CHAPTER 41 SUPPORT SYSTEMS AND LOCOMOTION

Chapter Outline

41.1 Diversity of Skeletons

A. Types of Skeletons
   1. Three types of skeletons occur in the animal kingdom.
   2. A hydrostatic skeleton occurs in cnidarians, flatworms, roundworms and annelids.
   3. An exoskeleton includes arthropods as well as molluscs with calcium carbonate shells.
   4. A bony endoskeleton is found in echinoderms and vertebrates.

B. Hydrostatic Skeleton
   1. A fluid-filled gastrovascular cavity or coelom can act as a **hydrostatic skeleton**.
   2. It offers support and resistance to the contraction of muscles for motility.
   3. Many animals use hydroskeletons.
      a. Hydras use a fluid-filled gastrovascular cavity to support tentacles that rapidly contract.
      b. Planaria easily glide over substrate with muscular contractions of body walls and cilia.
      c. Roundworms have a fluid-filled pseudocoelom and move when their longitudinal muscles contract against it.
      d. Earthworms are segmented with septa dividing the coelom into compartments; circular and longitudinal muscles contract in each segment to coordinate elongation and contraction.

C. Exoskeletons and Endoskeletons
   1. An **exoskeleton** is an external skeleton.
      a. Molluscs have exoskeletons that are predominantly calcium carbonate ($CaCO_3$).
      b. Insects and crustacea have jointed exoskeletons composed of **chitin**, a strong, flexible, nitrogenous polysaccharide.
      c. The exoskeleton provides protection against damage and enemies and also keeps tissues from drying out.
      d. Although stiffness provides support for muscles, the exoskeleton is not as strong as an endoskeleton.
      e. The clam and snail exoskeletons grow with the animals; their thick nonmobile $CaCO_3$ shell is for protection.
      f. The chitinous exoskeleton of arthropods is jointed and moveable.
      g. Arthropods must molt when their exoskeleton becomes too small; a molting animal is vulnerable to predators.
   2. Vertebrates have an **endoskeleton** composed of bone and cartilage that grows with the animal.
      a. The endoskeleton does not limit the space available for internal organs and it can support greater weight.
      b. Soft tissues surround the endoskeleton to protect it; injuries to soft tissue are easier to repair.
      c. Usually an endoskeleton has elements that protect vital internal organs.
      d. The jointed exoskeleton of arthropods and endoskeletons of vertebrates allow flexibility and helped arthropods and vertebrates colonize land.

41.2 The Human Skeletal System

A. Human Skeletal Functions
   1. Skeletons protect organs: skull (brain), vertebral column (spinal cord), and rib cage (heart and lungs).
   2. The large, heavy leg bones support the body against the pull of gravity.
   3. Leg and arm bones permit flexible body movement.
   4. The flat bones of the skull, ribs, and breastbone contain red bone marrow that manufactures blood cells.
   5. All bones store inorganic calcium and phosphorous salts.

B. Bone Growth and Renewal
   1. The prenatal human skeleton is cartilaginous; cartilage structures serve as “models” for bone construction.
      a. The cartilaginous models are converted to bones when calcium salts are deposited in the matrix,

first by cartilaginous cells and later by bone-forming cells called **osteoblasts**.
    b. Conversion of cartilaginous models to bones is called **endochondral ossification**.
    c. Some bones (e.g., facial bones) are formed without a cartilaginous model.
2. During endochondral ossification, there is a primary ossification center at the middle of a long bone; latter secondary centers form at the ends.
3. A cartilaginous growth plate occurs between primary and secondary ossification centers.
4. As long as the growth plate remains between the two centers, bone growth occurs.
5. The rate of growth is controlled by hormones, including growth hormones and sex hormones.
6. Eventually plates become ossified and bone stops growing; this determines adult height.
7. In adults, bone is continually being broken down and built up again.
    a. Bone-absorbing cells (**osteoclasts**) break down bone, remove worn cells, and deposit calcium in the blood.
    b. **Osteoblasts** form new bone, taking calcium from blood.
    c. Osteoblasts become entrapped in the bone matrix and become osteocytes in the lacunae of osteons.
    d. This continual **remodeling** allows bones to gradually change in thickness.
    e. Osteoclasts also determine the calcium level in the blood; calcium level is important for muscle contraction and nerve conduction and levels are controlled by the hormones PTH and calcitonin.
8. Adults need more calcium in the diet than do children to promote the work of osteoblasts.

C. Anatomy of a Long Bone
1. A long bone illustrates the principles of bone anatomy.
    a. A long bone consist of a central **medullary cavity** surrounded by **compact bone**.
    b. Ends are composed of **spongy bone** surrounded by a thin layer of **compact bone** and covered with **hyaline cartilage**.
    c. **Compact bone** contains many **osteons** (Haversian systems); bone cells in tiny chambers (lacunae) are arranged in concentric circles around central canals.
    d. **Central canals** contain blood vessels and nerves.
    e. The **lacunae** are separated by a matrix that contains protein fibers of collagen and mineral deposits.
2. **Spongy bone** has numerous plates and bars separated by irregular spaces.
    a. Spongy bone is lighter but designed for strength; solid portions of bone follow the lines of stress.
    b. Bone spaces are often filled with **red bone marrow**, a specialized tissue that produces blood cells.

D. Bones Make Up the Skeleton
1. The **axial skeleton** lies at the midline of the body and consists of the skull, vertebral column, sternum and ribs.
    a. The Skull
        1) The skull is formed by the cranium and the facial bones.
        2) Newborns have membranous junctions called **fontanels** that usually close by the age of two.
        3) The bones of the cranium contain **sinuses**, air spaces lined with mucous membrane that reduce the weight of skull and give a resonant sound to the voice.
        4) Two mastoid sinuses drain into the middle ear; **mastoiditis** is an inflammation that can lead to deafness.
        5) The **cranium** is composed of eight bones: a **frontal**, two **parietal**, an **occipital**, two **temporal**, a **sphenoid**, and an **ethmoid**.
        6) The spinal cord passes through the **foramen magnum**, an opening at the base of the skull in the **occipital bone**.
        7) Each temporal bone has an opening that leads to the middle ear.
        8) The sphenoid bone completes the sides of the skull and forms the floors and walls of the eye sockets.
        9) The ethmoid bone is in front of the sphenoid, part of the orbital wall, and a component of nasal septum.
        10) Fourteen **facial bones** include: **mandible**, two **maxillae**, two **palatine**, two **zygomatic**, two **lacrimal**, two **nasal**, and **vomer**.
        11) The **mandible** or lower jaw is the only movable portion of the skull; it contains tooth sockets.
        12) The **maxilla** forms the upper jaw and the anterior of hard palate; it also contains tooth sockets.
        13) The palatine bones make up the posterior portion of the hard palate and the floor of the nasal cavity.

14) The zygomatic gives us our cheekbone prominences.
15) Nasal bones form the bridge of the nose.
16) Other bones make up the nasal septum which divides the nose cavity into two regions.
17) The ears are elastic cartilage and lack bone; the nose is a mixture of bone, cartilage, and fibrous connective tissue.

b. The Vertebral Column and Rib Cage
1) The **vertebral column** supports the head and trunk and protects the spinal cord and the roots of the spinal nerves.
2) The vertebral column serves as an anchor for all of the other bones of the skeleton.
3) Seven **cervical vertebrae** are located in the neck.
4) Twelve **thoracic vertebrae** are in the thorax or chest.
5) The **lumbar** vertebrae are in the small of the back.
6) One **sacrum** is formed from five fused **sacral** vertebrae.
7) One **coccyx** is formed from four fused **coccygeal** vertebrae.
8) Normally, the spinal column has four normal curvatures that provide strength and resiliency in posture.
9) Scoliosis is an abnormal sideways curvature; hunchback and swayback are also abnormal.
10) Intervertebral disks between the vertebrae act as a padding to prevent the vertebrae from grinding against each other, and to absorb shock during running, etc.; they weaken with age.
11) Vertebral disks allow motion between vertebrae for bending forward, etc.
12) All twelve pairs of **ribs** connect directly to the thoracic vertebrae in back; seven attach directly to sternum.
13) Three pairs connect via cartilage to the sternum at front.
14) The two ribs totally unattached to the sternum are called "floating ribs."
15) The rib cage protects the heart and lungs, yet is flexible enough to allow breathing.

2. The Appendicular Skeleton

a. The **appendicular skeleton** consists of the bones within the **pectoral girdle** and upper limbs and the **pelvic girdle** and lower limbs.
b. The pectoral girdle is specialized for flexibility; the pelvic girdle is built for strength.
c. The components of the **pectoral girdle** are only loosely linked by **ligaments**.
1) The **clavicle** or "collarbone" connects with the sternum in front and the **scapula** in back.
2) The **scapula** connects with the clavicle; it is freely movable and held in place only by muscles.

d. The **humerus** is the long bone of the upper arm; its smoothly rounded head fits into a socket of the scapula.
e. The **radius** is the more lateral of the bones of the lower arm; it articulates with the humerus at the elbow joint, a hinge joint, and the radius crosses in front of the ulna for easy twisting.
f. The **ulna** is the more medial of the two bones of lower arm; its end is the prominence in your elbow.
g. The many hand bones increase its flexibility.
1) The wrist has eight **carpal bones** which look like small pebbles.
2) Five **metacarpal bones** fan out to form the framework of the palm.
3) The **phalanges** are the bones of fingers and thumb.

h. The **pelvic girdle** consists of two heavy, large **coxal** (**hip**) **bones**.
1) The coxal bones are anchored to the sacrum; together with the sacrum they form a hollow cavity that is wider in females than in males; it transmits weight from the vertebral column via sacrum to the **legs**.
2) The **femur** is the largest bone of the body; it is limited in the amount of weight that it can support.
3) The **tibia** has a ridge called the "shin"; its end forms the inside of the ankle.
4) The **fibula** is the smaller of the two bones; its end forms the outside of the ankle.

5) Seven **tarsal bones** are in each ankle; one receives the weight and passes it to the heel and ball of foot.
6) The **metatarsal bones** form the arch of the foot and provide a springy base.
7) The **phalanges** are the bones of the toes, which are stouter than the fingers.

E. Classification of Joints
1. Bones are joined at joints that are classified as fibrous, cartilaginous, or synovial.
2. **Fibrous joints**, such as those between the cranial bones, are immovable.
3. **Cartilaginous joints**, such as those between the vertebrae, are slightly moveable; the two hipbones are slightly movable because they are ventrally joined by cartilage and respond to pregnancy hormones.
4. **Synovial joints** are freely movable.
   a. Most joints are synovial joints, with the two bones separated by a cavity.
   b. **Ligaments** are fibrous connective tissue that bind bones to bone, forming a joint capsule.
   c. In a "double-jointed" individual, the ligaments are unusually loose.
   d. The joint capsule is lined with a synovial membrane that produces a lubricating synovial fluid.
   e. The knee represents a synovial joint.
      1) Knee bones are capped by cartilage; a crescent-shaped piece of cartilage, the meniscus, is between the bones.
      2) Athletes who injure the meniscus have torn this cartilage.
      3) The knee joint also contains 13 fluid-filled sacs called bursae to ease friction between the tendons and ligaments and tendons and bones.
      4) Inflammation of the bursae is bursitis; "tennis elbow" is a form of bursitis.
      5) The knee and elbow are hinge joints; the shoulder and hip are ball-and-socket joints.
   f. Synovial Joints
      1) Synovial joints are subject to arthritis.
      2) In rheumatoid arthritis, the synovial membrane becomes inflamed and thickened.
      3) The joint degenerates and becomes immovable and painful.
      4) This is likely caused by an autoimmune reaction.
      5) In osteoarthritis from old age, the cartilage at the ends of bones disintegrates; the bones then become rough and irregular.

41.3 The Human Muscular System

A. Muscle Tissue Function
1. Skeletal muscle contraction assists homeostasis by helping maintain constant body temperature.
2. Skeletal muscle contraction also causes ATP breakdown, releasing heat that is distributed about the body.

B. Macroscopic Anatomy and Physiology
1. Skeletal muscles are attached to the skeleton by **tendons** made of fibrous connective tissue.
2. When muscles contract, they only shorten or pull; therefore, skeletal muscles must work in **antagonistic pairs**.
   a. One muscle of an antagonistic pair bends the joint and brings a limb toward the body.
   b. The other one straightens the joint and extends the limb.
3. If a muscle is given a rapid series of stimuli, it responds to the next stimulus before completely relaxing.
4. Muscle contraction summates until it reaches a maximal sustained contraction, called **tetanus**.
5. Even at rest, muscles maintain tone by some fibers contracting; this is essential to maintaining posture.

C. Microscopic Anatomy and Physiology
1. A whole skeletal muscle consists of a number of **muscle fibers** in bundles.
2. Each muscle fiber is a cell but some have special features.
   a. A plasma membrane called the **sarcolemma** forms a T (**transverse**) **system**.
      1) **Transverse** (**T**) **tubules** penetrate down into the cell and contact with, but do not fuse with, the modified endoplasmic reticulum (the **sarcoplasmic reticulum**).
      2) Expanded portions or sacs of the sarcoplasmic reticulum are modified for Ca^{2+} ion storage; this encases hundreds and sometimes thousands of myofibrils.
   b. The **myofibrils** are contractile portions of fibers that lie parallel and run length of fiber.
   c. A light microscope shows light and dark bands called striations.
   d. An electron microscope shows that these striations of myofibrils are formed by placement of protein filaments within sarcomeres.

e. The two protein filaments are either thick (made of **myosin**) or thin (made of **actin**).
f. A **sarcomere** has repeating bands of actin and myosin that occur between two **Z lines** in a myofibril.
    1) The I band contains only actin filaments.
    2) The H zone contains only myosin filaments.

3. Sliding Filament Model
    a. As a muscle fiber contracts, sarcomeres within the myofibrils shorten.
    b. As a sarcomere shortens, actin filaments slide past the myosin; the I band shortens and the H zone disappears.
    c. **Sliding filament theory**: actin filaments slide past myosin filaments because myosin filaments have cross-bridges that pull actin filaments inward, toward their Z line.
    d. The contraction process involves the sarcomere shortening although the filaments themselves remain the same length.
    e. ATP supplies the energy for muscle contraction.
    f. Myosin filaments break down ATP to form cross-bridges that attach to and pull the actin filaments toward the center of the sarcomere.
4. ATP
    a. Muscle cells contain **myoglobin** that stores oxygen; cellular respiration does not immediately supply all of the ATP needed.
    b. Muscle fibers rely on a supply of stored creatine phosphate (phosphocreatine), a storage form of high-energy phosphate.
    c. **Creatine phosphate** does not directly participate in muscle contraction but regenerates ATP rapidly: creatine — P + ADP • ATP + creatine
    d. This reaction occurs in the midst of sliding filaments and is speedy.
    e. When all creatine phosphate is depleted, and if O_2 is in limited supply, fermentation produces a small amount of ATP, but this results in a buildup of lactate.
    f. The buildup of lactate partially accounts for muscle fatigue and represents **oxygen debt**.
    g. Lactate is transported to the liver; 20% is completely broken down to CO_2 and H_2O in aerobic respiration.
    h. The ATP gained from this respiration is then used to reconvert 80% of the lactate to glucose.
    i. In persons who train, the number of mitochondria increases, reducing need for fermentation.

D. Muscle Innervation
1. Muscles are stimulated to contract by motor nerve fibers.
2. The **neuromuscular junction** is region where an axon bulb is in close association with the sarcolemma of a muscle fiber.
3. An axon bulb contains synaptic vesicles filled with the neurotransmitter acetylcholine.
4. When nerve impulses travel down a motor neuron to axon bulb, vesicles merge with the presynaptic membrane and acetylcholine molecules are released into the synaptic cleft.
5. Acetylcholine rapidly diffuses to and binds with receptors on the sarcolemma.
6. The sarcolemma generates impulse spreading down the T tubule system to the sarcoplasmic reticulum where it triggers the release of Ca^{2+} ions out amongst the myofilaments.
7. The Ca^{2+} ions then initiate muscle contraction.

E. Contraction
1. Ca^{2+} ions bind to troponin, which causes tropomyosin threads to shift position.
2. The change in the structure of tropomyosin exposes the myosin heads with ATP binding sites.
3. The myosin heads function as ATPase enzymes, splitting ATP into ADP and P .
4. After attaching to actin filaments, the myosin cross-bridges bend forward and the actin filament is pulled along.
5. While ATP and Ca^{2+} ions are available, cross-bridges attach; as ADP and P are released, the cross-bridges change their positions and cause a power stroke as filaments pull together.
6. When another ATP molecule binds to the myosin head, the cross-bridge detaches and the cycle begins again.
7. When a nerve impulse ceases, active transport proteins in the sarcoplasmic reticulum pump calcium ions back into calcium storage sites.