ANIMAL FORM AND FUNCTION-II (ZOL-404)

PROTECTION, SUPPORT, AND MOVEMENT

CHAPTER # 23

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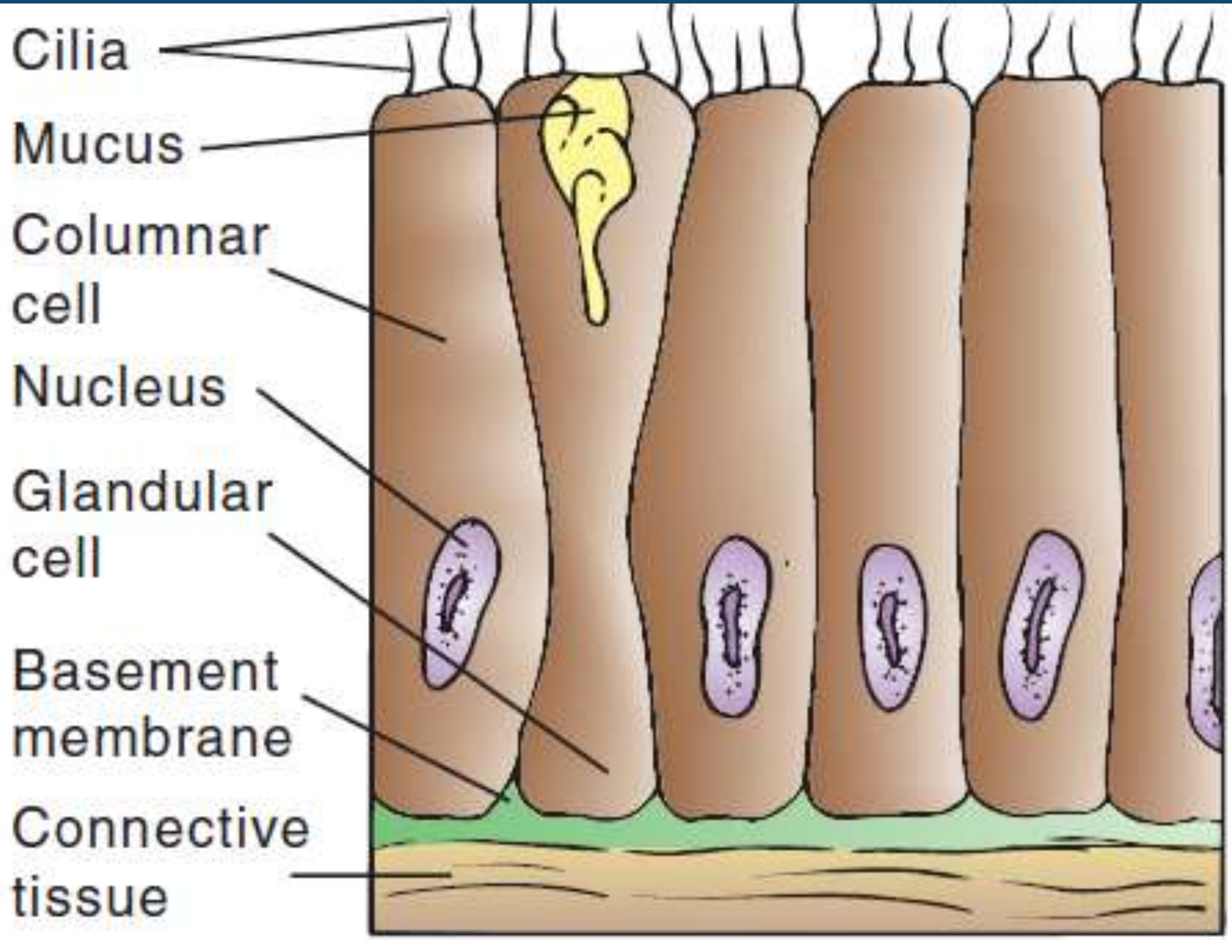
SUPERIOR GROUP OF COLLEGES, PAKPATTAN

PROTECTION: INTEGUMENTARY SYSTEMS

- The integument is the external covering of an animal. It protects the animal from mechanical and chemical injury and invasion by microorganisms.
- Many other diverse functions of the integument have evolved in different animal groups. These functions include
- 1. Regulation of body temperature
- 2. Excretion of waste materials
- 3. Conversion of sunlight into vitamin D
- 4. Reception of environmental stimuli, such as pain, temperature, and pressure
- 5. Locomotion
- 6. Movement of nutrients and gases.

THE INTEGUMENTARY SYSTEM OF INVERTEBRATES

- Some single-celled protozoa have only a plasma membrane for an external covering. This membrane is structurally and chemically identical to the plasma membrane of multicellular organisms. In protozoa, the plasma membrane has a large surface area relative to body volume, so that gas exchange and the removal of soluble wastes occur by simple diffusion. This large surface area also facilitates the uptake of dissolved nutrients from surrounding fluids. Other protozoa, such as Paramecium, have a thick protein coat called a pellicle outside the plasma membrane. This pellicle offers further environmental protection and is a semi rigid structure that transmits the force of cilia or flagella to the entire body of the protozoan as it moves.



Integument of Invertebrates. The integument of many invertebrates consists of a simple layer of columnar epithelial cells (epidermis) resting on a basement membrane. A thin layer of connective tissue lies under the basement membrane. Cilia and glandular cells may or may not be present.

- Most multicellular invertebrates have an integument consisting of a single layer of columnar epithelial cell.
- This outer layer, the epidermis, rests on a basement membrane. Beneath the basement membrane is a thin layer of connective tissue fibers and cells. Epidermal cells exposed at the surface of the animal may possess cilia.
- Some invertebrates possess cuticles that are highly variable in structure. For example, in some animals (rotifers), cuticles are thin and elastic, whereas in others (crustaceans, arachnids, insects), cuticles are thick and rigid and support the body.
- A disadvantage of cuticles is that animals have difficulty growing within them. As a result, some of these invertebrates (e.g., arthropods) periodically shed the old, outgrown cuticle in a process called molting or ecdysis

- In cnidarians, such as Hydra, the epidermis is only a few cell layers thick. Other cnidarians (e.g., the corals) have mucous glands that secrete a calcium carbonate ($CaCO_3$) shell. The outer covering of parasitic flukes and tapeworms is a complex syncytium called a tegument (L. tegumentum, tegere, to cover).
- Its main functions are nutrient ingestion and protection against digestion by host enzymes. Nematodes and annelids have an epidermis that is one cell thick and secretes a multilayered cuticle.
- The integument of echinoderms consists of a thin, usually ciliated epidermis and an underlying connective-tissue dermis containing $CaCO_3$. Arthropods have the most complex of invertebrate integuments, in part because their integument is a specialized exoskeleton.

THE INTEGUMENTARY SYSTEM OF VERTEBRATES

- Skin is the vertebrate integument. It is the largest organ (with respect to surface area) of the vertebrate body and grows with the animal.
- Skin has two main layers. As in invertebrates, the epidermis is the outermost layer of epithelial tissue and is one to several cells thick.
- The dermis (Gr. derma, hide, skin) is a thicker layer of connective tissue beneath the epidermis.
- A hypodermis ("below the skin"), consisting of loose connective tissue, adipose tissue, and nerve endings, separates the skin from deeper tissues.

The Skin of Jawless Fishes

- Jawless fishes, such as lampreys and hagfishes, have relatively thick skin. Of the several types of epidermal glandular cells that may be present, one secretes a protective cuticle. In hagfishes, multicellular slime glands produce large amounts of mucous slime that covers the body surface. This slime protects the animals from external parasites.

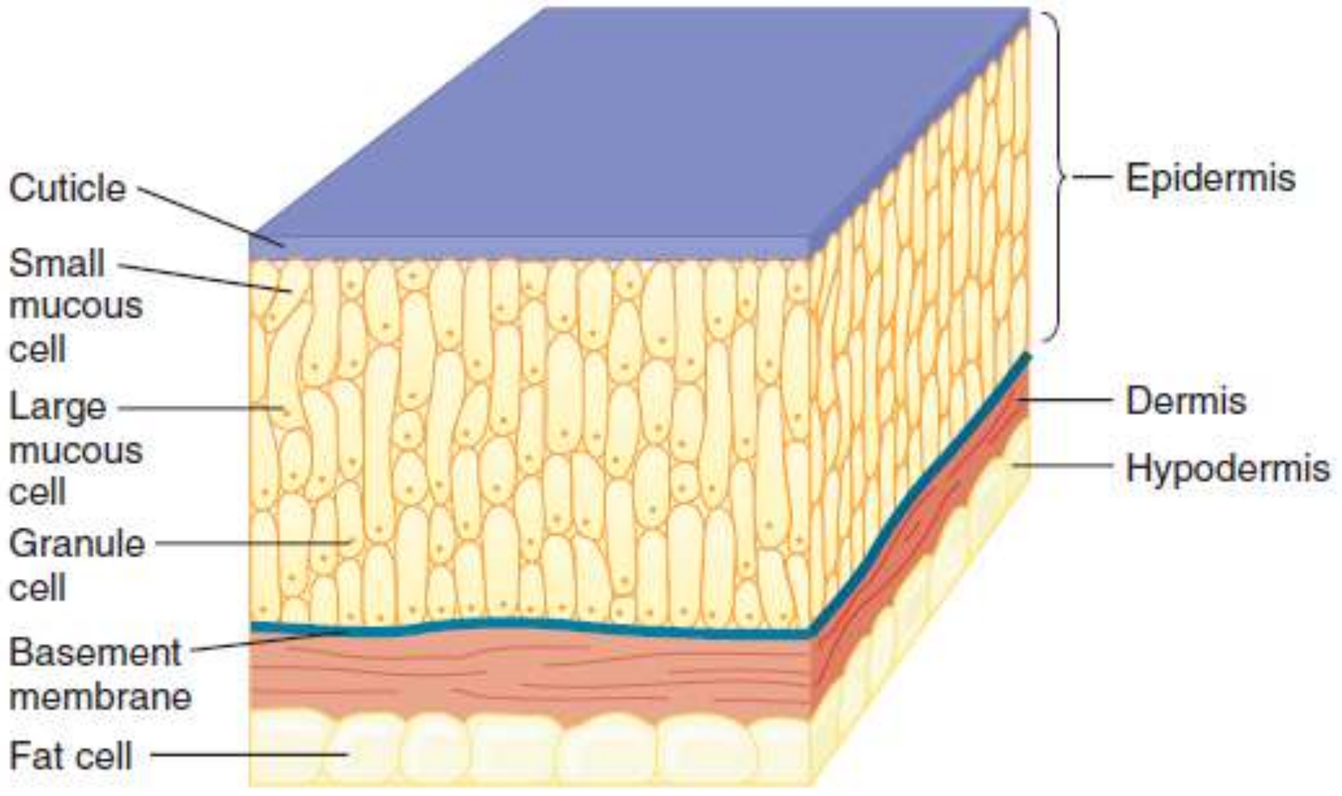


FIGURE 23.3

Skin of Jawless Fishes. The skin of an adult lamprey has a multilayered epidermis with glandular cells and fat storage cells in the hypodermis.

The Skin of Cartilaginous Fishes

- The skin of cartilaginous fishes (e.g., sharks) is multilayered and contains mucous and sensory cells. The dermis contains bone in the form of small placoid scales called denticles (little teeth). Denticles contain blood vessels and nerves and are similar to vertebrate teeth.

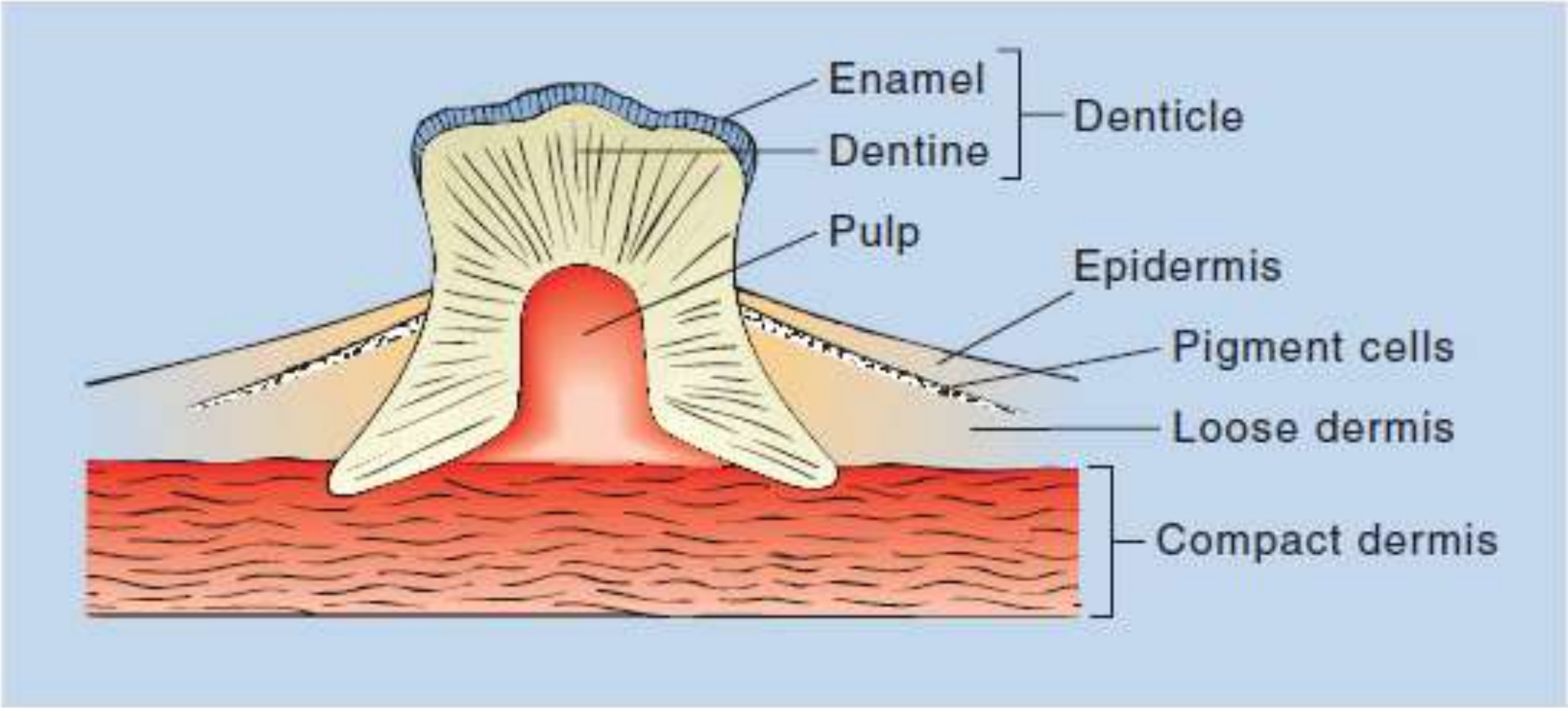


FIGURE 23.4

Skin of Cartilaginous Fishes. Shark skin contains toothlike denticles that become exposed through loss of the epidermal covering. The skin is otherwise fishlike in structure.

The Skin of Bony Fishes

- The skin of bony fishes contains scales. The skin of bony fishes is permeable and functions in gas exchange, particularly in the smaller fishes that have a large skin surface area relative to body volume. The dermis is richly supplied with capillary beds to facilitate its use in respiration. The epidermis also contains many mucous glands. Mucus production helps prevent bacterial and fungal infections, and it reduces friction as the fish swims.

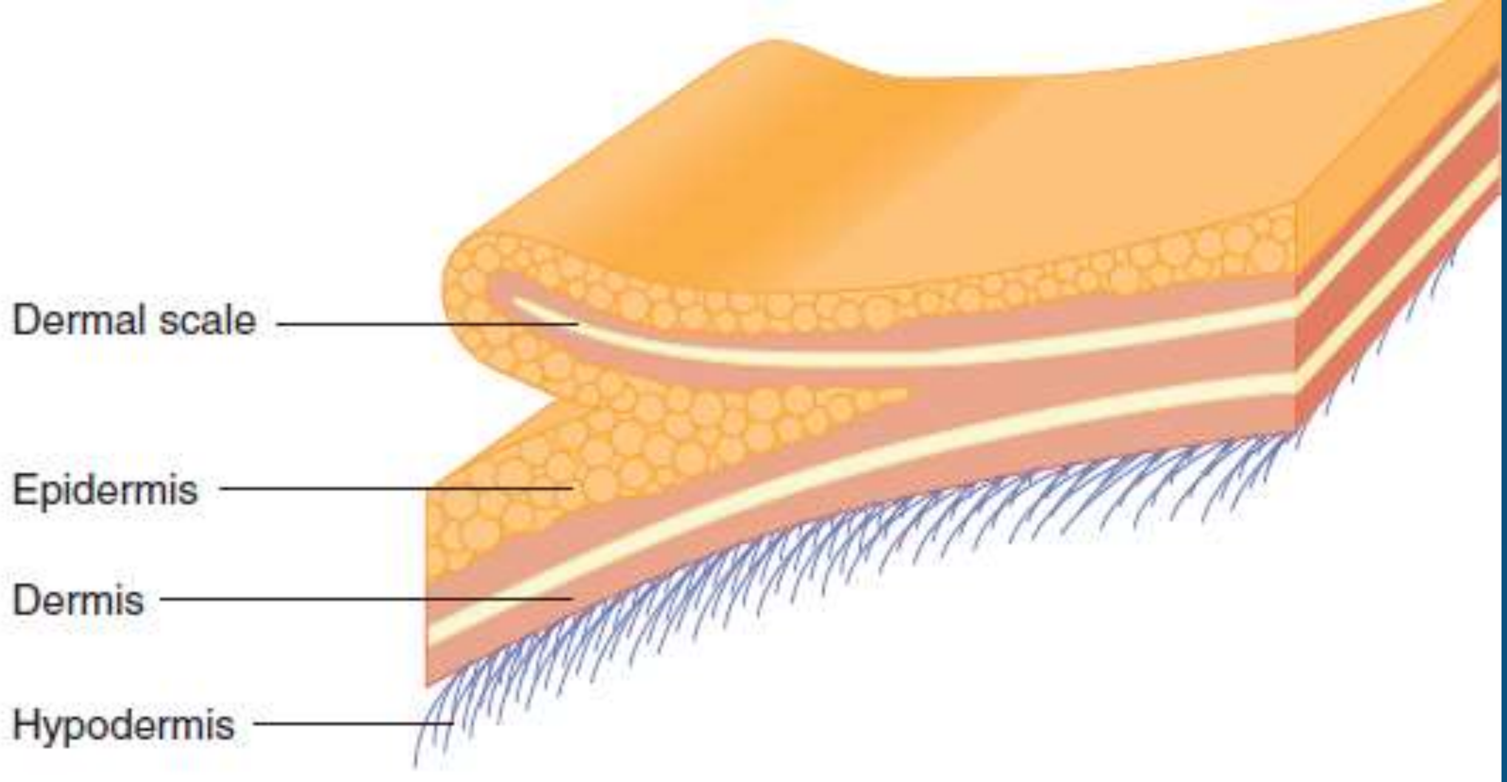


FIGURE 23.5

Skin of Bony Fishes. The skin of a typical bony fish has overlapping scales (two are shown here). The scales are layers of collagenous fibers covered by a thin, flexible layer of bone.

The Skin of Amphibians

- Amphibian skin consists of a stratified epidermis and a dermis containing mucous and serous glands plus pigmentation cells. Three problems associated with terrestrial environments are desiccation, the damaging effects of ultraviolet light, and physical abrasion.
- During amphibian evolution, keratin production increased in the outer layer of skin cells. (Keratin is a tough, impermeable protein that protects the skin in the physically abrasive, rigorous terrestrial environment.) The increased keratin in the skin also protects the cells, especially their nuclear material, from ultraviolet light. The mucus that mucous glands produce helps prevent desiccation, facilitates gas exchange when the skin is used as a respiratory organ, and makes the body slimy, which facilitates escape from predators.
- Within the dermis of some amphibians are poison glands that produce an unpleasant-tasting or toxic fluid that acts as a predator deterrent. Sensory nerves penetrate the epidermis as free nerve endings.

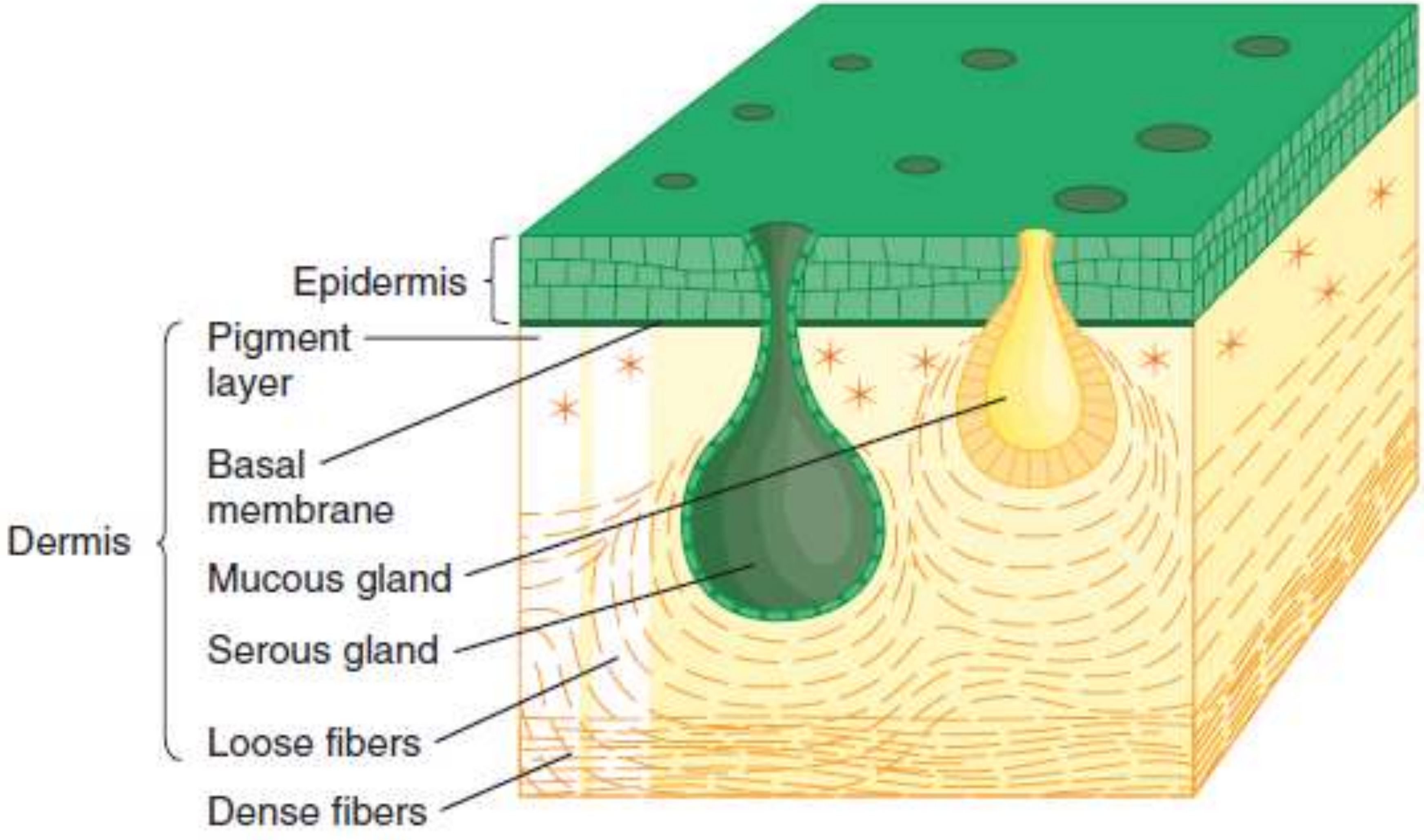


FIGURE 23.6

Skin of Amphibians. Frog skin has a stratified epidermis and several types of glands in the dermis. Notice the pigment layer in the upper part of the dermis.

The Skin of Reptiles

❖ The outer layer of the epidermis is thick, lacks glands, and is modified into keratinized scales. This thick, keratinized layer resists abrasion, inhibits dehydration, and protects like a suit of armor. During shedding or molting of the skin of many reptiles, the old outer layer separates from newly formed epidermis. Diffusion of fluid between the layers aids this separation.

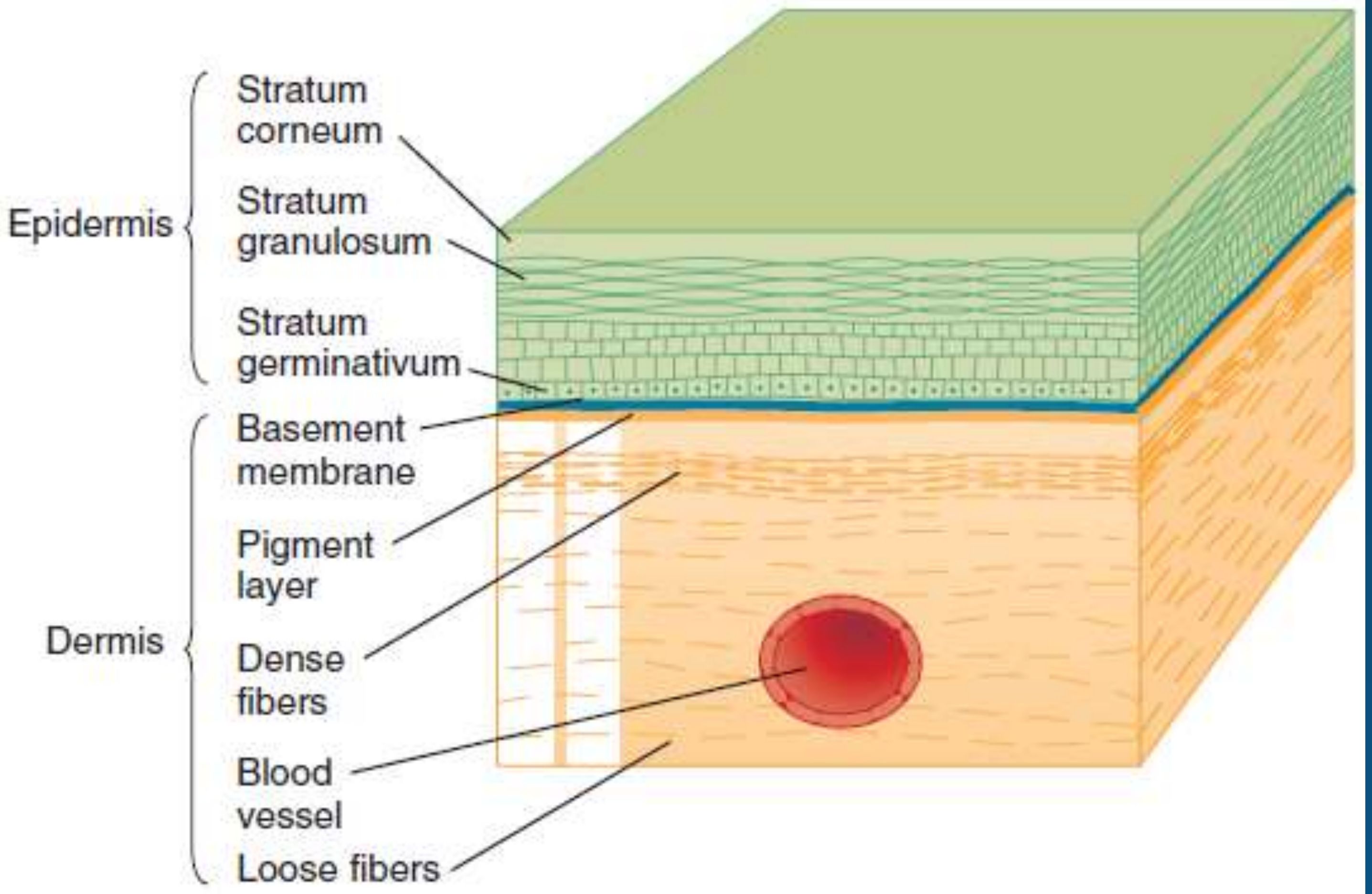
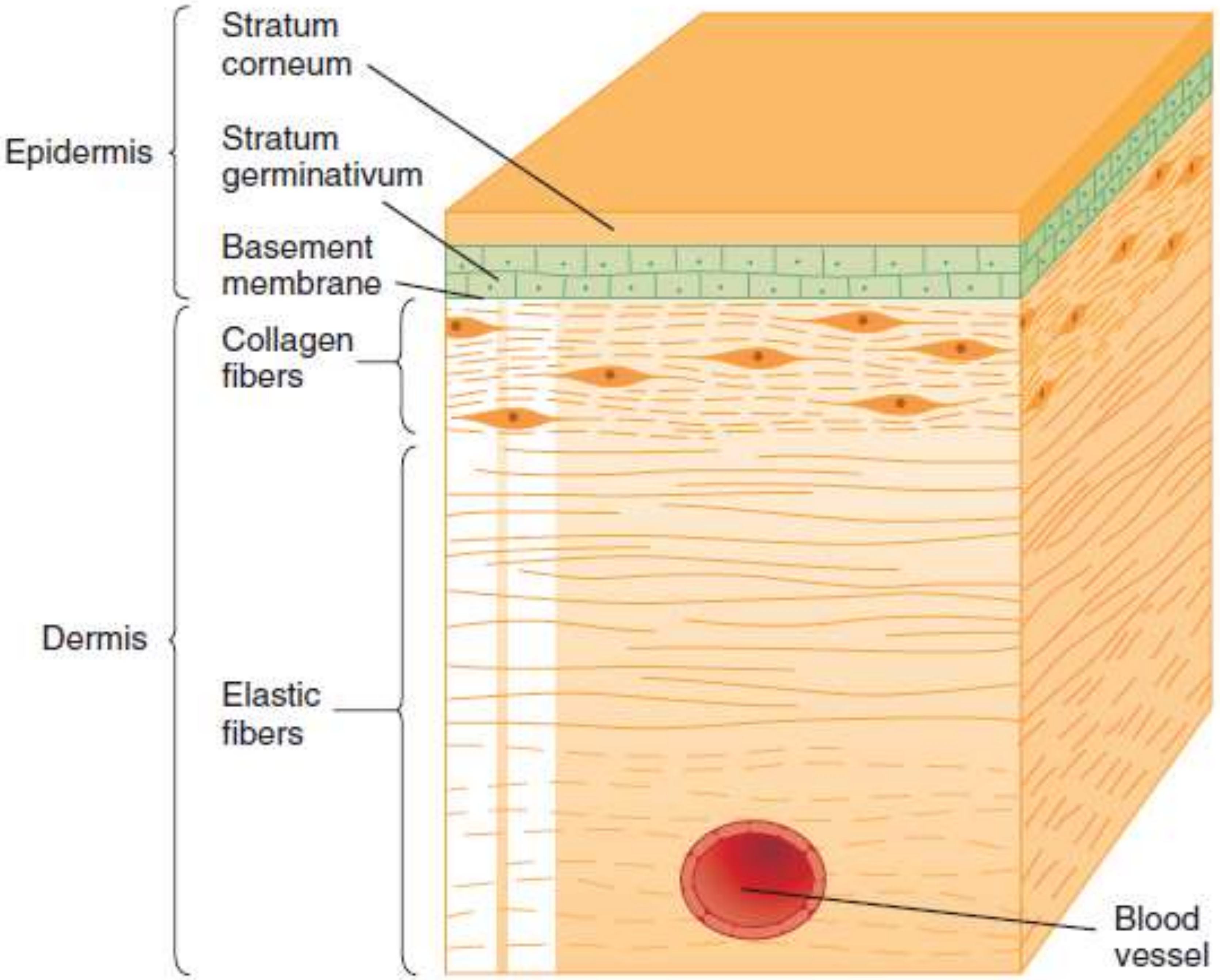


FIGURE 23.7

Skin of Reptiles. Lizard skin has the heavily keratinized outer epidermis (scales) characteristic of reptiles. Notice the absence of integumentary glands, making reptilian skin exceptionally dry.

The Skin of Birds

- Over most of the bird's body, the epidermis is usually thin and only two or three cell layers thick. The outer keratinized layer is often quite soft. The most prominent parts of the epidermis are the feathers.
- The dermis of birds is similar in structure to that of reptiles and contains blood and lymphatic vessels, nerves, and epidermally derived sensory bodies. Air spaces that are part of the avian respiratory system extend into the dermis. These air spaces are involved in thermal regulation. Associated with the feathers and their normal functioning is an incredibly complicated array of dermal smooth-muscle fibers that control the position of the feathers.
- Feather position is important in thermal regulation, flying, and behavior. Aquatic birds may also have fat deposits in the hypodermal layer that store energy and help insulate the body.

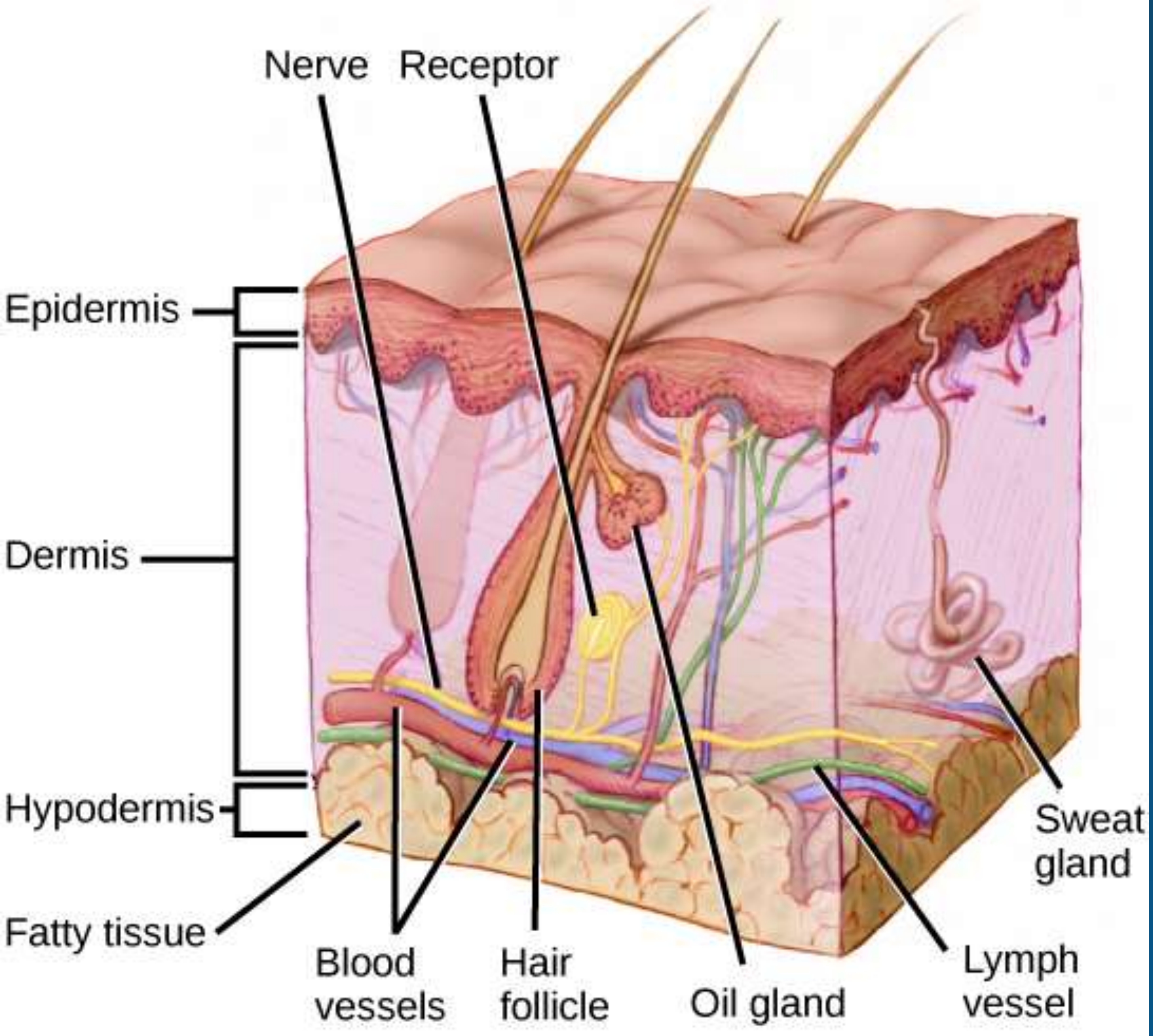

Epidermis
Stratum corneum
Stratum germinativum
Basement membrane
Dermis
Collagen fibers
Elastic fibers
Blood vessel

The Skin of Mammals

- The notable features of mammalian skin are:
- (1) hair;
- (2) a greater variety of epidermal glands than in any other vertebrate class;
- (3) a highly stratified, cornified epidermis; and
- (4) a dermis many times thicker than the epidermis.
- Keratinized cells make up the outer skin layer, called the stratum corneum. Because keratin is virtually insoluble in water, the stratum corneum prevents dehydration and is a first line of defense against many toxic substances and microorganisms.

The Skin of Mammals

- The thickest portion of mammalian skin is composed of dermis, which contains blood vessels, lymphatic vessels, nerve endings, hair follicles, small muscles, and glands.
- The hypodermis underneath the dermis is different from that of other vertebrate classes in that it consists of loose connective tissue, adipose tissue, and skeletal muscles. Adipose tissue stores energy in the form of fat and provides insulation in cold environments.
- In humans and a few other animals (e.g., horses), the skin regulates body temperature by opening and closing sweat pores and perspiring or sweating. The skin screens out excessive harmful ultraviolet rays from the sun, but it also lets in some necessary rays that convert a chemical in the skin into vitamin D. The skin is also an important sense organ, containing sensory receptors for heat, cold, touch, pressure, and pain.


Nerve
Receptor
Epidermis
Dermis
Hypodermis
Fatty tissue
Blood vessels
Hair follicle
Oil gland
Lymph vessel
Sweat gland

The Skin of Mammals

- The skin of humans and other mammals contains several types of glands. Sudoriferous glands (L. sudor, sweat), also called sweat glands, are distributed over most of the human body surface. These glands secrete sweat by a process called perspiration. Perspiration helps to regulate body temperature and maintain homeostasis, largely by the cooling effect of evaporation.
- In some mammals, certain sweat glands also produce pheromones.
- (A pheromone is a chemical that an animal secretes and that communicates with other members of the same species to elicit certain behavioral responses.)

The Skin of Mammals

- Sebaceous (oil) glands (L. sebum, tallow or fat) are simple glands connected to hair follicles in the dermis. They lubricate and protect by secreting sebum. Sebum is a permeability barrier, an emollient (skin-softening agent), and a protective agent against microorganisms. Sebum can also act as a pheromone.

- Mammalian skin color is due either to pigments that absorb or reflect light. Bright skin colors in venomous, toxic, or bad-tasting animals may deter potential predators. Other skin colors may camouflage the animal. In addition, colors serve in social communication, helping members of the same species to identify each other, their sex, reproductive status, or social rank.

The Skin of Mammals

- Hair is composed of keratin-filled cells that develop from the epidermis. The portion of hair that protrudes from the skin is the hair shaft, and the portion embedded beneath the skin is the root. An arrector pili muscle (smooth muscle; involuntary muscle) attaches to the connective-tissue sheath of a hair follicle surrounding the bulb of the hair root. When this muscle contracts, it pulls the follicle and its hair to an erect position. It helps warm the animal by producing an insulating layer of warm air between the erect hair and skin.
- Nails, like hair, are modifications of the epidermis. Nails are flat, horny plates on the dorsal surface of the distal segments of the digits (e.g., fingers and toes of primates). Other mammals have claws and hooves. Other keratinized derivatives of mammalian skin are horns (not to be confused with bony antlers) and the baleen plates of the toothless whales.

MOVEMENT AND SUPPORT: SKELETAL SYSTEMS

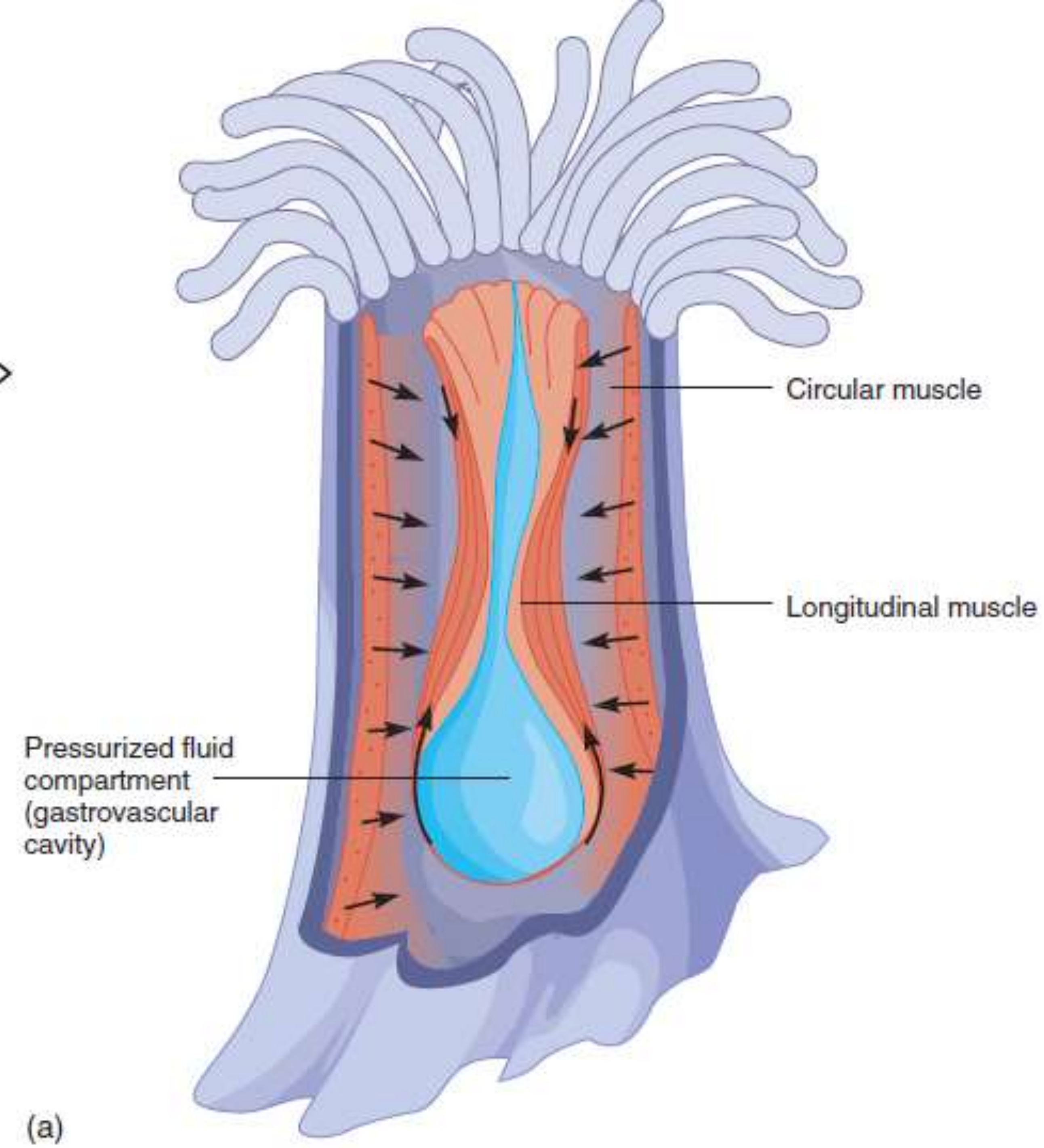
- Systems involved in movement and support evolved simultaneously with the increase in body size.
- Four cell types contribute to movement:
- (1) amoeboid cells,
- (2) flagellated cells,
- (3) ciliated cells, and
- (4) muscle cells.
- With respect to support, organisms have three kinds of skeletons:
- (1) fluid hydrostatic skeletons,
- (2) rigid exoskeletons, and
- (3) rigid endoskeletons.

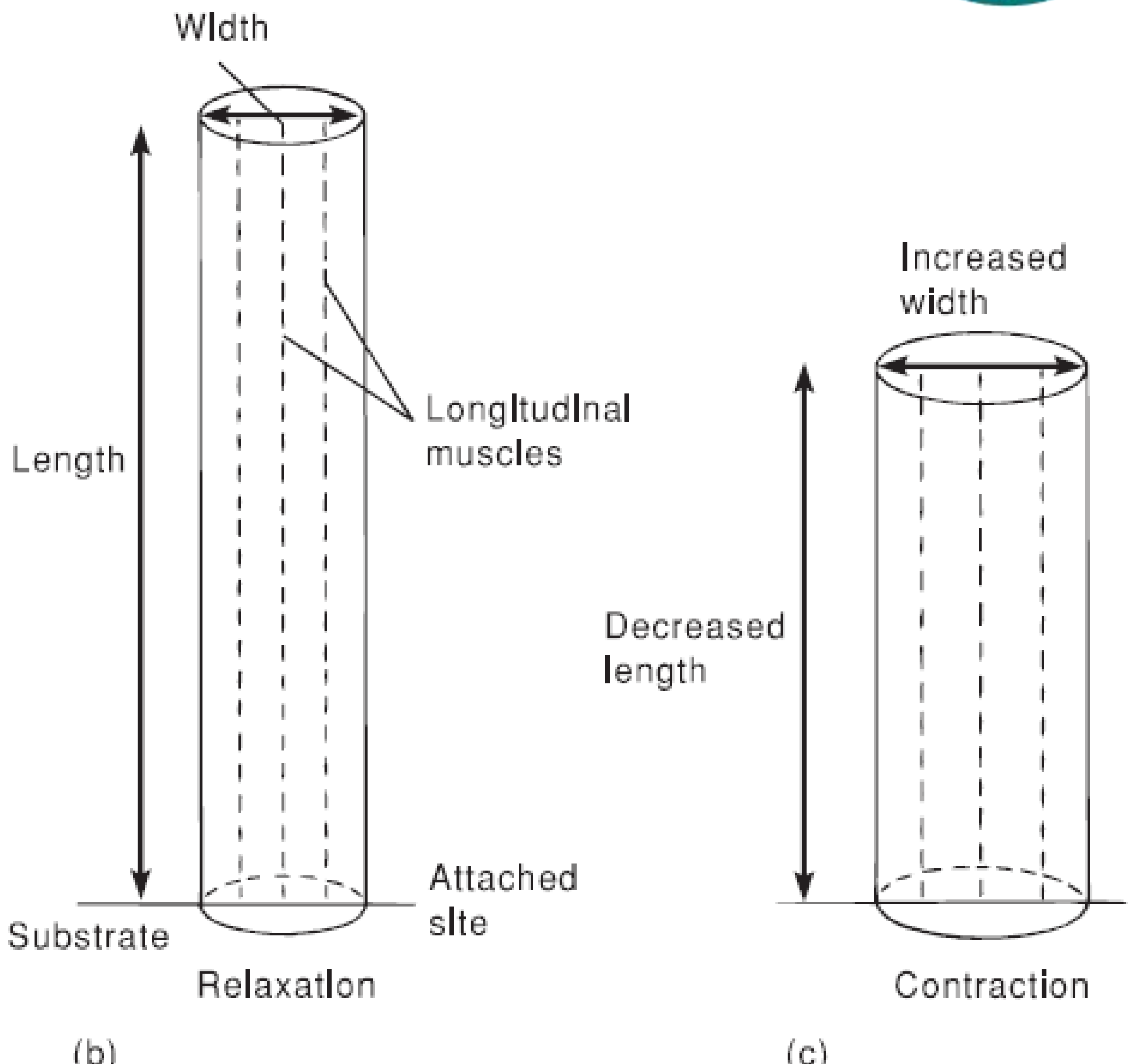
THE SKELETAL SYSTEM OF INVERTEBRATES

- The skeletal system of invertebrates is of following types.
  - Hydrostatic Skeletons
  - Exoskeleton
  - Endoskeleton
  - Mineralized Tissues and the Invertebrates

Hydrostatic Skeletons

- The hydrostatic skeleton is a core of liquid (water or a body fluid such as blood) surrounded by a tension-resistant sheath of longitudinal and /or circular muscles. It is similar to a water-filled balloon because the force exerted against the incompressible fluid in one region can be transmitted to other regions. Contracting muscles push against a hydrostatic skeleton, and the transmitted force generates body movements, as the movement of a sea anemone illustrates.
- Another example is the earthworm, Lumbricus terrestris. It contracts its longitudinal and circular muscles alternately, creating a rhythm that moves the earthworm through the soil. In both of these examples, the hydrostatic skeleton keeps the body from collapsing when its muscles contract.
- The invertebrate hydrostatic skeleton can take many forms and shapes, such as the gastrovascular cavity of acoelomates, a rhynchocoel in nemertines, a pseudocoelom in aschelminths, a coelom in annelids, or a hemocoel in molluscs. Overall, the hydrostatic skeleton of invertebrates is an excellent example of adaptation of major body functions to this simple but efficient principle of hydrodynamics—use of the internal pressure of body fluids.

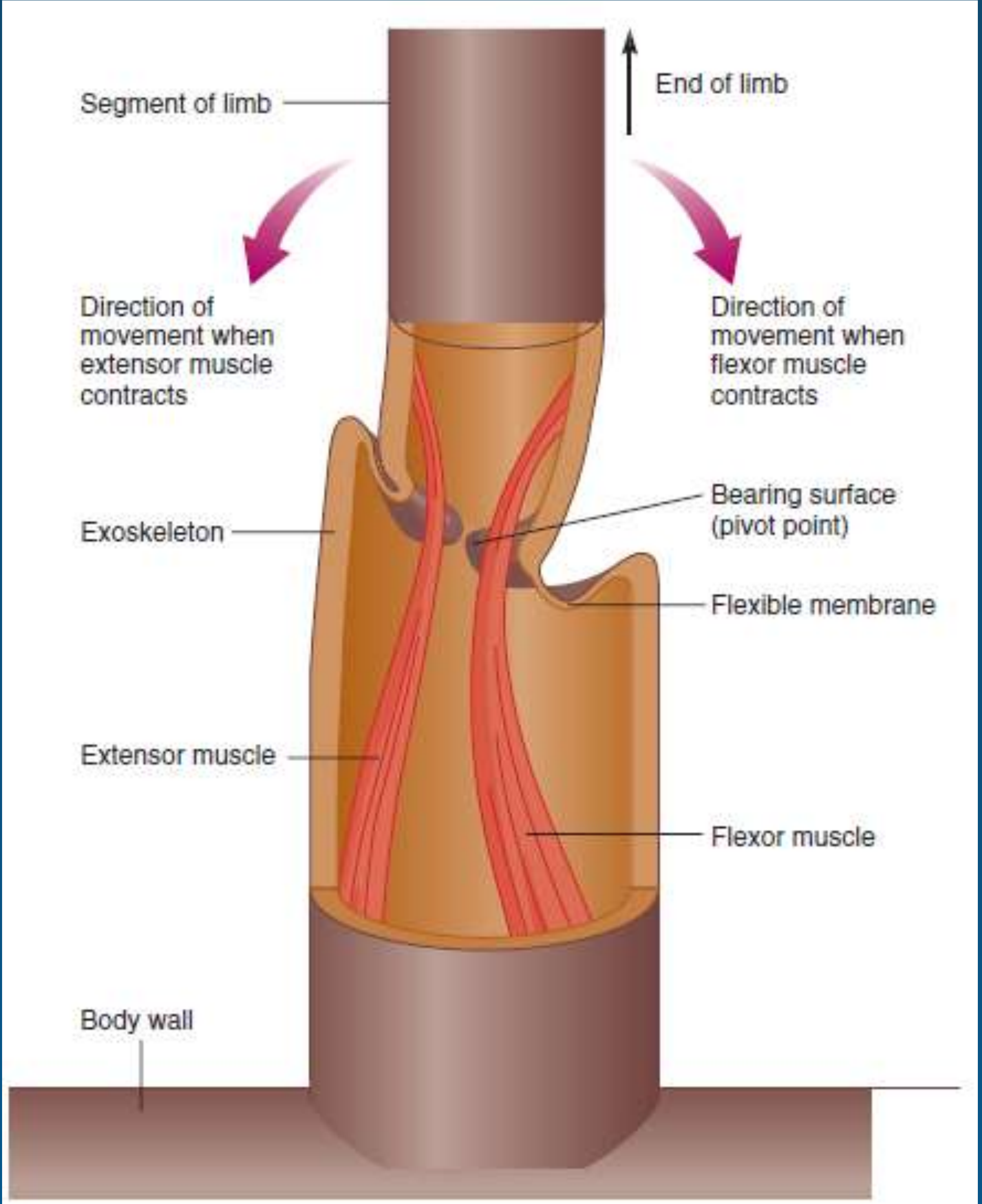

Circular muscle
Longitudinal muscle
Pressurized fluid compartment (gastrovascular cavity)
(a)


Width
Length
Longitudinal muscles
Substrate
Attached site
Relaxation
(b)
Increased width
Decreased length
Contraction
(c)

Exoskeletons

- ❖Rigid exoskeletons also have locomotor functions because they provide sites for muscle attachment and counterforces for muscle movements. Exoskeletons also support and protect the body, but these are secondary functions.
- ❖In arthropods, the epidermis of the body wall secretes a thick, hard cuticle that waterproofs the body. The cuticle also protects and supports the animal's soft internal organs.
- ❖In crustaceans (e.g., crabs, lobsters, shrimp), the exoskeleton contains calcium carbonate crystals that make it hard and inflexible— except at the joints. Besides providing shieldlike protection from enemies and resistance to general wear and tear, the exoskeleton also prevents internal tissues from drying out.

- In an arthropod, muscles attach to the interior of the exoskeleton. In this articulation of an arthropod limb, the cuticle is hardened everywhere except at the joint, where the membrane is flexible. Notice that the extensor muscle is antagonistic to (works in an opposite direction than) the flexor muscle



Endoskeletons

- Like the term implies, other body tissues enclose endoskeletons . For example, the endoskeletons of sponges consist of mineral spicules and fibers of spongin that keep the body from collapsing. Since adult sponges attach to the substrate, they have no need for muscles attached to the endoskeleton.
- Similarly, the endoskeletons of echinoderms (sea stars, sea urchins) consist of small, calcareous plates called ossicles. The most familiar endoskeletons, however, are in vertebrates and are discussed under "The Skeletal System of Vertebrates."

Mineralized Tissues and the Invertebrates

- Hard, mineralized tissues are not unique to the vertebrates. In fact, over two-thirds of the living species of animals that contain mineralized tissues are invertebrates. Most invertebrates have inorganic calcium carbonate crystals embedded in a collagen matrix.
- Cartilage is the supportive tissue that makes up the major skeletal component of some gastropods, invertebrate chordates (amphioxus), jawless fishes such as hagfishes and lampreys, and sharks and rays. Since cartilage is lighter than bone, it gives these predatory fishes the speed and agility to catch prey. It also provides buoyancy without the need for a swim bladder.

THE SKELETAL SYSTEM OF VERTEBRATES

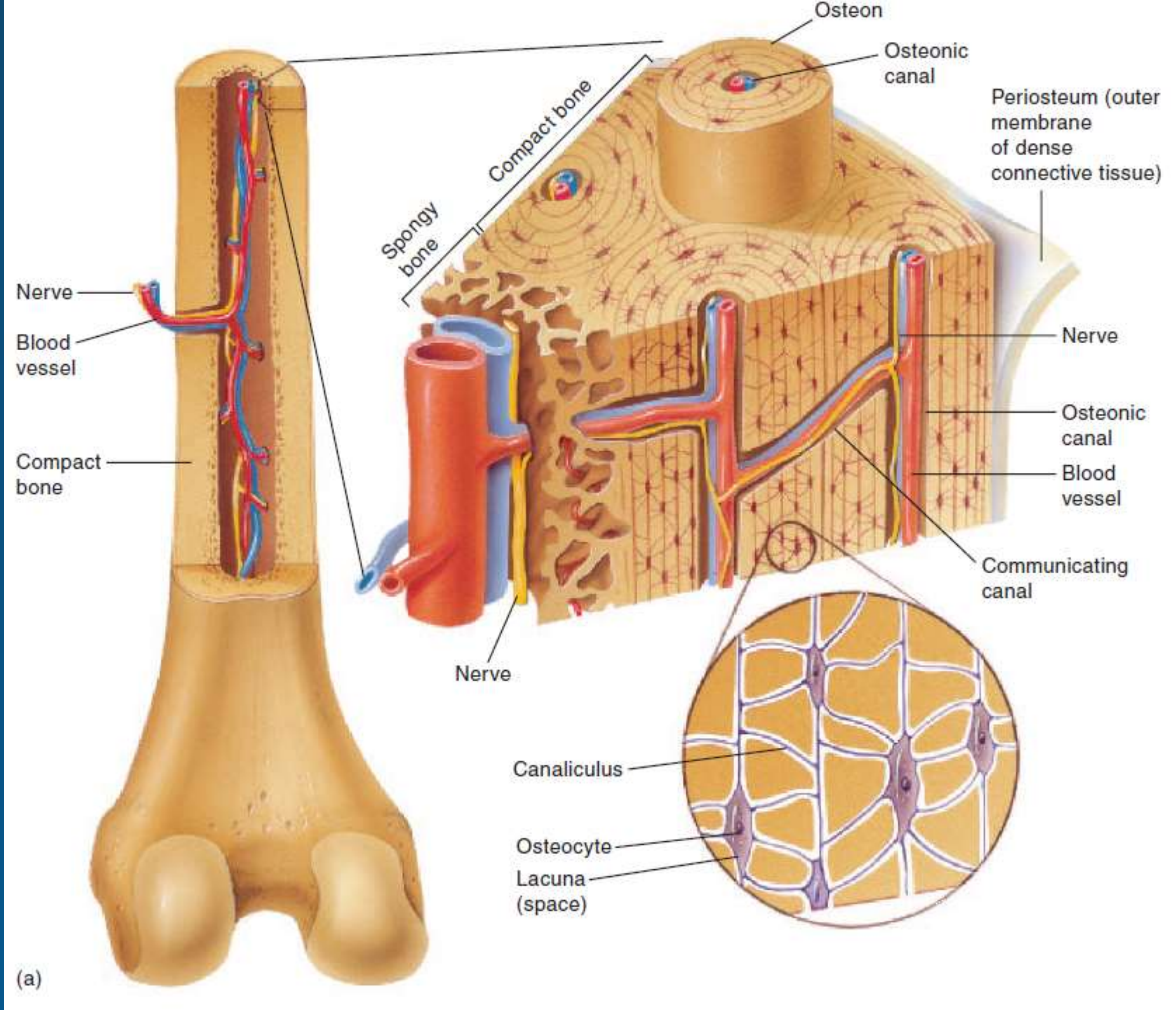
- The vertebrate skeletal system is an endoskeleton enclosed by other body tissues. This endoskeleton consists of two main types of supportive tissue: cartilage and bone.
- **Cartilage:**
- Cartilage is a specialized type of connective tissue that provides a site for muscle attachment, aids in movement at joints, and provides support. Like other connective tissues, it consists of cells (chondrocytes), fibers, and a cellular matrix.

Bone or Osseous Tissue

- Bone (osseous) tissue is a specialized connective tissue that provides a point of attachment for muscles and transmits the force of muscular contraction from one part of the body to another during movement. In addition, bones of the skeleton support the internal organs of many animals, store reserve calcium and phosphate, and manufacture red blood cells and some white blood cells.

- Bone tissue is more rigid than other connective tissues because its homogeneous, organic ground substance also contains inorganic salts—mainly calcium phosphate and calcium carbonate.

- When an animal needs the calcium or phosphate stored within bones, metabolic reactions (under endocrine control) release the required amounts.



Osteon
Osteonic canal
Periosteum (outer membrane of dense connective tissue)
Compact bone
Spongy bone
Nerve
Blood vessel
Compact bone
Nerve
Osteonic canal
Blood vessel
Communicating canal
Nerve
Canaliculus
Osteocyte
Lacuna (space)
(a)

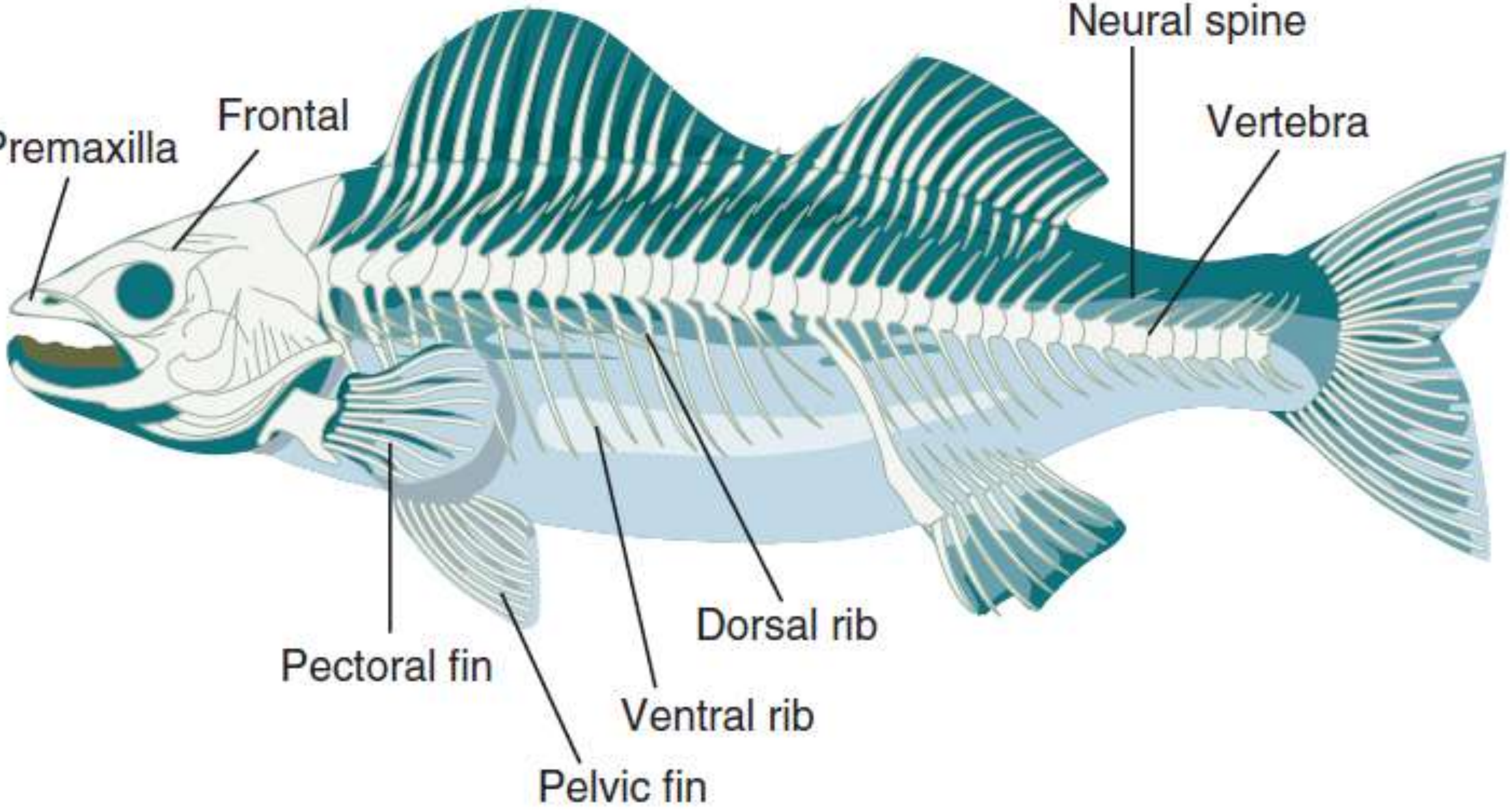
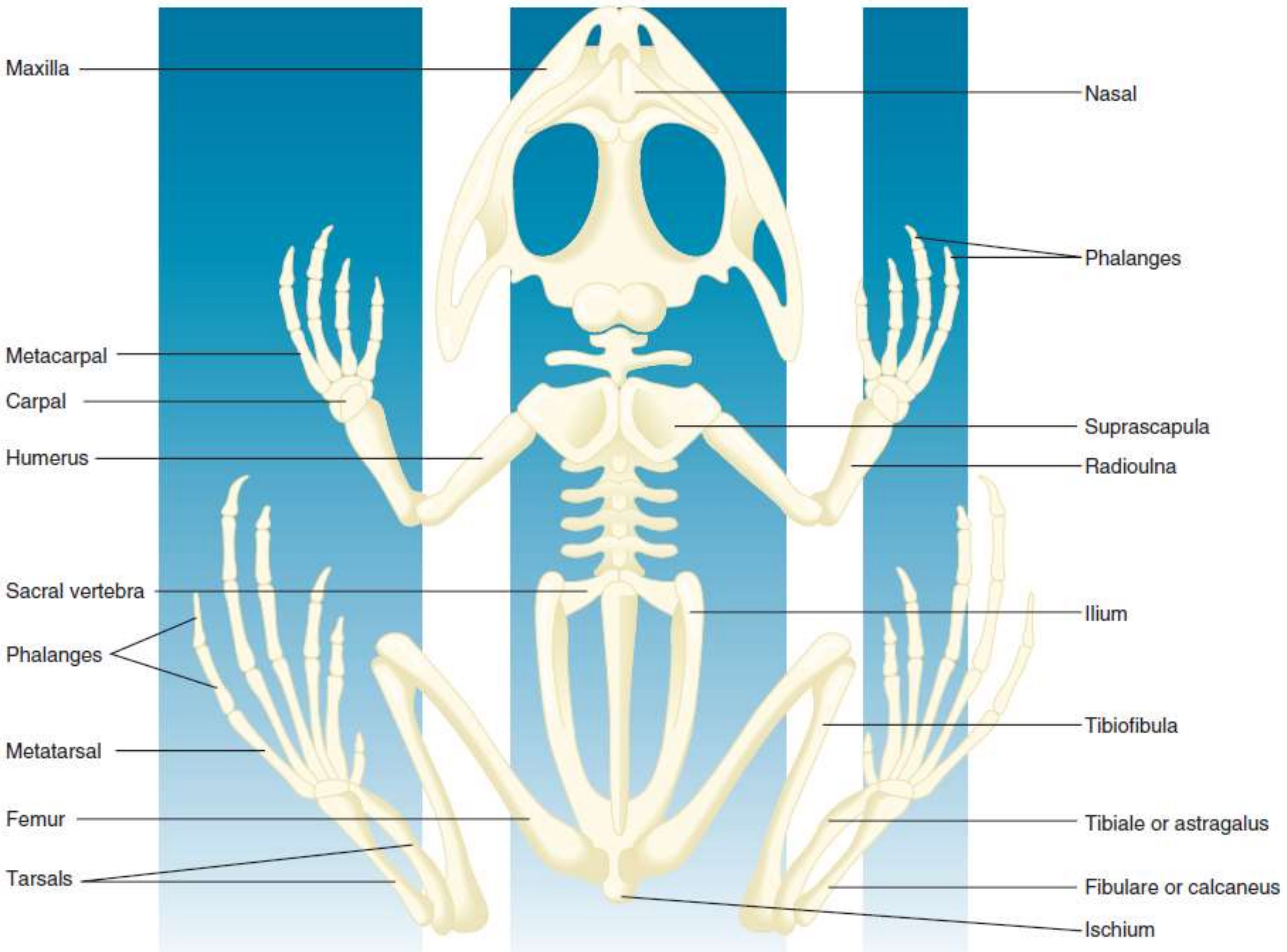


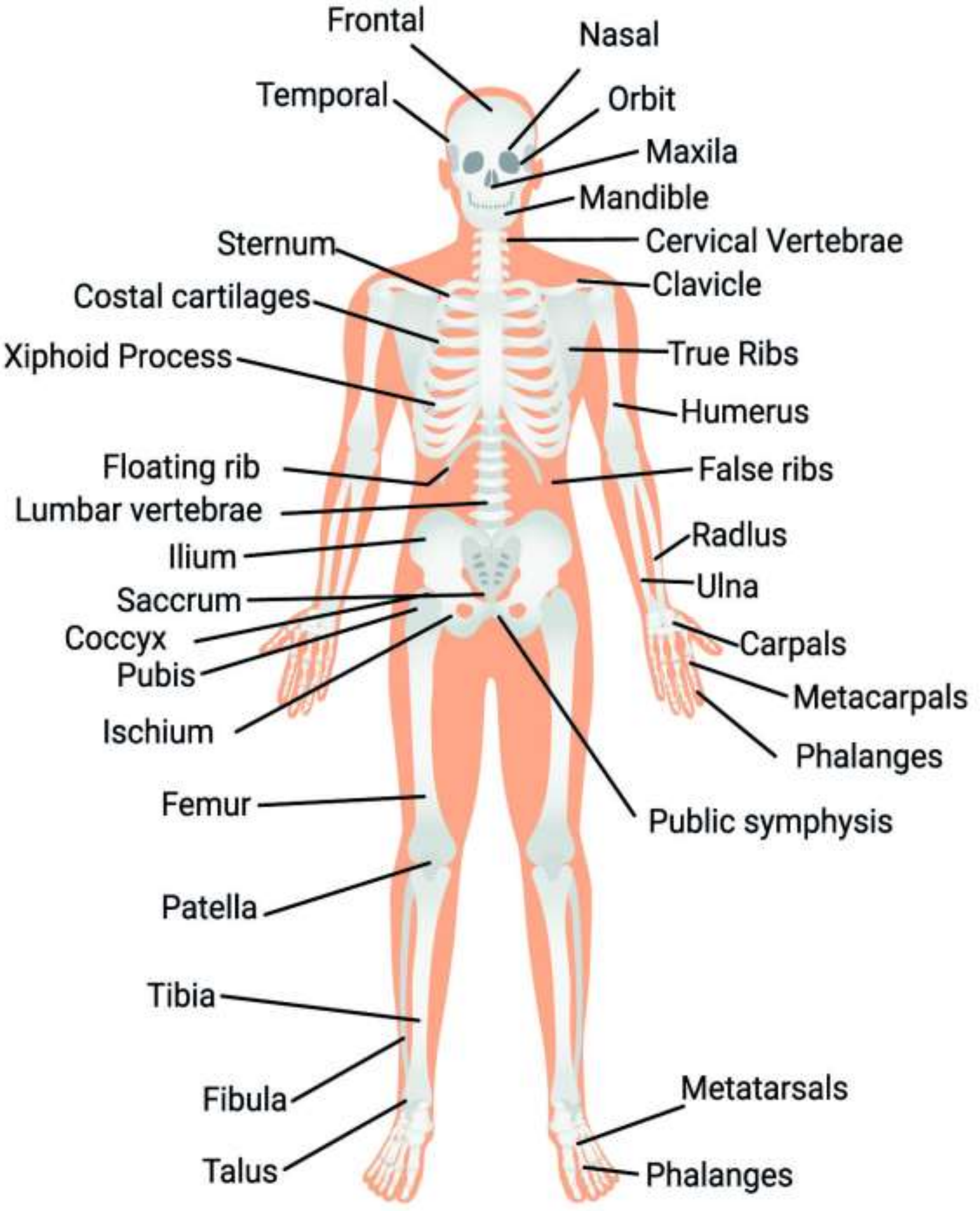
FIGURE 23.13

Fish Endoskeleton. Lateral view of the perch skeleton.


Maxilla
Nasal
Phalanges
Metacarpal
Carpal
Suprascapula
Humerus
Radioulna
Sacral vertebra
Ilium
Phalanges
Tibiofibula
Metatarsal
Femur
Tibiale or astragalus
Tarsals
Fibulare or calcaneus
Ischium

The Human Endoskeleton

❖ The human endoskeleton has two major parts: the axial skeleton and the appendicular skeleton. The axial skeleton is made up of the skull, vertebral column, sternum, and ribs. The appendicular skeleton is composed of the appendages, the pectoral girdle, and the pelvic girdles. These girdles attach the upper and lower appendages to the axial skeleton.



MOVEMENT: NONMUSCULAR MOVEMENT AND MUSCULAR SYSTEMS

- Movement is a characteristic of certain cells, protists, and animals. For example, certain white blood cells, coelomic cells, and protists such as Amoeba utilize nonmuscular amoeboid movement.
- Amoeboid movement also occurs in embryonic tissue movements, in wound healing, and in many cell types growing in tissue culture.
- Other protists and some invertebrates utilize cilia or flagella for movement. Muscles and muscle systems are found in various invertebrate groups from the primitive cnidarians to the arthropods (e.g., insect flight muscles).
- In more complex animals, the muscles attach to exo- and endoskeletal systems to form a motor system, which allows complex movements.

NONMUSCULAR MOVEMENT

- Nearly all cells have some capacity to move and change shape due to their cytoskeleton. It is from this basic framework of the cell that specialized contractile mechanisms emerged. For example, protozoan protists move by means of specific nonmuscular structures (pseudopodia, flagella, or cilia) that involve the contractile proteins, actin and myosin.

Amoeboid Movement

- As the name suggests, amoeboid movement was first observed in Amoeba. The plasma membrane of an amoeba has adhesive properties since new pseudopodia attach to the substrate as they form. The plasma membrane also seems to slide over the underlying layer of cytoplasm when an amoeba moves. The plasma membrane may be "rolling" in a way that is (roughly) analogous to a bulldozer track rolling over its wheels. A thin fluid layer between the plasma membrane and the ectoplasm may facilitate this rolling.

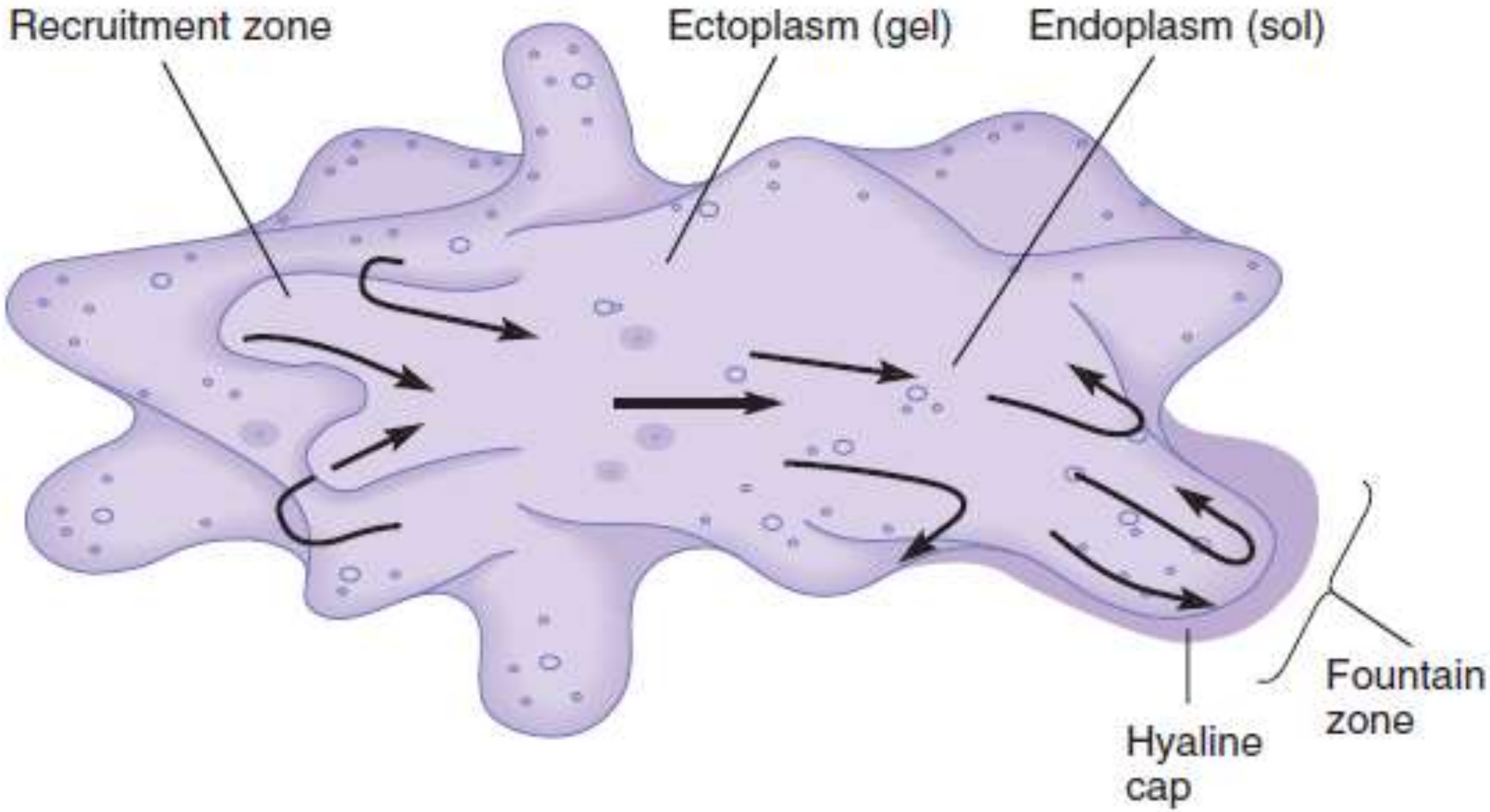


FIGURE 23.15

Mechanism of Amoeboid Movement. Endoplasm (sol) flows into an advancing pseudopodium. At the tip (fountain zone) of the pseudopodium, endoplasm changes into ectoplasm (gel). At the opposite end (recruitment zone) of the amoeba, ectoplasm changes into endoplasm and begins flowing in the direction of movement.

Ciliary and Flagellar Movement

- Cilia and flagella are similar, but cilia are shorter and more numerous, whereas flagella are long and generally occur singly or in pairs.
- Ciliary movements are coordinated. For example, in some ciliated protozoa, pairs of cilia occur in rows. Rows of cilia beat slightly out of phase with one another so that ciliary waves periodically pass over the surface of the protozoan.
- In fact, many ciliates can rapidly reverse the direction of ciliary beating, which changes the direction of the ciliary waves and the direction of movement.

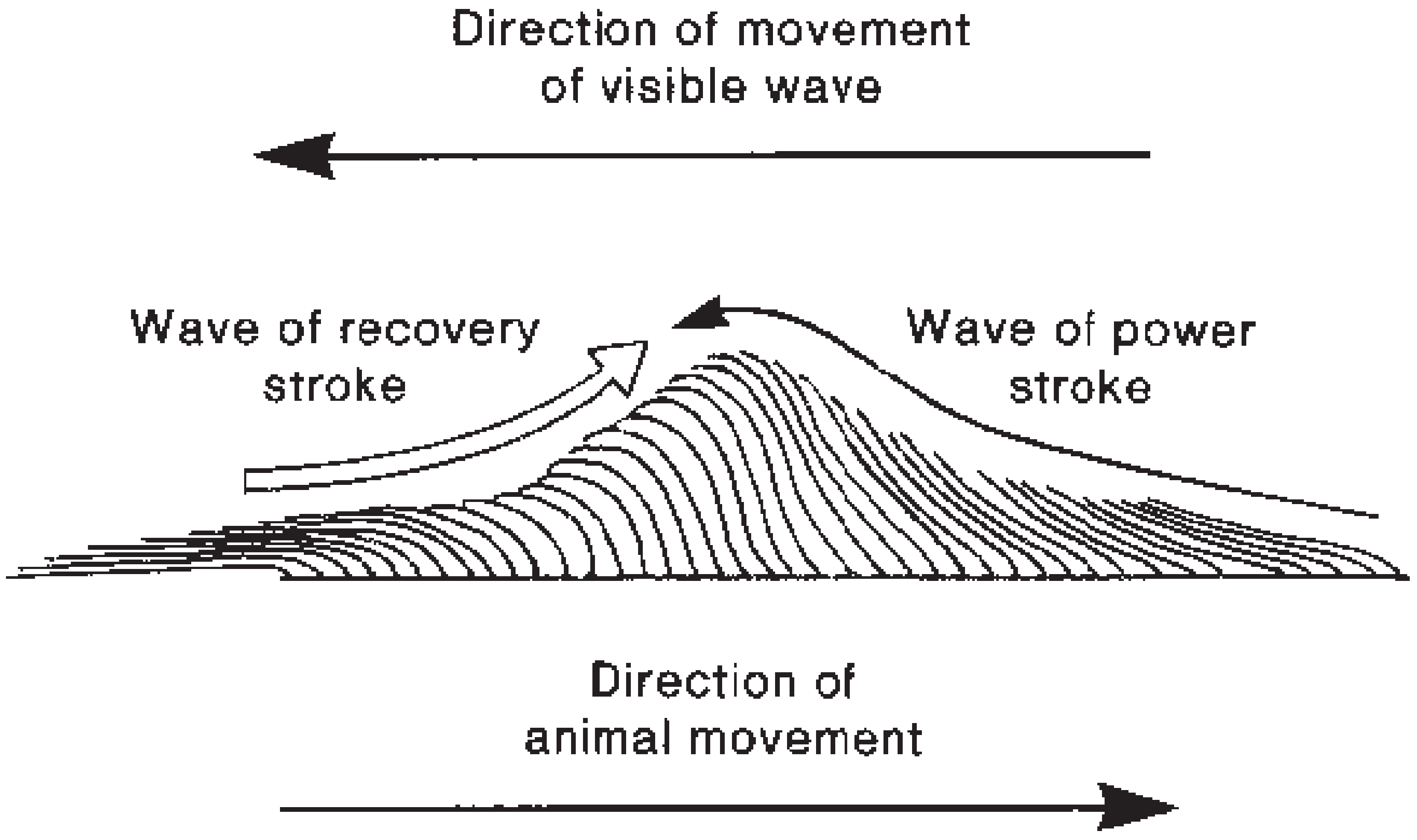


FIGURE 23.16

Ciliary Movement. A metachronal (coordinated) wave passing along a row of cilia.

ANIMAL MUSCLES

- Muscular tissue is the driving force, the power behind movement in most invertebrates and vertebrates. The basic physiological property of muscle tissue is contractility, the ability to contract or shorten. In addition, muscle tissue has three other important properties:
- (1) excitability (or irritability), the capacity to receive and respond to a stimulus;
- (2) extensibility, the ability to be stretched;
- (3) elasticity, the ability to return to its original shape after being stretched or contracted.

ANIMAL MUSCLES

- Animals may have one or more of the following types of muscle tissue: smooth, cardiac, and skeletal. The contractile cells of these tissues are called muscle fibers.
- Smooth muscle is also called involuntary muscle because higher brain centers do not control its contractions. Smooth muscle fibers have a single nucleus, are spindle shaped, and are arranged in a parallel pattern to form sheets.
- Smooth muscle maintains good tone (a normal degree of vigor and tension) even without nervous stimulation. It contracts slowly, but it can sustain prolonged contractions and does not fatigue (tire) easily.

ANIMAL MUSCLES

- Striated muscle fibers (cells) with single nuclei are common in invertebrates, but they occur in adult vertebrates only in the heart, where they are called cardiac muscle. Cardiac muscle fibers are involuntary, have a single nucleus, are striated (have dark and light bands), and are branched. This branching allows the fibers to interlock for greater strength during contraction.
- Hearts do not fatigue because cardiac fibers relax completely between contractions.

ANIMAL MUSCLES

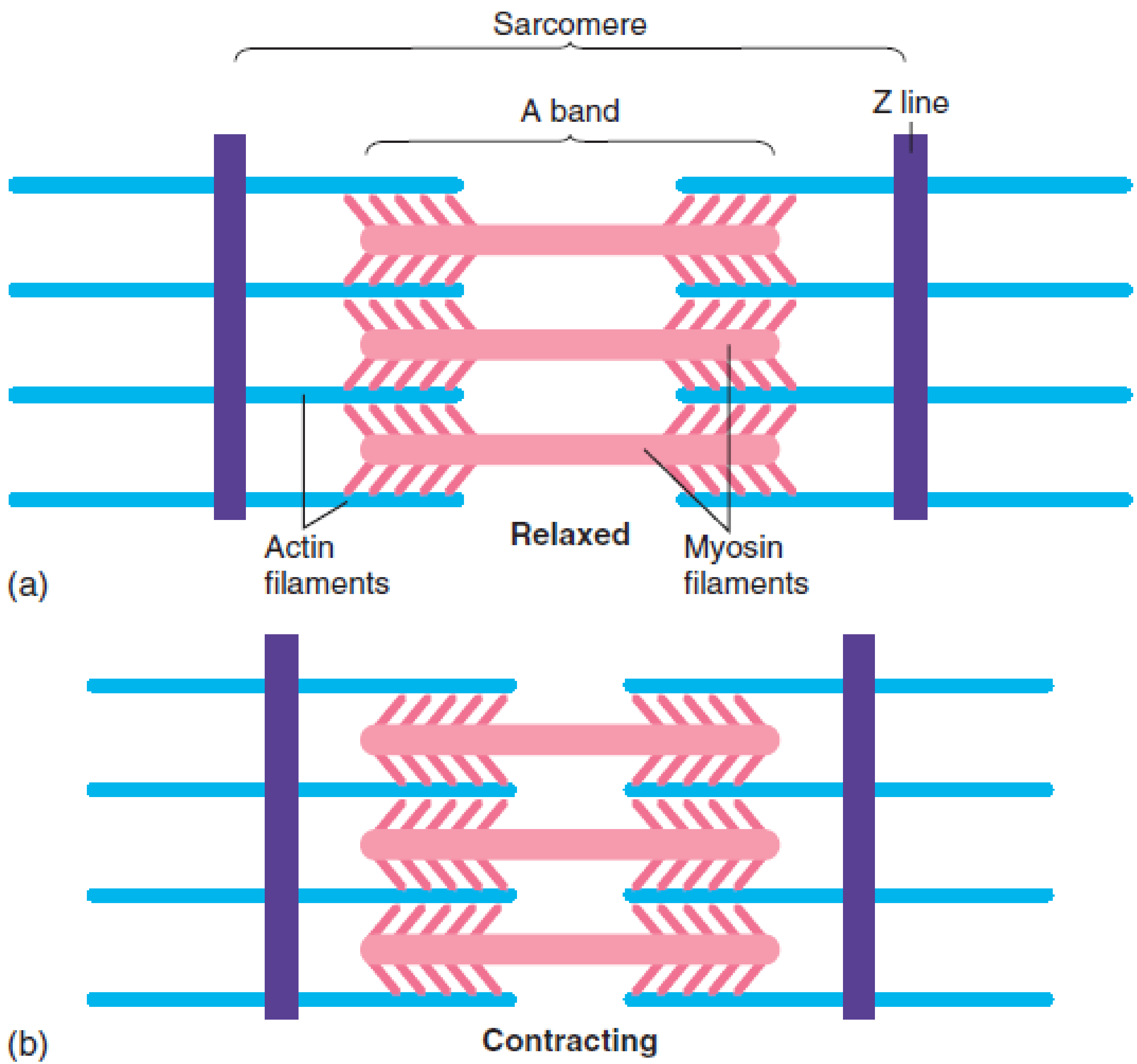
- Skeletal muscle, also a striated muscle, is a voluntary muscle because the nervous system consciously controls its contractions.
- Skeletal muscle fibers are multinucleated and striated. Skeletal muscles attach to skeletons. When skeletal muscles contract, they shorten.
- Thus, muscles can only pull; they cannot push. Therefore, skeletal muscles work in antagonistic pairs. For example, one muscle of a pair bends (flexes) a joint and brings a limb close to the body. The other member of the pair straightens (extends) the joint and extends the limb away from the body

THE MUSCULAR SYSTEM OF INVERTEBRATES

- The Locomotion of Soft-Bodied Invertebrates
- Terrestrial Locomotion in Invertebrates: Walking
- Terrestrial Locomotion in Invertebrates: Flight
- Terrestrial Locomotion in Invertebrates: Jumping

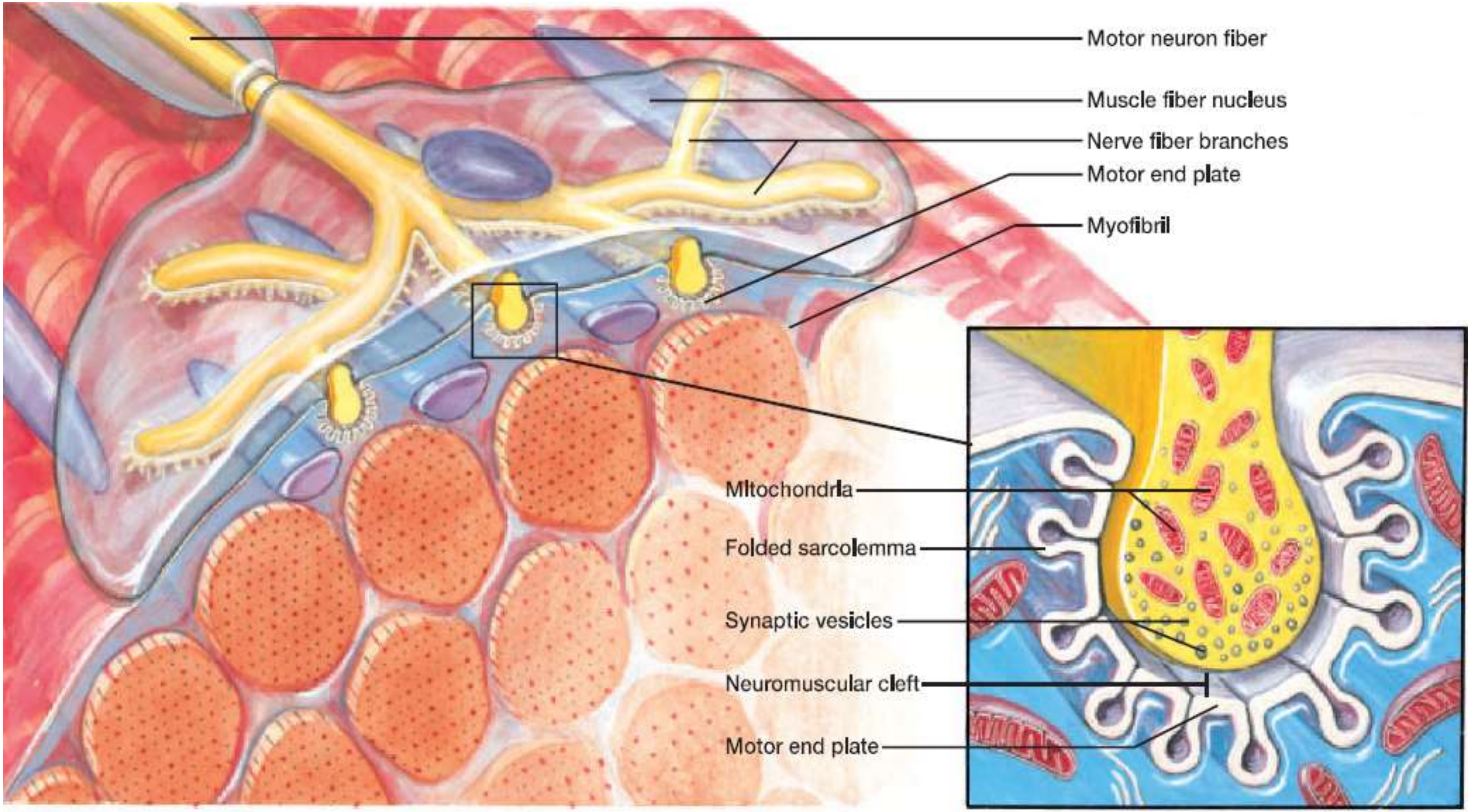
THE MUSCULAR SYSTEM OF VERTEBRATES

- The vertebrate endoskeleton provides sites for skeletal muscles to attach. Tendons, which are tough, fibrous bands or cords, attach skeletal muscles to the skeleton.
- Most of the musculature of fishes consists of segmental myomeres. Myomere segments cause the lateral undulations of the trunk and tail that produce fish locomotion.
- The transition from water to land entailed changes in the body musculature. As previously noted, the appendages became increasingly important in locomotion, and movements of the trunk became less important. The segmental nature of the myomeres in the trunk muscles was lost. Back muscles became more numerous and powerful.


Sarcomere
A band
Z line
Actin filaments
Relaxed
Myosin filaments
(a)
(b)
Contracting

Skeletal Muscle Contraction

- When observed with the light microscope, each skeletal muscle fiber (cell) has a pattern of alternate dark and light bands. This striation of whole fibers arises from the alternating dark and light bands of the many smaller, threadlike myofibrils in each muscle fiber. Electron microscopy and biochemical analysis show that these bands are due to the placement of the muscle proteins actin and myosin within the myofibrils. Myosin occurs as thick filaments and actin as thin filaments. The lightest region of a myofibril (the I band) contains only actin, whereas the darkest sregion (the A band) contains both actin and myosin.


Motor neuron fiber
Muscle fiber nucleus
Nerve fiber branches
Motor end plate
Myofibril
Mitochondria
Folded sarcolemma
Synaptic vesicles
Neuromuscular cleft
Motor end plate

Control of Muscle Contraction

- When a motor nerve conducts nerve impulses to skeletal muscle fibers, the fibers are stimulated to contract via a motor unit.
- A motor unit consists of one motor nerve fiber and all the muscle fibers with which it communicates. A space separates the specialized end of the motor nerve fiber from the membrane (sarcolemma) of the muscle fiber. The motor end plate is the specialized portion of the sarcolemma of a muscle fiber surrounding the terminal end of the nerve. This arrangement of structures is called a neuromuscular junction or cleft.

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- When nerve impulses reach the ends of the nerve fiber branches, synaptic vesicles in the nerve ending release a chemical called acetylcholine. Acetylcholine diffuses across the neuromuscular cleft between the nerve ending and the muscle-fiber sarcolemma and binds with acetylcholine receptors on the sarcolemma.
- The sarcolemma is normally polarized; the outside is positive, and the inside is negative. When acetylcholine binds to the receptors, ions are redistributed on both sides of the membrane, and the polarity is altered. This altered polarity flows in a wavelike progression into the muscle fiber by conducting paths called transverse tubules. Associated with the transverse tubules is the endoplasmic reticulum of muscle cells, called sarcoplasmic reticulum.

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- The altered polarity of the transverse tubules causes the sarcoplasmic reticulum to release calcium ions (Ca2+), which diffuse into the cytoplasm. The calcium then binds with a regulatory protein called troponin that is on another protein called tropomyosin. This binding exposes the myosin binding sites on the actin molecule that tropomyosin had blocked. Once the binding sites are open, the myosin filament can form cross-bridges with actin, and power strokes of cross-bridges result in filament sliding and muscular contraction.
- Relaxation follows contraction. During relaxation, an active transport system pumps calcium back into the sarcoplasmic reticulum for storage. By controlling the nerve impulses that reach the sarcoplasmic reticulum, the nervous system controls Ca2+ levels in skeletal muscle tissue, thereby exerting control over contraction.

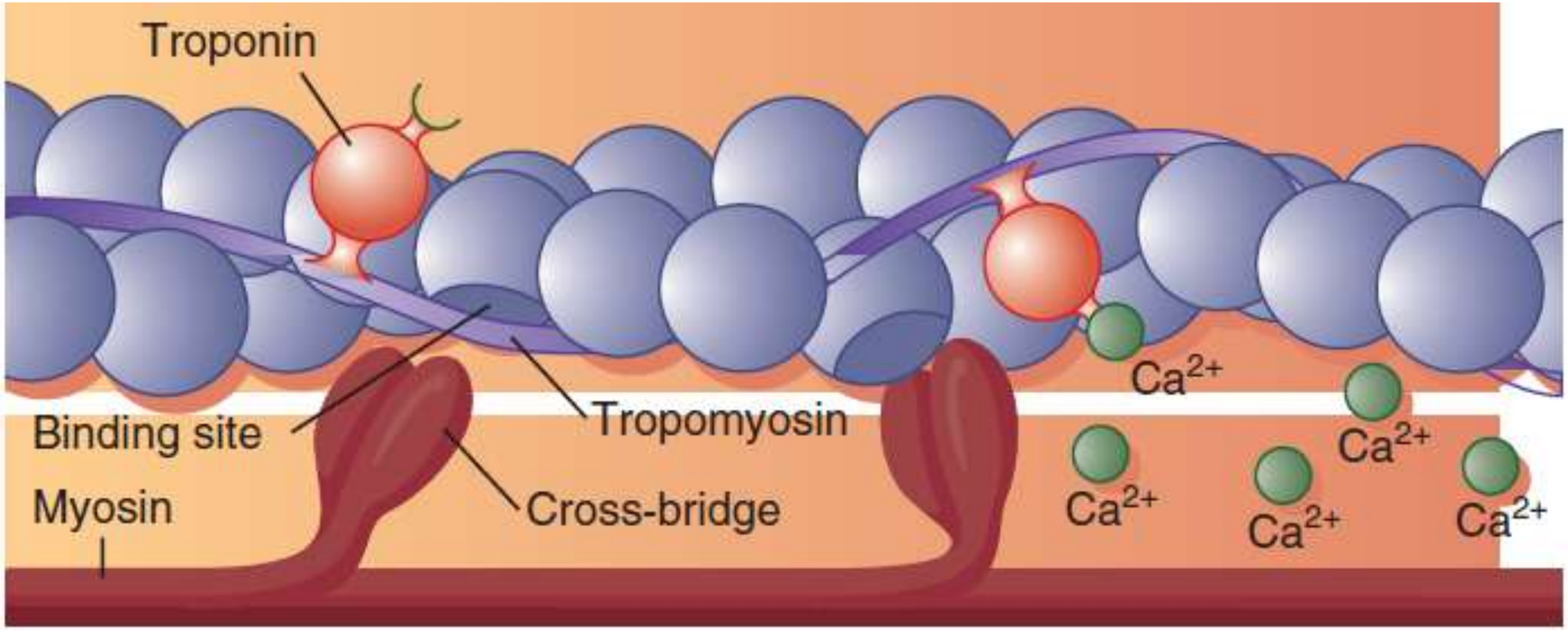

FIGURE 23.28

Model of the Calcium-Induced Changes in Troponin that Allow Cross-Bridges to Form between Actin and Myosin. The attachment of $Ca2^+$ to troponin moves the troponin-tropomyosin complex, which exposes a binding site on the actin. The myosin cross-bridge can then attach to actin and undergo a power stroke.

Thank You!