **Quadriceps Femoris:** A group of four muscles on the anterior thigh responsible for knee extension.
- **Receptor:** A protein on a cell that binds to specific chemical signals (like neurotransmitters or hormones), initiating a cellular response.
- **Rectus Abdominis:** A straight muscle of the anterior abdominal wall.
- **Rectus Femoris:** One of the four muscles of the quadriceps femoris group, located straight down the front of the thigh.
- **Recruiting:** The process of activating more motor units to increase the force of muscle contraction.
- **Reposition:** The movement of returning the thumb from opposition to its anatomical position. (Thumb only)
- **Rotation:** A pivoting movement of a bone around its own axis.
- **Sagittal Plane:** An anatomical plane that divides the body into right and left portions.
- **Sarcomere:** The basic contractile unit of a myofibril, extending from one Z-disc to the next Z-disc.
- **Sarcoplasmic Reticulum:** A specialized endoplasmic reticulum in muscle cells that stores and releases calcium ions.
- **Sartorius:** The longest muscle in the human body, running diagonally across the thigh.
- **Skeletal Muscle:** Striated, voluntary muscle tissue attached to bones, responsible for body movement. The primary component of the muscular system.
- **Sliding Filament Theory:** The mechanism of muscle contraction where actin and myosin filaments slide past each other, shortening the sarcomere.
- **Smooth Muscle:** Non-striated, involuntary muscle tissue found in the walls of hollow organs (e.g., stomach, intestines, uterus); responsible for pushing contents through. Not part of the muscular system.
- **Sternocleidomastoid:** A large, superficial neck muscle that flexes and rotates the head.
- **Striated:** Having a striped appearance due to the organized arrangement of actin and myosin filaments (characteristic of skeletal and cardiac muscle).
- **Supination:** Rotation of the forearm so the palm faces anteriorly (or upward if arm is flexed), positioning the radius and ulna parallel. (Forearm only)
- **Synapse:** A specialized junction where a neuron communicates with another cell (e.g., neuron, muscle cell).
- **Synaptic Cleft:** The tiny gap between the presynaptic neuron and the postsynaptic cell at a synapse.
- **Tendon:** A tough band of dense regular connective tissue that connects muscle to bone.

- **Thermogenesis:** The production of heat, often as a result of metabolic processes in the body, including muscle activity (e.g., shivering).
- **Vastus Lateralis:** One of the four muscles of the quadriceps femoris group, located on the lateral side of the thigh.
- **Vastus Medialis:** One of the four muscles of the quadriceps femoris group, located on the medial side of the thigh.
- **Viscera:** Internal organs within the body cavities.
- **Voltage:** A measure of electrical potential difference, or a gradient of electrical charge.
- **Z-disc (Z-line):** A protein structure that serves as the boundary of a sarcomere and anchors the thin (actin) filaments.