Chapter 13
Muscular System

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Points to ponder

- What are the three types of muscle tissue?
- What are the functions of the muscular system?
- How are muscles named and what are the muscles of the human body?
- How are skeletal muscles and muscle fibers structured?
- How do skeletal muscles contract?
- How do skeletal muscle cells acquire ATP for contraction?
- What is rigor mortis?
- What are some common muscular disorders?
- What are some serious muscle diseases?
- How do the skeletal and muscular system help maintain homeostasis?
- How are these two systems related to other systems in maintaining homeostasis?
3 Types of Muscles
(A Review)

1. Skeletal muscle
   • Attached to bones
   • Voluntary
   • Functions:
     • Contraction → moves bones
     • heat production → shivering
What are the functions of skeletal muscles?

1. Support the body
2. For movement by attaching to the skeleton
3. Help maintain a constant body temperature
4. Assist in movement in the cardiovascular and lymphatic vessels
5. Protect internal organs and stabilize joints
2. Cardiac muscle
   • Heart
   • Striated/Involuntary
   • Pumps blood
   • Distributes:
     • Nutrients
     • Waste products
     • Hormones
     • Heat regulation
3. Smooth muscle
- Involuntary
- Contraction
- Some locations:
  - Digestive tract
  - Blood vessels
13.1 Overview of the Muscular System

Review: Types of muscle tissue

Skeletal muscle
- has striated cells with multiple nuclei.
- occurs in muscles attached to skeleton.
- functions in voluntary movement of body.

Cardiac muscle
- has branching, striated cells, each with a single nucleus.
- occurs in the wall of the heart.
- functions in the pumping of blood.
- is involuntary.

Smooth muscle
- has spindle-shaped cells, each with a single nucleus.
- cells have no striations.
- functions in movement of substances in lumens of body.
- is involuntary.
- is found in blood vessel walls and walls of the digestive tract.

Figure 13.1 The three classes of muscles in humans.

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How are skeletal muscles attached?

- **Tendon** – connective tissue that connects muscle to bone
- **Origin** – attachment of a muscle on a stationary bone
- **Insertion** – attachment of a muscle on a bone that moves

Figure 13.2 Connecting muscle to bone.
Muscle Contraction: Produce Movement or Generate Tension

• Muscle groups
  ➢ Synergistic: groups work together
  ➢ Antagonistic: groups oppose each other
**Origin & Insertion**

- **Scapula**
- **Shoulder joint**
- **Origins from scapula and humerus**
- **Triceps muscle**
- **Origins from scapula**
- **Tendons**
- **Humerus**
- **Biceps muscle**
- **Ulna**
- **Radius**
- **Elbow joint**

*Origin → stationary bone
Insertion → the movable bone*
b) Movement. Antagonistic muscles produce opposite movements. The forearm bends when the biceps contracts and the triceps relaxes. The forearm straightens when the biceps relaxes and the triceps contracts.
Anterior muscles

- **Pectoralis major**
  - Draws arm forward and toward the body

- **Serratus anterior**
  - Helps raise arm
  - Contributes to pushes
  - Draws shoulder blade forward

- **Biceps brachii**
  - Bends forearm at elbow

- **Rectus abdominus**
  - Compresses abdomen
  - Bends backbone
  - Compresses chest cavity

- **External oblique**
  - Lateral rotation of trunk
  - Compresses abdomen

- **Adductor longus**
  - Flexes thigh
  - Rotates thigh laterally
  - Draws thigh toward body

- **Sartorius**
  - Bends thigh at hip
  - Bends lower leg at knee
  - Rotates thigh outward

- **Quadriceps group**
  - Flexes thigh at hips
  - Extends leg at knee

- **Tibialis anterior**
  - Flexes foot toward knee

- **Sternocleidomastoid**
  - Flexes & rotates head

- **Deltoid**
  - Abducts, flexes & extends arm

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Posterior muscles

- Deltoid: Raises, flexes & extends arm
- Trapezius: Lifts shoulder blade, braces shoulder, draws head back
- Triceps brachi: Straightens forearm at elbow (extends arm)
- Latissimus dorsi: Rotates and draws arm backward and toward body
- Gluteus maximus: Extends thigh, rotates thigh laterally
- Hamstring group: Draws thigh backward, bends knee
- Gastrocnemius: Bends lower leg at knee, bends foot away from knee
- Soleus: Plantar flexion
- Achilles tendon: Connects gastrocnemius muscle to heel
Muscle bundle (fascicle) surrounded by connective tissue (fascia)

Muscle Structure

- Long, tube shaped
- Multinucleate
- Packed with myofibrils
  - Myofibrils contain
    - Actin & Myosin

Whole muscle

Tendon

Bone

Single muscle cell (fiber)

13.2 Skeletal Muscle Fiber Contraction
Muscle Structure - myofibril

1 muscle cell contains many individual myofibrils

- Terminology for cell structure
  - Sarcolemma → cell membrane
  - Sarcoplasm → cytoplasm
  - SER → sarcoplasmic reticulum and stores calcium
Skeletal Muscle Contractile Unit

- **Sarcomere**: contractile unit
- **Z Lines**: attachment points for sarcomeres

a) A closer view of a section of a myofibril showing that it is composed of sarcomeres joined end to end at the Z-line.
13.2 Skeletal Muscle Fiber Contraction

The sarcomere: myofibrils (actin & myosin)

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Sarcomeres are relaxed.

Sarcomeres are contracted.

Figure 13.6 The structure of a skeletal muscle fiber.

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d) An electron micrograph cross section of a sarcomere in a region that contains both actin and myosin.
A muscle contains bundles of muscle fibers, and a muscle fiber has many myofibrils. A myofibril has many sarcomeres. A muscle contains bundles of muscle fibers, and a muscle fiber has many myofibrils. A myofibril has many sarcomeres.
13.2 Skeletal Muscle Fiber Contraction

The beginning of muscle contraction

Figure 13.7 Motor neurons and skeletal muscle fibers join neuromuscular junctions.
The beginning of muscle contraction

Myofibril

Sliding Filament Model

Myosin molecule head

Myosin molecule

Actin molecule

a) Relaxed state. The myosin heads do not make contact with actin.

- Myosin head not connected to actin
- Tropomyosin covers (blocks) binding site

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a) Resting sarcomere. In the absence of calcium the muscle is relaxed because the myosin heads cannot form cross-bridges with actin.
Nerve Activation of Individual Muscle Cells

Neuromuscular junction

1. Acetylcholine (ACh) released from neuron & binds to muscle fiber receptor

2. The electrical impulse ( ) is carried to the cell’s interior by the Transvers tubules

3. The electrical impulse triggers the release of Ca^{2+} from the sarcoplasmic reticulum

- Motor neuron
- Acetylcholine
- Electrical impulse
- T tubule
- Sarcoplasmic reticulum
- Muscle cell plasma membrane
- Z-line
- Myofibrils
4. Ca binds to Troponin
5. Troponin/tropomyosin complex shifts \( \rightarrow \) exposes myosin binding site
6. Myosin head with ADP + P binds to actin
7. Power stroke
8. 2\textsuperscript{nd} ATP binds to myosin head \( \rightarrow \) unbinds & relaxation

Cross-bridge attachment. The binding of calcium to troponin causes a shift in the troponin-tropomyosin complex, allowing cross-bridges to form.
Contraction: myosin heads form cross-bridges with actin bend, pulling the actin filaments toward the center of the sarcomere.

Muscle Structure and Function
13.2 Skeletal Muscle Fiber Contraction

Visualizing the roles of calcium and myosin in muscle Contraction

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Figure 13.8 The role of calcium ions and ATP during muscular contraction.

Function of Ca²⁺

1. ATP is split when myosin head is unattached.

2. ADP + P are bound to myosin as myosin head attaches to actin.

3. Upon ADP + P releases, power stroke occurs: head bends and pulls actin.

4. Binding of fresh ATP causes myosin head to return to resting position.

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Muscle Relaxation

- Nerve activation ends, contraction ends
- Calcium pumped back into sarcoplasmic reticulum
- Calcium removed from troponin
- Myosin binding site covered
- No calcium = no cross-bridges
13.3 Whole Muscle Contraction

Acquiring ATP for muscle contraction & relaxation

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**Anaerobic**
- creatine phosphate

**Anaerobic**
- glycogen

**Aerobic**
- glycogen or fatty acids

- fermentation

- lactate

- CO₂ + H₂O

- ATP

- ATP

- ATP

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How **b.** ATP is replenished?

Figure 13.11 The three pathways by which muscle cells produce the ATP energy needed for contraction.

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13.3 Whole Muscle Contraction

Where are the fuel sources for muscle contraction?

- Stored in the muscle
  - Glycogen
  - Fat
- In the blood
  - Glucose
  - Fatty acids

Figure 13.10 The sources of energy for muscle contraction.
Activity of Muscles Can Vary

- **Isotonic contractions**: muscle shortens, movement occurs
- **Isometric contractions**: muscle doesn’t shorten, no movement
- Degree of nerve activation
Figure 6.9

a) A motor unit consists of a motor neuron and all of the muscle cells it controls. Any one muscle cell is controlled by only one motor neuron, but a motor neuron controls more than one muscle cell.

b) Photograph of the muscle cells in a motor unit, showing branches of the motor neuron and neuromuscular junctions.
Degree of Nerve Activation Influences Force

• **All-or-none principle**
  - Individual muscle cells are completely contracting or are relaxed

• **Muscle tone**
  - Whole muscles – maintain intermediate level of force known as muscle tone

• **Recruitment**
  - Activation of additional motor units increases muscle tone
Muscle Twitch

- Complete cycle of contraction-relaxation in response to stimulus
- Can be observed using a myogram (laboratory recording of muscle activity)
  - Latent period
  - Contraction
  - Relaxation
  - Summation
  - Tetanic contraction
13.3 Whole Muscle Contraction

Physiology of skeletal muscle contraction

Figure 13.9 The three phases of a single muscle twitch and how summation and tetanus increase the force of contraction.

(a) The three phases of a single muscle twitch:
- **Latent period**: Initial delay before the muscle begins to contract.
- **Contraction period**: The muscle contracts, increasing force.
- **Relaxation period**: The muscle returns to its resting state.

(b) How summation and tetanus increase the force of contraction:
- **Summation**: Multiple stimuli occur rapidly, leading to an increase in force.
- **Tetanus**: Continuous stimuli for a prolonged period, leading to a maintained high force level.
- **Fatigue**: After prolonged activity, the force decreases due to muscle fatigue.

Stimuli → Force → Time → Fatigue
Figure 6.10

Myograph

Muscle force

Latent period
Contraction
Relaxation
Summation
Tetanus

Stimulus
0 Time (msec) 500

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13.3 Whole Muscle Contraction

Types of muscle fibers

Figure 13.12 Fast-twitch and slow-twitch muscle fibers differ in structure.

Fast-twitch muscle fiber
- is anaerobic
- has explosive power
- fatigues easily

Slow-twitch muscle fiber
- is aerobic
- has steady power
- has endurance

(left): © Lawrence Manning/Corbis; (middle): © Dr. Gladden Willis/Visuals Unlimited/Corbis; (right): © Corbis RF
Muscle Activity

- Two types of muscle fibers
  - **Slow twitch**: endurance, long duration contraction, contain myoglobin
    - Jogging, swimming, biking
Muscle Activity

- Two types of muscle fibers
  - **Fast twitch**: strength, white muscle, short duration contraction
    - Sprinting, weight lifting, tennis
## Muscle fiber types

<table>
<thead>
<tr>
<th></th>
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<th>Type Ila</th>
<th>Type IIb</th>
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<tr>
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<td>Slow oxidative</td>
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<tr>
<td>Twitch type</td>
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<td>[Myoglobin]</td>
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<td>Long term anaerobic</td>
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<td>Mitochondrial density</td>
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<td>Oxidative capacity</td>
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<tr>
<td>Glycolytic capacity</td>
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<td>Power produced</td>
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<td>Major storage fuel</td>
<td>Triglycerides</td>
<td>Creatine phosphate, glycogen</td>
<td>ATP, creatine phosphate</td>
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<tr>
<td></td>
<td>Uses lactic acid</td>
<td>Produces lactic acid/ creatine</td>
<td>Uses creatine phosphate</td>
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Muscle fiber comparison

Fast-twitch fibers
- Rely on CP and fermentation (anaerobic)
- Adapted for strength
- Light in color
- Few mitochondria
- Little or no myoglobin
- Fewer blood vessels than slow-twitch

Slow-twitch fibers
- Rely on aerobic respiration
- Adapted for endurance
- Dark in color
- Many mitochondria
- Myoglobin
- Many blood vessels
Exercise Training

• **Strength training**
  – Resistance training
    • Short, intense
    • Builds more fast-twitch myofibrils
Exercise Training

• Aerobic training
  ▪ Builds endurance
  ▪ Increases blood supply to muscle cells
  ▪ Reach target heart rate for at least 20 minutes, three times a week

“My doctor told me to start my exercise program very gradually. Today I drove past a store that sells sweat pants.”
Speed and Sustainability of Contraction

- **Skeletal muscle:** fastest
  - Fatigue varies with type of skeletal muscle & workload
- **Cardiac muscle:** moderate
  - Low fatigue (relaxation between contractions)
- **Smooth muscle:** Very slow
  - Partially contracted all of the time
  - General won’t fatigue
Anabolic steroids

- Anabolic steroids are a group of steroids that usually increase protein production.

- The most common side effects are high blood pressure, jaundice, acne, and greatly increased risk of cancer.

- Abuse of these drugs may also cause impotence and shrinking of the testicles.

- Anabolic steroid use may lead to increased aggressiveness and violent mood swings.

- Are they worth the risk? Should they be legal to use in athletics?
Diseases and Disorders of the Muscular System

- **Tetanus**

  Organisms enter through large, small, or even unrecognized wound. Deep, infected punctures are most susceptible, since organisms thrive best anaerobically.

  Toxin produced locally passes via bloodstream or along nerves to central nervous system.

  Motor neurons of spinal cord (anterior horn) and of brainstem become hyperactive because toxin specifically attacks inhibitory (Renshaw) cells.

  Spasm of jaw, facial and neck muscles (trismus (lockjaw), risus sardonicus) and dysphagia are often early symptoms after variable incubation period.

  Complete tetanic spasm in advanced disease. Patient rigid in moderate opisthotonus, with arms extended, abdomen boardlike.
13.4 Muscle Disorders

Common muscle disorders:

- **Spasms** – sudden, involuntary muscle contractions that are usually painful
- **Convulsions** (seizures) – multiple spasms of skeletal muscles
- **Cramps** – strong, painful spasms often of the leg and foot
- **Strain** – stretching or tearing of a muscle
- **Sprain** – twisting of a joint involving muscles, ligaments, tendons, blood vessels, and nerves
13.4 Muscle Disorders

Muscular diseases

- **Muscular dystrophy** – group of genetic disorders in which muscles progressively degenerate and weaken

![Types of Muscular Dystrophy](image)
13.4 Muscle Disorders

Muscular diseases

- **Myasthenia gravis** – autoimmune disorder
  - attacks the ACh receptor
  - weakens muscles of the face, neck, and extremities
Amyotrophic lateral sclerosis (ALS) or Lou Gehrig’s disease

- Motor neurons degenerate and die leading to loss of voluntary muscle movement.

**Amyotrophic lateral sclerosis (ALS)**

A type of motor neurone disease

- ALS is a rare neurological condition
- Progressive -- worsens with time -- with no cure
- Gradually muscles under voluntary control are affected, individuals lose strength, ability to speak, eat, move, breath
- Most people with ALS die of respiratory failure within 3 to 5 years of first symptoms

Stephen Hawking was diagnosed in his early 20s.

He defied predictions he would only live a few years but was wheelchair-bound and spoke through a computerised voice system.

Source: NIH/NHS
Both systems are involved with movement that allows us to respond to stimuli, digestion of food, return of blood to the heart, and moving air in and out of the lungs.

Both systems protect body parts.

Bones store and release calcium needed for muscle contraction and nerve impulse conduction.

Blood cells are produced in the bone.

Muscles help maintain body temperature.