The Muscular System
Objectives:

• List and describe the major functions of the muscular system
• Describe the structure of a skeletal muscle at the macroscopic and microscopic level
• Describe muscle contraction according to the sliding-filament theory
• Name and identify the location of major muscles and muscle groups of the body
• List and describe diseases and disorders of the muscular system.
Function of Muscles

- Produce movement
- Maintain posture
- Stabilize joints
- Generate heat in order to maintain constant internal body temp (homeostasis)
Characteristics of Muscles

• Muscle cells are elongated
  (muscle cell = muscle fiber)

• Contraction of muscles is due to the movement of microfilaments

• All muscles share some terminology
  • Prefix myo refers to muscle
  • Prefix mys refers to muscle
  • Prefix sarco refers to flesh

• Most are attached by tendons to bones
• Cells are multinucleate
• Striated – have visible banding
• Voluntary – subject to conscious control
• Cells are surrounded and bundled by connective tissue
Macroscopic Structure

• *Fascia* – on the outside of the epimysium, it is the hypodermis

• *Epimysium* – covers the entire skeletal muscle, comes together at end of muscles to form tendons and aponeuroses

• *Perimysium* – divides a skeletal muscle into bundles of fibers, called a fascicle, contains blood vessels and nerves

• *Endomysium* – around single muscle fiber
Microscopic Structure of Myofibril

- Cells are very large, multinucleate
- Nuclei are just beneath the sarcolemma
- Sarcolemma – specialized plasma membrane
- Transverse tubules (T-tubules) are continuous with the sarcolemma
- Sarcoplasmic reticulum – specialized smooth endoplasmic reticulum which stores calcium ions
Microscopic Structure of Myofibril

- Transverse tubules encircle myofibrils, which are actually bundles of actin and myosin protein myofilaments.

- Areas where T-tubules come into contact with the sarcoplasmic reticulum on either side are called triads. Expanded portions of the SR at the triads are called terminal cisternae and store huge amounts of calcium ions, about 40,000x as much as that in a normal cell!

- The release of these calcium ions from the terminal cisternae signals the beginning of a muscle contraction.
Microscopic Structure of Myofibril

- **Myofibril**
  - Bundles of myofilaments
  - Myofibrils are aligned to give distinct bands
    - I band = light band
    - A band = dark band

- **Sarcomere**: smallest functional unit of a muscle fiber
  - Contractile unit of a muscle fiber, which extends from one z line to the next z line.
The Sarcomere

• The A Band: Contains mostly thick (myosin) dark filaments and is subdivided into
  – M line: central portion of each thick filament; its proteins help to stabilize the thick filaments in their appropriate positions
  – H-zone: lighter regions on either side of M line, contains thick filaments only
  – Zone of overlap: thin filaments overlap between thick filaments
The Sarcomere

- The I Band: contains only thin (actin) lIght filaments
- Extends from A band of one one sarcomere to A band of next sarcomere
- Z lines mark the boundaries between adjacent sarcomeres.
- Z lines consist of connectins (proteins) that interconnect the thin filaments of each sarcomere
The Sarcomere
Microscopic Structure of Sarcomere

• Organization of the sarcomere
  – Thick filaments = myosin filaments
    • Composed of the protein myosin
    • Has ATPase enzymes
  – Thin filaments = actin filaments
    • Composed of the protein actin

(b) Myofibril or fibril
(complex organelle composed of bundles of myofilaments)
Microscopic Structure of Myofilaments

- Myosin filaments have heads (extensions, or cross bridges)
- Myosin and actin overlap somewhat
- At rest, there is a bare zone that lacks actin filaments; this is the location of the M line and the H zone.
Microscopic Structure of Myofilaments

• The thin filaments are composed mostly of actin but also contain troponin and tropomyosin.
• Actin contains an active site that can bind to a thick (myosin) filament
• Tropomyosin covers actin’s active site to prevent actin-myosin interactions (called crossbridging) and is also bound to troponin
• Troponin consists of a subunit bound to tropomyosin to lock them together and a subunit bound to actin to hold troponin-tropomyosin complex in position. Also contains a receptor that binds calcium ions.
Microscopic Structure of Myofilaments

Thin Filament Structure

- Tropomyosin
- Troponin complex
- G-actin
How Thick and Thin Filaments Work Together To Produce Movement: An Overview

- When calcium ions bind to troponin, troponin moves tropomyosin away from actin’s active site.
- Myosin binds to actin’s active site (cross bridging occurs)
- This results in thick and thin filaments sliding past one another, the sarcomeres shorten, and the muscle contracts.
Thick and Thin Filament Interaction: An Analogy

• Actin: the boyfriend in jail
• Myosin: his girlfriend
• Calcium: the bail money
• Troponin: the sheriff
• Tropomyosin: the jail bars

• When the bail money is placed into the sheriff’s hand, he removes the jail bars from the boyfriend so that the boyfriend and girlfriend can interact.
Properties of Muscle Fibers Which Produce Movement

- **Irritability** – ability to receive and respond to a stimulus
- **Contractility** – ability to shorten when an adequate stimulus is received
- **Extensibility** - ability to lengthen when it is relaxed and not being stimulated
How Muscle Fibers Produce Movement

• In order to produce movement, skeletal muscles must be stimulated by a motor neuron
• Motor unit
  – One neuron
  – Muscle cells stimulated by that neuron
• Neuromuscular junctions – association site of nerve and muscle
Neuromuscular Junction (NMJ)

**Synaptic cleft** – gap between nerve and muscle
- Nerve and muscle do not make contact
- Area between nerve and muscle is filled with interstitial fluid

**Neurotransmitter** – chemical released by nerve upon arrival of nerve impulse
- The neurotransmitter for skeletal muscle is acetylcholine (Ach)

Neurotransmitter attaches to receptors on the **sarcolemma**. The portion of the sarcolemma associated with the NMJ is called the **motor end plate**.

Invaginations (folds) of the motor end plate increase the surface area available for the binding of Ach.

Sarcolemma becomes permeable to sodium (Na+).
Neuromuscular Junction

Sodium rushing into the cell generates an action potential (electrical impulse).

The action potential travels across the sarcolemma, down the T-tubules, and is transmitted to the SR, changing its permeability to calcium ions.

Once this happens, the sarcoplasmic reticulum releases its calcium ions.

The calcium ions bind to troponin, causing it to remove tropomyosin from actin’s active site.

This uncovers actin’s active site so that the myosin heads can bind to actin and cross-bridging can occur. (This uses ATP, lots of it!)

This begins the contraction of the sarcomere units in the myofibrils.

Once started, the contraction of the muscle fiber cannot be stopped (All or none response- either the entire muscle fiber contracts or it does not contract at all.)
Sliding Filament Theory

- ATP hydrolysis by ATPase enzyme on the myosin filament causes the myosin head to move from the relaxed state to the upright excited state.
- Activation by nerve causes release of calcium which exposes the binding sites on actin filaments to which the heads of the myosin filaments bind sites on the thin filament.
- Myosin heads then bind to the exposed site of the Actin thin filament.
- Once the crossbridges form, the myosin head bends towards the M line or H zone.
- This continued action causes a sliding of the myosin along the actin pulling the actin filament and z lines toward the center or H zone. The H zone disappears.
- The result is that the muscle is shortened (contracted).
Sliding Filament Theory

(a) Protein complex

(b) Myosin binding site

(c) Upper part of thick filament only

Myosin myofilament
Actin myofilament

Ca^{2+}
Muscle Relaxation

• Nerve impulse stops. Ach is broken down by the enzyme, acetlacholinesterase (Achase).
• SR reabsorbs calcium ions, resulting in a decline of calcium ions that can bind to troponin.
• Troponin-tropomyosin complex returns (active sites of actin covered by tropomyosin). This prevents further crossbridge interaction with actin.
• No crossbridging=no sliding=end of contraction
Muscle Tension

• Remember, a muscle fiber is either “ON” or “OFF”. There is no partial contraction. The amount of tension in a muscle depends upon:

1. The frequency of stimulation of muscle fibers
2. The number of fibers stimulated.
Frequency of Muscle Fiber Stimulation

A. Twitch: a single cycle of (stimulus, contraction, relaxation) of a muscle fiber

Phases of a twitch:
1. Latent (lag) period: action potential sweeps across sarcolemma, calcium released by SR, no tension, contraction has not yet begun
2. Contraction phase: tension rises to a peak (cross bridges are interacting with actin’s active sites)
3. Relaxation phase: muscle tension falls as cross bridges detach.
Frequency of Muscle Fiber Stimulation

- Twitches do not accomplish anything useful.

B. Wave summation: if a second stimulus arrives before the relaxation phase ends, a second, more powerful contraction occurs. The addition of one twitch to another results in wave summation.
Frequency of Muscle Fiber Stimulation

C. Incomplete tetanus: If the muscle is continually stimulated and never allowed to relax completely, tension will rise to a peak. A muscle producing peak tension during rapid cycles of contraction and relaxation is said to be in incomplete tetanus.
Frequency of Muscle Fiber Stimulation

Complete tetanus: can be obtained by increasing the rate of stimulation until the relaxation phase is completely eliminated. The state of contraction is continuous.

Virtually, all normal muscular contractions involve the complete tetanus of the muscle fibers involved.
Number of Fibers Stimulated

• The total tension (or force) of a muscle contraction is also determined by how many muscle fibers are activated.

• Some neurons control a single muscle fiber, while others control hundreds or thousands.

• All of the muscle fibers controlled by one neuron is called a motor unit.
Number of Fibers Stimulated

- The size of the motor unit dictates how fine the control we have over the movement.
- One neuron + 2-3 fibers = very fine control (ex. Eye, fingers)
- One neuron + thousands of fibers = less precise control (ex. thigh, belly)
Number of Fibers Stimulated

- Recruitment: when a contraction begins with the activation of the smallest motor units (slowest), then gradually, larger (faster) motor units are activated - this causes the amount of tension in the muscle to rise steeply. This smooth but steady rise in tension produced by increasing the number of motor units activated is called recruitment.
Number of Fibers Stimulated

- Peak tension is produced when all motor units in a muscle are contracting in complete tetanus.
- However, these powerful contractions can not be maintained for very long at a time.
- During a **sustained tetanic contraction**, motor units are activated on a rotating basis so that at any one time, some motor units are resting while others are contracting in complete tetanus.
- Our muscles usually maintain sustained tetanic contractions at reduced tensions for longer periods of time rather than complete tetanic contractions at peak tension for brief periods of time.
Muscle Tone

• Some of the motor units within any particular muscle are always active, even when the entire muscle is not contracting.
• These active motor units tense and firm the muscle, giving it muscle tone: the resting tension in a muscle
• Little muscle tone = limp
• Moderate muscle tone = firm and solid
• Muscle tone stabilizes the position of bones and joints, and maintains body position and posture.
• When unconscious, muscle tone is lost. This is why the body goes limp and the tongue falls back into the throat.
Reflexes

- Sensory structures called muscle spindles within muscles keep in constant contact with the central nervous system about the length and position of the protein fibers in the muscle fiber.
- Distortion of these muscle spindles results in a reflex reaction: an automatic, involuntary response to a stimulus.
- This automatically adjusts muscle tone and body position or posture.
Types of Contractions

1. Isotonic: cross-bridge formation produces enough tension to overcome the resistance that is being applied to the muscle. When tension exceeds applied resistance, muscle shortens. Tension remains constant at a value that just exceeds applied resistance. (Ex. lifting an object, walking, running)

   a. Concentric: muscle tension exceeds resistance and muscle shortens

   b. Eccentric: tension developed is less than resistance, muscle is stretched by resistance (Ex. lowering a book onto a desk)
Types of Contractions

2. Isometric: Cross-bridge formation results in production of peak tension in the muscle, but it is not enough to overcome the resistance being applied - resistance does not move (Ex. Holding a heavy weight above the ground, pushing against a locked door, trying to lift a car.

• These type of contractions help you to oppose gravity, to maintain your posture, and to remain upright.
Types of Skeletal Muscle Fibers

1. Fast fibers: most are this type
   - Very large
   - Densely packed myofibrils
   - Large energy reserves/few mitochondria needed
   - Produce powerful contractions that use ATP in massive amounts—therefore, have to use anaerobic (without oxygen) metabolism, this produces lactic acid which causes this type of fiber to fatigue rapidly
   - Used for brief, powerful movements
   - White muscle (ex. breast and wing of chicken)
Types of Skeletal Muscle Fibers

2. Slow fibers: half the diameter of fast fibers
   - Take three times longer to contract
   - Less energy reserves/larger number of mitochondria- therefore, can contract for a longer period of time
   - Contain more capillaries that fast fibers= more oxygen= aerobic respiration= weaker contraction for longer period of time
   - Presence of vessels and blood causes muscles with lots of this type of fiber to be red/dark in appearance
   - Ex. Dark meat, leg and thigh in chicken
3. Intermediate fibers: properties in between fast and slow fibers
- Look like fast fibers
- Have more capillaries than fast fibers, so do not fatigue as quickly
- With physical conditioning, fast fibers can become intermediate fibers (and not fatigue as quickly)
Hypertrophy

- Muscles exposed to repeated, exhaustive stimulation will develop more mitochondria, more myofibrils, causing enlargement of the muscle, called muscle hypertrophy.
- Men have higher muscle mass than women due to the fact that the male hormone, testosterone, provides this repeated stimulation, resulting in hypertrophy. Testosterone, however, does have severe side-effects, including cancer and sterility.
Atrophy

• On the other hand, when a muscle is not stimulated on a regular basis, it loses muscle tone and mass.

• The muscle becomes smaller and weaker = muscle atrophy.

• In the beginning, atrophy is reversible. If let go too long, the damage, however, will become irreversible.

• “Use it or lose it”
Diseases and Disorders of the Muscular System

• **Muscular Dystrophy**: Series of genetic disorders characterized by the atrophy or wasting away of skeletal muscle. Duchenne Muscular Dystrophy is the most common and affects primarily males. The muscle tissue breaks down and is replaced by fat and fibrous tissue. DMD is characterized by weakness in the leg muscles which then rapidly spreads to the shoulders and other parts of the body. Death usually occurs by the age of 21 due to respiratory or cardiac muscle weakness.
Cerebral Palsy: This disorder is characterized by paralysis and or weakened muscles due to loss of muscle tone. It can be caused due to lack of oxygen to the region of the motor region of the cerebrum of the brain which controls conscious control of muscles. This is often attributed to complication during birth.
Diseases and Disorders of the Muscular System

• Poliomyelitis: Polio is due to a viral infection which affects the motor neurons that control skeletal muscles. It often leads to paralysis and can result in death by paralysis of the diaphragm. Due to vaccine developed by Jonas Salk, the virus has been virtually eliminated in the US. However, it still poses a threat in developing countries.
Diseases and Disorders of the Muscular System

• **Myalgia**: Muscle pain due to strain, tearing of muscle fibers. It also is a symptom of an immune response along with a fever.

• **Myositis**: Inflammation of muscle tissue due to injury or disease.

• **Charley Horse** (fibromyositis): Inflammation of muscle tissue and the tendons associated with that muscle due to injury (tear or severe bruising- contusion)

• **Cramps**: Painful, involuntary muscle spasms
Types of Body Movements

(a) Flexion and extension of the shoulder and knee

(b) Flexion, extension, and hyperextension

(c) Rotation
Points of A Muscle * Types of Muscle

• **Origin** - the point at which the muscle attaches to a structure to provide resistance to create movement.

• **Insertion** – the point at which the muscle attaches to the structure which is moved when it contracts.

• **Prime mover** – muscle with the major responsibility for a certain movement

• **Antagonist** – muscle that opposes or reverses a prime mover

• **Synergist** – muscle that aids a prime mover in a movement and helps prevent rotation

• **Fixator** – stabilizes the origin of a prime mover
Naming of Muscles

- **Direction of muscle fibers**
  - Example: *rectus* (straight)

- **Relative size of the muscle**
  - Example: *maximus* (largest), *major* (larger of group)

- **Location of the muscle**
  - Example: many muscles are named for bones (e.g., *temporalis*)

- **Number of origins**
  - Example: *triceps* (three heads)

- **Location of the muscles origin and insertion**
  - Example: *sterno* (on the sternum)

- **Shape of the muscle**
  - Example: *deltoid* (triangular)

- **Action of the muscle**
  - Example: *flexor* and *extensor* (flexes or extends a bone)
Superficial Muscles Anterior Surface
Superficial Muscles Posterior Surface
Superficial and Deep Muscles of the Trunk Posterior Surface
Muscles of Pelvic and Femoral Regions
Anterior Surface
Muscles of Lower Leg Anterior and Posterior Surface