

# **Title: Muscles**

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## **I. The structural and functional organization of muscles**

**A.** Functions of muscles include: movement, stability, communication (facilitate speech, writing), control of body openings and passages, and heat production.

### **B.** Skeletal muscle

1. Skeletal muscle is voluntary striated muscle usually attached to bone.
2. A typical muscle cell (fiber) is about 100  $\mu\text{m}$  long, but can be up to 30 cm long.
3. Skeletal muscle exhibits striations.

### **C.** Series-elastic components

1. The series-elastic components of muscular tissue are not excitable but do stretch and recoil.

## **II. Functional structure of skeletal muscle**

### **A.** The muscle fiber

#### 1. Myofilaments

Myofilaments are central to muscle contraction. Three kinds exist: thick filaments, thin filaments, and elastic filaments.

#### 2. Sarcomere

Sarcomere is the unit of contraction of a muscle fiber.

#### 3. Sarcoplasmic reticulum

Sarcoplasmic reticulum is a reservoir for calcium ions

## **III. The nerve-muscle relationship**

### **A.** Motor neurons

1. Skeletal muscle is innervated by somatic motor neurons from brainstem and spinal cord.
2. The axons of motor neurons are called somatic motor fibers.
3. Each muscle fiber is supplied by only one motor neuron.

### **B.** The motor unit

1. A motor unit consists of one nerve fiber and all the muscle fibers it innervates.
2. A motor unit behaves as a single functional unit and contracts as one.

### **C.** The neuromuscular junction

1. A nervous impulse triggers the release of neurotransmitter (acetylcholine) from synaptic vesicles.
2. ACh (Acetylcholine) receptors are present in the motor end plate.
3. Acetylcholinesterase is also present, it breaks down ACh after stimulation.

## **IV. Behavior of skeletal muscle fibers**

### **A.** Excitation-contraction coupling

1. During excitation-contraction coupling, action potentials in the muscle fiber lead to activation of the myofilaments.
2. After the action potential reaches the sarcoplasmic reticulum, it releases calcium ions into the cytosol.
4. Calcium ions bind to the troponin of the thin myofilaments, causing the troponin-tropomyosin complex to shift aside, exposing the active sites on the actin filament.

5. The heads of the myosin filaments can now bind to these active sites and initiate contraction.

#### **B. Contraction**

1. During the contraction phase, sliding of the thin myofilaments past the thick ones causes the muscle fiber to shorten.

2. The sliding filament theory of *Hanson and Huxley* suggests that thin filaments slide over thick ones, causing sarcomeres to shorten.

3. The head of each myosin molecule contains myosin ATPase that releases energy from ATP.

4. When the active sites on the actin filament are exposed, the myosin head contacts the active site, releases energy, and performs a power stroke.

5. At the end the myosin binds to a new ATP, releases the actin, and returns to its original position in a recovery stroke.

#### **C. Relaxation**

1. Acetylcholinesterase breaks down ACh so the muscle stops generating its action potentials.

2. Calcium is carried back to the sarcoplasmic reticulum by active transport.

#### **D. The length-tension relationship and tonus**

1. The degree of actin and myosin overlap determines tension development by contracting muscle.

2. If the muscle is already mostly contracted, stimulation will cause a weak contraction.

3. Conversely, if the muscle is overly stretched, little overlap exists between actin and myosin filaments, and contraction can damage the muscle.

### **V. Behavior of whole muscles**

#### **A. Threshold, latent period, twitch**

1. Muscle have a threshold or minimal voltage, necessary to produce a muscle contraction.

#### **B. Contraction strength of twitches**

1. The strength of contraction of a whole muscle is increased as more motor units join in.

2. Another way to produce a stronger muscle contraction is to stimulate the muscle at a higher frequency.

3. Muscle cells exhibit treppe, or the "*staircase phenomenon*", in response to a series of stimuli of the same strength.

#### **C. Isometric and isotonic contraction**

1. Isometric contraction is tensing of the muscles without a change in length.

2. Isotonic contraction is contraction with a change in muscle length but no change in tension.

### **VI. Muscle metabolism**

#### **A. ATP sources**

1. During exercise, muscles use energy produced by aerobic respiration (when there is an adequate supply of oxygen) and anaerobic fermentation (when oxygen is limited, and lactic acid accumulates).

#### **B. Slow- and fast-twitch fibers**

1. Slow-twitch fibers are well endowed with cellular machinery for aerobic metabolism. They are dark in color because they have more mitochondria, capillaries and myoglobin, and thus they are called *red muscles*.

2. Fast-twitch fibers are larger and produce twitches as short as 7.5 msec. They produce quick energy (phosphagen system) for stop-and-go activities. These fibers impart a white appearance to muscles (low content of myoglobin and capillaries).

### VII. Smooth muscle

1. Smooth muscle is composed of myocytes with a fusiform shape, only one nucleus, and no visible striations or sarcomeres.
2. There are no Z discs in smooth muscle, but its thin filaments attach to dense bodies on the sarcolemma.
3. There is scanty sarcoplasmic reticulum and no T tubules. Calcium enters through channels in the sarcolemma.
4. Most calcium for smooth muscle contraction comes from the extracellular fluid, not the sarcoplasmic reticulum, and it binds to calmodulin, not to troponin.
5. The two functional categories of smooth muscle are multiunit and single-unit.
6. Partly because of its latch-bridge mechanism, smooth muscle can remain partially contracted for a prolonged period without nervous stimulation. This ability, plus its fatigue-resistance, enables smooth muscle to maintain smooth muscle tone.
7. The ability of an organ such as the stomach or urinary bladder to expand results partly from the stress-relaxation response of smooth muscle.

### VIII. Comparison of cardiac, skeletal, and smooth muscle

Muscle Characteristic or Attribute	Cardiac Muscle	Skeletal Muscle	Smooth Muscle
Striated	Yes	Yes	No
Myosin	Yes	Yes	Yes
Actin connects to Z discs	Yes	Yes	No
Actin connects to dense bodies	No	No	Yes
Sarcomere	Yes	Yes	Functional
Troponin	Yes	Yes	No
Calmodulin	No	No	Yes
Sliding filament model of contraction	Yes	Yes	Yes
Ca <sup>2+</sup> required	Yes	Yes	Minimal
Ca <sup>2+</sup> from SR	Great amount	Great amount	Minimal
Ca <sup>2+</sup> from T tubules	Great effect	no effect	no effect
Effect of Ca <sup>2+</sup> concentration in ECF on strength of contraction	+		+++
Major ion causing depolarization	Na <sup>+</sup>	Na <sup>+</sup> , Ca <sup>2+</sup>	Ca <sup>2+</sup>
Type of contraction	Phasic	Phasic	Tonic/phasic