<u>Chapter 10 - Outline</u>

I. INTRODUCTION

A. Motion results from alternating contraction (shortening) and relaxation of muscles; the skeletal system provides leverage and a supportive framework for this movement.

B. The scientific study of muscles is known as *myology*.

II. OVERVIEW OF MUSCLE TISSUE

A. Types of Muscle Tissue

1. Skeletal muscle tissue is primarily attached to bones. It is striated and voluntary.
2. Cardiac muscle tissue forms the wall of the heart. It is striated and involuntary.
3. Smooth (visceral) muscle tissue is located in viscera. It is nonstriated (smooth) and involuntary.
4. See Chapter 4 for the histology of the 3 types of muscle.

B. Functions of Muscle Tissue

1. Through sustained contraction of alternating contraction and relaxation, muscle performs four key functions.
2. These functions are production of body movements, stabilizing body positions, moving substances within the body, and generating heat.

C. Properties of Muscle Tissue

1. Electrical excitability is the ability to respond to certain stimuli by producing electrical signals such as action potential (impulse).
2. Contractility is the ability to shorten and thicken (contract), generating force to do work.
    a. In an *isometric contraction*, the muscle develops tension but does not shorten.
    b. In an *isotonic contraction*, the tension remains constant while the muscle shortens.
3. Extensibility is the ability to be extended (stretched) without damaging the tissue.

4. Elasticity is the ability to return to original shape after contraction or extension.

III. SKELETAL MUSCLE TISSUE

A. Each skeletal muscle is a separate organ composed of cells called *fibers*.

B. Connective Tissue Components

1. *Fascia* is a sheet or band of fibrous connective tissue that is deep to the skin and surrounds muscles and other organs of the body.
    a. *Superficial fascia* (or *subcutaneous layer*) separates muscle from skin and functions to provide a pathway for nerves and blood vessels, stores fat, insulates, and protects muscles from trauma.
    b. *Deep fascia*, which lines the body wall and limbs and holds muscles with similar functions together, allows free movement of muscles, carries nerves, blood vessels, and lymph vessels, and fills spaces between muscles.
2. Other connective tissue components are *epimysium*, covering the entire muscle; *perimysium*, covering *fasciculi*; and *endomysium*, covering individual muscle fibers; all are extensions of deep fascia.
3. *Tendons* and *aponeuroses* are extensions of connective tissue (including the epi, peri, and endomysium) beyond muscle cells that attach muscle to bone or other muscle.
    a. *A tendon is* a cord of dense connective tissue that attaches a muscle to the periosteum of a bone.
    b. An *aponeurosis* is a tendon that extends as a broad, flat layer.

C. Nerve and Blood Supply

1. Nerves (containing motor neurons) convey impulses for muscular contraction.
2. Blood provides nutrients and oxygen for contraction.

D. Microscopic Anatomy of a Skeletal Muscle Fiber

1. During embryonic development, skeletal muscle fibers arise from *myoblast*.. A few myoblasts persist in mature skeletal muscle as *satellite cells*.

2. Sarcolemma, T Tubules, and Sarcoplasm
    a. Skeletal muscle consists of *fibers* (cells) covered by a sarcolemma .
    b. The fibers contain T tubules and sarcoplasm
        1) *T tubules* are tiny invaginations of the sarcolemma that quickly spread the muscle action potential to all parts of the muscle fiber.
        2) *Sarcoplasm* is the muscle cell cytoplasm and contains a large amount of glycogen for energy production and myoglobin for oxygen storage.
3. Myofibrils and Sarcoplasmic Reticulum
    a. Each fiber contains *myofibrils* that consist of thin and thick filaments (myofilaments).
    b. The *sarcoplasmic reticulum* encircles each myofibril. It is similar to smooth endoplasmic reticulum in nonmuscle cells and in the relaxed muscle stores calcium ions. A T tubule and two terminal cisterns of the sarcoplasmic reticulum on either side of it form a triad.
4. *Muscular atrophy* is a wasting away of muscles, whereas muscular hypertrophy is an increase in the diameter of muscle fibers (Clinical Application).
5. Filaments and the Sarcomere
    a. *Myofibrils* are composed of thick and thin filaments arranged in units called *sarcomeres*.
    b. *Sarcomeres* are the basic functional units of a myofibril and show distinct dark (A band) and light (I band) areas.
        1) The darker middle portion is the *A band* consisting primarily of the thick filaments with some thin filaments overlapping the thick ones (zones of overlap).
        2) The lighter sides are the *I bands* that consist of thin filaments only
        3) A *Z disc* passes through the center of the I band.

4) A narrow *H zone* in the center of each A band contains thick but no thin filaments.

5) Exercise can result in torn sarcolemma, damaged myofibrils, and disrupted Z discs (Clinical Application).

6. Muscle Proteins

   a. Contractile Proteins generate force during contraction.

      1) *Myosin*, the main component of thick filaments, functions as a motor protein. Motor proteins push or pull their cargo to achieve movement by converting energy from ATP into mechanical energy of motion or force. The head of the myosin molecule contains an ATPase enzyme.

      2) *Actin*, the main component of thin filaments, connects to the myosin for the sliding together of the filaments.

   b. Regulatory proteins help switch the contractions on and off.

      1) The regulatory proteins *tropomyosin* and *troponin* are a part of the thin filament.

      2) In relaxed muscle, tropomyosin, which is held in place by troponin, blocks the myosin-binding sites on actin preventing myosin from binding to actin.

   c. Structural proteins keep the thick and thin filaments in the proper alignment, give the myofibril elasticity and extensibility, and link the myofibrils to the sarcolemma and extracellular matrix. An example is *Titin*, which helps a sarcomere return to its resting length after a muscle has contracted or been stretched.

IV. CONTRACTION AND RELAXATION OF SKELETAL MUSCLE FIBERS

A. During muscle contraction, myosin cross bridges pull on thin filaments, causing them to slide inward toward the H zone; Z discs come toward each other and the sarcomere shortens, but the thick and thin filaments do not change in length. The sliding of filaments and shortening of sarcomeres causes the shortening of the whole muscle fiber and ultimately the entire muscle. This is called the *sliding filament mechanism*.

B. The Contraction Cycle

  1. At the beginning of contraction, the sarcoplasmic reticulum releases calcium ions which bind to troponin and cause the troponin-tropomysium complex to uncover the myosin-binding sites on actin. When the binding sites are “free”, the contraction cycle begins.
  2. The *contraction cycle* is a repeating sequence of events that causes the filaments to slide. It consists of ATP hydrolysis, attachment of myosin to actin to form cross bridges, the power stroke, and detachment of myosin from actin.

C. Excitation-Contraction Coupling

  1. An increase in calcium ion concentration in the cytosol starts muscle contraction; a decrease, stops it.
  2. The muscle action potential releases calcium ions from the sarcoplasmic reticulum that combine with troponin, causing it to pull on tropomyosin to change its orientation, thus exposing myosin-binding sites on actin and allowing the actin and myosin to bind together.
  3. The use of calcium ions to remove the contraction inhibitor and the joining of actin and myosin constitute the *excitation-contraction coupling*, the steps that connect excitation (a muscle action potential propagation through the T tubules) to contraction of the muscle fiber.

4. *Calcium ion active transport pumps* return calcium ions to the sarcoplasmic reticulum.
5. *Rigor mortis*, a state of muscular rigidity following death, results from a lack of ATP to split myosin-actin cross bridges (Clinical Application).

D. Length-Tension Relationship

1. The forcefulness of muscle contraction depends on the length of the sarcomeres within a muscle before contraction begins.

E. The Neuromuscular Junction

1. Muscle action potentials arise at the *neuromuscular junction (NMJ*), the synapse between a somatic motor neuron and a skeletal muscle fiber.
2. A *synapse* is a region of communication between two neurons or a neuron and a target cell.
   a. Synapses separate cells from direct physical contact.
   b. *Neurotransmitters* bridge that gap.
3. The neurotransmitter at a NMJ is *acetylcholine* (ACh).
4. A nerve action potential elicits a muscle action potential through the release of acetylcholine, activation of ACh receptors on the motor end plate, production of a muscle action potential, and termination of ACh activity by acetylcholinesterase.

V. MUSCLE METABOLISM

A. Active muscle cells require large quantities of ATP. There are three sources for ATP production in muscle cells.

   a. *Creatine phosphate* and ATP can power maximal muscle contraction for about 15 seconds and is used for maximal short bursts of energy (e.g., 100-meter dash)
   b. Creatine phosphate is unique to muscle fibers.

2. The partial catabolism of glucose to generate ATP occurs in *anaerobic cellular respiration* . This system can provide enough energy for about 30-40 seconds of maximal muscle activity (e.g., 300-meter race).
3. Muscular activity lasting more than 30 seconds depends increasingly on *aerobic cellular respiration* (reactions requiring oxygen). This system of ATP production involves the complete oxidation of glucose via cellular respiration (biological oxidation).
    a. Muscle tissue has two sources of oxygen: diffusion from blood and release by myoglobin inside muscle fibers.
    b. The aerobic system will provide enough ATP for prolonged activity so long as sufficient oxygen and nutrients are available.

B. The inability of a muscle to maintain its strength of contraction or tension is called *muscle fatigue*; it occurs when a muscle cannot produce enough ATP to meet its needs.

C. Elevated oxygen use after exercise is called *recovery oxygen consumption* (rather than the formerly used term oxygen debt).

VI. CONTROL OF MUSCLE TENSION

A. When considering the contraction of a whole muscle, the tension it can generate depends on the number of fibers that are contracting in unison.

B. A motor neuron and the muscle fibers it stimulates form a *motor unit*. A single motor unit may innervate as few as 10 or as many as 2,000 muscle fibers, with an average of 150 fibers being innervated by each motor neuron.

C. A *twitch contraction* is a brief contraction of all the muscle fibers in a motor unit in response to a single action potential.

1. A record of a muscle contraction is called a *myogram* and includes three periods: *latent, contraction, and relaxation*.

2. The *refractory period* is the time when a muscle has temporarily lost excitability with skeletal muscles having a short refractory period and cardiac muscle having a long refractory period.

D. Frequency of Stimulation

1. *Wave summation* is the increased strength of a contraction resulting from the application of a second stimulus before the muscle has completely relaxed after a previous stimulus.
2. A sustained muscle contraction that permits partial relaxation between stimuli is called *incomplete (unfused) tetanus* a sustained contraction that lacks even partial relaxation between stimuli is called *complete (fused) tetanus*. Most muscle contractions are asynchronous incomplete tetanic contractions of the motor units rather than complete tetanus.
3. When a muscle is allowed to relax completely and is stimulated immediately following relaxation, the second contraction will be stronger. This can be repeated with each contraction getting stronger to a maximum point. This is called treppe (the staircase effect) and is the basis for "warming-up" exercises.

E. The process of increasing the number of active motor units is called *recruitment* (*multiple motor unit summation*).

1. It prevents fatigue and helps provide smooth muscular contraction rather than a series of jerky movements.
2. Aerobic training builds endurance and anaerobic training builds muscle strength.

F. A sustained partial contraction of portions of a relaxed skeletal muscle results in a firmness known as *muscle tone*. At any given moment, a few muscle fibers within a muscle are contracted while most are relaxed. This small amount of contraction is essential for maintaining posture.

G. *Isotonic contractions* occur when a constant load is moved through the range of motions possible at a joint and include *concentric contractions* and *eccentric contractions; in an isometric* contraction, the muscle does not shorten but tension increases. An isometric contraction can be described as a contraction which is resisting a muscle stretch.

VII. TYPES OF SKELETAL MSUCLE FIBERS

A. All skeletal muscle fibers are not identical in structure or function.

1. Color varies according to the content of *myoglobin*, an oxygen-storing reddish pigment. Red muscle fibers have a high myoglobin content while the myoglobin content of white muscle fibers is low.
2. Fiber diameter varies as do the cells' allocations of mitochondria, blood capillaries, and sarcoplasmic reticulum.
3. Contraction velocity and resistance to fatigue also differ between fibers.

B. On the basis of structure and function, skeletal muscle fibers are classified as *slow oxidative*, *oxidative-glycolytic,* and *fast glycolytic fibers*.

C. Distribution and Recruitment of Different Types of Fibers

1. Most skeletal muscles contain a mixture of all three fiber types, their proportions varying with the usual action of the muscle. All fibers of any one motor unit, however, are the same.
2. Although the number of different skeletal muscle fibers does not change, the characteristics of those present can be altered by various types of exercise.

VIII. CARDIAC MUSCLE TISSUE

A. Cardiac muscle tissue is found only in the heart wall (see Chapter 20).

1. Its fibers are arranged similarly to skeletal muscle fibers.
    2. *Cardiac muscle fibers* connect to adjacent fibers by *intercalated discs* which contain *desmosomes* and *gap junctions.*

B. Cardiac muscle contractions last longer than the skeletal muscle twitch due to the prolonged delivery of calcium ions from the sarcoplasmic reticulum and the extracellular fluid.

C. Cardiac muscle fibers contract when stimulated by their own autorhythmic fibers.

D. This continuous, rhythmic activity is a major physiological difference between cardiac and skeletal muscle tissue.

IX. SMOOTH MUSCLE

A. *Smooth muscle* tissue is nonstriated and involuntary and is classified into two types: *visceral (single unit) smooth muscle* and *multiunit smooth muscle*

1. *Visceral (single unit) smooth muscle* is found in the walls of hollow viscera and small blood vessels; the fibers are arranged in a network.
2. *Multiunit smooth muscle* is found in large blood vessels, large airways, arrector pili muscles, and the iris of the eye. The fibers operate singly rather than as a unit.

B. Microscopic Anatomy of the Smooth Muscle

1. Sarcoplasm of smooth muscle fibers contains both thick and thin filaments which are not organized into sarcomeres.
2. Smooth muscle fibers contain intermediate filaments which are attached to dense bodies.

X. REGENERATION OF MUSCLE TISSUE

A. Skeletal muscle fibers cannot divide and have limited powers of regeneration; growth after the first year is due to enlargement of existing cells, rather than an increase in the number of fibers (although new individual cells may be derived from *satellite cells*).

1. The number of new skeletal muscle fibers formed from satellite cells is minimal.
2. Extensive repair results in *fibrosis*, the replacement of muscle fibers by scar tissue.

B. Cardiac muscle fibers cannot divide or regenerate.

C. Smooth muscle fibers have limited capacity for division and regeneration.