PART 2
Systemic Responses to Exercise

Chapter 5
Neuromuscular Function and Adaptations to Exercise

The Nervous System
Provides rapid communication between the brain and the different tissues and organs of the body.

Nerves - specialized cells that conduct **action potentials** along their axon.

Synapse - connection between nerves or a nerve and target tissue membrane.

Receptor - specific protein located on the membrane of a target tissue that binds to the **neurotransmitter** released by the nerve.

### Functional and Anatomical Divisions of the Nervous System

<table>
<thead>
<tr>
<th>Functional</th>
<th>Anatomical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Somatic</strong></td>
<td><strong>Central (CNS)</strong></td>
</tr>
<tr>
<td>- sensory</td>
<td>- brain</td>
</tr>
<tr>
<td>- motor</td>
<td>- spinal cord</td>
</tr>
<tr>
<td><strong>Autonomic</strong></td>
<td><strong>Peripheral</strong></td>
</tr>
<tr>
<td>- parasympathetic</td>
<td>- nerves - efferent</td>
</tr>
<tr>
<td>- sympathetic</td>
<td>- afferent</td>
</tr>
<tr>
<td><strong>Neurotransmitter</strong></td>
<td><strong>Locations</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Neurotransmitter</th>
<th>Locations</th>
<th>Functions During Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetylcholine</td>
<td>motor cortex, Aβ motor nerves</td>
<td>↑ muscle contraction, ↑ sweating</td>
</tr>
<tr>
<td>Norepinephrine</td>
<td>brainstem, sympathetic nerves</td>
<td>↑ heart rate, ↑ muscle metabolism</td>
</tr>
<tr>
<td>Epinephrine</td>
<td>adrenal medulla</td>
<td>↑ heart rate, ↑ muscle metabolism</td>
</tr>
<tr>
<td>Dopamine</td>
<td>basal ganglia</td>
<td>motor coordination</td>
</tr>
<tr>
<td>Serotonin</td>
<td>brainstem, spinal cord</td>
<td>↑ perception of fatigue</td>
</tr>
<tr>
<td>GABA</td>
<td>brainstem, spinal cord</td>
<td>motor coordination</td>
</tr>
</tbody>
</table>
Nerve-Muscle Interactions

Initiating Movement
Voluntary movement requires muscle contractions that are the result of neural processes that begin within the Central Nervous System (CNS).

Motor cortex - a localized region of the outer layers of the brain responsible for the origin of neural processing of complex voluntary movement.

Cerebellum - located at the base of the posterior region of the brain, the cerebellum refines motor patterns from the motor cortex, and "stores" more simple or "well trained" motor patterns.

Corticospinal tract - region of the brain and spinal cord where the nerves conveying movement patterns are directed to the spinal cord and their respective peripheral motor nerves.

Nerve Classification
Not all nerves of the body are the same. A useful classification scheme is based on the size (diameter) of the axon, and the presence of a myelin sheath around the axon.

For example, the largest of the peripheral myelinated nerves is the motor nerve, classified as an A nerve. As it innervates skeletal muscle, as distinct from a variety of sensory receptors, it is also designated as an α nerve, hence the abbreviation Aα nerve.

The smallest unmyelinated(slowest conduction) nerves convey temperature sensations and are termed C nerves.

Instigating Movement
Stimulation of the Aα motor nerves results in the propagation of action potentials to skeletal muscle fibers, eventually causing muscle contraction.

The Neuromuscular Junction
The special synapse between a branch of an Aα motor nerve and the sarcolemma of a skeletal muscle fiber.

The neurotransmitter - acetylcholine - is released by the pre-synaptic membrane. Binding of acetylcholine to its receptor on the sarcolemma causes sodium channels to open, depolarize the sarcolemma, and continue the propagation of the action potential across and within the muscle fiber.

Skeletal Muscle Contraction

Excitability - receive and propagate an action potential.

Contractility - contract/shorten

Elasticity - rapidly return to a pre-contraction length.

The demands of exercise require that skeletal muscles must be able to,
1. contract and generate a wide range of tensions/force,
2. alter tension/force in small increments, and
3. do this repeatedly and rapidly for durations that may vary from a few seconds to several hours.
**Structure and Function Terminology**

Striations - visual appearance through electron microscopy of an organized array of light and dark strands within sarcomeres.

Myofibrils - organized array of sarcomeres connected in series (end to end) along the length of a muscle fiber.

Sarcomeres - structural units of the myofiber where structural and contractile proteins are organized in a specific sequence, causing a striated appearance under electron microscopy.

Myosin - the largest of the contractile proteins

$S_1$ unit - the globular head region of myosin

Actin - a globular protein that forms a two stranded filament (F-actin) in vivo.

Tropomyosin - a rod shaped protein attached to actin in a regular repeating sequence.

Troponin - a 3 component protein that is associated with each actin-tropomyosin complex.

Sarcolemma - the cell membrane of skeletal muscle.

Motor Unit - a single Aα motor nerve and all the muscle fibers that it innervates.

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**Table 5.2: The sequence of events during muscle contraction**

<table>
<thead>
<tr>
<th>Step</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Depolarization of the sarcolemma and propagation of the depolarization down t-tubules to the sarcoplasmic reticulum.</td>
</tr>
<tr>
<td>2.</td>
<td>Calcium binds to troponin.</td>
</tr>
<tr>
<td>3.</td>
<td>The troponin-calcium complex induces a conformational change in the actin-tropomyosin interaction, allowing actin to bind to myosin.</td>
</tr>
<tr>
<td>4.</td>
<td>The actin-myosin binding allows the $S_1$ unit to move to the “unstrained” position, causing muscle contraction. During this process, ADP and Pi are released.</td>
</tr>
<tr>
<td>5.</td>
<td>The binding of ATP to the $S_1$ unit, and the immediate reaction producing ADP and Pi provides the free energy to move the $S_1$ unit into the “strained” position.</td>
</tr>
<tr>
<td>6.</td>
<td>Muscle contraction results from the shortening of every sarcomere in every muscle fiber of the motor units that are recruited.</td>
</tr>
<tr>
<td>7.</td>
<td>If ATP is replenished and available, ATP binds to the $S_1$ unit, is broken down to ADP and Pi, and causes the $S_1$ unit to move to the “strained” position. ADP and Pi remain attached to the $S_1$ unit.</td>
</tr>
<tr>
<td>8.</td>
<td>If calcium is still present in the cytosol due to continued neural stimulation, steps 1-7 will continue – termed contraction cycling.</td>
</tr>
<tr>
<td>9.</td>
<td>Relaxation occurs when action potentials are not received at the neuromuscular junction, causing calcium to be actively pumped back into the sarcoplasmic reticulum.</td>
</tr>
</tbody>
</table>

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**Type of Contractions**

- **Concentric**
- **Eccentric**
- **Isometric**
- **Isokinetic**

**Figure 5.11**

**Figure 5.12**

Isokinetic Contraction

- 120 °/s
- 120 °/s

Knee extension

Knee flexion
Length-tension Relationship

Changing muscle length alters the degree of actin-myosin interaction, thereby influencing the tension developed during contraction. Excessive stretch and shortening both impair tension development during contraction, producing an "inverted U" (∩) relationship between sarcomere length and contractile tension.

Force, Power and Contraction Velocity

Maximal contractile tension decreases with increases in the velocity of muscle shortening.

Maximal Voluntary Contraction (MVC) - occurs at zero velocity (isometric).

Summation - the increased contractile force resulting from the repeated stimulation of motor units at frequencies that prevent complete relaxation.

Tetanus - the continuous maximal tension resulting from when the stimulus frequency to a muscle has increased to extremely high values.

Muscle Tone - the firmness of muscle at rest due to the continual recruitment of small numbers of motor units.

Motor Units and Muscle Fiber Types

Based on research of animals (cat, dog, rat) it is known that,

1. there are numerous differences between the nerves and muscle fiber metabolic characteristics of skeletal muscle motor units,
2. for a given motor unit, all muscle fibers have similar metabolic profiles,
3. Both the nerve and muscle characteristics combine to differentiate motor unit types.
Table 5.3: Classification nomenclature of mammalian motor units

<table>
<thead>
<tr>
<th>Classification Method</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td>Red</td>
</tr>
<tr>
<td>Contractile Velocity</td>
<td>Slow-twitch</td>
</tr>
<tr>
<td>Contractile Velocity</td>
<td>I</td>
</tr>
<tr>
<td>and Metabolism</td>
<td>Slow-twitch</td>
</tr>
<tr>
<td></td>
<td>Fast-twitch</td>
</tr>
<tr>
<td></td>
<td>Fatigue</td>
</tr>
<tr>
<td></td>
<td>Fatigable</td>
</tr>
</tbody>
</table>

Motor Unit Recruitment
SO motor units are recruited first during exercise. As exercise intensity increases, there is a progressive and additive increase in FOG and FG motor unit recruitment. This order has been referred to as the "size principle".

Electromyography
Electromyography is the study of muscle function from the detection of the electrical activity emanating from the depolarization of nerves and muscle membranes that accompany contraction.

Human Muscle Biopsy and Histology
Morphological and metabolic characteristics of human muscle fibers have been researched using the method of percutaneous needle biopsy.

The information gained from biopsy research of human skeletal muscle includes:
1. Muscle enzyme activities
2. Muscle metabolite/substrate concentrations
3. Muscle fiber types (myosin ATPase stain)
4. Muscle fiber glycogen content (PAS stain)
5. Muscle capillary density
6. Muscle damage
Sensory Functions

The neural feedback from muscles and other peripheral tissues is also important for optimal function and the ability to exercise. See table 5.4. Such feedback is provided by sensory receptors.

An important sensory receptor is the muscle spindle, which responds to:

1. static stretch
2. dynamic stretch, and
3. changes in muscle length

Important Components of the Muscle Spindle

Intrrafusal fibers - fibers within the muscle spindle.

Nuclear bag fiber - a type of intrrafusal fiber that has nuclei located in the central enlarged region.

Nuclear chain fiber - a type of intrrafusal fiber that is thinner than the bag fiber and has nuclei located along the length of the fiber.

Primary (Ia) afferent - nerve that surrounds the central region of the bag and chain fibers.

Annulospiral ending - structure formed from the wrapping of the Ia afferent nerve around an intrrafusal fiber.

Gamma (γ) efferent - the type of motor nerve that innervates the contractile regions of the intrrafusal fibers.

Fiber Types, Motor Units and Exercise Performance

The muscle metabolic differences between motor units has implications to exercise and athletic performance.

Determining the muscle fiber type proportions and metabolic capacities of muscles integral to the exercise/athletic event can indicate a person’s potential for success in certain events.

> SO muscle fibers > oxidative capacity > endurance
Neuromuscular Adaptations to Exercise

The dissimilar metabolic characteristics of muscle fibers from different motor units, combined with the recruitment transition from slow- to fast-twitch emphasizes the need to interpret metabolic changes during exercise relative to the types of motor units recruitment.

During incremental exercise, the increasing FT motor unit recruitment results in:
- ↑ glycogenolysis
- ↑ carbohydrate oxidation
- ↑ muscle lactate production
- ↓ metabolic efficiency

Training Adaptations

Fiber Size and Number

Hypertrophy - the increased size (x sect’l area) of skeletal muscle fibers.

Hyperplasia - the increase in the numbers of muscle fibers within a muscle.

Increases in muscle size occur mainly from hypertrophy. Hypertrophy is greater for resistance than endurance exercise. Hyperplasia probably occurs, but only at a small level (< 5%)?

Neural Adaptations

During the initial weeks of strength training, muscular strength increases without evidence of hypertrophy or hyperplasia. Why?

↑ maximal motor unit recruitment

↑ synchronous recruitment of motor units

Strength gains are also greater and more rapid when an eccentric component is used during lifting.

Atrophy

Occurs when training is stopped, and involves a decrease in muscle fiber size.