Chapter 8

Muscular System

Introduction:

A. All movements require muscle which are organs using chemical energy to contract.

B. The three types of muscle in the body are *skeletal, smooth*, and *cardiac* muscle.

C. This chapter focuses on skeletal muscle.

Structure of a Skeletal Muscle

A. Each muscle is an organ, comprised of skeletal muscle tissue, nervous tissue, blood, and other connective tissues

B. Connective Tissue Coverings

1. Layers of dense connective tissue, called fascia, surround and separate each muscle.
2. This connective tissue extends beyond the ends of the muscle and gives rise to tendons that are fused to the periosteum of bones.

3. Sometimes muscles are connected to each other by broad sheets of connective tissue called aponeuroses.

4. The layer of connective tissue around each whole muscle is the *epimysium*; the *perimysium* surrounds individual bundles (fascicles) within each muscle; and each muscle cell (fiber) is covered by a connective tissue layer called *endomysium*.

C. Skeletal Muscle Fibers

1. Each muscle fiber is a single, long, cylindrical muscle cell.

2. Beneath the *sarcolemma* (cell membrane) lies *sarcoplasm* (cytoplasm) with many mitochondria and nuclei; the sarcoplasm contains myofibrils.

a. Thick filaments of myofibrils are made up of the protein myosin.

b. Thin filaments of myofibrils are made up of the protein actin.

c. The organization of these filaments produces *striations*.

3. A sarcomere extends from one Z line to the next.

   a. *I bands* (light bands) made up of actin filaments are anchored to Z lines.

   b. *A bands* (dark bands) are made up of overlapping thick and thin filaments.

   c. In the center of A bands is an *H zone*, consisting of myosin filaments only.

4. Beneath the sarcolemma of a muscle fiber lies the sarcoplasmic reticulum (endoplasmic reticulum), which is associated with transverse (T) tubules (invaginations of the sarcolemma).

   a. Each T tubule lies between two *cisternae* of the sarcoplasmic reticulum and is open to the outside of the muscle fiber.

   b. The sarcoplasmic reticulum and transverse tubules activate the muscle contraction mechanism when the fiber is stimulated.

D. Neuromuscular Junction

1. The site where the motor neuron and muscle fiber meet is the neuromuscular junction.

   a. The muscle fiber membrane forms a motor end plate in which the sarcolemma is tightly folded and where nuclei and mitochondria are abundant.

   b. The cytoplasm of the motor neuron contains numerous mitochondria and *synaptic vesicles* storing neurotransmitters. Its functional connection is called a synapse.

Skeletal Muscle Contraction

A. Muscle contraction involves several components that result in the shortening of sarcomeres, and the pulling of the muscle against its attachments.

B. Role of Myosin and Actin

1. Myosin consists of two twisted strands with globular cross-bridges projected outward along the strands.
2. Actin is a globular protein with myosin binding sites; tropomysosin and troponin are two proteins associated with the surface of the actin filaments.

3. According to the sliding filament model of muscle contraction, the myosin crossbridge attaches to the binding site on the actin filament and bends, pulling on the actin filament; it then releases and attaches to the next binding site on the actin, pulling again.

4. Energy from the conversion of ATP to ADP is provided to the cross-bridges from the enzyme ATPase, causing them to be in a “cocked” position.

C. Stimulus for Contraction

1. The motor neuron must release the neurotransmitter acetylcholine from its synaptic vesicles into the synaptic cleft in order to initiate a muscle contraction.

2. Protein receptors in the motor end plate detect the neurotransmitters, and a muscle impulse spreads over the surface of the sarcolemma and into the T tubules, where it reaches the sarcoplasmic reticulum.

3. Upon receipt of the muscle impulse, the sarcoplasmic reticulum releases its stored *calcium* to the sarcoplasm of the muscle fiber.

4. The high concentration of calcium in the sarcoplasm interacts with the troponin and tropomyosin molecules, which move aside, exposing the myosin binding sites on the actin filaments.

5. Myosin cross-bridges now bind and pull on the actin filaments, causing the sarcomeres to shorten.

6. After the nervous impulse has been received, acetylcholinesterase rapidly decomposes the acetylcholine.

7. Then, calcium is returned to the sarcoplasmic reticulum, and the linkages between myosin and actin are broken.

D. Energy Sources for Contraction

1. Energy for contraction comes from molecules of *ATP*. This chemical is in limited supply and so must often be regenerated

2. Creatine phosphate, which stores excess energy released by the mitochondria, is present to regenerate ATP from ADP and phosphate.

3. Whenever the supply of ATP is sufficient, creatine phosphokinase promotes the synthesis of creatine phosphate.

4. As ATP decomposes, the energy from creatine phosphate can be transferred to ADP molecules, converting them back to ATP.

E. Oxygen Supply and Cellular Respiration

1. The early phase of cellular respiration yields few molecules of ATP, so muscle has a high requirement for oxygen, which enables the complete breakdown of glucose in the mitochondria.
2. Hemoglobin in red blood cells carries oxygen to muscle.
3. The pigment myoglobin stores oxygen in muscle tissue.

F. Oxygen Debt

1. During rest or moderate activity, there is enough oxygen to support aerobic respiration.

2. Oxygen deficiency may develop during strenuous exercise, and *pyruvic acid* forms then reacts to form *lactic acid* accumulates as an end product of anaerobic respiration.

   a. *Lactic acid* diffuses out of muscle cells and is carried in the bloodstream to the liver.

3. Oxygen debt refers to the amount of oxygen that liver cells require to convert the accumulated lactic acid into glucose, plus the amount that muscle cells need to resynthesize ATP and creatine phosphate to their original concentrations.

4. Repaying an oxygen debt may take several hours.

G. Muscle Fatigue

1. When a muscle loses its ability to contract during strenuous exercise, it is referred to as *fatigue*.
2. Muscle fatigue usually arises from the accumulation of lactic acid in the muscle.
    a. A lowered pH as a result of accumulated lactic acid prevents the muscle from contracting.
3. A muscle cramp occurs due to a lack of ATP required to return calcium ions back to the sarcoplasmic reticulum so muscle fibers can relax.

H. Heat Production

1. Contraction of skeletal muscle represents an important source of heat for the body.

2. Much of the energy produced through the reactions of cellular respiration is lost as heat (another source of heat for the body).

Muscular Responses

A. One method of studying muscle function is to remove a single fiber and connect it to a device that records its responses to electrical stimulation.

B. Threshold Stimulus

1. A muscle fiber remains unresponsive to stimulation unless the stimulus is of a certain strength, called the threshold stimulus.

C. Recording a Muscular Contraction

1. A single, short contraction involving only a few motor units is referred to as a twitch.
2. A myogram is the recording of an electrically-stimulated muscle contraction.
3. A latent period is a brief delay between the stimulation and beginning of the contraction

4. When a muscle fiber contracts, it contracts to its full extent *(all-or-none response).*

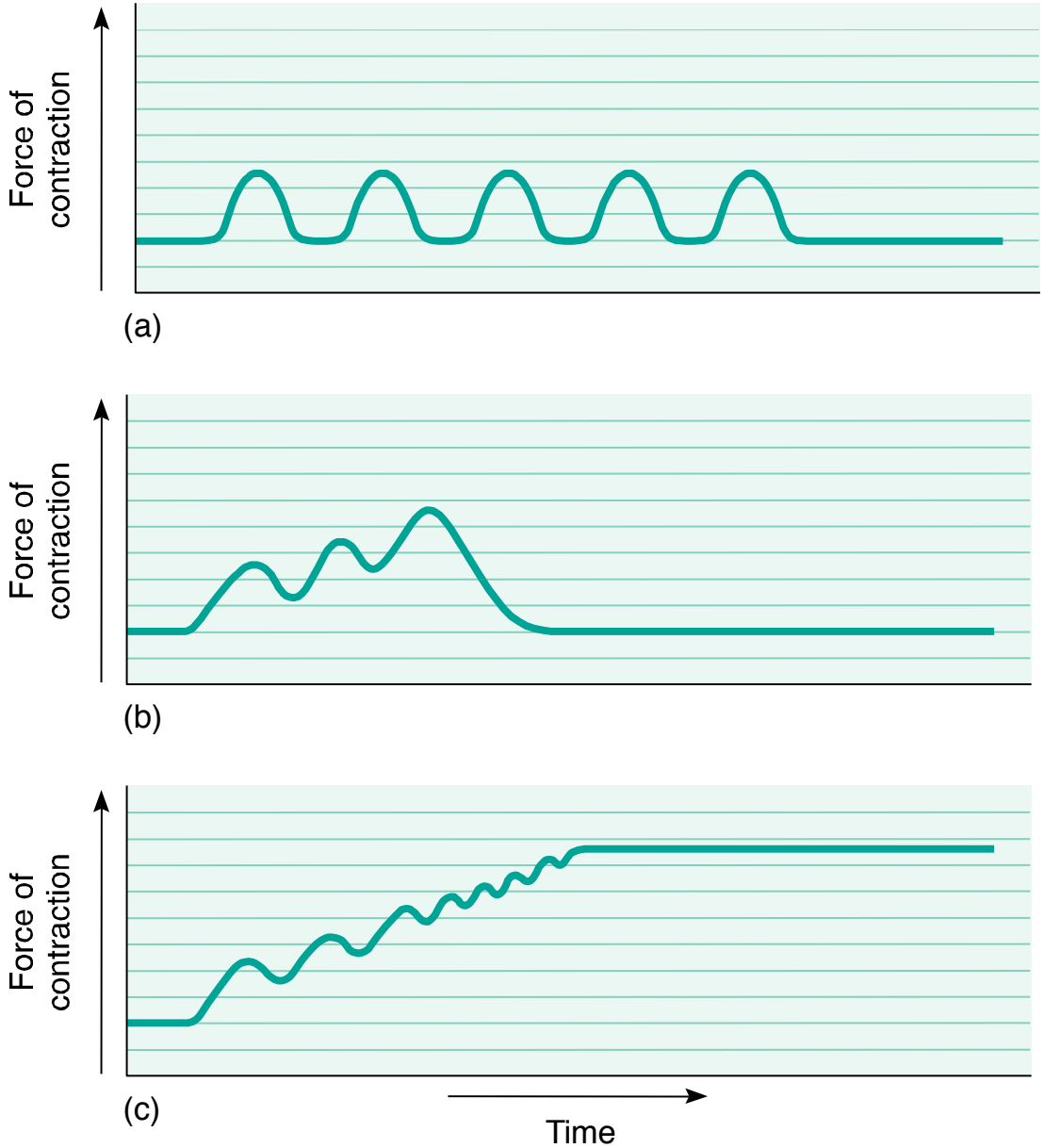
5. The latent period is followed by a period of contraction and a period of relaxation.

E. Summation

1. A muscle fiber receiving a series of stimuli of increasing frequency reaches a point when it is unable to relax completely and the force of individual twitches combine by the process of summation.

2. If the sustained contraction lacks any relaxation, it is called a tetanic contraction.

Fig08.12



F. Recruitment of Motor Units

1. A motor neuron and the muscle fibers it controls make up a motor unit; when stimulated to do so, the muscle fibers of the motor unit contract all at once.

2. An increase in the number of activated motor units within a muscle at higher intensities of stimulation is called recruitment.

G. Sustained Contractions

1. Summation and recruitment together can produce a *sustained contraction* of increasing strength.
2. Muscle tone is achieved by a continuous state of sustained contraction of motor units within a muscle.

Smooth Muscles

A. Smooth Muscle Fibers

1. Smooth muscle cells are elongated with tapered ends, lack striations and have a relatively undeveloped sarcoplasmic reticulum.

2. Multiunit smooth muscle and visceral muscle are two types of smooth muscles.

a. In multiunit smooth muscle, such as in the blood vessels and iris of the eye, fibers occur separately rather than as sheets.

b. Visceral smooth muscle occurs in sheets and is found in the walls of hollow organs; these fibers can stimulate one another and display *rhythmicity*, and are thus responsible for peristalsis in hollow organs and tubes.

B. Smooth Muscle Contraction

1. The myosin-binding-to-actin mechanism is mostly the same for smooth muscles and skeletal muscles.
2. Both acetylcholine and norepinephrine stimulate and inhibit smooth muscle contraction, depending on the target muscle.

3. Hormones can also stimulate or inhibit contraction.

4. Smooth muscle is slower to contract and relax than is skeletal muscle, but can contract longer using the same amount of ATP.

Cardiac Muscle

A. The mechanism of contraction in cardiac muscle is essentially the same as that for skeletal and smooth muscle, but with some differences.

B. Cardiac muscle has transverse tubules that supply extra calcium, and can thus contract for longer periods.

C. Complex membrane junctions, called *intercalated discs*, join cells and transmit the force of contraction from one cell to the next, as well as aid in the rapid transmission of impulses throughout the heart.

D. Cardiac muscle is self-exciting and rhythmic, and the whole structure contracts as a unit.