Chapter 9: The Muscular System

→ Module 9.1: Overview of Skeletal Muscles

Structure of a Skeletal Muscle

Skeletal muscles are not made of muscle cells alone

- Skeletal muscle contains blood vessels that supply muscle cells with oxygen and glucose, and remove wastes, and nerves that coordinate muscle contraction
- Skeletal muscle also contains connective tissue
- Each individual muscle cell (fiber) is surrounded by the ____________
- Several muscle cells are bundled together into a ___________by the ___________
- All fascicles that make up a muscle are, in turn, enclosed by the ____________
- Interconnected connective tissues taper down and connect to tendons or other connective tissues; attach muscle to bone or other structure to be moved

Functions of Skeletal Muscles

- Muscle contractions are involved in more than just movement of bones at a joint:
  -
  - Contraction of **diaphragm** muscle is a vital function associated with respiratory system
  - ______________________ – sitting, standing, holding head upright
  - Skeletal muscles attached to facial skin allow for facial expression; muscles in throat assist with swallowing
  - Sphincters composed of skeletal muscle allow conscious control over opening and closing of body openings
  - ____________of soft tissue – abdominal walls, pelvic floor

- **Functional groups of muscles**: generally takes cooperation of several individual muscles working as a group to perform a movement or action
  - ____________ (**prime movers**) provide most force for a given muscle action
  - ____________have opposite action of agonist; allows for modulation and control of agonist movement
  - ____________aid agonists by supplying supplemental force, minimizing unwanted movement, and by helping to stabilize joints
  - ____________also provide stabilizing force that anchors a bone; protection from injury due to unnecessary movements
- **Muscle origin and insertion** – skeletal muscles begin and end at distinct anatomical locations
  - ____________– anchoring point on a bone, where skeletal muscle "originates from"; typically not involved directly with movement of joint
  - ____________– moving end of muscle whose tendon attaches to a bone or other structures

Chapter 10: Muscle Tissue and Physiology

→ Module 10.1: Overview of Muscle Tissue

Types of Muscle Tissue

- The three types of cells in muscle tissue are
  -
  -
  -
- Generating a force called **muscle tension** is a basic function common to each muscle tissue type
- **Skeletal Muscle**
  - Shape –
  - Striations –
  - # of Nuclei –

- Control –
- Location –

- **Cardiac Muscle**
  - Shape –
  - Striations –
  - # of Nuclei –
  - Control –
  - Location –
  - Intercalated discs

- **Smooth Muscle Tissue**
  - Shape –
  - Striations –
  - # of Nuclei –
  - Control –
  - Location –

Properties of Muscle Cells

1. **Contractility** – ability to contract where proteins in the cell draw closer together
2. ____________– ability of a cell to respond to a stimulus
3. **Conductivity** – ability of a cell to conduct electrical changes across the plasma membrane

4. _____________– ability of a cell that allows it to be stretched without being ruptured

5. _____________– ability of a cell that allows it to return to its original length

Structure of Muscle Cells

- **Myocytes** (muscle cells)
  -
  - Sarcolemma
  - Sarcoplasmic reticulum (SR)
  -

→ Module 10.2: Structure and Function of Skeletal Muscle Fibers

Structure of the Skeletal Muscle Fiber

- Skeletal muscle tissue consists of many _____________and their surrounding _____________ (extracellular matrix)

- _____________ **tubules** (**T-tubules**) - inward extensions of sarcolemma that surround each myofibril

Structure of the Myofibril

Myofilaments - hundreds to thousands make up myofibrils (3 types):

- **Thick filaments** –

- **Thin filaments** –

- **Elastic filaments** –

Duchenne Muscular Dystrophy (DMD)

- **DMD** is a degenerative muscular disease occurring almost exclusively in boys
- Caused by a defective gene for the protein ___________, coded on **X chromosome**

Dystrophin is a structural protein found in **striated muscle fibers** that anchors the sarcolemma to the surrounding connective tissue and to the myofibrils

In the absence of normal **dystrophin**, the sarcolemma breaks down and the muscle fiber is destroyed and replaced with **fatty** and **fibrous connective tissue**

Symptoms (arising between 2 and 12 years of age) include weakness of the proximal limb muscles and a waddling gait; generally wheelchair-bound by age 12 and dead from **respiratory** or **cardiac failure** by age 20

Putting It All Together: The Big Picture of Skeletal Muscle Structure

- Multiple muscle fibers (surrounded by extracellular matrix called the **endomysium**) form a **fascicle**
- Each ________is surrounded by a layer of connective tissue called the **perimysium**
- **Bundles** of **fascicles** make up a skeletal **muscle**, which is surrounded by the _____________, a connective tissue layer
- The **perimysium** and **epimysium** come together at the end of the muscle to form a _____________that binds the muscle to its attaching structure (usually bone)
- Skeletal muscles are enclosed by a layer of thick connective tissue called _____________, which anchors them to the surrounding tissues and holds groups of muscles together

Sarcomere

- The **sarcomere** –**functional unit** where contraction occurs
- Striations:
  - _____________ – only thin filaments
  - _____________ – both thin and thick filaments

- **I band**
- **Z disc (line)**
-
-
- **M line**

The Sliding-Filament Theory

- Sliding filament theory (mechanism) explains how tension is generated during muscle contraction

The **I band** and the **H zone** ____________while the

A band remains ____________

Z-discs closer together, shortening the sarcomere

____________are arranged end to end within each **myofibril** and when simultaneously contracted, shorten the whole **muscle fiber**

→ Module 10.4: The Process of Skeletal Muscle Contraction and Relaxation

The Neuromuscular Junction

- **Motor neuron**
- ____________**–** junction between neuron and muscle cell
- The **axon terminal** of the neuron contains **synaptic vesicles** filled with the neurotransmitter ____________ (**ACh**)
- The ____________________is the **space** between **axon terminal** and muscle fiber
- The **motor end plate** is a specialized region of the muscle plasma membrane

Skeletal Muscle Contraction

Muscle contraction can be broken down into **three phases**:

1.

- An action potential signals the release of acetylcholine from the axon terminal into the synaptic cleft
- Acetylcholine diffuses across the synaptic cleft where it can bind to receptors on the motor end plate
- Channels open allowing Na^+ ions to enter the muscle fiber generating a muscle potential

Review

1. The end plate potential is generated by the influx of _______ into the motor end plate.
   a. calcium
   b. sodium
   c. potassium
   d. chloride
2. Acetylcholine is released from the synaptic terminus in response to
   a. A ligand binding to a receptor on the synaptic terminus
   b. Sodium flowing into the synaptic terminus
   c. Potassium entering the synaptic terminus
   d. An action potential arriving at the synaptic terminus
3. The term “synaptic cleft” refers to
   a. A fold on the motor end plate
   b. A vesicle in the synaptic terminus
   c. The gap between the neuron and the muscle fiber
   d. The space between adjacent muscle fibers

2.

- The muscle potential signals the ER to release Ca^{++} into the cytosol
- Calcium ions bind to ____________
-
- Active sites of actin are exposed

Review

1. ________ is released from the SR in response to arrival of an action potential
    a. Na^+
    b. K^+
    c. P_i
    d. Ca^{++}
2. Tropomyosin
    a. Covers actin active sites
    b. Binds calcium ions
    c. Is a small, globular protein
    d. Has three subunits

3.

- The myosin head becomes cocked once an ________is bound
- The head is able to bind to the active site of actin forming a crossbridge
- A ____________occurs when ADP + P_i are released from the myosin head
- Myosin can bind to another ATP which breaks the link with the actin active site

The crossbridge cycle may be repeated as long as the stimulus to contract continues and ATP is available

Review

1. Hydrolysis of ATP is responsible for
    a. Release of the myosin heads from the actin active sites
    b. Recocking of the myosin heads
    c. The power stroke
    d. The movement of tropomyosin, exposing the actin active sites

2. The binding of ATP to myosin is responsible for

    a. Release of the myosin heads from the actin active sites
    b. Recocking of the myosin heads
    c. The power stroke
    d. The movement of tropomyosin, exposing the actin active sites

3. The power stroke

    a. Pulls the thick filaments toward the Z lines
    b. Positions the myosin heads in their high-energy position
    c. Shortens the length of the thin filaments
    d. Pulls the thin filaments toward the M lines

Botulism and Botox

- The bacterium ________________________produces the most lethal known biological poison—as little as one gram of crystalline toxin is enough to kill about **one million adults**

- Exposure to the **botuminum toxin** through contaminated food causes the disease **botulism**:

The toxin binds to motor neurons of the NMJ and **blocks** the release of acetylcholine from synaptic vesicles

This paralyzes the affected muscle, and without proper treatment, death from **respiratory failure** will follow

- The toxin can be used to treat painful muscle spasm and migraine headaches when injected in minute quantities; also used cosmetically to relax facial muscles (as ____________)

Skeletal Muscle Relaxation

1. ______________________ (AChE) degrades the ACh
2. ATP breaks ____________
3. Calcium ions are pumped back into the ________(active transport)
4. Troponin and tropomyosin block the active sites of actin

Review

1. During muscle fiber relaxation

    a. Calcium levels in the sarcoplasm rise
    b. Calcium is pumped back into the SR
    c. Calcium is released from the SR
    d. Calcium is pumped into the extracellular fluid

2. Acetylcholinesterase in the synaptic cleft degrades acetylcholine, allowing

    a. Depolarization of the motor end plate
    b. Calcium levels in the sarcoplasm to rise
    c. Tropomyosin to expose actin active sites
    d. Sodium channels to close

3. Which aspect of muscle relaxation requires ATP?

    a. Motor end plate repolarization
    b. Blockage of actin active sites by tropomyosin
    c. Sarcomeres returning to their original length
    d. Pumping calcium ions back into the SR

Rigor Mortis

- The progressive stiffening (contraction) of skeletal muscles begins about 3–4 hours after death, as the pumps that drive calcium ions back into the SR no longer have ATP to fuel their activity
- As a result, Ca^{++} ions remain in the cytosol, where they bind to troponin and initiate muscular contraction all over the body
- The muscle fibers are unable to relax without ____________, so the myosin heads cannot detach from actin
- The muscles remain contracted until the proteins of the myofilaments begin to degenerate, about 48–72 hours after death

→ Module 10.5: Energy Sources for Skeletal Muscle

Sources of Energy for Muscle Contraction

- The required ATP is generated by:

Immediate cytosolic reactions

____________**catabolism** in the cytosol

____________**catabolism** in the mitochondria

Immediate Sources of Energy

- The main immediate energy is stored as ATP in the muscle fiber and is rapidly consumed during muscle contraction
- _____________ ___________– it can immediately regenerate enough ATP for about 10 seconds of maximum muscle activity

Creatine Supplementation

- Research has demonstrated that supplementation with ____________does mildly improve performance for activities that require short bursts of muscle activity
- The effects on **endurance-type activities** are minimal to nonexistent
- Creatine may actually be detrimental in some cases:
    - Causes **weight gain** from **water retention**
    - **Massive doses** may cause **kidney damage**
- Skeletal muscles have a maximal storage capacity for creatine; therefore, huge doses are a waste of money because the excess is simply excreted in the urine

Glycolytic Energy Sources

-
    - Occurs in cytosol
    - ____________catabolism

Break glucose down into pyruvate

Glucose found in the blood and stored in muscle or liver cells as glycogen

It can replenish ATP for 30–40 seconds of sustained contraction

- Glycolysis, or anaerobic catabolism, does not require oxygen directly

If oxygen is abundant, pyruvate formed by glucose catabolism enters the ____________for oxidative catabolism

If oxygen is not abundant, the pyruvate is converted into lactic acid

Oxidative Energy Sources

- Oxidative catabolism or aerobic catabolism

Requires ____________directly

The amount of ATP produced depends on the type of fuel used by the fiber (glucose can produce 30 – 38 ATP)

Oxidative catabolism is the predominant energy source after one minute of contraction and provides nearly 100% of the necessary ATP after several minutes; it can provide ATP for hours, as long as oxygen and fuels are available

→ Module 10.6: Muscle Tension at the Fiber Level

Twitch Contraction

- A **muscle twitch** is the smallest muscle contraction
- The three phases of a twitch on a myogram include the following:

Relaxation period

- The ____________**period** begins at the onset of the latent period and ends at the beginning of the contraction period
- During this time (about 5 ms) the muscle fiber is unable to respond to further stimuli

- Cardiac muscle and smooth muscle have refractory periods as long as their contractions, so the cells must fully relax before they can contract a second time

Tension Production and the Timing and Frequency of Stimulation

- _________ ___________**-** increase in tension caused by repeated stimulation

The pumps in the SR membranes have inadequate time to pump all of the released calcium ions back into the SR before the fiber is restimulated

Therefore, the concentration of calcium ions in the cytosol increases with each stimulation

- **____________(incomplete) tetanus**

Results when fibers are stimulated about 50 times per second

Fiber partially relaxes between stimuli

- **____________** (**complete**) **tetanus**

Occurs when the fiber is stimulated at a rate of 80–100 stimuli per second

Fib er does not relax between stimuli

The Length-Tension Relationship

-

Classes of Skeletal Muscle Fibers

-

Small diameter, slow-twitch fibers

Slow fibers rely on oxidative catabolism and have large numbers of mitochondria

Well-developed blood supply and myoglobin molecules

Slow fibers predominate in postural muscles that must sustain contractions for long durations

•

Large diameter, fast twitch fibers that fatigue quickly

Rely mainly on glycolytic catabolism with fewer mitochondria

Lower levels of myoglobin and less extensive blood

There are three subtypes that are categorized based on their energy production method

- **IIa** (**fast oxidative-glycolytic**)
- **IIx** (**fast oxidative**)
- **IIb** (**fast glycolytic**) – produce extremely fast, powerful twitches

- Most muscles contain all fiber classes, each of which is stimulated under different conditions

A baseball player sitting in the dugout uses primarily type I fibers in the back and abdomen to remain sitting upright

When the player gets up and jogs to the plate to bat, primarily type IIa fibers in the legs are used

When the player hits the ball, the bat is swung using type IIx and IIb fibers in the arms

→ Module 10.7: Muscle Tension at the Organ Level

Motor Units

- **_____________ unit –** A single motor neuron and all the muscle fibers that it innervates
- The number of fibers in a motor unit varies depending on the motor unit's function

Muscles requiring fine motor control have small motor units (as few as 10 muscle fibers per motor unit, as in the larynx and fingers)

Those requiring less control (and generation of more power) have large motor units (as many as 2000–3000 fibers per motor unit, as in the postural muscles of the back, or the large muscles of the legs)

- Initiation of a contraction activates a small number of motor units

- As greater force is required more motor units must be stimulated, a process known as _____________
-

Vital for the maintenance of erect posture, stabilization of joints, heat production, and preserving a level of preparedness for movement

The nervous system alternates which motor units it activates, so that some can rest while others contract

Types of Muscle Contractions

- _____________**contractions** (tension generated by the muscle is constant, but muscle length changes):

Isotonic _____________contractions maintain constant **tension** while the muscle shortens

Isotonic _____________contractions maintain constant tension but the muscle lengthens

- _____________**contractions** is where the muscle length remains unchanged because the external force applied equals that generated by the muscle
- A muscle is able to lengthen while it is contracting because the elastic filaments in its myofibrils allow it to stretch considerably

→ Module 10.8: Skeletal Muscle Performance

A&P in the Real World

Delayed-Onset Muscle Soreness

- The phenomenon of muscle soreness following exercise was thought for many years to be due to the accumulation of lactic acid produced during glycolysis
- Current research suggests instead that it is more likely due to minor structural damage, in particular, that caused by isotonic eccentric muscle contractions
- The most effective treatment for DOMS is more exercise; unfortunately, once the exercise ceases, the pain returns until the muscle is sufficiently conditioned through training

- Other treatment modalities such as massage, topical therapies, acupuncture, and oral medications have shown little benefit

Changes Caused By Physical Training

- ____________– the changes in muscle structure as a result of changes in function related to physical training

The majority of mature skeletal muscle fiber nuclei are ____________ (do not undergo mitosis)

____________**cells** (a small population of unspecialized cells) do retain mitotic ability, can help repair injured skeletal muscle

Changes in response to training are within the muscle fibers and do not involve changes in the number of muscle fibers

- **Endurance training** – more repetitions with lighter weight

Increased oxidative enzymes, and mitochondria

More efficient use of fatty acids and non-glucose fuels for ATP production

Increases in the blood vessel network supplying the muscle

- **Resistance** (**strength**) **training** – fewer repetitions with heavier weight

The diameter of the muscle fibers increase

A decreased proportion of mitochondrial proteins and blood supply to the muscle because of fiber enlargement, not because mitochondria or vessels are actually lost

- Disuse leads to:

a decrease in the number of myofibrils

a decrease in the size of the fiber

a decrease in oxidative enzymes, which is termed

a decline in both strength and endurance

Muscular Fatigue

- ____________is the inability to maintain a given level of intensity during activity

The depletion of creatine phosphate, glycogen, and glucose involved in ATP production

Decreased availability of ____________to muscle fibers

Environmental conditions, particularly extreme heat; sweating in response to heat may also cause electrolyte disturbances

→ Module 10.9: Smooth and Cardiac Muscle

Smooth Muscle

- ________ _________ has the following functions:

____________ propels materials through hollow organs

Sphincters that control the passage of materials

Changes diameter of tubing to regulate flow rates through hollow organs (blood vessels, the respiratory tract, and the gastrointestinal tract)

- Smooth muscle cells contain myosin and actin filaments arranged differently than in skeletal and cardiac muscle; there are no ____________, and therefore no ____________
- Both thick and thin filaments are longer and the thin filament lacks ____________

Types of Smooth Muscle:

- Single unit smooth muscle is

The predominant type in the body

Impulse spreads rapidly through the cells causing the cells to contract in a coordinated wave as a single unit

Respond to multiple stimuli including mechanical, hormonal, neural

- Multi-unit smooth muscle:

Made up of individual cells that contract independently

Responds primarily to nerve stimulation

Cardiac Muscle

- Cardiac muscle cells are structurally similar to skeletal fibers with some major differences:

Shorter, branched cells with one nucleus and abundant myoglobin

Do not require stimulation from the nervous system

Naming of Muscles

1. Action:
2. Direction:
3. Location:
4. Divisions:
5. Shape:
6. Attachment:
7. Latin names:

Levator scapulae

Gluteus maximus

Transversus abdominis

Internal oblique

Rectus abdominis

Flexor carpi ulnaris

Adductor longus

Brachialis

Sternocleidomastoid

Biceps brachii

Pectoralis major

Sartorius

Triceps brachii

Quadriceps femoris

Deltoid

Trapezius

Rhomboideus

External oblique

Platysma

Buccinator

Serratus ventralis

Masseter

Vastus lateralis