CHAPTER 50: LOCOMOTION

CHAPTER SYNOPSIS

Animals possess three types of skeletons. Hydrostatic skeletons, found in soft-bodied invertebrates, are fluid-filled cavities surrounded by muscle fibers. Exoskeletons are hard, chitinous cases that surround the bodies of arthropods. Vertebrates and echinoderms possess endoskeletons in which muscles are attached to a rigid internal skeleton. The human body is composed of 206 bones divided into the appendicular skeleton (limbs, pectoral, and pelvic girdles) and the axial skeleton (skull, backbone, and ribcage). Bones are composed of cartilage fibers coated with calcium salts. New bone is formed by osteoblast cells in concentric layers around nerve and blood vessel-containing Haversian canals. Bones connect to one another at immovable, slightly movable, or freely movable joints and are connected to muscles via cartilaginous tendons. Skeletal muscles provide movement in vertebrate organisms. Synergistic muscles work together to cause movement while antagonistic muscles oppose each other, moving a bone in opposite directions.

Vertebrate skeletal muscle cells contain a great number of muscle fibers that are the key to their ability to contract. The cytoplasm of this fiber is called sarcoplasm; the central myofibrils are constructed of repeating sarcomere units. An individual sarcomere consists of Z lines to which actin filaments are attached. The actin filaments do not reach completely from one Z line to the next, the gap is bridged by myosin filaments. Both ends of a myosin filament move simultaneously, pull the Z lines together, and contract the sarcomere. Synchronous contraction of all sarcomeres within a myofibril shortens the entire myofibril. Uniform contraction of all of the myofibrils results in compression of the entire muscle. On a molecular level, muscle contraction occurs when the myosin heads form cross-bridges with the actin fibers, each requiring the expenditure of one ATP molecule.

Calcium plays an integral role in the control of muscle contraction. The myosin heads are normally bound by tropomyosin held in place by troponin molecules. Calcium alters the shape of the troponin molecules, which repositions the tropomyosin away from the myosin. Only then can the myosin heads bind to the actin filaments, resulting in muscle shortening. Vertebrate skeletal muscle contraction is initiated by impulses from nerves. A neuromuscular junction occurs where a nerve innervates a muscle fiber. Stimulation of the motor neuron causes the release of acetylcholine which causes the muscle fiber to initiate its own electrical impulses. Those carry to the T tubules and the sarcoplasmic reticulum, which results in the release of calcium and shortening of the muscle fibers. When the stimulus stops, the calcium is taken back up by the sarcoplasmic reticulum and the fibers relax. This entire process is called excitation-contraction coupling. Whole units of muscle tissue contract smoothly because of the recruitment of muscle fibers within a motor unit

A twitch is a single brief contraction of a muscle A second shock immediately after the first causes summation as the contraction adds to that of the first. Tetanus results when there is no visible relaxation between twitches and there is a smooth, sustained muscle contraction. Skeletal muscle is composed of two distinctly different types of fibers. Type I fibers, also called slow-twitch fibers, require a substantial length of time (in milliseconds) to reach maximum tension. As expected, type II or fast-twitch fibers, reach maximum tension in just a few milliseconds. Slow-twitch fibers have substantial resistance to fatigue and have a high capacity for aerobic respiration. They have a rich capillary supply, numerous mitochondria, and a high concentration of myoglobin to improve delivery of oxygen. Fast-twitch fibers have fewer capillaries and mitochondria and are better adapted to respire anaerobically due to high concentrations of glycolytic enzymes.

Cardiac muscle is composed of chains of single cells with individual nuclei. Each is electrically coupled to its neighbors by gap junctions forming a single myocardial unit. Contraction is initiated in the pacemaker and spreads throughout the myocardium via the gap junctions. The cells in each chamber of the heart contract in synchrony. Smooth muscle cells are long, spindle-shaped cells with individual nuclei. They surround many internal organs and all blood vessels except capillaries. Smooth muscle actin and myosin proteins are not organized into sarcomere units and lack sarcoplasmic reticulum, calcium is stored in the extracellular fluid. Some smooth muscle cells contract with nervous stimulation, others contract spontaneously.

Animals are mobile organisms that have evolved the ability to move in water, on land, and in the air. Many aquatic animals move through the water through undulations of their bodies against the water. Other animals use the same locomotor actions to swim as they would to walk on land. Terrestrial animals exhibit particular walking gaits depending on the number of legs that they possess. In general, tetrapods are capable of speedier movement on land than arthropods. Only four groups of animals have evolved flight. In all of them, propulsion is achieved as the wings press downward against the air.

CHAPTER OBJECTIVES

ä Characterize the three different kinds of animal skeletons.

ä Identify the primary components of the axial and appendicular skeletons.

ä Understand the basic structure of bone tissue and how it is formed.

ä Know the three types of joints and give an example of each.

ä Differentiate between synergistic and antagonistic sets of muscles.

ä Understand the microscopic anatomy of skeletal muscle and how it results in movement in the vertebrates.

ä Explain the molecular aspects of muscle contraction as it relates to myofilaments, actin, and myosin.

ä Understand the effects of calcium on muscle contraction.

ä Understand how the nervous and muscular systems interact to produce movement.

ä Understand how twitch, summation, and tetanus affect forceful muscle contractions.

ä Compare slow-twitch and fast-twitch muscle fibers.

ä Differentiate among skeletal, cardiac, and smooth muscle tissue with respect to form and function.

ä Compare locomotion of animals through water, over land, and in the air.

KEY TERMS

acetylcholine (ACh)
antagonist
cross-bridge
cross-bridge cycle
endoskeleton
excitation-contraction coupling
exoskeleton
fast-twitch (type II) fiber
freely movable joint
gap junction
hydrostatic skeleton
hypertrophy
immovable joint
insertion
isometric contraction
isotonic contraction
motor unit
muscle fatigue
muscle fiber
myofibril
myoglobin
myosin
origin
recruitment
sarcomere
sliding filament mechanism
slightly movable joint
slow-twitch (type I) fiber
summation
synergist
tetanus
thick myofilament
thin myofilament
transverse (T) tubule
tropomyosin
troponin
twitch

CHAPTER OUTLINE

50.0 Introduction

I. MOBILITY OF ANIMALS

A. Most Animals Move From Place to Place
  1. Plants and fungi move by growing
  2. Only animals explore environment via locomotion — fig 50.1

B. Animals Move by Use of Muscles and Bones

50.1 A skeletal system supports movement in animals

I. TYPES OF SKELETONS

A. How Animal Locomotion Is Accomplished
  1. Results from force of muscles acting on rigid skeleton
  2. Three types of animal skeletons
    a. Hydrostatic skeleton
    b. Exoskeleton
    c. Endoskeleton
  3. Hydrostatic skeletons
    a. Found in soft-bodied invertebrates
    b. Fluid-filled cavity surrounded by muscle fibers
    c. Pressure of fluid raised when muscles contract
    d. Example: Earthworms
      1) Wave of contraction of circular muscles compresses body
      2) Fluid pressure pushes body forward
      3) Longitudinal muscle contractions pull rest of body forward — fig 50.2
  4. Exoskeletons — fig 50.3a
    a. Surround body as a rigid, hard case
    b. Found in arthropods, made of chitin
    c. Limit size of animal due to weight of large, thick exoskeleton
  5. Endoskeletons
    a. Found in vertebrates and echinoderms
    b. Muscles attached to rigid internal skeleton
    c. Soft, flexible exterior stretches to accommodate movement of skeleton
    d. Vertebrate skeleton composed of cartilage or bone
      1) Bone is a living tissue capable of growth
      2) Can self-repair and remodel in response to stress

B. The Vertebrate Skeleton — fig 50.3b
  1. The axial skeleton
    a. Form axis of body
    b. Support and protect organs in head, neck, and chest
  2. The appendicular skeleton
    a. Include bones of limbs, pectoral, and pelvic girdles
    b. Attached to axial skeleton
  3. Functions of skeletal systems
    a. Support and protect body
    b. Serve as levers for forces of muscle contractions
    c. Blood cells form in bone marrow
    d. Matrix of bone serves as reservoir of calcium and phosphate ions

II. THE STRUCTURE OF BONE

A. Special Form of Connective Tissue
1. Organic extracellular matrix of collagen fibers
2. Impregnated with hydroxyapatite (calcium phosphate) crystals
3. Composition of crystals with collagen is unique
a. Hydroxyapatite is strong and rigid but brittle
b. Collagen is flexible but weak
c. Collagen spreads stress over many crystals
d. Makes bone more resistant to fractures

B. Formation of Bone
1. A bone is living, dynamic tissue
a. New bone formed by osteoblast cells
b. Secrete collagen fibers that are subsequently calcified
c. After calcification cells are called osteocytes, trapped within lacunae of bone
d. Osteoclasts dissolve bone, help remodel bone when physical stress
2. Microstructure of bone: A Haversian system
a. Lamellae: Concentric layers of bone surrounding Haversian canals
b. Parallel Haversian canals interconnect, carry blood vessels and nerve fibers
c. Blood flow allows osteocytes to remain alive when embedded in calcified matrix
3. Two types of bone formation
a. Flat bones like skull
1) Osteoblasts located in web of dense connective tissue
2) Produce bone within that tissue
b. Long bones
1) Cartilage skeleton initial template for bone formation
2) Bone formed as cartilage degenerates
3) Cartilage remains at articular surface and growth plates
4) Growth in height occurs at growth plates
5) Plates ultimately calcified, growth stops
4. Long bones composed of two elements fig 50.4
a. Ends and interiors are open lattice of spongy bone
1) Spaces contain marrow
2) Most blood cells formed in bone marrow
b. Surrounded by concentric layers of compact bone tissue
1) Bone is much denser
2) Gives bone strength to withstand mechanical stress

50.2 Skeletal muscles contract to produce movements at joints

I. TYPES OF JOINTS

A. Bones Interact at Joints or Articulations
1. Skeletal movements produced by contraction and shortening of muscles
2. Tendons attach skeletal muscles to bones

B. Three Kinds of Joints fig 50.5
1. Immovable joints fig 50.5a
a. Include sutures
b. Example: Cranial bones
c. Open areas of dense connective tissue in fetus as skull is not fully formed
1) Allows for passage of head through birth canal
2) Bone later replaces most connective tissue

2. Slightly movable joints fig 50.5b
   a. Bones bridged by cartilage
   b. Example: Vertebral bones in spine
      1) Pads of cartilage are intervertebral disks
      2) Cushion and allow flexibility
   c. Also called cartilaginous joints
3. Freely moveable joints fig 50.5c
   a. Called synovial joints
   b. Articulated end located within synovial capsule with lubricating fluid
   c. Ends of bone capped with cartilage
   d. Synovial capsule strengthened by ligaments
   e. Bones move in direction dictated by structure of joint
      1) Finger joint has hinge-like movement
      2) Thigh bone-pelvis joint has ball-and-socket structure

II. ACTIONS OF SKELETAL MUSCLES

A. Skeletal Muscles Produce Movement of Skeleton

1. Muscles attach to bones
   a. Are usually attached to two different bones
   b. May be attached to another structure like skin
2. Connection of muscle to bone called tendon
   a. Attachment at origin remains relatively stationary during contraction
   b. Insertion end of muscle is attached to bone that moves
      1) Contraction of biceps muscle in upper arm
      2) Forearm is insertion of muscle
      3) Shoulder is origin of muscle
      4) Forearm moves toward shoulder

B. Muscles May Work in Groups

1. Synergists produce same action at joint
2. Antagonists produce opposing actions
3. Example: Lower leg muscles fig 50.6
   a. Quadriceps group extends knee joint
   b. Quadricep muscles are synergists to each other
   c. Hamstring muscles contract cause flexion at knee
   d. Quadriceps and hamstrings are antagonists
   e. Muscles that antagonize are relaxed when opposing set is contracted

C. Isometric and Isotonic Contractions

1. Muscles must generate force greater than opposing forces preventing movement
2. Example: Lifting a weight
   a. Force of muscle movement greater than force of gravity on weight
   b. Muscle and all fibers shorten in length
3. Isotonic contraction
   a. Muscle shortens
   b. Constant force of contraction throughout shortening process
   c. Means “same strength”
4. Isometric contraction
   a. Precedes isotonic contraction, tension absorbed by tendons, other elastic tissue
   b. Means “same length”
   c. Provides tautness and stability to body

50.3 Muscle contraction powers animal locomotion

I. THE SLIDING FILAMENT MECHANISM OF CONTRACTION

A. Microscopic Anatomy of Skeletal Muscle — fig 50.7
1. Each muscle contains numerous muscle fibers
   a. Each fiber encloses a bundle of 4 to 20 myofibrils
   b. Myofibril composed of thin and thick myofilaments
      1) Have cross-striations that produce alternating light-dark appearance
      2) Result from organization of myofilaments
2. Light and dark banding results from thin and thick myofilaments
   a. Thick filaments stack together to form dark A bands
   b. Thin filaments alone form light I bands
3. Structure of a sarcomere — fig 50.8
   a. I band divided in half by Z line, disc of protein
   b. Thin filaments anchored to protein disks of Z line
   c. Myofibril structure repeats from Z line to Z line
   d. Repeating structure called a sarcomere, smallest subunit of muscle contraction
4. Thin and thick filaments overlap
   a. Overlap not complete in resting muscle
   b. Center, lighter portion called H band
   c. Portion on either side contains interdigitating filaments
5. Appearance changes when muscle contracts
   a. Muscle contracts and shortens because myofibrils contract and shorten
   b. Myofilaments do not shorten
   c. Thin filaments slide deeper into A band — fig 50.9
   d. H bands become narrower, ultimately disappear
   e. I bands also become narrower as A bands come closer together
6. Process called sliding filament mechanism of contraction

B. Molecular Aspects of Muscle Contraction
1. Cross-bridges extend from thick to thin filaments
   a. Thick filament molecular structure
      1) Myosin proteins each with a protruding head — fig 50.10
      2) Heads form cross-bridges
   b. Thin filament molecular structure
      1) Globular actin proteins twisted into double helix — fig 50.11
      2) Molecular appearance of sarcomere — fig 50.12a
2. Muscle contraction associated with cleaving ATP to ADP + P_i
   a. At rest, myosin heads function as ATPase enzymes
   b. Hydrolysis activates myosin heads
   c. "Cocks" heads so they can bind to actin and form cross-bridges
3. Cross-bridge formation causes conformational change
   a. Pulls thin filament toward center of sarcomere — fig 50.12b
   b. Called the power stroke
   c. Binding another ATP detaches myosin head from actin
   d. Continues cross-bridge cycle — fig 50.13
      1) Lack of ATP in dead animal causes myosin to remain bound to actin
      2) Causes stiffened condition called rigor mortis

II. THE CONTROL OF MUSCLE CONTRACTION

A. The Role of Ca^{++} in Contraction

1. In relaxed muscle myosin heads are "cocked", unable to bind to actin
2. Attachment site physically blocked by tropomyosin
   a. Tropomyosin lies against thin filament
   b. Cross-bridges can't form, filaments can't slide
3. Troponin, a regulatory protein, moves tropomyosin out of the way
   a. Troponin binds to tropomyosin
   b. Form complex regulated by calcium ion concentration in muscle cell cytoplasm
   c. In relaxed muscle Ca^{++} in cytoplasm is low — fig 50.14
   d. Tropomyosin blocks myosin heads from binding to actin, prevents contraction
   e. Increase levels of Ca^{++}
      1) Ca^{++} binds to troponin
      2) Ca^{++}-troponin- tropomyosin complex shifted from myosin heads on actin
      3) Cross-bridges can form, power strokes occur, contraction produced
4. Muscles store Ca++ in sarcoplasmic reticulum (SR) — fig 50.15
   a. Modified endoplasmic reticulum
   b. Stimulation of muscle fiber causes release of Ca^{++} from SR
      1) Electrical impulse travels down muscle fiber through transverse (T) tubules
      2) Triggers release of Ca^{++} from SR
   c. Ca^{++} diffuses into myofibrils
   d. Ca^{++} binds to troponin, causes contraction
5. Muscle contraction regulated by nerve activity
6. Nerves influence distribution of Ca^{++} in muscle fiber

B. Nerves Stimulate Contraction

1. Muscle contraction stimulated by motor neurons
2. Associated with somatic motor neurons in skeletal muscle — fig 49.12
   a. Axon of one motor neuron synapses with a number of muscle fibers
   b. One axon can stimulate several fibers
      1) In some animals one fiber innervated by more than one motor neuron
      2) In humans, fiber has a single synapse with a branch of an axon
3. Events associated with muscle contraction
   a. Motor neuron releases neurotransmitter chemical
      1) Acetylcholine (Ach) released by somatic motor neurons
      2) Excites muscle fiber, stimulates it to produce own electrical impulses
   b. Impulses carried along membrane of muscle fiber
      1) Also carried along T tubules
      2) Tubules extend deep into muscle fiber
   c. Impulses along T tubules carried to sarcoplasmic reticulum
      1) Stimulates release of Ca^{++}
      2) Binds to troponin
      3) Exposes cross-bridge binding sites
      4) Stimulates contraction
4. When impulses stop, nerve no longer releases Ach
   a. Impulses in muscle fiber cease
   b. No impulse in T tubules, Ca^{++} returned to SR by active transport
   c. Troponin not bound to Ca^{++}
   d. Tropomyosin returns to inhibitory position
   e. Muscle relaxes
5. Process called excitation-contraction coupling
   a. Neurons produce electrical excitation of muscle fiber
   b. Coupled to contraction through action of Ca^{++}

C. Motor Units and Recruitment
1. Motor unit: Set of muscle fibers controlled by one neuron fig 50.16
2. Motor neuron produces impulses, all fibers in motor unit contract together
3. Allows for fine gradation of strength of muscle contraction
   a. Motor unit with few fibers requires finer degree of control
   b. Results in small contractile force, as in movement of eyes
   c. For greater force, more motor units are activated
4. Motor units occur in variety of sizes in most muscles
   a. Weakest contractions, activation of few small units
   b. Stronger contraction may activate more small units
   c. Initial increments are small, more units brought on
5. Recruitment
   a. Use of increased number and sizes of motor units
   b. Causes greater contraction of muscle

III. TYPES OF MUSCLE FIBERS

A. Muscle Fiber Twitches
1. Twitch: Single brief contraction
   a. Muscle fiber stimulated by single electric shock
   b. Fiber contracts rapidly and relaxes
   c. Increasing stimulus voltage increases strength of twitch to a maximum
2. Summation fig 50.17
   a. Second shock added immediately after first, second twitch adds to first
   b. Relaxation time between twitches gets shorter as strength of contraction increases
3. Tetanus
   a. No visible relaxation between twitches
   b. Produces smooth, sustained contraction

B. Slow-Twitch (Type I) versus Fast-Twitch (Type II) Muscle Fibers fig 50.18
1. Fast-twitch fibers
   a. Muscles that move eyes have high proportion of fast-twitch fibers
   b. Reach maximum tension in 7.3 msec
2. Slow-twitch fibers
   a. Soleus muscle in leg has high proportion of slow-twitch fibers
   b. Requires 100 msec to reach maximum tension
3. Characteristics of slow-twitch fibers
   a. Some muscles must be able to sustain contraction for long time without fatigue
   b. Resistance to fatigue characteristic of slow-twitch fibers
   c. Have high capacity for aerobic respiration
      1) Rich capillary supply
      2) Numerous mitochondria
      3) Numerous aerobic respiratory enzymes
      4) High concentration of myoglobin pigment, improves delivery of oxygen
      5) Also called red fibers due to myoglobin
4. Characteristics of fast-twitch fibers
   a. Thicker fibers, fewer capillaries and mitochondria
   b. Less myoglobin, called white fibers
   c. Adapted to respire anaerobically
      1) Large stores of glycogen
      2) High concentrations of glycolytic enzymes
   d. Provide rapid generation of power
   e. Grow thicker and stronger with weight training
5. Comparable to dark (red) and white meat of chicken and turkey

6. Human muscles also contain type intermediate to I and II
   a. Are fast-twitch with high oxidative capacity
   b. Are more resistant to fatigue
   c. Proportion increased by endurance training

C. Muscle Metabolism During Rest and Exercise
   1. Resting muscles utilize aerobic respiration of fatty acids
   2. Exercising muscles also use muscle glycogen and blood glucose as energy sources
   3. Large amounts of ATP required in muscle contraction
      a. Needed for movement of cross-bridges
      b. Required to pump Ca^{++} into sarcoplasmic reticulum for relaxation
   4. Rapid production of ATP associated with creatine phosphate
      a. Combine ADP with phosphate from creatine phosphate
      b. Previously formed by adding creatine to phosphate from ATP in respiration
   5. Skeletal muscles initially respire anaerobically in heavy exercise
      a. Time required to increase oxygen supply to muscles, 45 to 90 seconds
      b. Continues with aerobic respiration if exercise is moderate
   6. Aerobic capacity
      a. Maximal oxygen uptake, maximum oxygen consumption by aerobic respiration
      b. Affects intensity of exercise for a given person
   7. Lactate threshold also affects exercise intensity
      a. Percentage of maximal oxygen uptake with rise in blood lactate levels
      b. Associated with anaerobic exercise

D. Muscle Fatigue and Physical Training
   1. Use-dependent decrease in ability to generate force
   2. Mainly occurs from operating under anaerobic conditions
      a. High activity causes buildup of lactic acid
      b. Also depletes stores of glycogen in muscle
      c. Energy production then comes from fat
   3. Athletes can perform more exercise before muscle fatigue sets in
   4. Endurance training does not increase muscle size
      a. Muscle size increase dependent on high intensity resistance
      b. Exemplified by weight training
      c. Increases thickness of fast-twitch fibers
      d. Muscles increase via hypertrophy not by increase in numbers by cell division

IV. COMPARING CARDIAC AND SMOOTH MUSCLES

A. Similarities of Cardiac and Smooth Muscle
   1. Found within internal organs
   2. Generally not under conscious control

B. Differences Between Cardiac and Smooth Muscle
   1. Cardiac muscle is striated, contracted via sliding filaments
   2. Smooth muscle is not striated
   3. Actin and myosin filaments present, arranged less regularly in cell

C. Cardiac Muscle
   1. Composed of striated fibers, orientation different than skeletal fibers
      a. Composed of shorter branched cells with individual nucleus
      b. Cells interconnect at intercalated disks fig 50.19
      c. Fused membranes pierced by gap junctions
         1) Permit diffusion of ions

        2) Spread electrical excitation from one cell to next
    d. Mass of cells form single, functioning unit called myocardium
2. Structure critical to heart muscle function
    a. Spontaneous contraction initiated at one location called pacemaker
    b. Not initiated by impulses in motor neurons, but by cardiac muscle itself
    c. Impulses spread from pacemaker throughout myocardium via gap junctions
3. Heart has two myocardia
    a. One receives blood from body, other ejects blood to body
    b. Cells in each chamber of heart stimulated as single unit
        1) Cardiac muscles cannot summate or show tetanus
        2) Would interfere with cycle necessary for pumping

D. Smooth Muscle
1. Surrounds hollow internal organs like stomach, intestines, bladder, uterus
2. Surrounds blood vessels (except capillaries)
3. Long, spindle-shaped cells with individual nucleus
    a. Individual myofibrils of actin and myosin not organized into sarcomeres
    b. Parallel arrangements of thick and thin filaments cross diagonally
    c. Thick filaments attached to dense bodies or plasma membrane
    d. Have 10 to 15 thin filaments per thick filament
    e. Striated muscle fibers have 3 thin filaments per thick filament
4. Smooth muscle cells do not have sarcoplasmic reticulum
    a. Ca^{++} comes from extracellular fluid
    b. Ca^{++} binds to calmodulin in extracellular fluid
    c. Complex activates certain enzyme
    d. Enzyme phosphorylates myosin heads, permits formation of cross-bridges
5. Strength of contraction increases with amount of Ca^{++} that enters cytoplasm
    a. Drugs can block entry of Ca^{++} into cells, causing vascular smooth muscles to relax
    b. Blood vessels dilate, reduces work heart must do to pump blood through them
6. Some smooth muscles contract only when stimulated by nervous system
    a. Muscles lining walls of blood vessels
    b. Muscles in iris of eye
7. Other smooth muscle like gut lining can contract spontaneously
    a. Contain special cells that produce electrical impulses
    b. Spread impulses to adjacent cells through gap junctions
    c. Leads to slow, steady contraction of tissue
8. Smooth muscle can contract even when greatly stretched
    a. Skeletal and cardiac muscle can't contract if too stretched
        1) Thick and thin filaments must interdigitate
        2) Otherwise cross-bridges can't form
    b. Example: Uterus
    c. Internal organs are frequently stretched, must still be able to contract

V. MODES OF ANIMAL LOCOMOTION

A. Animals Are Uniquely Mobile Organisms
1. Locomotion requires propulsive and control mechanisms
2. Most propulsive mechanisms employ contraction of muscles to generate force
3. Nervous system initiates and coordinates quantity, quality, position of contractions
4. Two general types of large animal active locomotion
    a. Appendicular locomotion: Produced by oscillating appendages
    b. Axial locomotion: Bodies undulate, pulse, or undergo peristaltic waves
5. Gravity and frictional drag are physical impediments to movement

B. Locomotion in Water
   1. Many aquatic invertebrates move in manners similar to terrestrial animals
   2. Some marine invertebrates swim via hydraulic propulsion
   3. Swimming in water presents specific challenges
      a. Gravity influence reduced by buoyancy of water
      b. Primary retarding factor is frictional drag
      c. Body shape important to reduce friction and turbulence
   4. Action of vertebrate swimming uses body or appendages to move against water
      a. Eels exhibit body undulations to move through water — fig 50.20a
         1) Undulations caused by alternating muscle contractions on left and right sides
         2) Body segments push against water in turn
         3) Moving wave forces eel forward
      b. Fish, reptiles, amphibians move only posterior portion of bodies
         1) Often only caudal (rear) fin moves
         2) Allows for specialization of front of body
         3) Sacrifices little propulsive force
      c. Whales use top and bottom undulating body waves
         1) Fish have highly segmented bodies, capable of side to side undulations
         2) Whales lack this arrangement
      d. Tetrapod vertebrates usually swim with appendicular locomotion
         1) Birds propel bodies by motion of webbed feet
         2) Frogs, turtles, marine mammals swim with webbed hind legs
         3) Some marine animals swim with forelegs pulling through the water

C. Locomotion on Land
   1. Mollusk locomotion is not very efficient
      a. Glide on secreted path of mucus
      b. Push bodies along with muscular foot
   2. Vertebrates and arthropods exhibit rapid surface locomotion
      a. Bodies raised above surface of ground
      b. Movement from jointed appendages pushing against ground
   3. Legs provide support as well as propulsion
      a. Sequence of leg movement is important
      b. Cannot push body center of gravity beyond leg zone of support
      c. Sequence needed to maintain body stability
   4. Number of walking limbs effects walking gait
      a. Vertebrates are tetrapods, arthropods have 6 or more legs
      b. Many legs increase stability, but may reduce maximum speed possible
   5. Typical tetrapod walking gait
      a. Left hind leg, left foreleg, right hindleg, right foreleg
      b. Can initiate motion with any limb, not just posterior pair as in insects
      c. Increase speed by overlapping movements
      d. Highest speeds associated with asymmetric gaits
         1) Horse at gallop has no more than 2 supporting legs, may have none
         2) Reduces friction against ground, increases speed
   6. Many animals use strong rear legs to propel selves forward — fig 50.21
   7. Some vertebrates use peristaltic motions to slide over surface of ground
      a. Snakes use serpentine motion with series of sinuous curves
      b. Propulsion is not by wave of contraction of undulating body like eels
      c. Produce simultaneous lateral thrust in body segments touching ground
      d. Thrust comes from outside end of inward-curving side of body loop

D. Locomotion in Air
   1. Flight has evolved in insects, pterosaurs, birds, and bats
   2. Propulsion achieved by pushing downward against air with wings
      a. Insects are small and achieve sufficient lift
      b. Larger animals need wings with convex cross section to achieve lift
         1) Air travels farther over top surface of wing
         2) Air over top moves faster, creates lift
   3. Similar limb movement in birds and some insects
      a. Alternate contraction of muscles
      b. Extensors are elevators, flexor muscles are depressors
   4. Some insects have extremely fast wing beats
      a. Movement faster than nerve can carry impulses
      b. Flight muscles attached to stiff wall of thorax, not to wings
      c. Contraction of one muscle set triggers other set to contract
   5. Vertebrate flight evolved first in pterosaurs
      a. Shared skies with birds for 100 million years
      b. May have flown at different times of day to reduce competition
      c. Similar sharing occurs now between birds and night-flying bats

INSTRUCTIONAL STRATEGY

PRESENTATION ASSISTANCE:

Discuss bone healing associated with electrical currents which speed bone growth along natural stress lines. Exercise has an effect on bone growth as indicated by the diameter of a pitcher's pitching versus non-pitching arm. It may also help combat bone deterioration that occurs with age and osteoporosis. Discuss the physiology of muscular dystrophy, myasthenia gravis, and/or atrophy of unused muscles.

Myosin and actin are not simply interdigitated, illustrated by interposing the fingers of the left and right hand with each set of fingers representing a protein. Rather, the fingers of both hands are actin, adding myosin is like holding short pencils between your fingers when they are placed tip to tip. As contraction proceeds, your finger tips get closer together, as do your hands (representing the Z lines).

VISUAL RESOURCES:

Bring in examples of bone and muscle tissue, readily obtained at the local meat market. Ask the butcher to bisect a long bone in both directions to show the internal structure.

Myosin looks like a bundle of double-headed golf clubs where the heads are hinged to the handles.

Place a pencil (actin) on a smooth surface (even the overhead projector) "walk" your fingers (myosin heads) along its length so that it moves backwards under your fingers.