Chapter 10 Muscle Tissue and Physiology

Chapter Outline

Module 10.1 Overview of muscle tissue (Figures 10.1–10.2)

A. **Types of Muscle Tissue (Figure 10.1)**

1. The three types of cells in muscle tissue are_____,_____, and_____muscle.
2. **What function do all three muscle tissue types share in common?** _____

   _____

   What are some other functions of muscle tissue? _____

   _____

   _____

3. **Striated muscle tissue**

   a. **What do skeletal muscle cells and cardiac muscle cells have in common?** _____

   _____

   _____

   b. **Skeletal muscle cells** are known as fibers due to their length and appearance. They are multinucleated cells whose contractions are voluntary or controlled by conscious thought.

   c. **Cardiac muscle cells**, found only in the heart, are short and highly branched. Each cell has one to two nuclei and _____ discs between adjacent cells. Contraction is involuntary or not controlled by conscious thought.

4. **Smooth muscle tissue**

   a. **What makes smooth muscle different from skeletal and cardiac muscle tissues?** _____

   _____

   _____

b. Smooth muscle cells are long and flat with "spindle-shaped" pointed ends and a single centrally located nucleus.

c. Smooth muscle cells are found lining most hollow organs, in the eye, skin, and some glands ducts. Their contractions are involuntary.

B. **Properties of Muscle Cells**

1. **Define contractility**. _____

_____

_____

2. **Define excitability**. _____

_____

_____

3. **Define conductivity**. _____

_____

_____

4. **Define extensibility**. _____

_____

_____

5. **Define elasticity**. _____

_____

_____

C. **Structure of Muscle Cells (Figure 10.2)**

1. **Myocytes** or muscle cells are described using specialized terminology.

a. The sarcoplasm is the_____of the myocyte.

b. The sarcolemma is the_____of the myocyte.

2. **Myofibrils** are cylindrical organelles found in each of the three muscle cell types. Myofibrils are made up of bundles of specialized proteins that allow for contraction.

3. The **sarcoplasmic reticulum (SR**) is modified endoplasmic reticulum that forms a web-like network surrounding the myofibrils. It stores and releases _____ ions.

Module 10.2 Structure and Function of Skeletal Muscle Fibers (Figures 10.3–10.9)

A. **Structure of the Skeletal Muscle Fiber (Figures 10.3–10.4)**

1. **Muscle tissue** consists of many fibers and their surrounding endomysium.
2. **Skeletal muscle** fibers are thin cylinders but can be quite long and thick. Skeletal muscle fibers are formed by the fusion of many embryonic myoblasts giving each fiber multiple nuclei.
3. The_____, the most abundant organelle, are made up of mostly contractile proteins.
4. The_____(SR) surrounds the myofibrils and stores and releases calcium ions.
5. Transverse tubules (T-tubules) are deep inward extensions of _____ that are filled with extracellular fluid.
6. Terminal cisternae are enlarged sections of_____found flanking each T-tubule. Two terminal cisternae and their corresponding T-tubule form a _____.

B. Structure of the Myofibril (Figures 10.5–10.6)

1. The myofibril is made of hundreds to thousands of myofilaments, including contractile proteins that generate_____, regulatory proteins that dictate when a fiber may contract, and structural proteins that maintain proper alignment and fiber stability.
2. There are three types of myofilaments:_____filaments, _____ filaments, and_____filaments.
    a. **Thick filaments** are composed of bundles of_____. Each myosin has globular heads at each end linked by intertwining tails. Myosin heads are connected to the tails by a hinge-like neck. Each myosin head has an active site that binds with actin
    b. **Thin filaments** are composed of the proteins_____, _____, and_____. **Actin** is a contractile protein that has active sites that bind with the myosin heads of the thick filament. **Tropomyosin** is a long rope-like regulatory protein that twists around_____, covering up its active sites. **Troponin** is a small globular regulatory protein that holds

_____ in place and assists with turning contractions on and off.

c. **Elastic filaments** are composed of a single massive, spring-like structural protein called_____that stabilizes the myofibril structure and resists excessive stretching force.

5. Putting it All Together: The Big Picture of Skeletal Muscle Structure is shown in Figure 10.6.

C. **Myofilament Arrangement and the Sarcomere (Figures 10.7–10.8)**

1. Striations appear microscopically as alternating light, or **I**, **bands**, where only _____ filaments are found and dark, or A, bands, where both _____ and_____filaments are found.
2. The **A band** ("a" in dark, mnemonic) contains the zone of overlap, the region where we find thick and thin filaments and where tension is generated during contraction. In the middle of the A band where only thick filaments exist is the_____(HA, mnemonic, H is in the A band). The_____line (M is in the middle, mnemonic) is a dark line in the middle of the A band made up of structural proteins.
3. The_____**disc** is found in the middle of the **I band** and is composed of structural proteins.

D. **The Sliding-Filament Mechanism of Contraction (Fig. 10.9)**

1. The sarcomere extends from one_____to the next. It is the functional unit where contraction occurs. The sliding filament mechanism explains how tension is generated during muscle contraction.

a. During a contraction, both the_____and the _____ narrow while the A band remains unchanged.

b. Myosin heads attach to actin to pull the thin filaments towards the M line, which brings_____closer together, shortening the sarcomere.

c. Sarcomeres are arranged end to end within each myofibril and when simultaneously contracted, contract the whole muscle fiber.

Module 10.3 Skeletal Muscle Fibers as Electrically Excitable Cells (Figures 10.10–10.11)

A. **Membrane Potentials in Our Cells**

1. **Membrane potentials** are due to an unequal distribution of ions near the plasma membrane resulting in a polarized resting state.
    a. A thin layer of _____ charged ions exists in the cytosol on the inside of the cell while a thin layer of _____ charged ions exists on the outside of the cell.
    b. This separation of charges creates an electrical gradient (core principle).
2. **Electrical energy** is discussed in terms of electrical potentials. The membrane potential of a cell is the electrical potential that exists across the plasma membrane.
3. The **resting membrane potential** is the electrical potential across the sarcolemma of a resting muscle fiber and measures _____ mV.

B. **The Na+/K+ ATPase Pump, Sodium and Potassium Ion Concentration Gradients (Figure 10.10)**

1. Resting membrane potentials change when the barrier to ion movement is removed from the plasma membrane.
2. **Sodium** and **potassium ions** move through the sarcolemma using protein channels and carriers. These ions only move by diffusion if a gradient exists between the two regions on either side of the plasma membrane.
3. **How is the concentration gradient maintained?** _____

    _____

    _____

    a. The pump moves _____ Na+ ions out of the cell and _____ K+ ions into the cell.
    b. The activity of the pump creates a high concentration of Na+ in the _____ fluid while the concentration in the cytosol remains lower.
    c. This creates a high concentration of K+ in the _____ while the concentration in the extracellular fluid remains lower.

C. **Action Potentials (Figure 10.11)**

1. Action potentials are brief, temporary changes in the membrane potential of a cell from a resting negative value to a_____value, and then back to its resting negative value.
2. Action potentials are generated by opening gated ion channels in the plasma membrane. Two types are_____-gated and_____-gated channels.
    a. **What do ligand-gated channels (chemically-gated) open in response to?** _____
    _____
    b. **What do voltage-gated channels open and close in response to?** ____
    _____
    _____
3. An action potential occurs in two basic stages:
    a. **Describe depolarization**. _____
    _____
    _____
    _____
    b. **Describe repolarization**. _____
    _____
    _____
    _____

Module 10.4 The Process of Skeletal Muscle Contraction and Relaxation (Figures 10.12–10.18)

A. **The Neuromuscular Junction (NMJ) (Figure 10.12)**

1. The **NMJ** is where a single motor neuron communicates with many _____ fibers.
    a. _____ are chemicals that trigger changes in a target tissue when released allowing for cell to cell communication (Core Principle).

b. _____ is the neurotransmitter released from a motor neuron that stimulates a muscle fiber.

2. There are three components of the NMJ:

a. The_____of the neuron contains synaptic vesicles filled with acetylcholine.

b. The_____is the space between axon terminal and muscle fiber.

c. The_____is a specialized region of the muscle fiber plasma membrane that has ligand-gated Na+ channels. Acetylcholine is the ligand that opens the gates that allows Na+ to diffuse into the cell.

B. **Skeletal Muscle Contraction (Figures 10.13–10.16**)

1. Muscle contraction can be broken down into three parts: Excitation phase, Excitation-Contraction coupling, and Contraction phase.

2. **Summarize how the excitation phase begins**. _____

_____

_____

_____

a. **Acetylcholine** diffuse across the synaptic cleft where it can bind to _____-gated channels found in the motor end plate of the muscle fiber plasma membrane.

b. **What is an end-plate potential?** _____

_____

_____

c. **How is an end-plate potential accomplished?** _____

_____

_____

_____

d. **How is a functional muscle contraction produced?** _____

_____

_____

e. Motor neurons continue to fire action potentials as acetylcholine is rapidly degraded by the enzyme _____ in the synaptic cleft.

3. **Excitation-contraction coupling** is the link between the stimulus and the contraction.

a. An end-plate potential leads to the opening of voltage-gated _____ channels in the sarcolemma surrounding the motor end plate, which triggers an action potential.

b. Action potentials propagate down the_____, which signals the terminal cisternae to open voltage-gated Ca++ channels, releasing Ca++ into the cytosol.

4. **Summarize how the contraction phase begins**. _____

_____

_____

_____

a. The myosin head becomes cocked once an ATP is bound and it energy is gathered by hydrolysis, ATP →→ ADP + Pi.

b. **What does the cocked myosin head bind?** _____

_____

_____

c. **What promotes a power stroke?** _____

_____

_____

_____

d. **How is another crossbridge cycle accomplished?** _____

_____

_____

What is required for the crossbridge cycle to repeat? _____

_____

_____

C. **Muscle Relaxation (Fig. 10.17**)

1. Muscle relaxation occurs in two separate events
2. First motor neuron action potentials stop signaling for the release of _____ from axon terminals.
    a. Any acetylcholine left in the synaptic cleft is rapidly degraded by the enzyme_____.
    b. Since acetylcholine no longer can bind to the motor end plate, the end plate potentials stop as ligand-gated_____channels close.
    c. **Summarize how repolarization occurs**. _____

    _____

    _____

    _____
3. **Calcium ions** are actively pumped back into the _____ terminal cisternae.
    a. Voltage-gated calcium channels close as the _____ repolarize.
    b. Calcium ion concentration in the cytosol returns to normal.
    c. **How do the positions of troponin and tropomyosin change in the absence of calcium ions?** _____

    _____

    _____

    How does this change in position return the muscle to a relaxed state? _____

    _____

    _____

    _____

D. **Putting it All Together**: **The Big Picture of Skeletal Muscle Contraction and Relaxation (Figure 10.18)**

Module 10.5 Energy sources for skeletal muscle (Figure 10.19)

A. **Immediate sources of energy for muscle contraction (Figure 10.19a)**

1. The main immediate energy is stored as_____in the muscle fiber and is rapidly consumed during muscle contraction.

2. **Creatine phosphate concentration** in the cytosol is 5–6 times higher than ATP; can immediately regenerate enough ATP for about_____seconds of maximum muscle activity.

B. **Glycolytic energy sources (Figure 10.19b)**

1. **Glycolysis** is a series of reactions that occurs in the cytosol all cells. Glycolysis breaks_____down into_____and provides energy (ATP) for muscle contraction once immediate sources of energy are depleted.
2. Glycolysis, or anaerobic catabolism, does not require_____directly but the amount of oxygen present leads to the following two possible scenarios:
    a. **What happens to pyruvate if oxygen is abundant?** _____

    _____

    _____

    _____

    b. **What happens to pyruvate if oxygen is not abundant?** _____

    _____

    _____

    _____

    _____
3. Glycolysis uses glucose found in the blood and stored as glycogen. Glycolysis can replenish ATP for 30–40 second of sustained contraction.

C. **Oxidative Energy Sources (Figure 10.19b)**

1. **Oxidative catabolism**, or aerobic catabolism, requires oxygen directly. Oxidative catabolism allows for longer lasting muscle contractions because these reactions produce many more_____molecules than glycolysis.
2. Oxidative catabolism is the predominant energy source after_____minute of contraction and provides nearly 100% of ATP after several minutes.
3. Electrons are used to synthesize ATP in the mitochondria where they are transferred to oxygen as the final step in aerobic catabolism.

4. Some oxygen is supplied by the blood but the majority is bound to the oxygen-carrier_____.

5. **When glucose levels are exhausted, what molecules can be catabolized to generate ATP? _____**

_____

Module 10.6 Muscle Tension at the Fiber Level (Figures 10.20–10.24)

A. **Twitch Contraction (Figure 10.20)**

1. A **muscle twitch** is the smallest unit of contraction
2. The three phases of a twitch on a myogram recording include the following:
    a. **Describe what happens during the latent period**. _____

    _____

    _____

    b. D**escribe what happens during the contraction period**. _____

    _____

    _____

    c. **Describe what happens during the relaxation period**. _____

    _____

    _____

    _____
3. The _____ period begins at the onset of the latent period and ends at the beginning of the contraction period. During this time the muscle fiber is unable to respond to further stimuli.

B. **Tension production and the Timing and Frequency of Stimulation (Figure 10.21)**

1. Repeated stimulation of a fiber results in progressively greater tension production.
2. Calcium ion levels remain elevated in the_____as SR pumps cannot keep up with successive stimuli.
3. Waves of contractions have additive effects known as _____. The tension produced depends on the frequency of motor neuron stimulation resulting in two possibilities:

a. _____**tetanus** results when fibers are stimulated about 50 times per second and the fiber partially relaxes between stimuli. Tension pulsates and increases to a maximum of 80% of the maximum (Figure 10.21a).

b. _____ **tetanus** occurs when the fiber is stimulated at a rate of 80–100 stimuli per second and the fiber does not relax between stimuli. Tension stays constant at nearly 100% of the maximum (Figure 10.21b).

C. **The Length-Tension Relationship (Figure 10.22)**

1. The **length-tension relationship** states that the optimal length of a sarcomere is about 100-120% of the natural length of the sarcomere.
2. At this natural length a sarcomere can generate the greatest tension.
    a. The length of the sarcomere must be short enough to allow for a generous zone of overlap between thin and thick filaments.
    b. But the length of the sarcomere must be long enough for the thick filaments to pull the thin filaments toward the_____line without running into the_____-discs.

D. **Concept Boost**: **Understanding how events at the myofilaments produce tension of a whole muscle (Figure 10.23)**

E. **Classes of Skeletal Muscle Fibers (Figure 10.24)**

1. There are two main classes of skeletal muscle fibers:
    a. Type_____and Type _____
    b. **How are the two main types of skeletal muscle fibers classified?**

    _____

    _____

2. **Type I** fibers are small diameter, slow-twitch fibers that contract slowly to produce less force for a longer period of time.
    a. **Slow-twitch fibers** have low myosin ATPase activity.
    b. Slow-twitch fibers rely on_____catabolism and have large numbers of mitochondria, a well-developed blood supply, and

myoglobin molecules; this gives them a characteristic "dark meat" red color.

c. Slow-twitch fibers predominate in postural muscles that must sustain contractions for long durations of time.

3. **Type II** fibers are large diameter, fast twitch fibers that fatigue quickly.

a. **Fast-twitch fibers** have high myoglobin ATPase activity and rely mainly on_____catabolism for the production of ATP.

b. **Compare the number of mitochondria, myoglobin and the blood supply in fast-twitch fibers to slow-twitch fibers**. _____

_____

_____

_____

c. There are three subtypes that are categorized based on their energy production method: IIa (fast oxidative-glycolytic), IIx (fast oxidative), and IIb (fast glycolytic). Subtypes produce progressively stronger and faster contractions.

d. Examples of muscles with large numbers of type II fibers include eye muscles.

4. Most muscles contain combinations of both fiber types. The proportion of fibers, either slow or fast, is dependent on the function of the muscle itself (structure-function core principle).

Module 10.7 Muscle Tension at the Organ Level (Figures 10.25–10.26)

A. **Motor Units (Figure 10.25)**

1. A single **motor neuron** and all the muscle fibers that it innervates define a _____ unit.

2. **Motor units** are considered either slow, composed of type_____fibers only; or fast, composed of type_____fibers only.

3. The number of fibers varies depending on the motor unit's function. Muscles requiring fine motor control have small motor units, and those requiring less control have large motor units.

4. As greater force is required more motor units must be stimulated, a process known as_____.
5. **Muscle tone** is a baseline level of involuntary activation of motor units.
6. Explain why muscle tone is vital. _____

_____

_____

B. **Types of Muscle Contractions (Figure 10.26)**

1. **Isotonic concentric contractions** maintain constant tension while the muscle _____. The force generated by the muscle is greater that the external force.
2. **Isotonic eccentric contractions** maintain constant tension but the muscle _____ as the external force applied is greater than the force generated by the muscle.
3. **Isometric contractions** occur when the muscle length remains unchanged because the external force applied equals that generated by the muscle.

Module 10.8 Skeletal Muscle Performance (Figure 10.27)

A. **Changes Caused by Physical Training (Figure 10.27**)

1. The principle of **myoplasticity** describes the changes in muscle structure as a result of changes in function related to physical training.
2. **List the changes, primarily biochemical that result from endurance training** (Figure 10.27a):
    a. _____
    b. _____
    c. _____
3. **Resistance**, or strength, training causes primarily anatomical changes, including increased number of myofibrils and hypertrophy of the fiber itself (Figure 10.27b).
4. **Disuse** leads to anatomical and biochemical changes including a decrease in the number of myofibrils and size of the fiber and a decrease in oxidative enzymes.

B. **Muscular Fatigue**

1. **Define fatigue**. _____

2. **Fatigue** is caused by multiple factors:

    a. _____

    b. _____

    c. _____

    d. _____

C. **Excess Postexercise Oxygen Consumption (EPOC) and the Recovery Period**

1. **EPOC** is a mechanism that allows the body to recovery from exercise-induced homeostatic imbalances.

2. **What causes EPOC?** _____

_____

_Module 10.9 Smooth and Cardiac Muscle (Figures 10.28–10.29)

A. **Smooth muscle**

1. Smooth muscle has the following functions:

    a. _____

    b. _____

    c. _____

2. Smooth muscle cells contain myosin and actin filaments are arranged differently than seen in skeletal and cardiac muscle as there are no _____. Thin filaments radiate from dense bodies to surround a single thick filament.

3. Other dense bodies link a smooth muscle cell to surrounding smooth muscle cells which allow for tension transmission from cell to cell.

4. In smooth muscle cells, both thick and thin filaments are longer and the thin filament lacks_____. Myosin heads are found along the entire length of the thick filament.

5. **What other features do smooth muscle cells lack?** _____

_____

6. **Smooth Muscle Contraction and Relaxation**

    a. Smooth muscle cells respond to multiple stimuli including mechanical, hormonal, nervous system, and local pacemaker cell stimuli.

b. **Contraction** of smooth muscle involves influx of extracellular calcium ions that bind to_____, which activates myosin light chain kinase. This in turn activates myosin ATPase.

c. Repeated contraction cycles pull actin along myosin, causing the cell to change shape from thin and flat to fat and globular.

d. Only about 1/100th the amount of ATP is required when compared to skeletal fiber contractions.

e. **Relaxation** occurs when Ca++ is removed from the cytosol, MLCK is deactivated, and the myosin ATPase is deactivated.

f. **What is the latch state?** _____

_____

7. **Types of Smooth Muscle**

a. **Single unit smooth muscle** is found in all _____ where they are linked electrically by gap junctions.

b. **Multi-unit smooth muscle** is found in the_____, _____, and_____. These are individual cells that contract independently to allow for precision.

B. **Cardiac Muscle**

1. **Cardiac muscle cells** are structurally similar to skeletal fibers with some noticeable major differences.
2. **Intercalated discs** link cells together both electrically by gap junctions and physically by desmosomes permitting the heart to contract as a coordinated unit.
3. **Cardiac pacemaker cells** are autorhythmic. Pacemaker cells are found in specific regions of the heart where they spontaneously generate action potentials. **What is the function of the pacemaker cells?**

_____

_____