Intro to Muscles

- ➔ Latin " mus " means "little mouse" – muscles are named after mice for how they move under skin
- ➔ Muscles are unique; they can turn chemical (ATP) energy into mechanical energy and so can exert force
- ➔ Root words meaning "muscle" or "flesh": myo- , mys- , sarco-
- ➔ Muscles – distinct organs made of vascularized, innervated muscle fibers (cells) surrounded by connective tissue

The three *classifications* of muscle tissue are. . .

1. Skeletal Muscle Tissue – skeletal, striated, voluntary; tires easily, very adaptable
2. Cardiac Muscle Tissue – cardiac, striated, involuntary; tireless; paced by pacemaker (mostly)
3. Smooth Muscle Tissue – visceral, nonstriated, involuntary; slow and sustained contractions

The *special characteristics* of muscle tissue are. . .

1. Excitability/Responsiveness/Irritability – ability to sense and respond to a stimulus
2. Contractility – ability to shorten forcibly
3. Extensibility – ability to be stretched or extended
4. Elasticity – ability to recoil after being stretched

Muscle Functions

Movement – locomotion and manipulation

Maintaining Posture & Position – muscles counteract gravity and other forces

Stabilizing Joints – stronger muscles stabilize their joints better, remember?

Generating Heat – contraction generates heat; skeletal muscle generates most

And more. . . – protect viscera, forms valves, control pupil size, make hair stand on end

Skeletal Muscle: Gross Anatomy and Microscopic Anatomy

- Muscle – a distinct organ made of vascularized, innervated muscle fibers (cells) surrounded by an epimysium and/or an aponeurosis (connective tissue membranes)

- Fascicle – a bundle of *muscle fibers* surrounded by a membrane called a perimysium

- Muscle Fiber – an elongated, multinucleate cell made of *myofibrils*; surrounded by a membrane called endomysium

- Myofibril – an organelle unique to muscle cells; composed of dark "A bands" and light "I bands;" myofibrils are separated into contractile segments called *sarcomeres*

- Sarcomere – a contractile segment of a myofibril; contains *actin myofilaments* & *myosin myofilaments;* composed of one A band in the middle with half an I band on either side of it, bordered by "Z discs" on either end

- Myofilaments – thick bundles of myosin filaments surround (and are surrounded by) thin actin filaments; myosin filament "heads" connect to active sites on actin filaments to form cross bridges , then thick myosin filaments do one "rowing stroke" to contract muscles; elastic filaments help recover from stretching

➔ Check out pp. 278-280

Sliding Filament Model of Contraction

o Thin actin filaments are pulled toward sarcomere centers by cross-bridge "myosin head" activity of the thick myosin filaments. → Check out p. 284

Muscle Types (Review)
-3 types of muscle tissue: skeletal, cardiac, and smooth
-types differ in structure, location, function, and means of activation

Muscle Similarities
-*Skeletal* and *smooth* muscle cells are elongated muscle fibers
-Muscle contraction uses two kinds of myofilaments – actin and myosin
-Muscle terminology is similar
- -Sarcolemma – muscle plasma membrane
- -Sarcoplasm – cytoplasm of a muscle cell
- -Prefixes – myo, mys, and sarco all refer to muscle (or flesh)

Skeletal Muscle: Nervous and Circulatory Connections
-Each muscle is served by one nerve, an artery, and one or more veins
-Each skeletal muscle *fiber* has a nerve ending which controls contraction
-Contracting fibers obtain oxygen and nutrients via arteries
-Wastes are removed via veins

Skeletal Muscle: Attachments
-Most skeletal muscles span joints and are attached to bone in 2 or more places
-When muscles contract, the muscle's insertion (the more movable bone) moves toward the muscle's origin (the less movable bone)
-Muscles attach:
- Directly – epimysium of the muscle is fused to the periosteum of a bone
- Indirectly – connective tissue wrappings extend beyond the muscle as a tendon or aponeurosis

Microscopic Anatomy of a Skeletal Muscle Fiber (Review/Overview)

fibers: long, cylindrical cells with multiple nuclei; surrounded by a plasma membrane called a sarcolemma and filled with cytoplasm called sarcoplasm; fibers contain the usual organelles + *sarcoplasmic reticula*, *T tubules*, and *myofibrils* (myofibrils contain *microfilaments* actin and myosin bundled into segments called sarcomeres) →check out p. 279-280

Sarcoplasmic Reticulum (SR)

-an elaborate, smooth endoplasmic reticulum that surrounds each myofibril

-regulates intracellular levels of Ca^{2+}

-controlled by signals from T tubules

→check out p.283

T Tubules

-continuous with the sarcolemma

-penetrate into the cell's interior at each A band–I band junction

-function to conduct impulses to the deepest regions of the muscle by forming "triads" with paired terminal cisternae of SR

-impulses from T tubules signal for the release of Ca^{2+} from SR's terminal cisternae

→check out p.283

Triad Relationships

-T tubules and SR provide tightly linked signals for muscle contraction

-A double zipper of integral membrane proteins protrudes into the intermembrane space

-*T tubule proteins* act to sense voltage from nerves

-*SR* "*foot proteins*" are receptors that regulate Ca^{2+} release from the SR cisternae

Skeletal Muscle Contraction

-In order to contract, a skeletal muscle must:

- -Be stimulated by a nerve ending
- -Propagate (broadcast) an electrical current, called an action potential, along its sarcolemma
- -Have a rise in intracellular Ca^{2+} levels (the final trigger for contraction)

-Linking the electrical signal to the contraction is called excitation-contraction coupling

Nerve Stimulus of Skeletal Muscle

-stimulation is enacted by *motor neurons* of the somatic nervous system

-Axons of these neurons travel to muscle cells in nerves

-Axons of motor neurons begin to branch profusely as they enter muscles

-Each axonal branch forms a neuromuscular junction with a single muscle *fiber* (muscle cell), ~halfway along fiber's length

Neuromuscular Junctions

-A neuromuscular junction is formed from:

-Axonal endings, which have small membranous sacs (synaptic vesicles) that contain the neurotransmitter acetylcholine (ACh)

-The motor end plate of a muscle, a specific part of the sarcolemma that contains receptors sensitive to ACh

-Though exceedingly close, axonal ends and motor end plates of muscle fibers are always separated by a space called the synaptic cleft

Phases leading to muscle fiber contraction (p.285)

Phase 1: When a nerve impulse reaches the end of an axon at the neuromuscular junction. . .

-Voltage-regulated calcium channels open and allow Ca^{2+} to enter the axon

-Ca^{2+} inside the axon terminal causes axonal vesicles to fuse with the axonal membrane, releasing ACh into the synaptic cleft via exocytosis

-ACh diffuses across the synaptic cleft to bind to ACh receptors on the sarcolemma

- Binding of ACh on sarcolemma initiates an action potential in the muscle

Phase 2: Excitation-Contraction Coupling

-Once generated, the action potential:

-Is propagated (continued) along the sarcolemma

-Travels down the T tubules into cell/fiber

-Triggers release of Ca^{2+} from terminal cisternae

-Ca^{2+} binds to troponin and causes:

-The blocking action of tropomyosin to cease

-Actin active binding sites to be exposed

-Myosin cross bridges alternately attach and detach

-Thin filaments move toward the center of the sarcomere (hydrolysis of ATP powers this cycling process)

-Ca^{2+} is removed into the SR, tropomyosin blockage is restored, and the muscle fiber relaxes

→check out p. 290-291

Destruction of Acetylcholine

-ACh bound to ACh receptors is quickly destroyed by the enzyme acetylcholinesterase

-This destruction *prevents / allows* (circle one) continued muscle fiber contraction in the absence of additional stimuli

→check out homeostatic imbalance *myasthenia gravis*, p. 285

Action Potential -A transient depolarization event that includes polarity reversal of a sarcolemma (or nerve cell membrane) and the propagation of an action potential along the membrane

Role of Acetylcholine (Ach)

-ACh binds to its receptors at the motor end plate

-Binding opens chemically-gated (ligand-gated) channels

-Na^+ and K^+ diffuse out and the interior of the sarcolemma becomes less negative (this event is called depolarization)

Depolarization

-Initially, this is a local electrical event called end plate potential

-Later, it ignites an action potential that spreads in all directions across the sarcolemma and deep into the cell/fiber through T tubules

Role of Ionic Calcium (Ca^{2+}) in the Contraction Mechanism

-At low intracellular Ca^{2+} concentration:

-Tropomyosin blocks the binding sites on actin

-Myosin cross bridges cannot attach to binding sites on actin

Result: The relaxed state of the muscle is enforced

-At higher intracellular Ca^{2+} concentrations:

-hyper-calcium-activated troponin undergoes a conformational change

-This change moves tropomyosin away from actin's binding sites

Result: Myosin head can now bind and cycle

Sequential Events of Contraction

- Cross bridge formation – myosin heads attach to actin filaments
- Working (power) stroke – myosin heads pivot and pull actin filaments toward sarcomere center (M line)
- Cross bridge detachment – ATP attaches to myosin head and the cross bridge detaches
- "Cocking" of the myosin head – energy from hydrolysis of ATP cocks the myosin head into the high-energy state

Contraction of Skeletal Muscle Fibers

-Contraction – refers to the activation of myosin's cross bridging activity (force-generating sites)

-Shortening occurs when the tension generated by the cross bridge exceeds forces opposing shortening

-Contraction ends when cross bridges become inactive, the tension generated declines, and relaxation is induced

Contraction of Skeletal Muscle (Organ Level)

-Contraction of muscle fibers (cells) and muscles (organs) is similar

-The two types of muscle contractions are:

-Isometric contraction – increasing muscle tension (muscle does not shorten during contraction)

-Isotonic contraction – decreasing muscle length (muscle shortens during contraction)

Motor Unit: The Nerve-Muscle Functional Unit

- motor unit - a motor neuron and all the muscle fibers it supplies
- number of muscle fibers per motor unit: four to hundreds
- fine movement control (fingers, eyes) requires small motor units
- large, powerful movements (thighs, hips) require large motor units

-Muscle fibers from a motor unit are spread throughout the muscle; therefore, contraction of a single motor unit causes weak contraction of the entire muscle

Muscle Twitch

muscle twitch - the response of a muscle to a single, brief threshold stimulus

-The three phases of a muscle twitch are:

1. Latent period – first few milli-seconds after stimulation when excitation contraction coupling is taking place
2. Period of contraction – cross bridges actively form and the muscle shortens
3. Period of relaxation – Ca^{2+} is reabsorbed into the SR, and muscle tension goes to zero

Muscle Tone

Muscle tone - the constant, slightly contracted state of all muscles, which does not produce active movements

Purpose of muscle tone - Keeps the muscles firm, healthy, and ready to respond to stimulus

Spinal reflexes are responsible for muscle tone because they:

-Activate one motor unit after another

-Respond to activation of stretch receptors in muscles and tendons

Muscle Metabolism: Energy for Contraction

- ATP - the only source used directly for contractile activity

- Regeneration of ATP - As soon as available stores of ATP are hydrolyzed (4-6 seconds), they are regenerated by:
    - -The interaction of ADP with creatine phosphate (CP)
    - -Anaerobic glycolysis
    - -Aerobic respiration

Muscle Metabolism: Anaerobic Glycolysis

Anaerobic Glycolysis – energy metabolism in the absence of Oxygen (O_2)

-Occurs when muscle contractile activity reaches 70% of maximum:

-Effects:

- -Bulging muscles compress blood vessels
- -Oxygen delivery is impaired
- -Pyruvic acid is converted into lactic acid

-The lactic acid:

- -Diffuses into the bloodstream
- -Is picked up and used as fuel by the liver, kidneys, and heart
- -Is converted back into pyruvic acid by the liver

Muscle Fatigue

Muscle fatigue – muscle in a state of physiological inability to contract

-Occurs when:

- -ATP production < ATP use
- -relative deficits of ATP occur, causing contractures
- -Lactic acid accumulates in muscle
- -Ionic imbalances are present

Intense exercise produces rapid muscle fatigue (with rapid recovery)

- -Na^+-K^+ pumps cannot restore ionic balances quickly enough

Low-intensity exercise produces slow-developing fatigue

- -SR is damaged and Ca^{2+} regulation is disrupted

Oxygen Debt

Oxygen debt – the extra amount of O_2 needed in order to restore a vigorously exercised muscle to a normal, resting state

To recover:

-Oxygen reserves must be replenished
-Lactic acid must be converted to pyruvic acid
-Glycogen stores must be replaced
-ATP and CP reserves must be resynthesized

Heat Production During Muscle Activity

Amount of energy released as useful work during muscle activity: 40%

Amount of energy released as heat during muscle activity: 60%

Overheating – dangerously high body temp; usu. prevented by radiation of heat from the skin, made more effective by sweating

Smooth Muscle

-shape of smooth muscle fibers: spindle-shaped

-diameter of smooth muscle fibers: 2-10 mm

-lengths of smooth muscle fibers: several hundred mm

-connective tissue wrapping: fine endomysium

Compared to skeletal muscle, smooth muscle. . .

-Lacks *coarse* connective tissue sheaths
-Is organized into two layers of fibers: longitudinal and circular
-Is found in walls of hollow organs (except the heart)
-Has no neuromuscular junctions (has diffuse junctions instead)
-Has essentially the same contractile mechanisms as skeletal muscle
-Diagonally arranged microfilaments (corkscrew contraction)
→check out table on p.310 for most in-depth comparison of muscle types

Peristalsis

Peristalsis – alternating contractions and relaxations of smooth muscle layers that mix and squeeze substances through the lumen of hollow organs

-When the longitudinal layer contracts, the organ dilates and shortens

-When the circular layer contracts, the organ elongates

Regulation of Contraction in Smooth Muscle

Nervous:

-no neuromuscular junctions

-Innervating nerves have bulbous swellings called varicosities

-Varicosities release neurotransmitters into wide synaptic clefts called diffuse junctions

Chemical:

- some smooth muscle lack nerves and are only activated by chemicals

Special Features of Smooth Muscle Contraction

-Unique characteristics of smooth muscle include:

-Smooth muscle tone

-Slow, prolonged contractile activity

-Low energy requirements

-*stress-relaxation response* to stretch

Response to Stretch

The stress-relaxation response:

-smooth muscle resists stretch only briefly, then relaxes at its new length

-new length retains its ability to contract

-enables organs such as stomach and bladder to temporarily store contents

Developmental aspects of Muscles

Embryonic development: muscles form from *myoblasts*; growth is regulated by complex electrochemical interactions with other developing muscle fibers and nerves

Childhood: at birth, movement is mostly reflexive; nerve-muscle coordination develops in a head-to-to and proximal-to-distal direction

Adolescence: peak *natural* neural control is reached; can be improved via training, exercise

Adulthood: muscles respond to use, but are otherwise unchanged in healthy individuals

Aging: Connective tissue replaces skeletal tissue gradually, *sarcopenia* occurs; smooth muscle is largely unaffected (except by *atherosclerosis* in blood vessels); muscles still respond positively to moderate use

Homeostatic Imbalance: Muscular Dystrophy

Muscular dystrophy – group of inherited muscle-destroying diseases where muscles enlarge due to fat and connective tissue deposits, but muscle fibers atrophy

Duchenne muscular dystrophy (DMD)

-World's most common genetic disorder
-Inherited, sex-linked disease carried by females and expressed in males (1/3500)
-Diagnosed between the ages of 2-10
-Victims become clumsy and fall frequently as their muscles fail
-Progresses from the extremities upward, and victims die of respiratory failure in their 20s
-Caused by a lack of the cytoplasmic protein *dystrophin*
-There is no cure, but myoblast transfer therapy shows promise