Muscle II

By

Dr. Carmen Rexach
Physiology
Mt SAC Biology Department
Muscle tone

• Slightly contracted state of muscles even at rest
• Maintained by stretch reflexes
• Function
  - Helps stabilize joints
  - Improves posture
  - Creates optimal length for muscle contraction
Reflexes and stretch receptors

- Muscle spindle
- Alpha Gamma (ΑΓ) coactivation
- Skeletal muscle reflexes
- Golgi tendon organ
Muscle spindle apparatus

- Intrafusal fibers
- Afferent fibers carrying sensory information
- Extrafusal fibers
- Efferent fibers

α, γ
Regardless of the reason for a change in length, the stretched spindle in scenario (a) generates a burst of action potentials as the muscle is lengthened; in scenario (b), the shortened spindle produces fewer action potentials from the spindle.
Muscle spindle apparatus

Continuous sensory input regarding muscle length
Muscle spindle fibers

- **extrafusal fibers** = ordinary muscle fibers
- **Intrafusal fibers** = thin muscles in center in CT sheath
  - parallel to extrafusal fibers
  - lack contractile apparatus in the center region
    - nuclear bag fibers = loose nuclei
    - nuclear chain fibers = nuclei in rows
  - two types of sensory neurons
    - **primary** = central region, increased firing at beginning of stretch
    - **secondary** = contracting poles, sustained firing
  - lengthening of muscle fibers results in increased firing
Alpha-gamma coactivation

• **Coactivation**
  - muscle tone = normal resting length and state of contraction produced by spindle activation

• **Alpha (α) motor neurons**
  - extrafusal

• **Gamma (γ) motor neurons** = intrafusal
  - active stretch results in:
    • increased sensitivity
    • enhanced stretch reflex
Reflexes: Control on a local level

• Utilizes spinal cord and includes sensory and motor component of spinal nerves

• Three major types
  - Patellar reflex
  - Flexor reflex
  - Crossed-extensor reflex
Reflexes

• All muscles have stretch reflex
• EX: Patellar reflex
  - monosynaptic, ipsilateral, monosegmental
  - 1) strike patellar ligament
  - 2) muscle & muscle spindle stretched
  - 3) synapse with motor neurons
  - 4) extrafusal fibers stimulated
  - 5) isotonic contraction
  - 6) knee jerk response
Tapping the patellar tendon lengthens the stretch receptor in the associated extensor muscle in the thigh; responses include:

- compensatory contraction in that muscle (A and C),
- relaxation in the opposing flexor (B), and
- sensory afferent delivery to the brain.
Patellar reflex
Flexor (withdrawl) reflex

- Polysynaptic
- Ipsilateral
- Intersegmental
Contraction of the extensor muscle on the thigh tenses the Golgi tendon organ and activates it to fire action potentials. Responses include:

Inhibition of the motor neurons that innervate this muscle (A), and excitation in the opposing flexor’s motor neurons (B).

Note: NMJ = neuromuscular junction
Crossed-extensor reflex

- Polysynaptic
- Contralateral
- Intersegmental
1. Pain sensory afferents detect pain in foot and send action potentials via dorsal horn of spinal cord.

2. Interneurons in the cord activate extensor muscles on the “pained” side of the body and flexor muscles on the opposite side of the body.

3. Muscles move body away from painful stimulus.
Golgi tendon organs

- Continuous monitoring of tension in tendons
- Increased firing when muscle is stretched
- Sensory neurons synapse in spinal cord with interneurons
- Inhibitory synapses prevent excessive contraction or passive stretching
Golgi Tendon Organ
Sensory input modifies and refines motor commands
<table>
<thead>
<tr>
<th>TABLE 10-1</th>
<th>Conceptual Motor Control Hierarchy for Voluntary Movements</th>
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**I. Higher centers**
- Function: forms complex plans according to individual’s intention and communicates with the middle level via “command neurons.”
- Structures: areas involved with memory and emotions, supplementary motor area, and association cortex. All these structures receive and correlate input from many other brain structures.

**II. The middle level**
- Function: converts plans received from the highest level to a number of smaller motor programs, which determine the pattern of neural activation required to perform the movement. These programs are broken down into subprograms that determine the movements of individual joints. The programs and subprograms are transmitted through descending pathways to the lowest control level.
- Structures: sensorimotor cortex, cerebellum, parts of basal nuclei, some brainstem nuclei.

**III. The lowest level (the local level)**
- Function: specifies tension of particular muscles and angle of specific joints at specific times necessary to carry out the programs and subprograms transmitted from the middle control levels.
- Structures: levels of brainstem or spinal cord from which motor neurons exit.
Muscle metabolism

- No ATP “storage”
- 3 pathways for regeneration
  - Direct phosphorylation of ADP by CP
  - Anaerobic mechanisms
  - Aerobic respiration
Creatine phosphate

- Rapid renewal of ATP
  - ATP transfers terminal phosphoryl groups to form compounds with similar high energy character
- creatine phosphate
  - present at 3x higher concentration in skeletal muscle
  - produced by liver
  - $\text{CP} + \text{ADP} \rightarrow \text{C} + \text{ATP}$
Anaerobic mechanisms

• Glycolysis and lactic acid formation
• Relatively short term source of energy
  - Uses large amounts of glucose with low energy yield
  - Effects of lactic acid
• Conversion of pyruvic acid to lactic acid during oxygen debt
Aerobic respiration

• Primary source of ATP for muscle during rest or light exercise
• Complete breakdown of $C_6H_{12}O_6$ to $CO_2 + H_2O + ATP$
Energy requirements

• Primary source of energy for muscle
  - fatty acids
• Primary source of energy for exercising muscle
  - muscle glycogen
  - blood borne glucose
Oxygen

- Aerobic vs anaerobic threshold
- maximal oxygen uptake
  - primary determinants
    - age, sex, size
  - effects of training
    - 20% improvement
- oxygen debt
  - oxygen borrowed from hemoglobin/myoglobin
  - extra oxygen requirements during exercise
  - As oxygen decreases, lactic acid increases...why?
Muscle fatigue

• **Definition**
  - Inability to maintain particular muscle tension when contraction is sustained or reproduce particular tension during rhythmic contraction over time

• **Contractures = cramps**
  - States of continuous contraction

• **Two types of fatigue**
  - Intense exercise of short duration
    • ionic imbalance from which quick recovery possible
  - Prolonged low intensity exercise
    • damage to SR
    • effects Ca^{++} concentration and muscle activation
Muscle fatigue and lactic acid accumulation

- Recent studies on individual, isolated muscles in vitro suggest that lactic acid may improve muscle performance.
- Severe plasma acidosis (whole body model), however, may impair muscle performance by interfering with CNS interaction with muscle.

Source:
- Cairns SP.
- Institute of Sport and Recreation Research New Zealand, Faculty of Health and Environmental Sciences, Auckland University of Technology, Auckland, New Zealand. simeon.cairns@aut.ac.nz
Removal of lactic acid

• Occurs when adequate levels of oxygen are available for aerobic metabolism

• 2 pathways
  - Some lactic acid is converted back to pyruvic acid in tissues
  - Remaining lactic acid reconverted to glucose (gluconeogenesis) in liver
    • Used to replenish glycogen stores in muscle tissue
What causes muscle fatigue?

- The exact mechanism is unknown
- **Candidates**
  - Lactic acid
    - Now determined to protect against muscle fatigue
    - Decreased pH counteracts effects of K+ on the excitability and force exerted by muscle
  - K+ accumulation
    - >10mM or more leads to decrease in muscle force
    - Occurs when lactic acid is also accumulating, counteracting the effect of K+
  - Inorganic phosphate accumulation in tissues
    - Large amount of ATP is used during muscle contraction
    - Increased contraction produces increased amounts of inorganic phosphate
    - Appears to be most likely candidate, but uncertain how this works
Factors influencing the strength of muscle contraction

- Number of fibers stimulated
- Thickness of the muscle fibers
- Frequency of stimulation
  - Greater stimulation = greater force (additive)
- Initial length of the muscle fiber at rest
  - ideal resting length
  - sarcomere too short
  - sarcomere too long
How muscle fibers are classified

- Speed of contraction
- Major pathways for forming ATP
Types of muscle fibers

• Each muscle is a mixture of fibers
  - Proportions determined by genetics and muscle action
• Some evidence that types of exercise can result in transform type IIb into type IIa
• One motor unit only contains one type of fiber
• Slow Twitch = Type I
• Fast Twitch
  - Type IIa
  - Type IIb
Muscle fibers

- **Slow twitch (oxidative) = Type I**
  - red fibers
    - High levels of myoglobin
    - more mitochondria
    - more capillaries
  - Fire less rapidly
  - Found in large numbers in postural muscles
  - Helpful in long distance running
    - fatigue resistant = aerobic respiration
Muscle fibers

- **Fast twitch = Type II**
  - **Type IIa (fast oxidative)**
    - Red fibers
    - Lots of mitochondria
    - Many capillaries
    - High contraction velocity due to quick splitting of ATP
    - Fatigue resistant, but not as much as type I
    - Helpful for swimming
Muscle fibers

• Fast twitch
  – Type IIb = fast glycolytic
    • White fibers
    • Low myoglobin content
    • Few mitochondria and capillaries
    • Lots of glycogen
    • Fatigue easily
    • Split ATP quickly
    • Useful for sprinting
Slow-oxidative skeletal muscle responds well to repetitive stimulation without becoming fatigued; muscles of body posture are examples.

Fast-oxidative skeletal muscle responds quickly and to repetitive stimulation without becoming fatigued; muscles used in walking are examples.

Fast-glycolytic skeletal muscle is used for quick bursts of strong activation, such as muscles used to jump or to run a short sprint.
All three types of muscle fibers are represented in a typical skeletal muscle, and, under tetanic stimulation, make the predicted contributions to the development of muscle tension.
Adaptation to exercise

• Endurance training
  - increased mitochondria
  - aerobic respiratory enzymes
  - 20% increase in oxygen uptake
  - decrease type IIB, increase type IIA
  - increase triglyceride content
  - muscle size remains same

• Resistance training
  - increased thickness type II fibers
  - increased synthesis actin/myosin
  - new sarcomeres added
  - new myofibrils inserted
Smooth muscle

• single cells, no striations
• Circular layer arrangement
• no sarcomeres or troponin
• actin:myosin ratio = 13:1
Smooth muscle contraction

- utilizes $Ca^{++}$/calmodulin mechanism
- graded depolarizations
- single unit vs multi-unit
- autonomic innervation
Thick (myosin-based) and thin (actin-based) filaments, biochemically similar to those in skeletal muscle fibers, interact to cause smooth muscle contraction.
Steps of smooth muscle contraction

- $Ca^{++}$ binds to calmodulin
- Calmodulin activates myosin light chain kinase
- Phosphate transferred to myosin from ATP = phosphorylated cross bridges
- Interact with actin = fibers shorten
- Removal of $Ca^{++}$ causes muscle fiber to relax
Smooth muscle

↑ Cytosolic Ca\(^{2+}\)

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Ca\(^{2+}\) binds to calmodulin in cytosol

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Ca\(^{2+}\)-calmodulin complex binds to myosin light-chain kinase

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Myosin light-chain kinase uses ATP to phosphorylate myosin cross-bridges

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Phosphorylated cross-bridges bind to actin filaments

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Cross-bridge cycle produces tension and shortening

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Skeletal muscle

↑ Cytosolic Ca\(^{2+}\)

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Ca\(^{2+}\) binds to troponin on thin filaments

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Conformational change in troponin moves tropomyosin out of blocking position

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Myosin cross-bridges bind to actin

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Cross-bridge cycle produces tension and shortening
Rhythmic changes in the membrane potential of smooth muscles results in rhythmic patterns of action potentials and therefore rhythmic contraction; in the gut, neighboring cells use gap junctions to further coordinate these rhythmic contractions.
Cardiac muscle

• Myocardium
  - gap junctions
  - spontaneous depolarization
• cells
• straited with sarcomeres