Chapter 11

The Neuromuscular System and Exercise

Slide Show developed by:
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Objectives

1. Identify the major structural components of the central nervous system that control human movement.

2. Diagram the anterior motor neuron, and discuss its role in human movement.

3. Draw and label the basic components of a reflex arc.

4. Define (1) motor unit, (2) neuromuscular junction, (3) autonomic nervous system, (4) excitatory postsynaptic potential, and (5) inhibitory postsynaptic potential.

5. Explain factors associated with neuromuscular fatigue.

6. Describe the function of muscle spindles and Golgi tendon organs.
Objectives (Cont.)

7. Draw and label a skeletal muscle fiber’s ultra-structural components.

8. Describe the sequence of chemical and mechanical events during skeletal muscle contraction and relaxation.

9. Contrast slow-twitch and fast-twitch (including subdivisions) muscle fiber characteristics.

10. Outline muscle fiber-type distribution patterns among diverse groups of elite athletes.

11. Explain how exercise training modifies muscle fibers and fiber types.
Nervous System

- Central nervous system (CNS)
  - Brain
  - Spinal Cord

- Peripheral Nervous System (PNS)
  - Cranial Nerves
  - Spinal Nerves
The Nervous System
CNS- The Brain

- Six main divisions:
  1. Medulla oblongata
  2. Pons
  3. Midbrain
  4. Cerebellum
  5. Diencephalon
  6. Telencephalon

- Longitudinal fissure
- Left and right hemispheres
- Cerebral cortex or gray matter:
  - Occipital
  - Parietal
  - Temporal
  - Frontal
CNS - The Brain (Cont.)

Sagittal Cross-View

Anterior

Sagittal View

Posterior
CNS - Spinal Cord

• Encased by 33 vertebrae separated by intervertebral discs

• Ventral horn and dorsal horn:
  ▪ Interneurons
  ▪ Sensory neurons
  ▪ Motor neurons

• **Pyramidal tract:** Transmits impulses downward through the spinal cord

• **Extrapyramidal tract:** Originates in the brain stem and connect at all levels of the spinal cord
CNS- Spinal Cord (Cont.)
Brain Neurotransmitters

- Chemical messengers that diffuse across the synapse to combine with a targeted receptor molecule on the postsynaptic membrane to facilitate depolarization or hyperpolarization

- Three important brain neurotransmitter categories:
  1. **Monoamines:** Epinephrine, norepinephrine, serotonin, histamine, and dopamine
  2. **Neuropeptides:** Arginine, vasopressin, angiotensin II, enkephalins, and endorphins
  3. **Nitric oxide**
PNS

- 31 pairs of spinal nerves
  - 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal
- 12 pairs of cranial nerves
- Include:
  - **Afferent nerves** that relay sensory information from muscles, joints, skin, and bones toward the brain
  - **Efferent nerves** that transmit information away from the brain to glands and muscles
    - Somatic and autonomic nervous systems
Somatic Nervous System

- Innervates skeletal muscle
- Somatic efferent nerve firing excites muscle activation
Autonomic Nervous System

- Innervate smooth muscle in the intestines, sweat and salivary glands, myocardium, and some endocrine glands
- Functions as a unit to maintain constancy in the internal environment
- Sympathetic and Parasympathetic
  - Sympathetic nerve fibers mediate excitation
  - Parasympathetic activation inhibits excitation
The Autonomic Nervous System

Comparison of effects of sympathetic and parasympathetic activation on end organs

<table>
<thead>
<tr>
<th>End organ</th>
<th>Sympathetic effects</th>
<th>Parasympathetic effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skeletal muscle</td>
<td>Increase blood flow</td>
<td>Decrease blood flow</td>
</tr>
<tr>
<td>Vasoconstriction</td>
<td>Increase</td>
<td>Decrease</td>
</tr>
<tr>
<td>Sweat glands</td>
<td>Increase perspiration</td>
<td>No effect</td>
</tr>
<tr>
<td>Heart</td>
<td>Increase force and contraction rate</td>
<td>Decrease force and contraction rate</td>
</tr>
<tr>
<td>Gastric motility</td>
<td>Decrease</td>
<td>Increase</td>
</tr>
<tr>
<td>Eyes</td>
<td>Dilate pupils</td>
<td>Constrict pupils</td>
</tr>
<tr>
<td>Secretion of digestive juices</td>
<td>Decrease</td>
<td>Increase</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>Increase mean pressure</td>
<td>Decrease mean pressure</td>
</tr>
<tr>
<td>Airways</td>
<td>Increase diameter</td>
<td>Decrease diameter</td>
</tr>
</tbody>
</table>
Sympathetic Nervous System

- Supply the heart, smooth muscle, sweat glands, and viscera
- Neurons exit the spinal cord and enter a series of ganglia near the cord’s sympathetic chain.
- The nerves terminate relatively far from the target organ in adrenergic fiber endings that release norepinephrine.
- Excitation occurs during fight-or-flight situations that require whole-body arousal for emergencies.
  - Accelerates breathing and heart rate, pupils dilate, and blood flows from the skin to deeper tissues
Parasympathetic Nervous System

- Neurons exit the brain stem and sacral segments of the spinal cord to supply the thorax, abdomen, and pelvic regions.
- Release acetylcholine
- The postganglionic parasympathetic nerve fibers produce effects opposite of sympathetic fibers.
Parasympathetic Nervous System

(page 346)
Integration of Sympathetic and Parasympathetic Nervous System

- Most organs receive simultaneous sympathetic and parasympathetic stimulation.
- Both maintain a constant degree of activation called neural tone.
- Depending on physiologic need, one system becomes more active while the other becomes inhibited, allowing for a finer level of control at the end organs.
Nerve Supply to Muscle

- About 420,000 motor nerves exist yet a single nerve usually supplies numerous individual muscle fibers.

- The ratio of muscle fibers to nerves generally relates to a muscle’s particular movement function.
  - A basic rule states that less complex movements have a higher ratio of muscle fibers to motor nerves, while complex eye and hand movements that require more specialized movements have a much lower ratio.
Nerve Supply to Muscle
(page 348)
Nerve Supply to Muscle
(page 349)
The Motor Unit

- Skeletal muscle fibers and their corresponding innervating anterior **motoneuron**
- The functional unit of movement
- A whole muscle contains many motor units, each of which contains a single motoneuron and its composite muscle fibers.
Motor Unit Anatomy

• Consists of:
  - Cell body houses the control center.
  - Axon extends from the cord and delivers an impulse to the muscle fibers it innervates.
  - Dendrites receive impulses through spinal cord connections and conduct them toward the cell body.

• Nerve cells conduct impulses in one direction only down the axon away from the stimulation point.

• All of a motor unit’s muscle fibers disperse over sub-regions of the muscle with other motor unit fibers.
Motor Unit Anatomy (Cont.)

- **Myelin sheath** encircles the axon of nerve fibers and keeps the electrical current from leaving the bare axon while allowing a high signal transmission speed.

- **Schwann cells** in the peripheral nervous system, encase the bare axon and then spiral around it.
  - **Nodes of Ranvier** account for the higher transmission velocity.
Neuromuscular Junction or Motor End-Plate

- Provides interface between the end of a myelinated motoneuron and a muscle fiber
- Functions to transmit nerve impulses to muscle fibers
- Presynaptic terminals lie close to with the sarcolemma
- Synaptic cleft is the region where neural impulse transmission occurs
- Excitation occurs at the neuromuscular junction
  - Acetylcholine provides the chemical stimulus to change an electrical neural impulse into a chemical stimulus at the motor end-plate.
Facilitation

• A motoneuron generates an action potential when its micro-voltage decreases sufficiently to reach its threshold for excitation.

• Effective dis-inhibition fully activates muscle groups during maximal lifting.

• Enhanced neuromuscular activation accounts for considerable improvements in muscular strength without concurrent increases in muscle size.
Inhibition

- Some presynaptic terminals generate inhibitory impulses by releasing chemicals that increase postsynaptic membrane permeability to potassium and chloride ions.
- This increases the membrane’s resting electrical potential to create an inhibitory postsynaptic potential that makes the neuron more difficult to fire.
- **Gamma-aminobutyric acid and glycine** exert inhibitory effects.
- Neural inhibition serves protective functions and reduces the input of unwanted stimuli to produce smooth, purposeful responses.

![Diagram of a neuron and synapse](image)
Motor Unit Characteristics

- **Twitch Characteristics:** In response to a single electrical impulse, some units develop high twitch tensions while others develop low twitch tensions and others generated intermediate tension.

- **Tension-Generating Characteristics:** Different motor units and muscles they innervate can develop different amounts of tension based on many factors.
  - Governed by three factors:
    1. all-or-none principle
    2. graduation of force principle
    3. level of motor unit recruitment patterns.
All-or-None Principle

• If a stimulus triggers an action potential in the motoneuron, all of the accompanying muscle fibers contract synchronously.

• A single motor unit cannot generate strong and weak contractions; either the impulse elicits a contraction or it does not.

• Once the neuron fires and the impulse reaches the neuromuscular junction, the muscle cells always contract to the fullest extent.
Gradation of Force Principle

- The force of muscle action varies from slight to maximal in one of two mechanisms:
  - Increasing the number of motor units recruited
  - Increasing the frequency of motor unit discharge
Motor Unit Recruitment

- The process of adding motor units to increase muscle force

**Size Principle:** Motoneurons with progressively larger axons become recruited as muscle force increases.

- Selective recruitment and firing pattern of the fast-twitch and slow-twitch motor units that control movement provide the mechanism to produce the desired coordinated response.
Neuromuscular Fatigability

• The decline in muscle tension or force capacity with repeated stimulation during a given time period

• Four factors that decrease the force-generating capacity:
  1. Exercise-induced alterations in levels of CNS neurotransmitters serotonin, 5-hydroxytryptamine, dopamine, and Acetylcholine
  2. Reduced glycogen content in active muscle fibers during prolonged exercise
  3. Increased level of blood and muscle lactate
  4. Fatigue at the neuromuscular junction
Proprioceptors

- Specialized sensory receptors sensitive to stretch, tension, and pressure in the muscles, joints, and tendons
- Relay critical information about muscular dynamics, limb position, and kinesthesia and proprioception to conscious and subconscious portions of the central nervous system
- Allows continual monitoring of the progress of any movement or sequence of movements, and serves as the basis for modifying subsequent motor actions
Proprioceptors (page 353)
Muscle Spindles

- Provide mechano-sensory information about changes in muscle fiber length and tension
- Primarily respond to muscle stretch through reflex action by initiating a stronger muscle action to counteract the stretch
- More spindles exist in muscles that routinely perform complex movements.
Stretch Reflex

- The stretch reflex consists of three main components:
  1. Muscle spindle that responds to stretch
  2. Afferent nerve fiber that carries the sensory impulse from the spindle to the spinal cord
  3. Efferent spinal cord motor neuron that activates the stretched muscle fibers
Stretch Reflex
(page 356)
Golgi Tendon Organs (GTOs)

- Connect in series to extrafusal fibers and also are located in ligaments of joints to primarily detect differences in muscle tension rather than length.

- When activated by excessive muscle tension or stretch, Golgi receptors immediately transmit signals to cause reflex inhibition of the muscles they supply.

- Protect muscle and its connective tissue harness from injury by sudden, excessive load or stretch.
Skeletal Muscle Structure

- There are three layers of skeletal muscle tissue
  1. Epimysium
  2. Perimysium
  3. Endomysium
    - Sarcolemma
      - Sarcoplasm
      - Sarcoplasmic reticulum
Three Layers of Skeletal Muscle
(page 360)
A sarcomere is the functional unit of a muscle fiber extending from Z-line to Z-line.
Skeletal Muscle Ultrastructure

• Muscle Fiber
  ▪ Myofibrils
    • Myofilaments
      • Actin and Myosin (proteins)
Skeletal Muscle Ultrastructure (page 363)
**Sarcomere**

- Comprises the functional unit of the muscle cell
- The actin and myosin filaments provide the mechanical mechanism for muscle
- The position of the sarcomere’s thin actin and thicker myosin proteins overlaps the two filaments.
Functional Striations (bands)

- The center of the A band contains the **H zone**, a region of lower optical density because of the absence of actin filaments in this region.
- The **M line** bisects the central portion of the H zone and delineates the sarcomere’s center.
- The M line contains the protein structures that support the arrangement of myosin filaments.
- The **Z lines** form the connections between sarcomeres.
**Sarcomere (page 366)**

**A** Resting sarcomere

**B** Cross-section of myofibrils
Sliding Filament Theory

• General theory of how muscles contract at the sub-cellular level.

• Muscle fibers shorten or lengthen because thick and thin myofilaments glide past each other without the filaments themselves changing length.

• The myosin crossbridges, which cyclically attach, rotate, and detach from the actin filaments with energy from ATP hydrolysis, provide the molecular motor to drive fiber shortening.
Crossbridges

- The globular head of the myosin crossbridge provides the mechanical power stroke for actin and myosin filaments to glide past each other.

- During muscle activation, each crossbridge undergoes repeated but independent cycles of attachment and detachment to actin.

- A single crossbridge moves only a short distance, so crossbridges must attach, produce movement, and detach thousands of times to shorten the sarcomere.
Crossbridges (page 367)
Muscle Biopsy
(page 372)
# Muscle Fiber Typing

**Table 11.3 Classification of Human Skeletal Muscle Fiber Types**

<table>
<thead>
<tr>
<th>FIBER TYPE</th>
<th>TYPE I FIBERS</th>
<th>TYPE IIa FIBERS</th>
<th>TYPE IIx FIBERS</th>
<th>TYPE IIb FIBERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contraction time</td>
<td>Slow</td>
<td>Moderately fast</td>
<td>Fast</td>
<td>Very fast</td>
</tr>
<tr>
<td>Size of motor neuron</td>
<td>Small</td>
<td>Medium</td>
<td>Large</td>
<td>Very large</td>
</tr>
<tr>
<td>Resistance to fatigue</td>
<td>High</td>
<td>Fairly high</td>
<td>Intermediate</td>
<td>Low</td>
</tr>
<tr>
<td>Activity used for</td>
<td>Aerobic</td>
<td>Long-term anaerobic</td>
<td>Short-term anaerobic</td>
<td>Short-term anaerobic</td>
</tr>
<tr>
<td>Maximum duration of use</td>
<td>Hours</td>
<td>&lt;30 minutes</td>
<td>&lt;5 minutes</td>
<td>&lt;1 minute</td>
</tr>
<tr>
<td>Force production</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Mitochondrial density</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Capillary density</td>
<td>High</td>
<td>Intermediate</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Oxidative capacity</td>
<td>High</td>
<td>High</td>
<td>Intermediate</td>
<td>Low</td>
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<tr>
<td>Glycolytic capacity</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Major storage fuel</td>
<td>Triacylglycerol</td>
<td>Creatine phosphate, glycogen</td>
<td>Creatine phosphate, glycogen</td>
<td>Creatine phosphate, glycogen</td>
</tr>
<tr>
<td>Myosin-heavy chains, human genes</td>
<td>MYH7</td>
<td>MYH2</td>
<td>MYH1</td>
<td>MYH4</td>
</tr>
</tbody>
</table>

*MYH7 is also known as myosin or myosin heavy chain 4.*

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Fast-Twitch Muscle Fiber Characteristics

- Rapidly transmit action potentials
- High activity level of myosin ATPase
- Rapid rate of calcium release and uptake by the sarcoplasmic reticulum
- Generate rapid crossbridge turnover
Fast-Twitch Subdivisions

- **Type IIA fiber**
  - Exhibits fast shortening speed and a moderately well-developed capacity for energy transfer from both aerobic and anaerobic sources
  - Represents the fast–oxidative–glycolytic fibers

- **Type IIX fiber**
  - Possesses the greatest anaerobic potential and most rapid shortening velocity
  - Represents the fast–glycolytic fiber

- **Type IIB fiber**
  - Extremely fast fiber contractile response
  - Lowest mitochondrial density and oxidative capacity
Slow-Twitch Muscle Fibers

- Generate energy for ATP resynthesis predominantly by aerobic energy transfer
- Possess a low activity level of myosin ATPase, a slow speed of contraction, and a glycolytic capacity less well developed than fast-twitch counterparts
- Resist fatigue and power prolonged aerobic exercise
- Slow-oxidative fibers
Muscle Fiber Type Distribution Differences

- Muscle fiber type distribution differs in individuals.
- Genetic code largely determines a person’s predominant fiber type.
- Specific exercise training improves the metabolic capacity of each fiber type.
The End