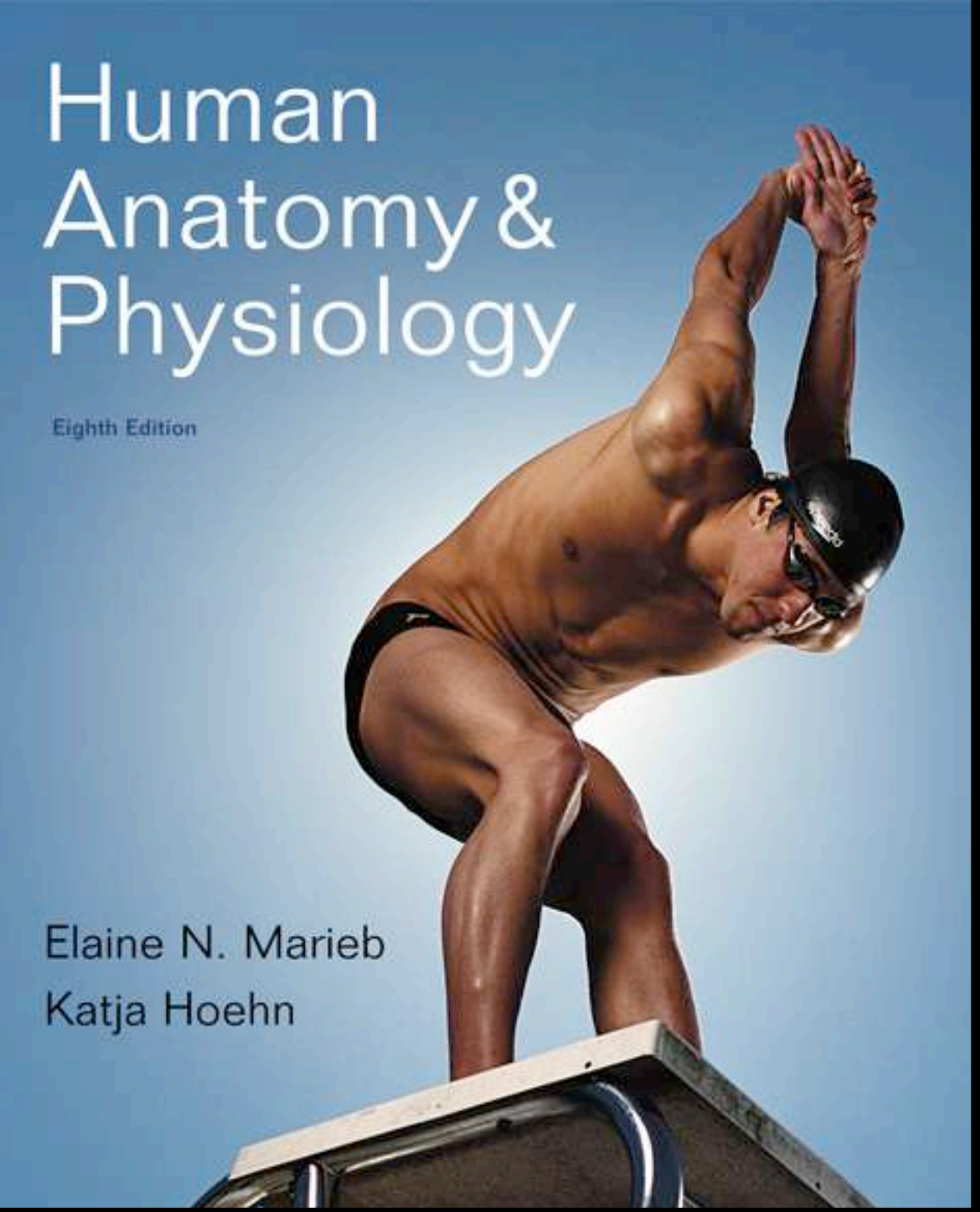

PowerPoint® Lecture Slides
prepared by
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CHAPTER 9

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

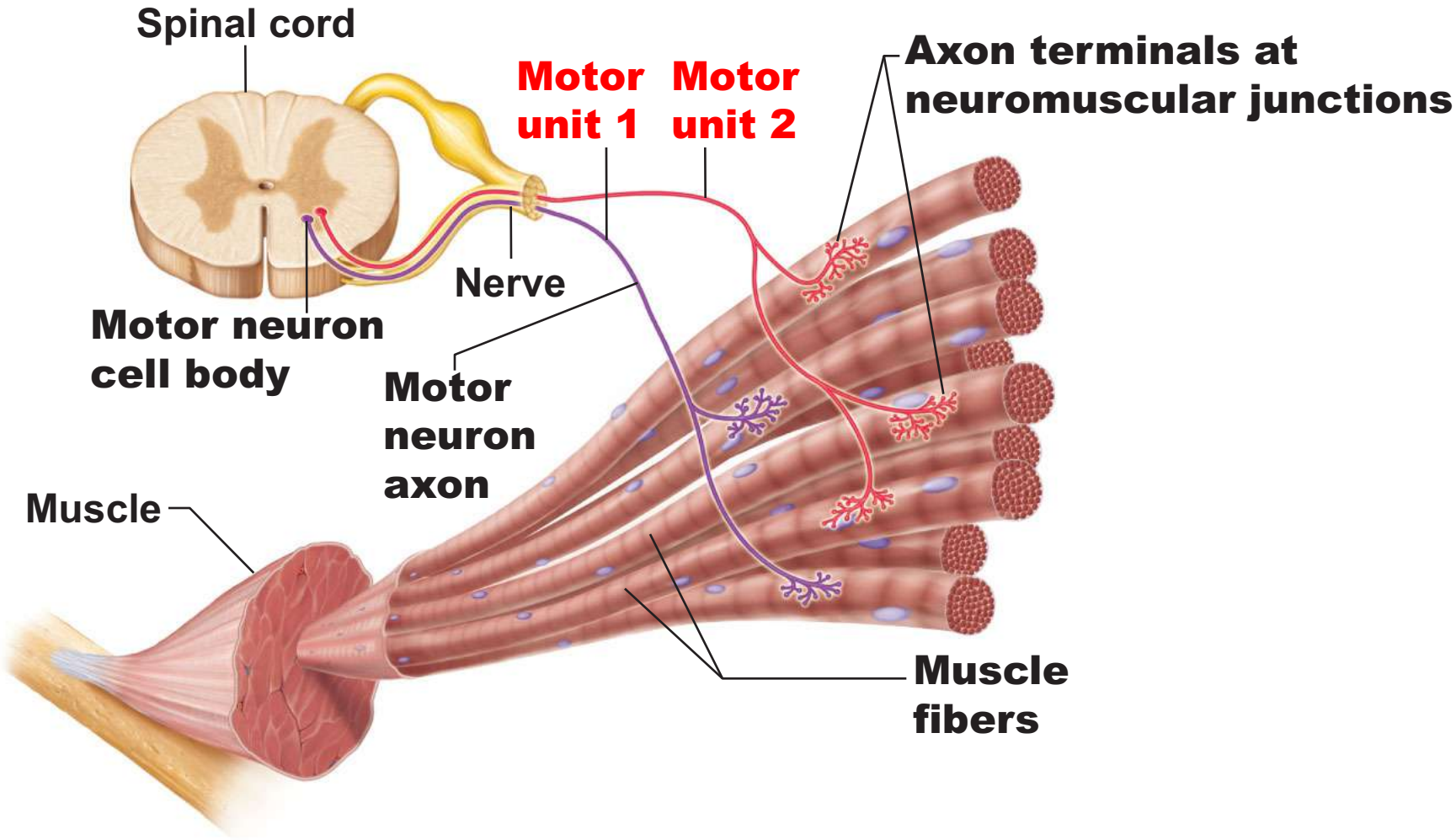
3. Contraction does not **always shorten a muscle:**
   - Isometric contraction: no shortening; muscle tension increases but does not exceed the load
   - Isotonic contraction: muscle shortens because muscle tension exceeds the load
   - Isokinetic exercise

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



Axons of motor neurons extend from the spinal cord to the muscle. There each axon divides into a number of axon terminals that form neuromuscular junctions with muscle fibers scattered throughout the muscle.

Figure 9.13a

Motor Unit

- Small motor units in muscles that control fine movements. Few small muscle fibers activated by a neuron (fingers, eyes)
- Large motor units in large weight-bearing muscles. Many large muscle fibers activated by a neuron (thighs, hips)

Motor Unit

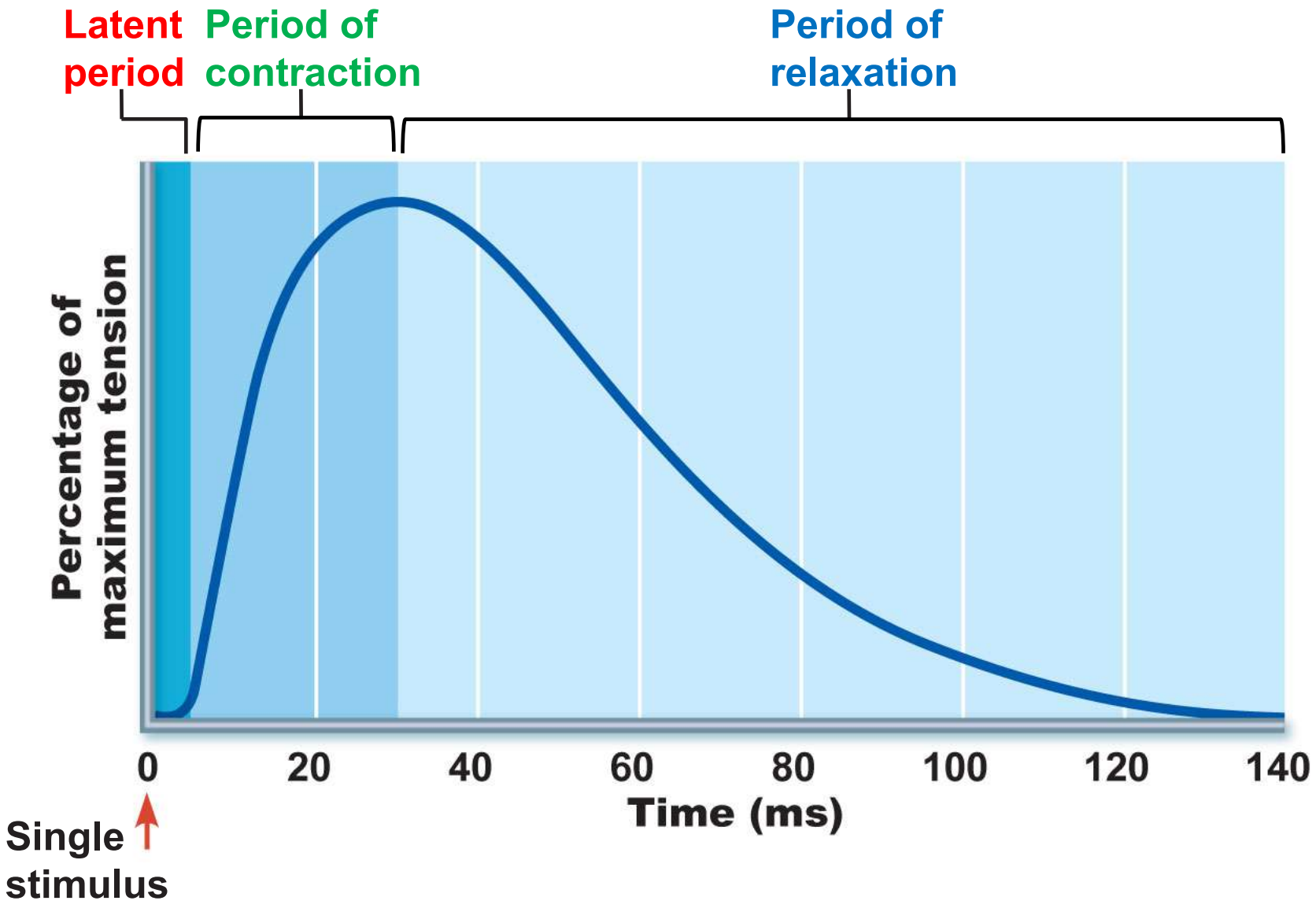
- Muscle fibers from a motor unit are spread throughout the muscle so that a single motor unit causes weak contraction of entire muscle
- Motor units in a muscle usually contract asynchronously; helps prevent fatigue

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

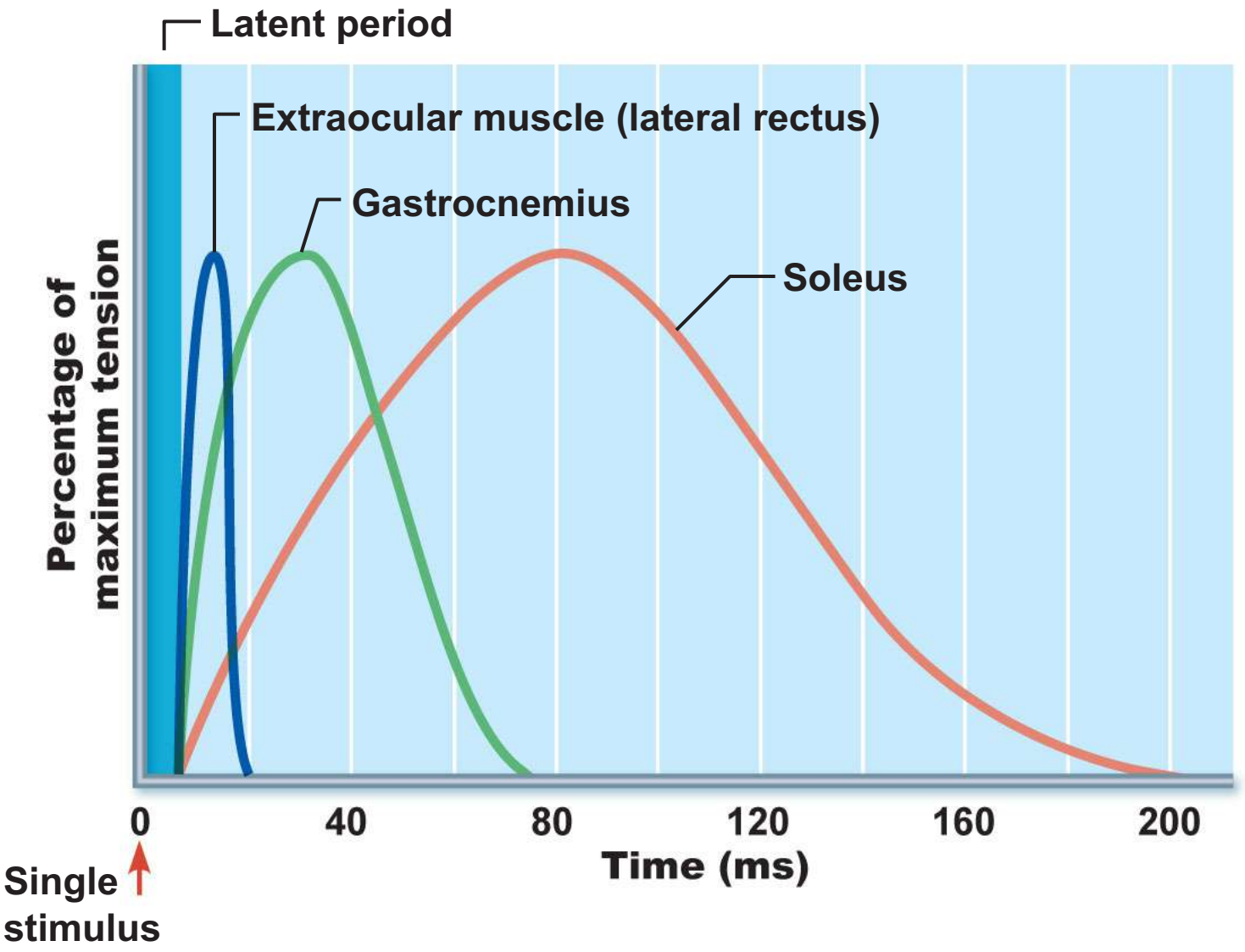


(a) Myogram showing the three phases of an isometric twitch

Figure 9.14a

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

Graded Muscle Responses

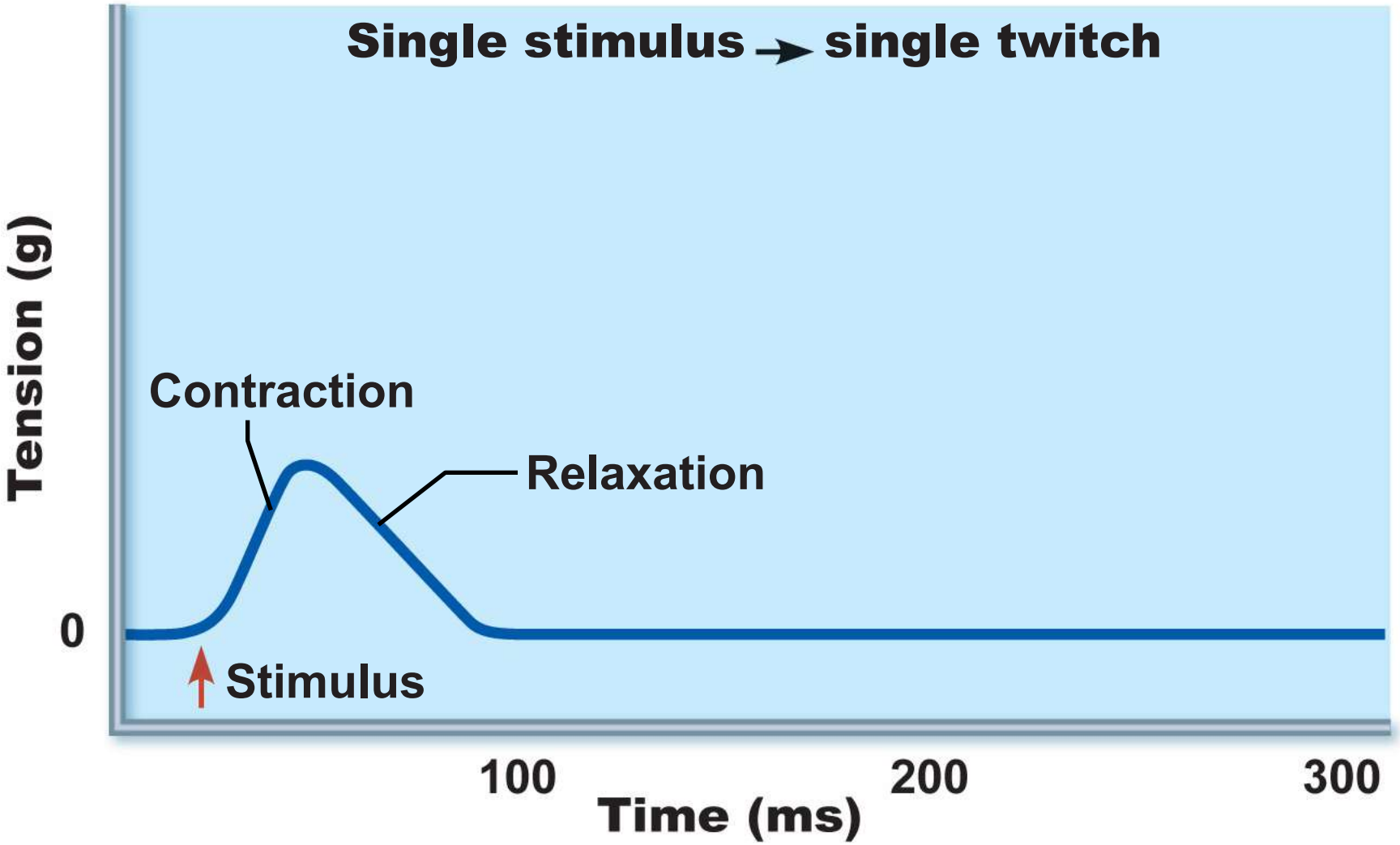
- Variations in the degree of muscle contraction
- Required for proper control of skeletal movement

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

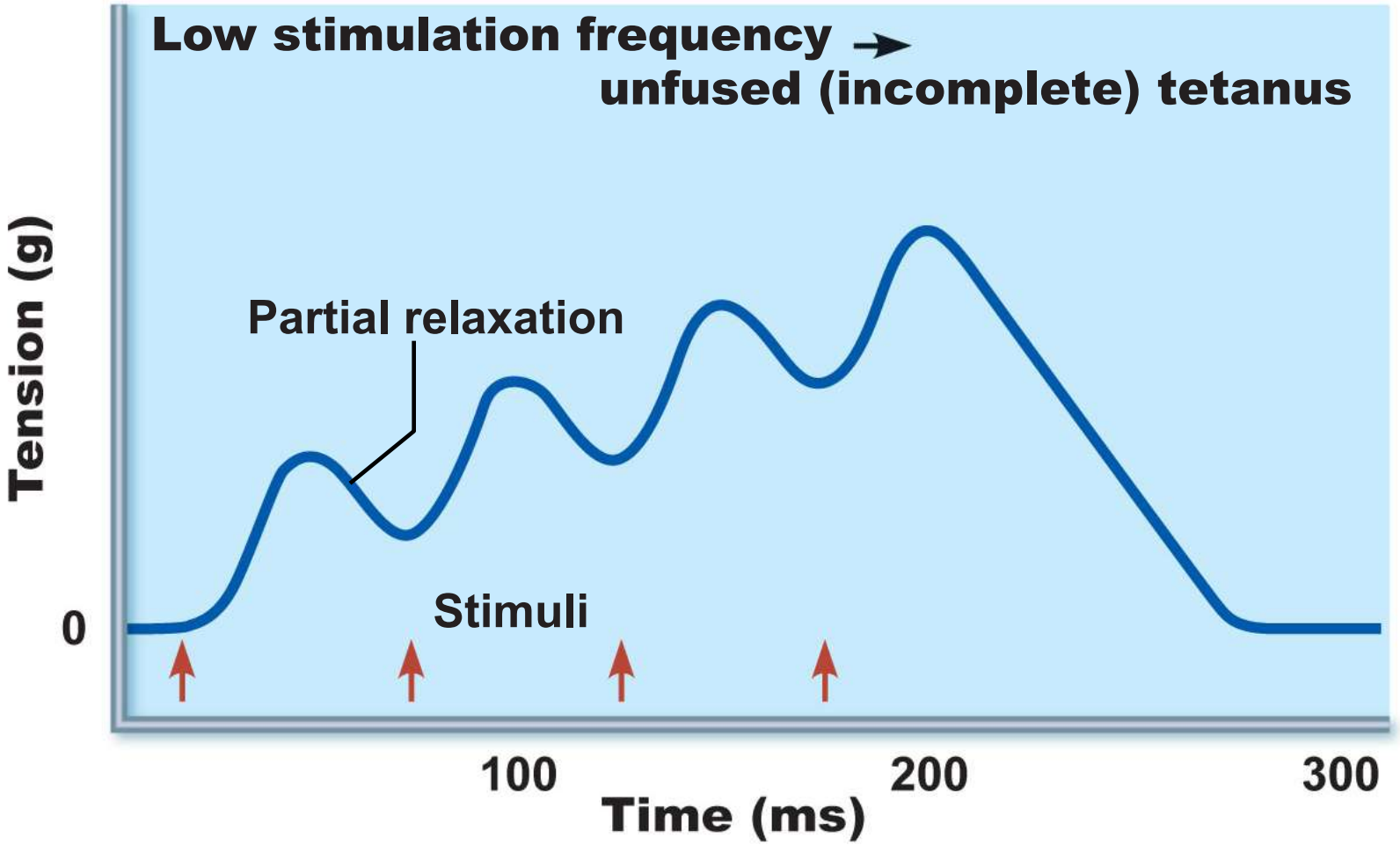


A single stimulus is delivered. The muscle contracts and relaxes

Figure 9.15a

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 → temporal (wave) summation
- Further increase in stimulus frequency → unfused (incomplete) tetanus

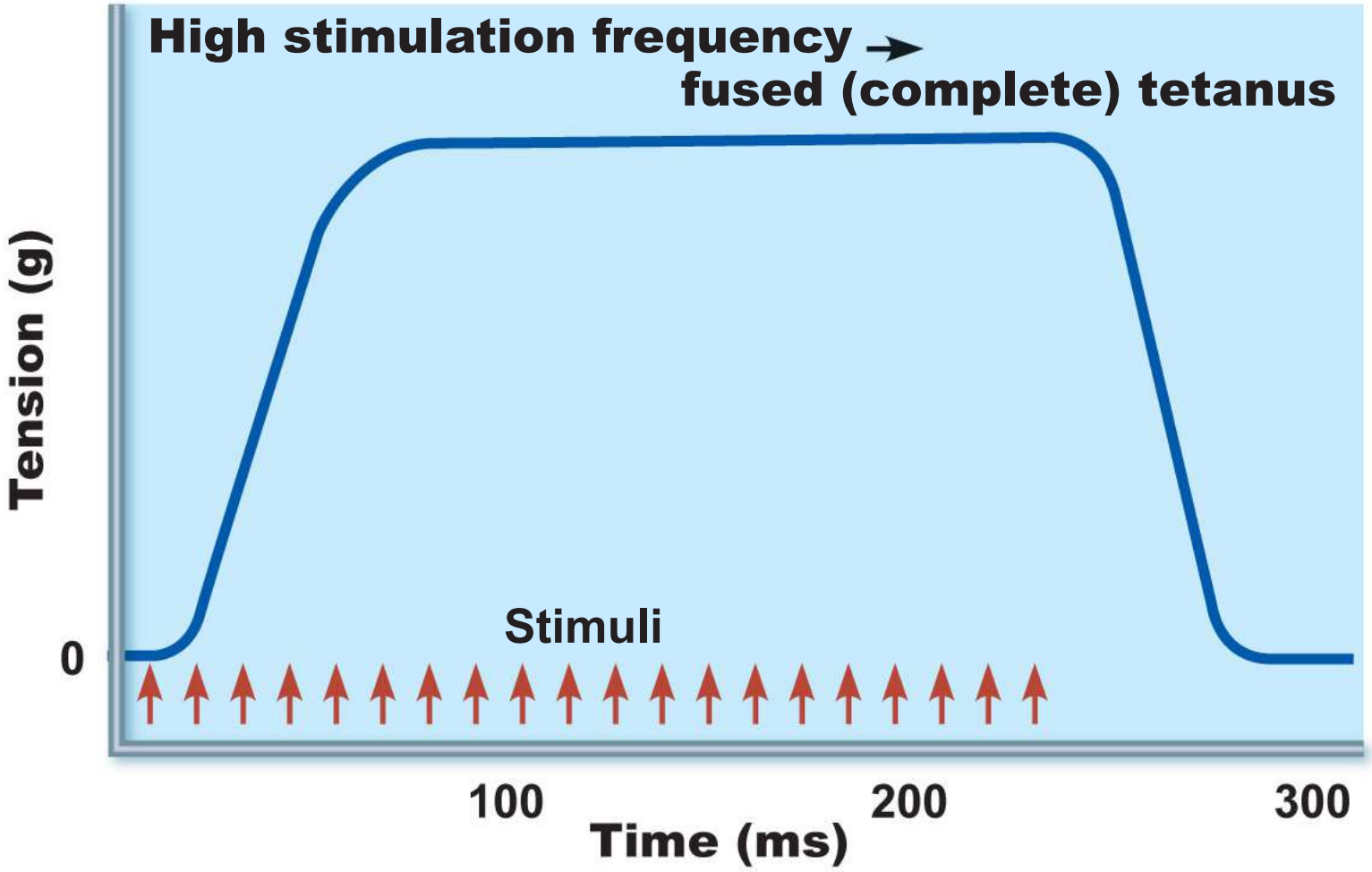


(b) If another stimulus is applied before the muscle relaxes completely, then more tension results. This is temporal (or wave) summation and results in unfused (or incomplete) tetanus.

Figure 9.15b

Response to Change in Stimulus Frequency

- If stimuli are given quickly enough, fused (complete) tetany results



(c) At higher stimulus frequencies, there is no relaxation at all between stimuli. This is fused (complete) tetanus.

Figure 9.15c

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

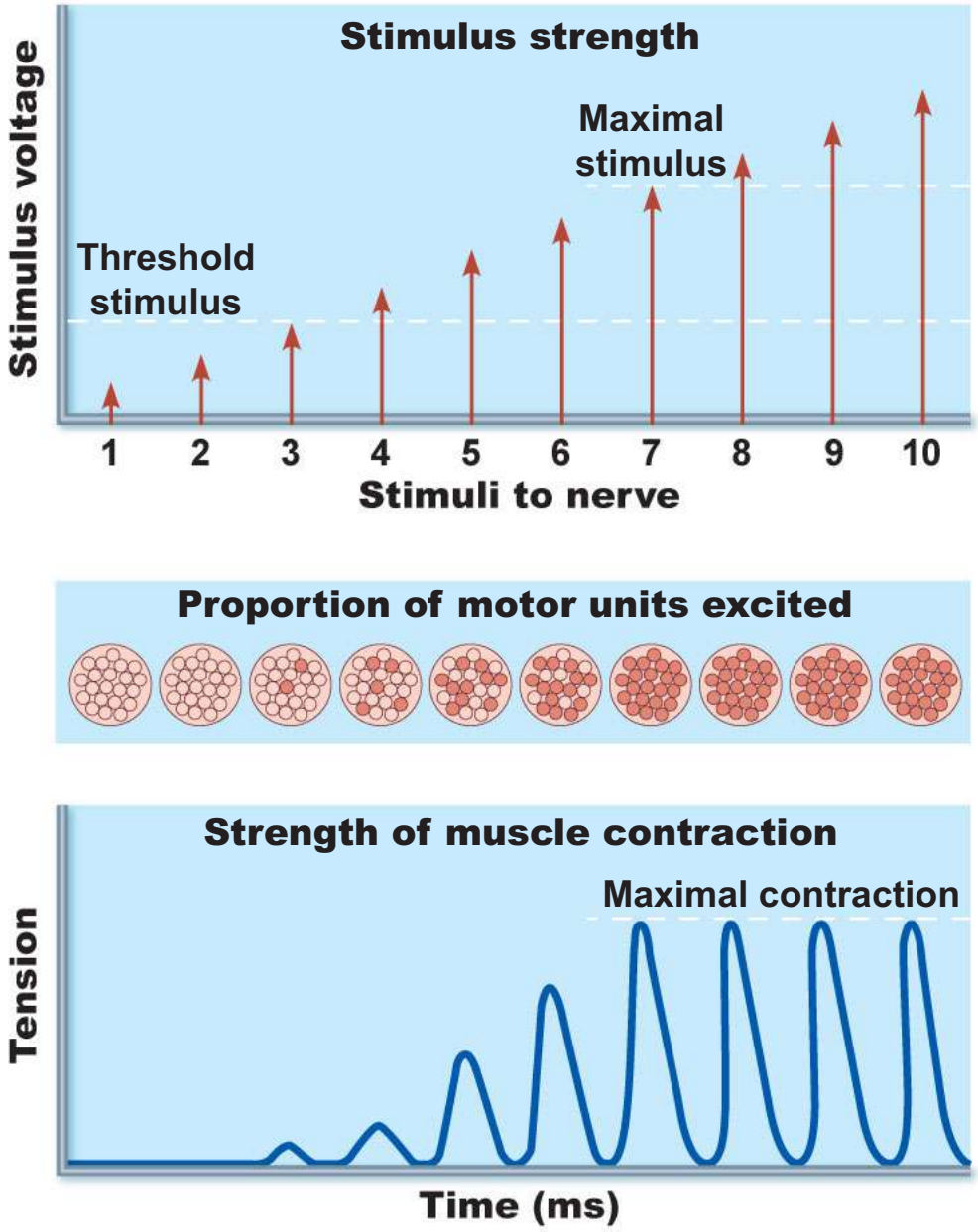


Figure 9.16

Response to Change in Stimulus Strength

- Size principle: motor units with larger and larger fibers are recruited as stimulus intensity increases

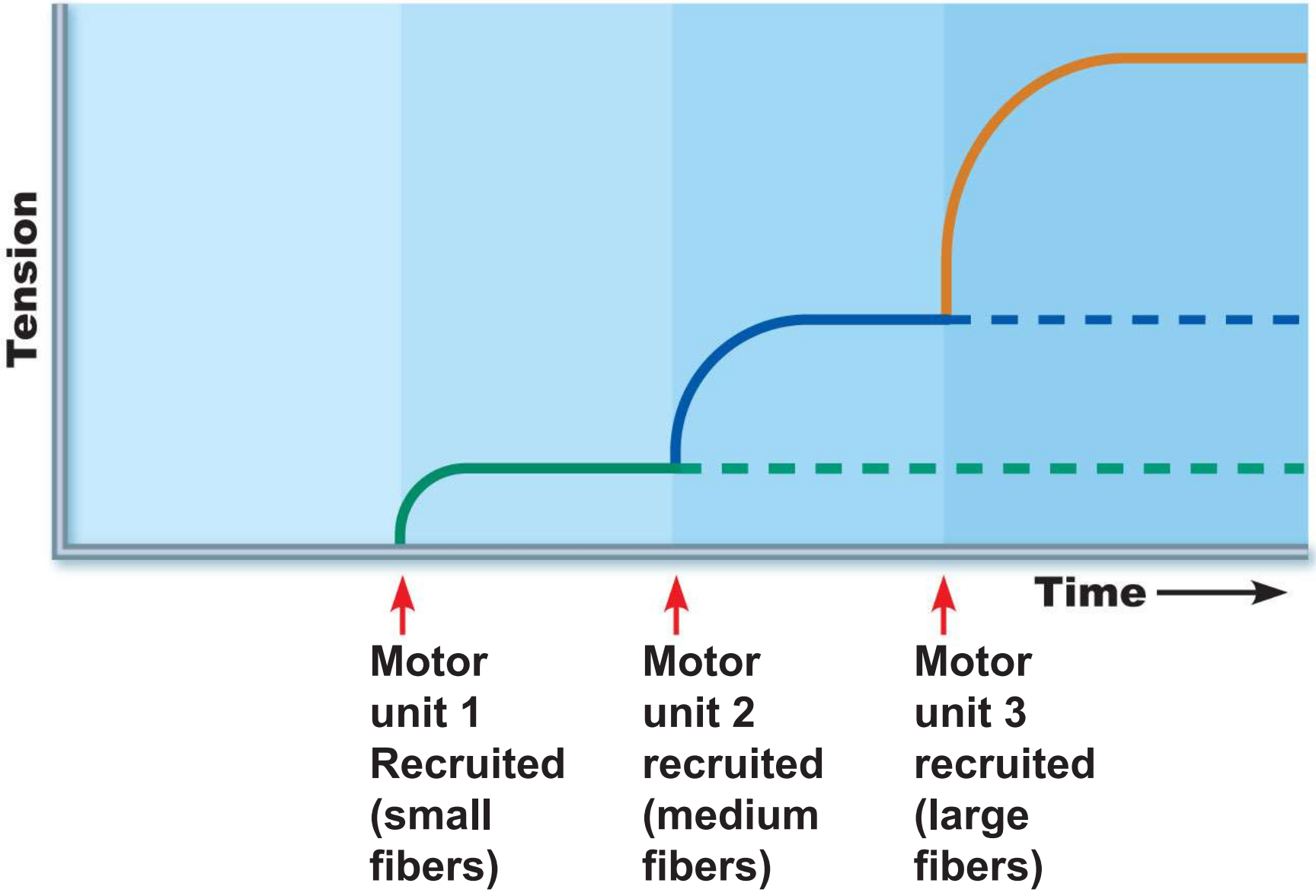


Figure 9.17

Muscle Tone

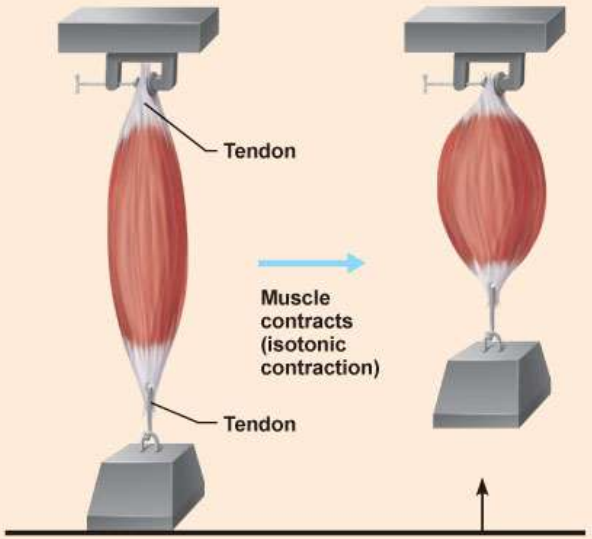
- Constant, slightly contracted state of all muscles
- Due to spinal reflexes that activate groups of motor units alternately in response to input from stretch receptors in muscles
- Keeps muscles firm, healthy, and ready to respond

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

(a) Concentric isotonic contraction

On stimulation, muscle develops enough tension (force) to lift the load (weight). Once the resistance is overcome, the muscle shortens, and the tension remains constant for the rest of the contraction.



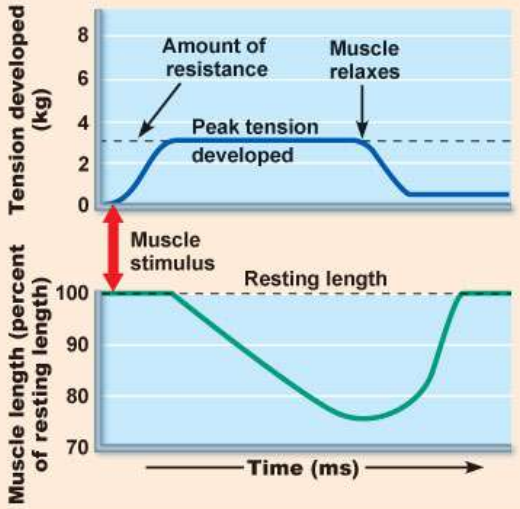


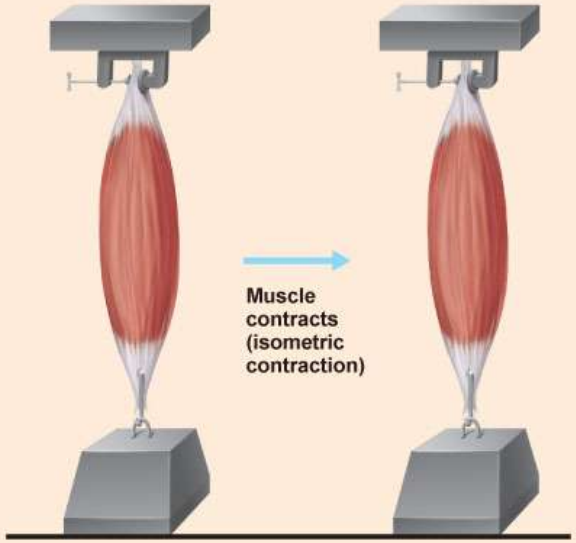
Figure 9.18a

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.



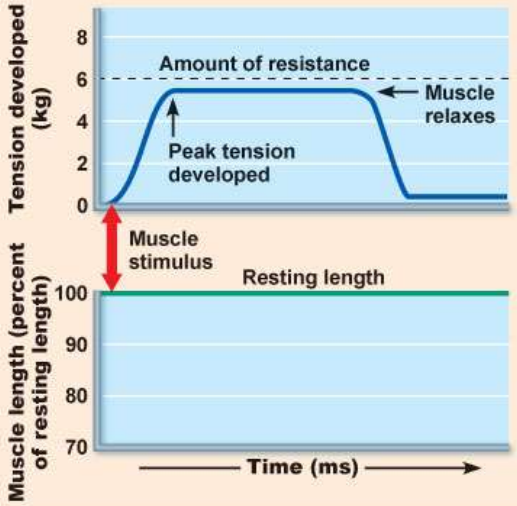


Figure 9.18b

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

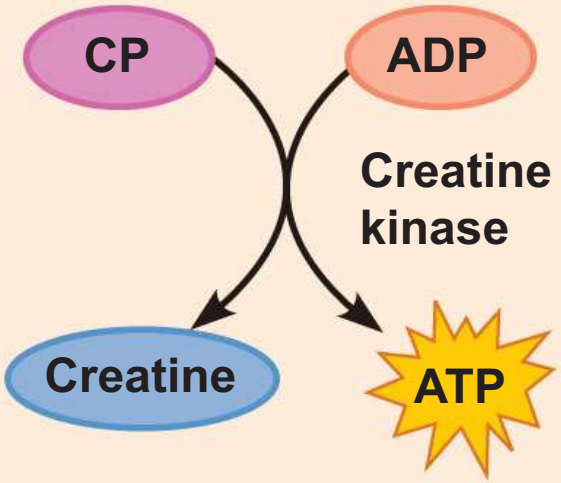
Muscle Metabolism: Energy for Contraction

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

(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

- At 70% of maximum contractile activity:
  - Bulging muscles compress blood vessels
  - Oxygen delivery is impaired
  - Pyruvic acid is converted into lactic acid (fermentation)

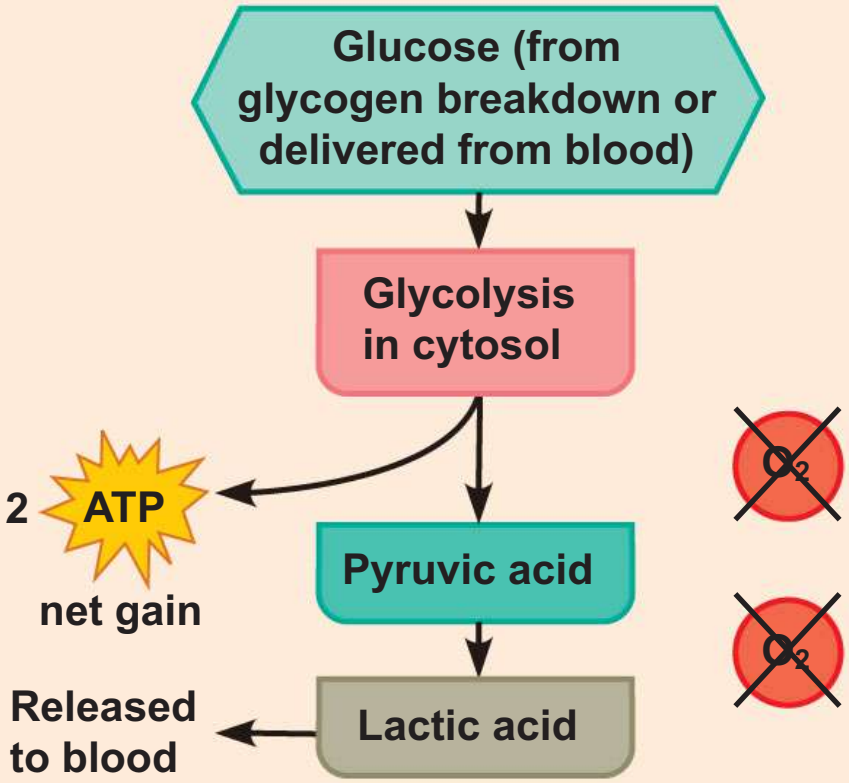
Anaerobic Pathway

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

(b) Anaerobic pathway

Glycolysis and lactic acid formation

Energy source: glucose



Oxygen use: None
Products: 2 ATP per glucose, lactic acid
Duration of energy provision:
60 seconds, or slightly more

Figure 9.19b

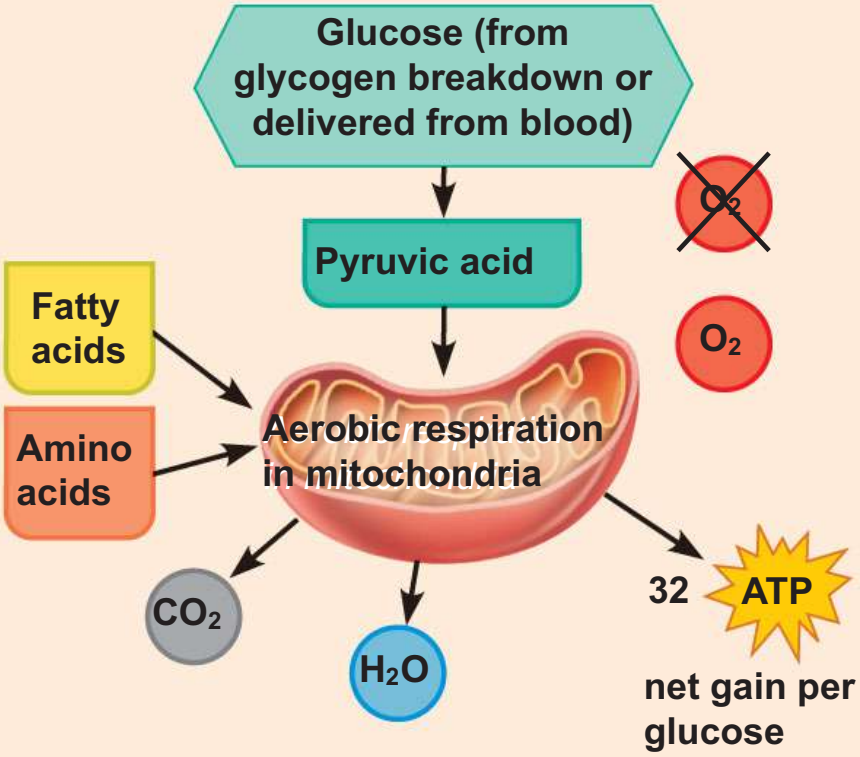
Aerobic Pathway

- 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
- Complete metabolic pathways

(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