Muscular Tissue

Muscle Metabolism: Production of ATP in Muscle Fibers

- Stored ATP
  - 3 seconds
- Energy transferred from stored creatine phosphate
  - 12 seconds
- Aerobic ATP production
- Anaerobic glucose use
  - 30-40 seconds

- In a state of homeostasis, muscle use of O\textsubscript{2} and nutrients is balanced by the production of manageable levels of waste products like
  - CO\textsubscript{2}
  - Heat - 70-80% of the energy used by muscles is lost as heat - muscle activity is important for maintaining body temperature
  - Lactic acid (anaerobic)
Muscle Fatigue

- The inability of a muscle to contract forcefully after prolonged activity

Oxygen Consumption After Exercise

- Oxygen Debt, or "Excess Post-Exercise Oxygen Consumption" (EPOC) is the amount of $O_2$ repayment required after exercise in skeletal muscle to:
  - Replenish ATP stores
  - Replenish creatine phosphate and myoglobin stores
  - Convert lactic acid back into pyruvate so it can be used in the Krebs cycle to replenish ATP

Control of Muscle Tension: Motor Units

- Motor Unit is composed of a motor neuron plus all of the muscle cells it innervates
  - High precision
    - Fewer muscle fibers per neuron
    - Laryngeal and extraocular muscles (2-20)
  - Low precision
    - Many muscle fibers per neuron
    - Thigh muscles (2,000-3,000)

Florescent dye is used to show the terminal processes of a single neuron which terminate on a few muscle fibers

Activities requiring extreme precision (like the subtle and rapid movements of the eye) involve muscles with very small motor units (1-4 muscle fibers/neuron)
• All-or-none principle of muscle contraction
• When an individual muscle fiber is stimulated to depolarization, and an action potential is propagated along its sarcolemma, it must contract to its full force—it can’t partially contract
• Also, when a single motor unit is recruited to contract, all the muscle fibers in that motor unit must all contract at the same time

Twitch Contraction
• A twitch is recorded when a stimulus that results in contraction (force) of a single muscle fiber is measured over a very brief millisecond time frame

• There is a brief delay called the latent period as the AP sweeps over the sarcolemma and Ca²⁺ ions are released from the sarcoplasmic reticulum (SR)
• During the next phase the fiber is actively contracting
• This is followed by relaxation as the Ca²⁺ ions are re-sequestered into the SR and myosin binding sites are covered by tropomyosin
• Temporary loss of excitability is call the refractory period – All muscle fibers in a motor unit will not respond to a stimulus during this short time

Frequency of Stimulation
• Applying increased numbers of action potentials to a muscle fiber (or a fascicle, a muscle, or a muscle group) results in fusion of contractions (tetanus) and the performance of useful work

Motor Unit Recruitment
• Two motor units, one in green, the other in purple, demonstrate the concept of progressive activation of a muscle known as recruitment
• Recruitment allows a muscle to accomplish increasing gradations of contractile strength

Muscle Tone
• A small amount of tautness or tensions in the muscle due to weak, involuntary contractions of its motor units
• Established by neurons in the brain and spinal cord that excite the muscle’s motor neurons
• Muscles become flaccid (a state of limpness) when muscle tone is lost
Isotonic & Isometric Contractions

- Isotonic contractions results in movement
  - Concentric isotonic is a type of muscle contraction in which the muscle shorten while generating force
  - Eccentric isotonic is a contraction in which muscle tension is less than the resistance (the muscle lengthens)
- Isometric contractions results in no movement
  - Muscle force and resistance are equal
  - Supporting objects in a fixed position and posture

Types of Skeletal Muscle Fibers

- Skeletal muscle fibers are not all alike in appearance or function
  - Red muscle fibers (the dark meat in chicken legs) have a high myoglobin content, more mitochondria, more energy stores, and a greater blood supply
  - White muscle fibers (the white meat in chicken breasts) have less myoglobin, mitochondria, and blood supply

Slow Oxidative Fibers

- Slow oxidative fibers (SO) are small, appear dark red, are the least powerful type.
  - They are very fatigue resistant
  - Used for endurance like running a marathon

Fast Oxidative-Glycolytic Fibers

- Fast oxidative-glycolytic fibers (FOG) are intermediate in size, appear dark red, and are moderately resistant to fatigue.
  - Used for walking

Fast Glycolytic Fibers

- Fast glycolytic fibers (FG) are large, white, and powerful
  - Suited to intense anaerobic activity of short duration
Distribution & Recruitment of Different Types of Fibers

- Most skeletal muscles are a mixture of all three types of skeletal muscle fibers; about half the fibers in a typical skeletal muscle are slow oxidative (SO) fibers.
- Within a particular motor unit all the skeletal muscle fibers are the same type.
- The different motor units in a muscle are recruited in a specific order depending on the task being performed (fast anaerobic activity for maximal force, etc.).

Exercise & Skeletal Muscle Tissue

- The ratio of FG and SO fibers in each muscle is genetically determined and helps account for individual differences in performance.
- Various types of exercises can induce changes in the fibers in a skeletal muscle.
  - Diameter, number of mitochondria, blood supply, and strength.
  - Endurance vs. Strength.
  - Greater elasticity contributes to flexibility and greater ROM.

Effective Stretching

- Stretching cold muscles does not increase flexibility and may cause injury.
- Tissues stretch best when slow, gentle force is applied at elevated tissue temperatures — Warm-ups.

Strength Training

- Exercising with progressively heavier resistance for the purpose of strengthening the musculoskeletal system.
- Increases bone strength by increasing the deposition of bone minerals.
- Increasing the muscle mass raises resting metabolic rates.
- Helps to prevent other injuries.
- Reduction in feelings of stress and fatigue.
- With an increase in tolerance, it takes longer to build up lactic acid, reducing the probability of muscle spasms.

Exercise-induced muscle damage

- After intense exercise electron micrographs reveal considerable muscle damage including torn sarcolemmas and disrupted Z-discs.
- Blood levels of proteins normally confined only to muscle (including myoglobin and the enzyme creatine kinase) increase as they are released from damaged muscle.
Cardiac Muscle Tissue

- In response to a single AP, cardiac muscle contracts 10-15 times longer than skeletal muscle, and must continue to do so, without rest, for the life of the individual.
- To meet this constant demand, cardiac muscle generally uses the rich supply of O₂ delivered by the extensive coronary circulation to generate ATP through aerobic respiration.

Smooth Muscle Tissue

- Like cardiac muscle, smooth muscle (in your deep organs) is autorhythmic and is not under voluntary control (your heart beats and your stomach digests without you thinking about it).
- Unlike cardiac (and skeletal muscle) however, smooth muscle has a low capacity for generating ATP and does so only through anaerobic respiration (glycolysis).

Microscopic Anatomy of Smooth Muscle Tissue

- A single relaxed fiber is thickest in the middle and tapers at the ends.
- Centrally located nucleus.
- Thick to thin filaments in 1:10 to 1:15 ratios.
- Contain intermediate filaments but no striations.
- Lack t-tubules but have caveolae.

Physiology of Smooth Muscle

- Thin filaments attach to dense bodies.
- In contraction, the smooth muscle fiber twists as a helix, and rotates in the opposite direction as it relaxes.
- Visceral (single-unit) smooth muscle is found in the walls of hollow viscera and of small blood vessels.
  - Many fibers for a network that contracts in unison.
- Multiunit smooth muscle is found in large blood vessels, large airways to the lungs, arrector pili muscles, and the eye.
  - Fibers operate independently.
• The duration of contraction and relaxation of smooth muscle is longer than in skeletal muscle since it takes longer for Ca2+ to reach filaments
• Smooth muscle fibers contract in response to nerve impulses, hormones, and local factors
• Can stretch considerably and still maintain their contractile function

Tissue Regeneration of Muscular
• Skeletal muscle fibers cannot divide and have limited powers of regeneration
• Cardiac muscle fibers can regenerate under limited circumstances
• Smooth muscle fibers have the best capacity for division and regeneration

Development of Muscle
• With few exceptions, muscles develop from mesoderm
• Skeletal muscles of the head and limbs develop from general mesoderm
• Other skeletal muscles develop from the mesoderm of somites

Aging & Muscular Tissue
• In part due to decreased levels of physical activity, with aging humans undergo a slow, progressive loss of skeletal muscle mass that is replaced largely by fibrous connective tissue and adipose tissue
• Muscle strength at 85 is about half that at age 25
• Compared to the other two fiber types, the relative number of slow oxidative fibers appears to increase

Spasm
• A sudden involuntary contraction of a single muscle within a large group of muscles – usually painless

Cramp
• Involuntary and often painful muscle contractions
• Caused by inadequate blood flow to muscles (such as in dehydration), overuse and injury, and abnormal blood electrolyte levels

Disease States and Disorders
• Fibrosis (myofibrosis)
  • Replacement of muscle fibers by excessive amounts of connective tissues (fibrous scar tissue)
• Myosclerosis
  • Hardening of the muscle caused by calcification
• Both myosclerosis and muscle fibrosis occur as a result of trauma and various metabolic disorders