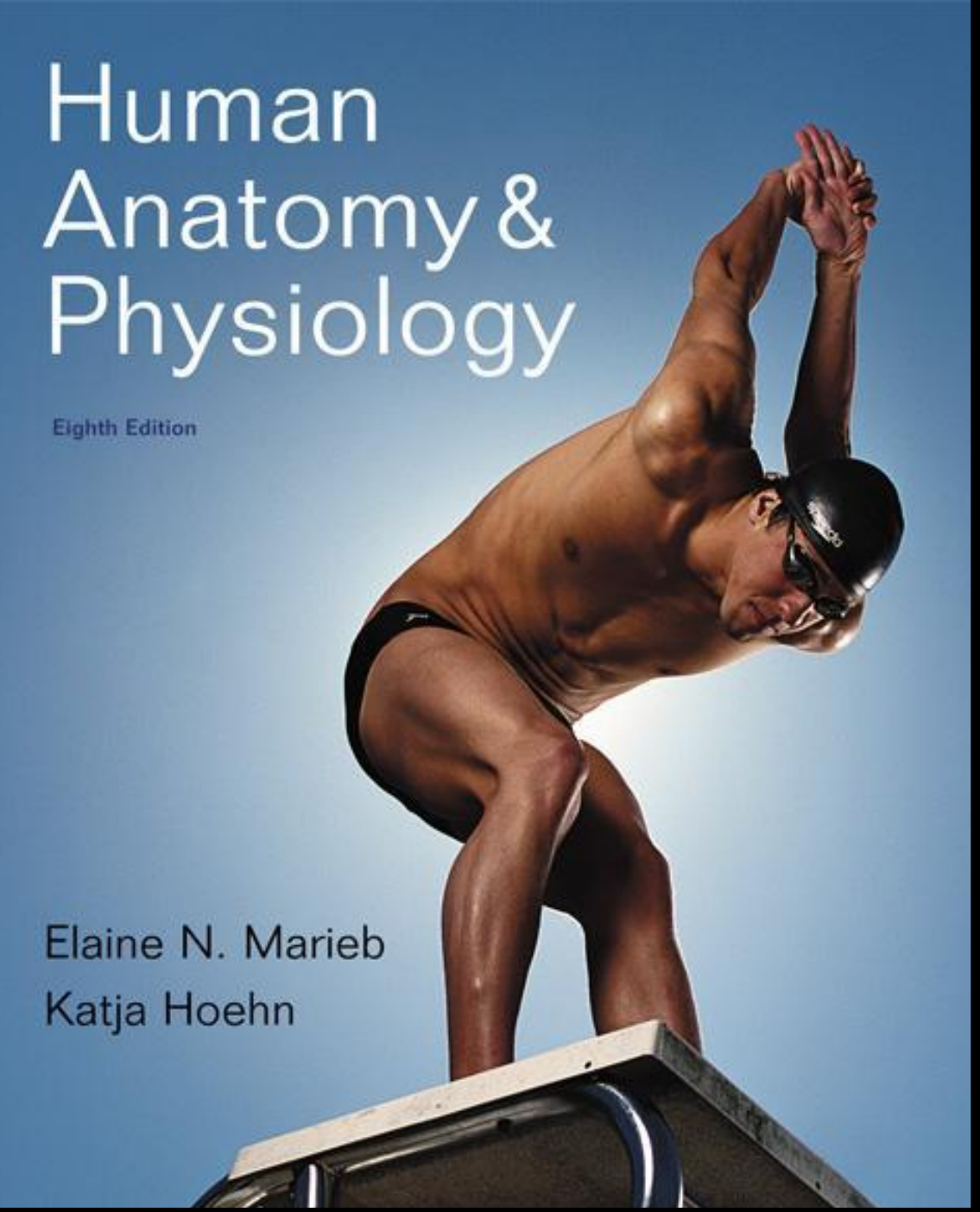


PowerPoint® Lecture Slides
prepared by
Janice Meeking,
Mount Royal College

CHAPTER 9

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

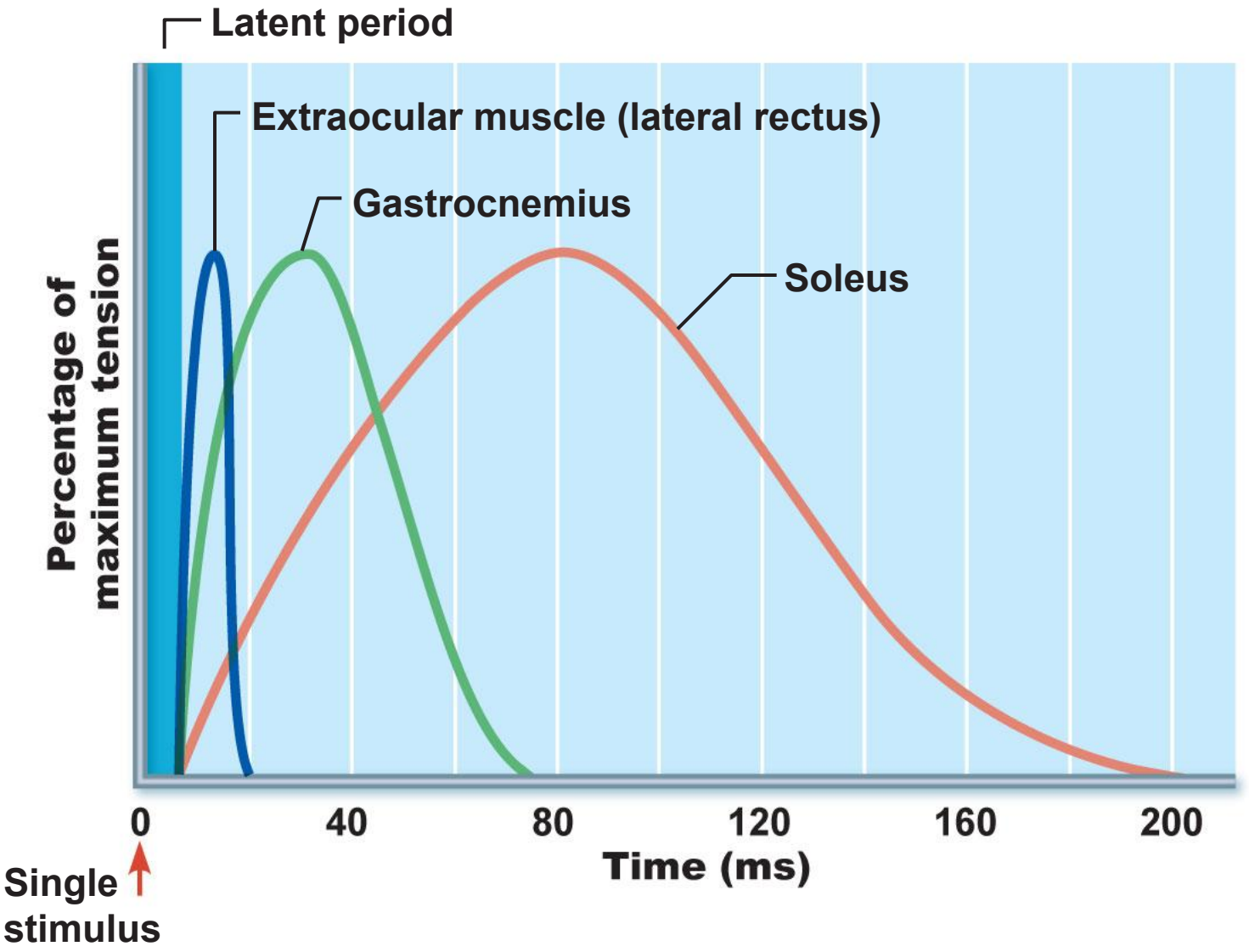
4. Force and duration of contraction vary in response to stimuli of different frequencies and intensities

Muscle Twitch

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

Muscle Twitch Comparisons

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



(b) Comparison of the relative duration of twitch responses of three muscles

Figure 9.14b

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

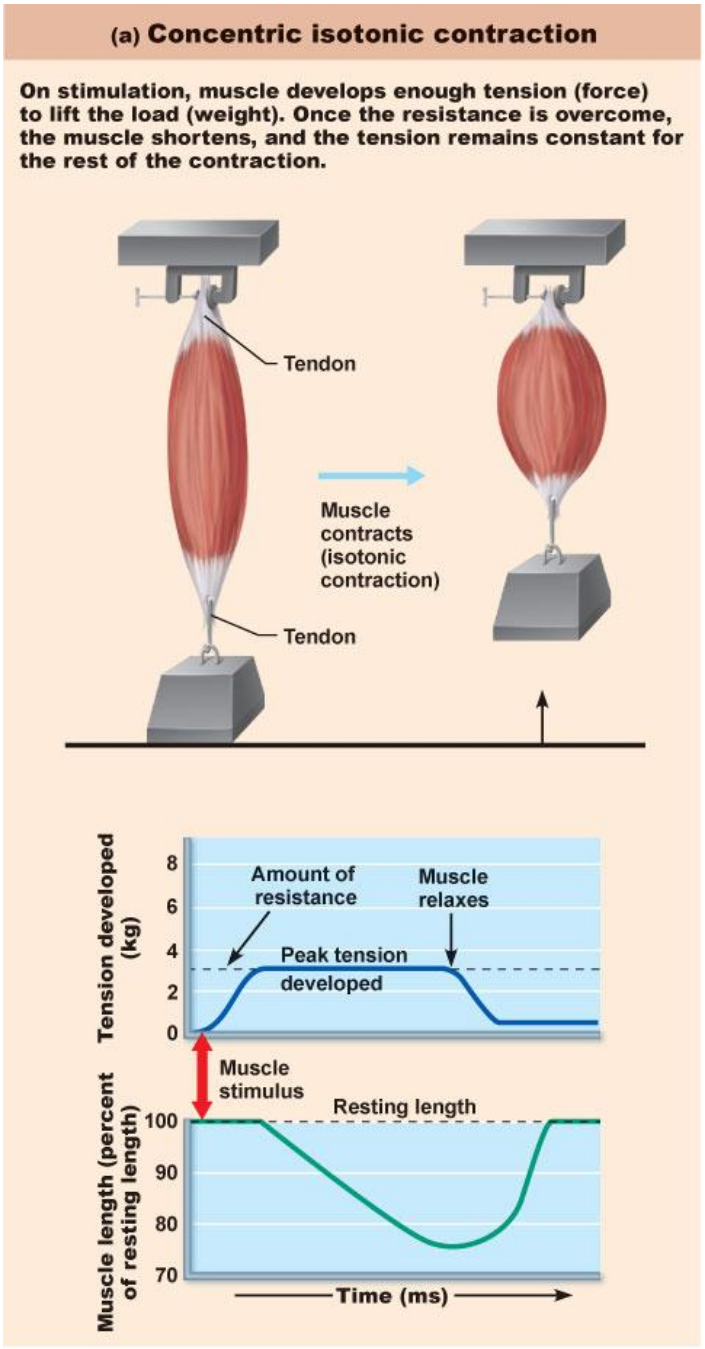


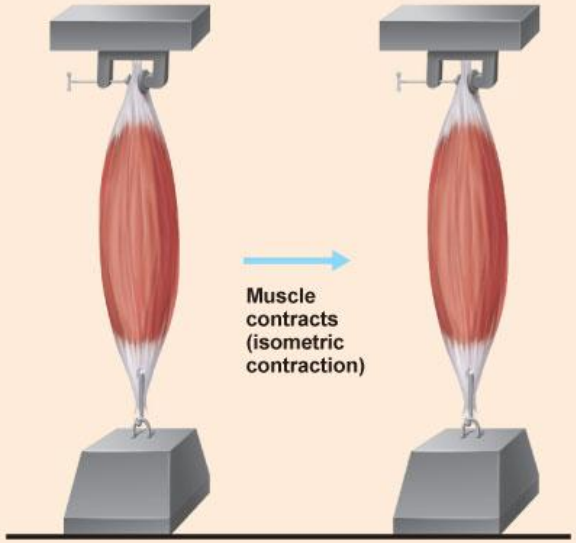
Figure 9.18a

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

(b) Isometric contraction

Muscle is attached to a weight that exceeds the muscle's peak tension-developing capabilities. When stimulated, the tension increases to the muscle's peak tension-developing capability, but the muscle does not shorten.



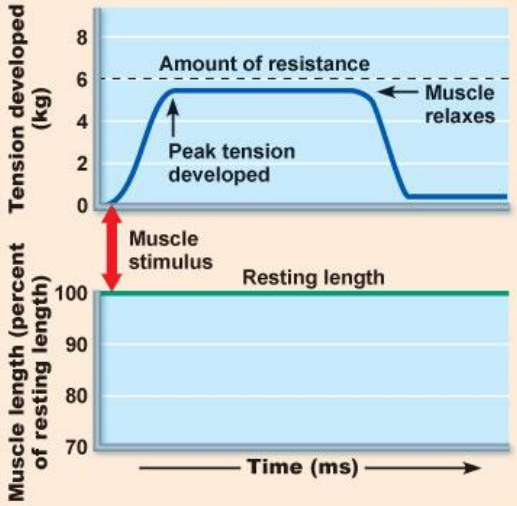


Figure 9.18b

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

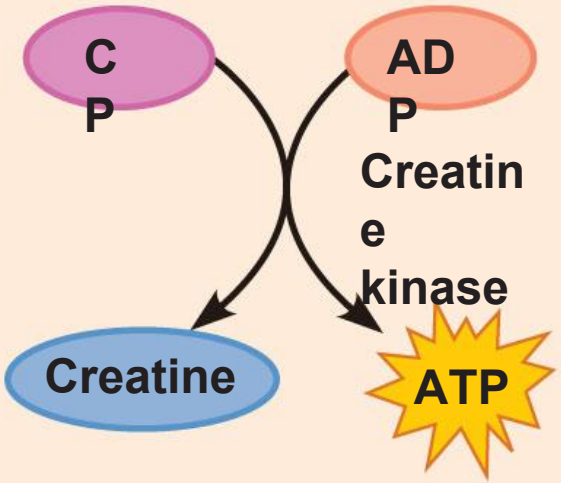
Muscle Metabolism: Energy for Contraction

- ATP is regenerated by:
  - Direct phosphorylation of ADP by creatine phosphate (CP)
  - Anaerobic pathway (glycolysis)
  - Aerobic respiration (fermentation)

(a) Direct phosphorylation

Coupled reaction of creatine phosphate (CP) and ADP

Energy source:
CP



Oxygen use: None

Products: 1 ATP per CP, Creatine

Duration of energy provision:
15 seconds

Figure 9.19a

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

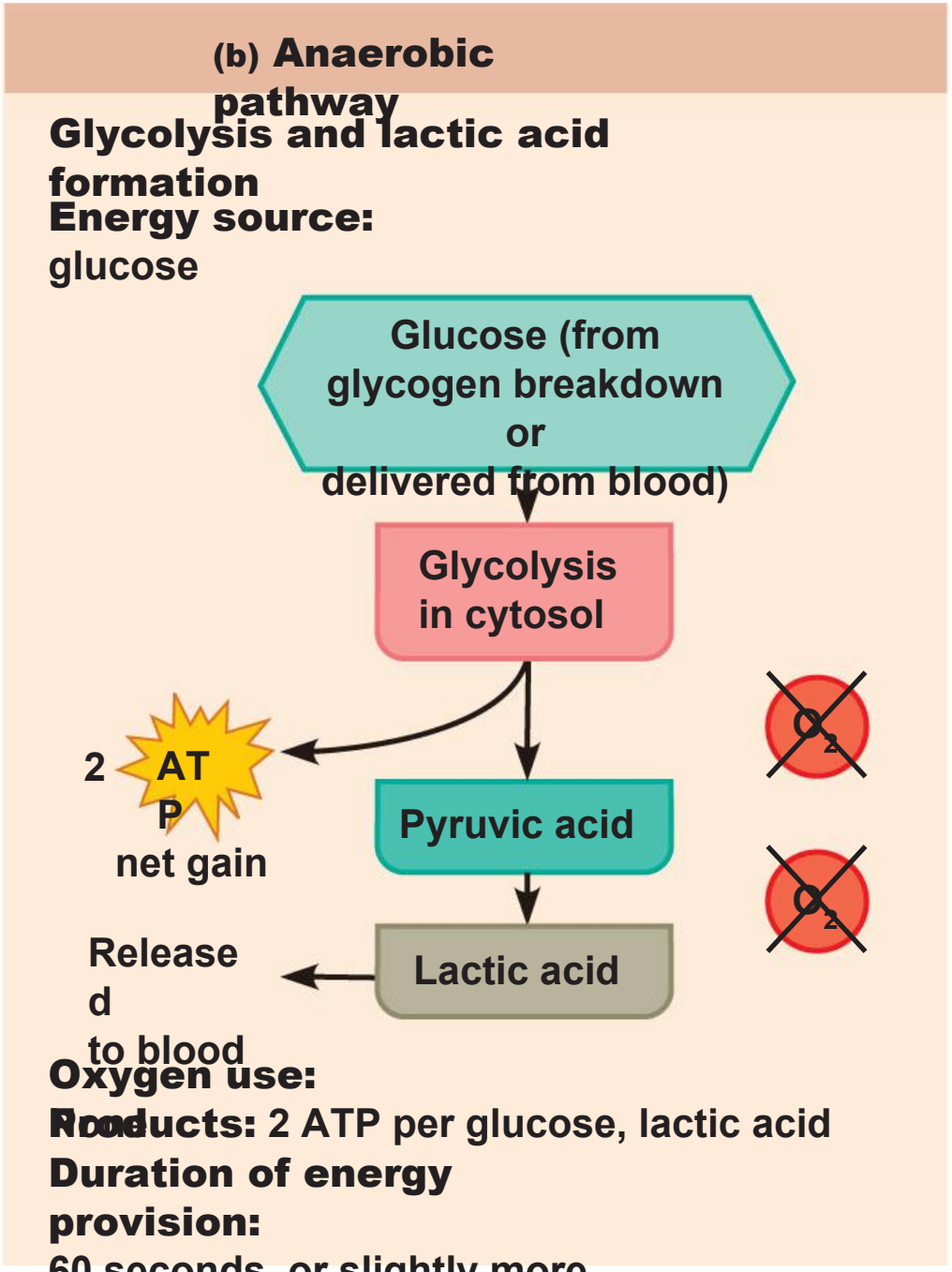


Figure 9.19b

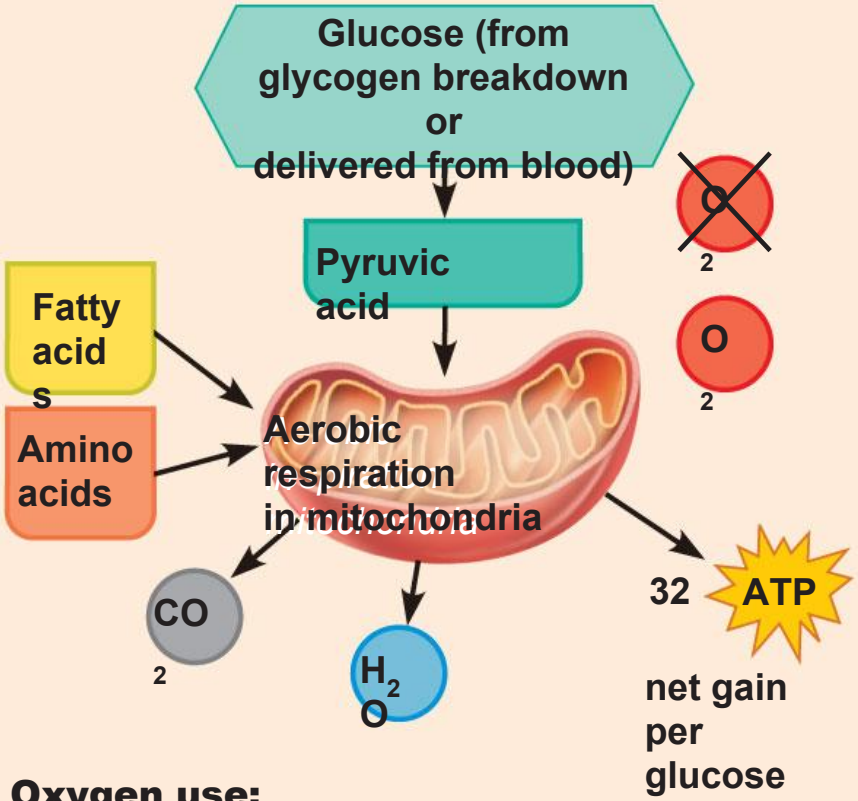
Aerobic Pathway

- 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

(c) Aerobic pathway

Aerobic cellular respiration

Energy source: glucose; pyruvic acid;
free fatty acids from adipose tissue;
amino acids from protein catabolism



Oxygen use: Required

Products: 32 ATP per glucose, CO_2, H_2O

Duration of energy provision: Hours

Figure 9.19c

Short-duration exercise

6 seconds | 10 seconds | 30–40 seconds | End of exercise

ATP stored in muscles is used first.

ATP is formed from creatine Phosphate and ADP.

Glycogen stored in muscles is broken down to glucose, which is oxidized to generate ATP.

Prolonged-duration exercise

Hours

ATP is generated by breakdown of several nutrient energy fuels by aerobic pathway. This pathway uses oxygen released from myoglobin or delivered in the blood by hemoglobin. When it ends, the oxygen deficit is paid back.

Figure 9.20

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

FYI for Muscle Fatigue Lab…

Muscle fatigue = physiological inability to contract

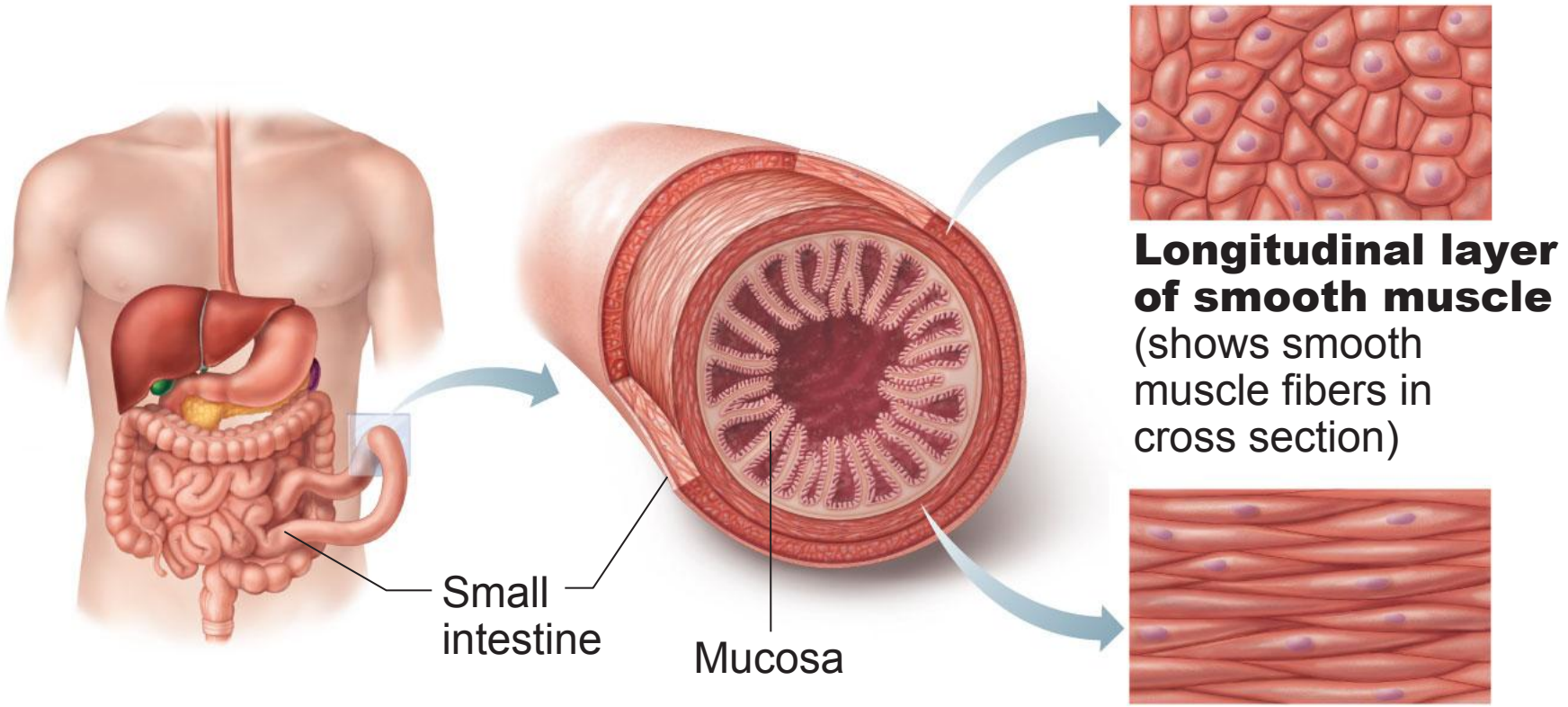
Oxygen deficit = extra oxygen needed after exercise for certain bodily functions

→ When you're done with the lab - **Project work time**! (these are due **next week!!**)

Warm Up!

Smooth Muscle

- Found in walls of most hollow organs (except heart)
- Usually in two layers (longitudinal and circular)



(a)

(b) Cross section of the intestine showing the smooth muscle layers (one circular and the other longitudinal) running at right angles to each other.

Figure 9.26

Peristalsis

- Alternating contractions and relaxations of smooth muscle layers that mix and squeeze substances through the lumen of hollow organs
  - Longitudinal layer contracts; organ dilates and shortens
  - Circular layer contracts; organ constricts and elongates

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

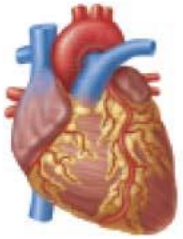
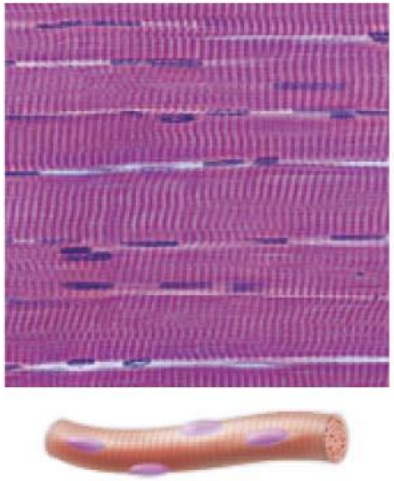
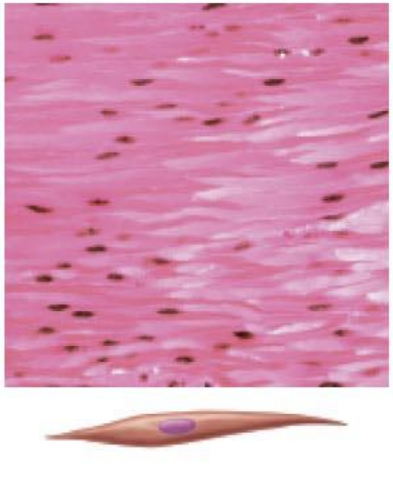
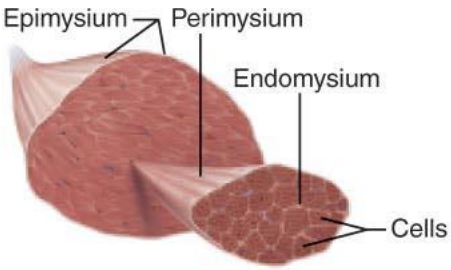
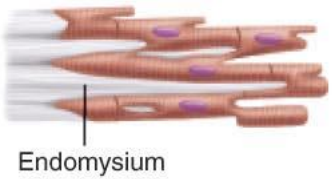
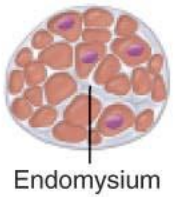
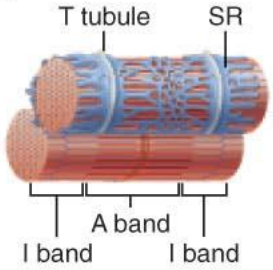
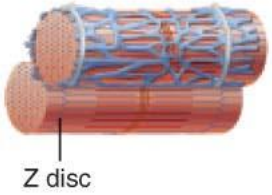
CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Body location	Attached to bones or (some facial muscles) to skin 	Walls of the heart 	Single-unit muscle in walls of hollow visceral organs (other than the heart); multiunit muscle in intrinsic eye muscles, airways, large arteries 
Cell shape and appearance	Single, very long, cylindrical, multinucleate cells with obvious striations 	Branching chains of cells; uni- or binucleate; striations 	Single, fusiform, uninucleate; no striations 

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Connective tissue components	Epimysium, perimysium, and endomysium 	Endomysium attached to fibrous skeleton of heart 	Endomysium 
Presence of myofibrils composed of sarcomeres	Yes	Yes, but myofibrils are of irregular thickness	No, but actin and myosin filaments are present throughout; dense bodies anchor actin filaments
Presence of T tubules and site of invagination	Yes; two in each sarcomere at A-I junctions 	Yes; one in each sarcomere at Z disc; larger diameter than those of skeletal muscle 	No; only caveolae

Contraction of Smooth Muscle

- Slow, synchronized contractions
- Cells are electrically coupled by gap junctions
- Some cells are self-excitatory (depolarize without external stimuli); act as pacemakers for sheets of muscle
- Rate and intensity of contraction may be modified by neural and chemical stimuli

Contraction of Smooth Muscle

- Sliding filament mechanism
- Final trigger is ↑ intracellular Ca^{2+}
- Ca^{2+} is obtained from the SR and extracellular space

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

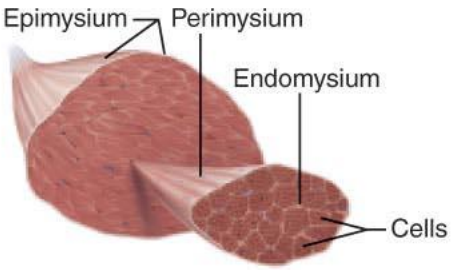
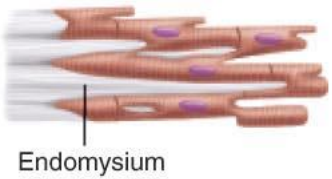
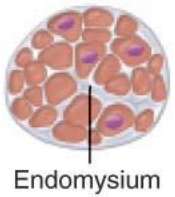
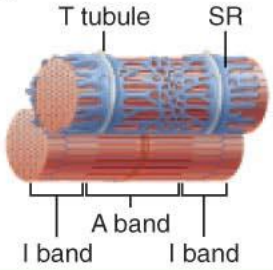
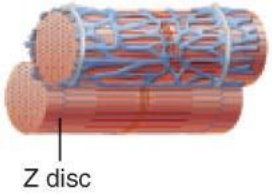
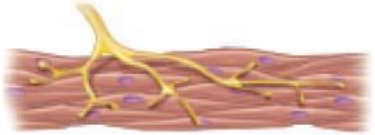
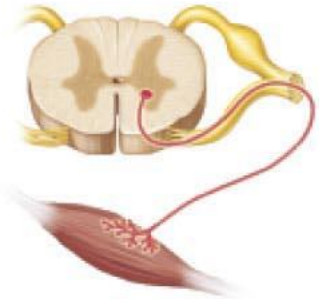
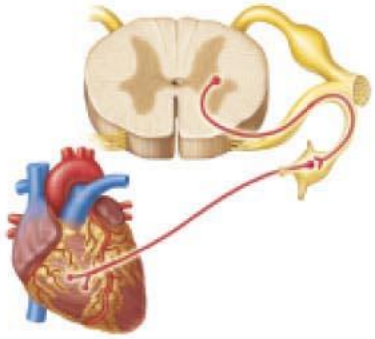
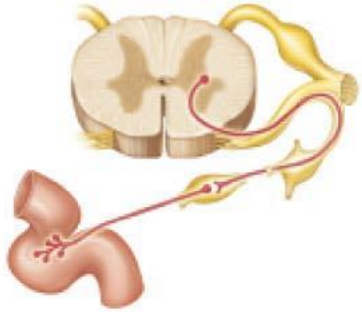
CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Connective tissue components	Epimysium, perimysium, and endomysium 	Endomysium attached to fibrous skeleton of heart 	Endomysium 
Presence of myofibrils composed of sarcomeres	Yes	Yes, but myofibrils are of irregular thickness	No, but actin and myosin filaments are present throughout; dense bodies anchor actin filaments
Presence of T tubules and site of invagination	Yes; two in each sarcomere at A-I junctions 	Yes; one in each sarcomere at Z disc; larger diameter than those of skeletal muscle 	No; only caveolae

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle *(continued)*

CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Elaborate sarcoplasmic reticulum	Yes	Less than skeletal muscle (1–8% of cell volume); scant terminal cisternae	Equivalent to cardiac muscle (1–8% of cell volume); some SR contacts the sarcolemma
Presence of gap junctions	No	Yes; at intercalated discs	Yes; in single-unit muscle
Cells exhibit individual neuromuscular junctions	Yes 	No	Not in single-unit muscle; yes in multiunit muscle 
Regulation of contraction	Voluntary via axon terminals of the somatic nervous system 	Involuntary; intrinsic system regulation; also autonomic nervous system controls; hormones; stretch 	Involuntary; autonomic nerves, hormones, local chemicals; stretch 

Developmental Aspects

- All muscle tissues develop from embryonic myoblasts
- Multinucleated skeletal muscle cells form by fusion
- Growth factor agrin stimulates clustering of ACh receptors at neuromuscular junctions
- Cardiac and smooth muscle myoblasts develop gap junctions

Developmental Aspects

- Cardiac and skeletal muscle become amitotic, but can lengthen and thicken
- Myoblast-like skeletal muscle satellite cells have limited regenerative ability
- Injured heart muscle is mostly replaced by connective tissue
- Smooth muscle regenerates throughout life

Developmental Aspects

- Muscular development reflects neuromuscular coordination
- Development occurs head to toe, and proximal to distal
- Peak natural neural control occurs by midadolescence
- Athletics and training can improve neuromuscular control

Developmental Aspects

- Female skeletal muscle makes up 36% of body mass
- Male skeletal muscle makes up 42% of body mass, primarily due to testosterone
- Body strength per unit muscle mass is the same in both sexes

Muscular Dystrophy

- Group of inherited muscle-destroying diseases
- Muscles enlarge due to fat and connective tissue deposits
- Muscle fibers atrophy

Developmental Aspects

- With age, connective tissue increases and muscle fibers decrease
- By age 30, loss of muscle mass (sarcopenia) begins
- Regular exercise reverses sarcopenia
- Atherosclerosis may block distal arteries, leading to intermittent claudication and severe pain in leg muscles