Muscles and Muscle Tissue: Part B

**Review Principles of Muscle Mechanics**

1. Same principles apply to contraction of a single fiber and a whole muscle
2. Contraction produces tension, the force exerted on the load or object to be moved

**Review Principles of Muscle Mechanics**

3. Contraction does not always shorten a muscle:
   - Isometric contraction: no shortening; muscle tension increases but does not exceed the load
   - Isotonic contraction: muscle shortens because muscle tension exceeds the load

**Review Principles of Muscle Mechanics**

4. Force and duration of contraction vary in response to stimuli of different frequencies and intensities

**Motor Unit: The Nerve-Muscle Functional Unit**

- Motor unit = a motor neuron and all (four to several hundred) muscle fibers it supplies

**Motor Unit**

- Small motor units in muscles that control fine movements (fingers, eyes)
- Large motor units in large weight-bearing muscles (thighs, hips)

**Motor Unit**

- Muscle fibers from a motor unit are spread throughout the muscle so that a single motor unit causes weak contraction of entire muscle
- Motor units in a muscle usually contract asynchronously; helps prevent fatigue

**Muscle Twitch**
• Response of a muscle to a single, brief threshold stimulus
• Simplest contraction observable in the lab (recorded as a myogram)

**Muscle Twitch**
• Three phases of a twitch:
  • Latent period: events of excitation-contraction coupling
  • Period of contraction: cross bridge formation; tension increases
  • Period of relaxation: Ca\(^{2+}\) reentry into the SR; tension declines to zero

**Muscle Twitch Comparisons**
Different strength and duration of twitches are due to variations in metabolic properties and enzymes between muscles

**Graded Muscle Responses**
• Variations in the degree of muscle contraction
• Required for proper control of skeletal movement
Responses are graded by:
  1. Changing the frequency of stimulation
  2. Changing the strength of the stimulus

**Response to Change in Stimulus Frequency**
• A single stimulus results in a single contractile response—a muscle twitch

**Response to Change in Stimulus Frequency**
• Increase frequency of stimulus (muscle does not have time to completely relax between stimuli)
• Ca\(^{2+}\) release stimulates further contraction $\rightarrow$ temporal (wave) summation
• Further increase in stimulus frequency $\rightarrow$ unfused (incomplete) tetanus

**Response to Change in Stimulus Frequency**
• If stimuli are given quickly enough, fused (complete) tetany results

**Response to Change in Stimulus Strength**
• Threshold stimulus: stimulus strength at which the first observable muscle contraction occurs
• Muscle contracts more vigorously as stimulus strength is increased above threshold
• Contraction force is precisely controlled by recruitment (multiple motor unit summation), which brings more and more muscle fibers into action

Response to Change in Stimulus Strength
• Size principle: motor units with larger and larger fibers are recruited as stimulus intensity increases

Muscle Tone
• Constant, slightly contracted state of all muscles
• Due to spinal reflexes that activate groups of motor units alternately in response to input from stretch receptors in muscles
• Keeps muscles firm, healthy, and ready to respond

Isotonic Contractions
• Muscle changes in length and moves the load
• Isotonic contractions are either concentric or eccentric:
  • Concentric contractions—the muscle shortens and does work
  • Eccentric contractions—the muscle contracts as it lengthens

Isometric Contractions
• The load is greater than the tension the muscle is able to develop
• Tension increases to the muscle’s capacity, but the muscle neither shortens nor lengthens

Muscle Metabolism: Energy for Contraction
• ATP is the only source used directly for contractile activities
• Available stores of ATP are depleted in 4–6 seconds

Muscle Metabolism: Energy for Contraction
• ATP is regenerated by:
  • Direct phosphorylation of ADP by creatine phosphate (CP)
  • Anaerobic pathway (glycolysis)
• Aerobic respiration

**Anaerobic Pathway**
- At 70% of maximum contractile activity:
  - Bulging muscles compress blood vessels
  - Oxygen delivery is impaired
  - Pyruvic acid is converted into lactic acid

**Anaerobic Pathway**
- Lactic acid:
  - Diffuses into the bloodstream
  - Used as fuel by the liver, kidneys, and heart
  - Converted back into pyruvic acid by the liver

**Aerobic Pathway**
- Produces 95% of ATP during rest and light to moderate exercise
- Fuels: stored glycogen, then bloodborne glucose, pyruvic acid from glycolysis, and free fatty acids

**Muscle Fatigue**
- Physiological inability to contract
- Occurs when:
  - Ionic imbalances ($K^+$, $Ca^{2+}$, $P_i$) interfere with E-C coupling
  - Prolonged exercise damages the SR and interferes with $Ca^{2+}$ regulation and release
- Total lack of ATP occurs rarely, during states of continuous contraction, and causes contractures (continuous contractions)

**Oxygen Deficit**
Extra $O_2$ needed after exercise for:
- Replenishment of
  - Oxygen reserves
  - Glycogen stores
  - ATP and CP reserves
- Conversion of lactic acid to pyruvic acid, glucose, and glycogen

**Heat Production During Muscle Activity**
- ~ 40% of the energy released in muscle activity is useful as
work

• Remaining energy (60%) given off as heat
• Dangerous heat levels are prevented by radiation of heat from the skin and sweating