CHAPTER 20

Unifying Concepts of Animal Structure and Function

Objectives

Introduction Explain how geckos are able to walk on walls and ceilings.

The Hierarchy of Structural Organization in an Animal

20.1 Explain how the structure of a bird is adapted for flight.
20.2 Describe the levels of organization in an animal's body.
20.3 Define a tissue and list the four animal tissue types.
20.4–20.7 Describe the four main tissues, noting their structures and their functions.
20.8 Describe the structure of organs.
20.9 Describe the general structures and functions of the twelve major organ systems in vertebrate animals.
20.10 Compare the advantages and disadvantages of X-ray, CT, MRI, MRM, and PET imaging technologies.

Exchanges with the External Environment

20.11 Describe the systems that help exchange materials between an animal and its environment.
20.12 Define the concept of homeostasis.
20.13 Explain how thermoregulation is an example of homeostasis.

Key Terms

anatomy
physiology
tissue
epithelial tissue
epithelium
basement membrane
mucous membrane
connective tissue
loose connective tissue
adipose tissue
blood
fibrous connective tissue
cartilage
bone
muscle tissue
skeletal muscle
cardiac muscle
smooth muscle
nervous tissue
neuron
organ
organ system
digestive system
respiratory system
circulatory system
lymphatic system
immune system
excretory system
endocrine system
reproductive system
nervous system
muscular system
skeletal system
integumentary system
interstitial fluid
homeostasis
negative feedback

Word Roots

ecto- = outside; **-therm** = heat (*ectothermic:* organisms that do not produce enough metabolic heat to have much effect on body temperature)

endo- = inside (*endothermic:* organisms with bodies that are warmed by heat generated by metabolism; this heat is usually used to maintain a relatively stable body temperature higher than that of the external environment)

fibro- = a fiber (*fibrous connective tissue:* a dense tissue with large numbers of collagenous fibers organized into parallel bundles)

homeo- = same; **-stasis** = standing, posture (*homeostasis:* the steady-state physiological condition of the body)

inter- = between (*interstitial fluid:* the internal environment of vertebrates, consisting of the fluid filling the space between cells)

Lecture Outline

Introduction *Climbing the Walls*

A. Each animal species is an accumulation of different structural and functional adaptations to life in its particular environment.

B. This is particularly evident when one studies animals in extreme environments or with unique adaptations such as the gecko (chapter-opening photo).

1. Most vertebrates cannot walk up a wall or on a ceiling, so how does a gecko accomplish this "feat"?
2. Much discussion went in to speculating how geckos walk on ceilings but it wasn't until a team of scientists and engineers examined the feet carefully that the answer became clear.
3. The pictures illustrate specialized structures (setae and spatulae) at the end of each toe that allow the unique walking function. The answer can be found at the molecular level and is due to attractions between a special protein, keratin, and a force called the van der Waals force (see Chapter 3).

C. This chapter introduces the unit on animals. Each succeeding chapter examines how animals meet needs like nutrition, obtaining and distributing oxygen, responding to stimuli, waste removal, movement, and reproduction.

D. In this chapter, the general, overall body organization is discussed: cells to tissues to organs to organ systems.

I. The Hierarchy of Structural Organization in an Animal

Module 20.1 Structure fits function in the animal body.

A. **Anatomy** and **physiology** are the studies of structure and function, respectively.

B. Feathers are dead protein called keratin (just like the keratin at the ends of gecko toes) formed into complex three-dimensional structures by special pits in a bird's skin. These form airfoils (Figure 20.1).
Review: Birds' feathers are derived from scales (Module 18.21).

C. The bones of a bird's wing are homologous with those of the human arm (Module 15.11) but have been modified for flight. A bird's bones are reduced in number and motility, allowing the wing to function as a unit, and they are hollow but strongly reinforced, to reduce weight.

D. Flight muscles sit below the bird, mostly off the wings, so the wings do not have to work hard to move the weight. This position also provides balance.
NOTE: The bones of the wings of birds and bats are homologous, following the typical tetrapod pattern. Bird flight and bat flight are analogous. Contrast how bats, mammals that developed independently of birds, fly with how birds fly. The power stroke of birds, a downward stroke, uses only the pectoralis major muscle. In contrast, bats have four power stroke muscles, the pectoralis major and three other muscles.

Module 20.2 Animal structure has a hierarchy.

A. *Review:* Hierarchy of organization (Module 1.1; Figure 1.1).

B. There is even a hierarchy of structure in a feather, from the molecules of keratin, to the arrangements of keratin in the feather's parts (shaft, barbs, and barbules), to the arrangement of these parts into the whole feather (Figure 20.1).
NOTE: There are genetic advantages in building structures by repeating parts. Recall the advantages of segmentation in animal evolution (Module 18.10).

C. In the whole animal, the hierarchy of structure is as follows: cells, tissues (cooperating cells), organs (cooperating tissues), organ systems (cooperating organs), organism (cooperating organ systems) (Figure 20.2).

Module 20.3 Tissues are groups of cells with a common structure and function.

A. *Review:* Animal cell junctions (Module 4.19; Figure 4.19B).

B. The cells composing a **tissue** (from the Latin word for "weave") are specialized: Their particular structure enables them to perform their particular function.

C. Cells in tissues are held together, within the context of the nonliving material they organize, with sticky glue that coats the cells or with special membrane junctions.

D. There are four major categories of tissue: epithelial, connective, muscle, and nervous.

Module 20.4 Epithelial tissue covers and lines the body and its parts.

NOTE: Epithelial tissue is avascular.

A. **Epithelial tissue** occurs as sheets of closely packed cells. One "free" surface forms barriers or exchange surfaces; the other surface is attached to underlying tissues by a **basement membrane.**
Review: The attachment to the underlying basement membrane is accomplished by a type of anchoring junction (illustrated, but not labeled, in Figure 4.19B).

B. Tissues are categorized according to the number of cell layers and the shape of the individual cells (Figure 20.4A–D). Simple **epithelium** consists of a single layer of cells and stratified epithelium consists of multiple layers of cells. Cells may be squamous, cuboidal, or columnar in shape.
NOTE: A third type of layering is pseudostratified; as the name implies, it consists of a single layer of cells that give the impression of being layered. Some epithelium consists of transitional cells, which do not maintain a single shape.

C. The structure of each type of epithelium fits its function.

D. Stratified squamous epithelium regenerates rapidly by division of the cells at its attached surface; it covers surfaces that are subject to abrasion, such as the epidermis and the lining of the esophagus.

E. Simple squamous epithelium is thin and leaky, suitable for the exchange of materials by diffusion; it lines our lungs and blood vessels.
Preview: The lungs, a component of the respiratory system, are discussed in Chapter 22.

F. Cuboidal epithelium and columnar epithelium have large cells that make secretory products and form large, often folded, surface areas. They line the digestive tract and air tubes, where they form a moist epithelium, a **mucous membrane.**

G. The mucous membranes of air tubes are important for keeping debris out of the lungs. Particles get trapped in the mucoid secretions, and cilia beat them up and out of the air tubes.
NOTE: Smoking paralyzes cilia and thus allows debris to reach the lungs that would otherwise be trapped and removed. Further, the paralysis of cilia in the oviducts probably contributes to the higher incidence of ectopic pregnancies among smokers.

Module 20.5 Connective tissue binds and supports other tissues.

A. There are six connective tissue types that consist of a sparse population of cells scattered in a nonliving matrix that is synthesized by the cells.
NOTE: **Connective tissue** contains three fiber types. Collagen fibers provide strength, elastic fibers resilience, and reticular fibers a supportive network. The function of a given connective tissue can be deduced from the relative abundance of each of these types of fiber.

B. **Loose connective tissue** is a loose weave of the protein collagen; it holds many other tissues and organs in place (Figure 20.5A).
NOTE: There are several types of loose connective tissue: areolar connective tissue, adipose tissue, and reticular connective tissue. If one of these is not specified, and you cannot tell from the context, it is often areolar connective tissue that is being referred to.

C. **Adipose tissue** contains fat stored in closely packed adipose cells that are used to pad and insulate the body and store energy (Figure 20.5B).

D. **Blood** has a fluid matrix (plasma, consisting of water, salts, and proteins) and red and white blood cells. It functions in transport and immunity (Figure 20.5C).
Preview: Blood, a component of the circulatory system, is discussed in more detail in Chapter 23. Immunity is discussed in greater detail in Chapter 24.

E. **Fibrous connective tissue** consists of densely packed collagen fibers that form tendons (muscles to bone) and ligaments (bone to bone) (Figure 20.5D).
NOTE: The type of fibrous connective tissue discussed here is dense regular connective tissue. Another type, dense irregular connective tissue, is found (for example) in the deeper (reticular) layer of the dermis. As their names imply, a difference between the two is the regular versus scattered arrangement of collagen fibers.

F. **Cartilage** is strong but flexible skeletal material with collagen fibers embedded in a rubbery matrix (Figure 20.5E).
NOTE: There are three types of cartilage. Hyaline cartilage (e.g., embryonic skeleton), elastic cartilage (e.g., outer ear) and fibrocartilage (e.g., intervertebral discs).

G. **Bone** is rigid tissue made of collagen fibers embedded in calcium salts (Figure 20.5F).
Preview: Bone tissue is discussed in more detail in Modules 30.3 and 30.5.

Module 20.6 Muscle tissue functions in movement.

Preview: Skeletal muscle is discussed in more detail in Modules 30.7–30.10.

A. **Muscle tissue** consists of bundles of long muscle cells (muscle fibers) and is the most abundant tissue in most animals (Figure 20.6).

B. **Skeletal muscle** is attached to bones by tendons and is responsible for voluntary movement. Its cells are multinucleate, striated, and unbranched.

C. **Cardiac muscle** causes the involuntary contractions of the heart. Its cells are striated and branched.

D. **Smooth muscle** is found in the walls of the digestive tract, urinary bladder, and arteries. Its cells are unstriated, spindle-shaped, and cause slow, but strong, involuntary movements.

Module 20.7 Nervous tissue forms a communication network.

Preview: The nervous system is discussed in more detail in Chapters 28 and 29.

A. The nervous system functions to relay information regarding the internal and external environments and to relay information from one part of the body to another.
NOTE: The nervous system and the endocrine system (Chapter 26) are the control and communication systems of the body. The difference is that the nervous system acts more rapidly than the endocrine system, and the effects of nervous system activity are not as long-lasting as those of the endocrine system.

B. **Nervous tissue** consists of interconnected **neurons,** cells specialized to conduct nerve signals, and other cells that support the neurons. They function in transmitting sensory signals and in coordinating internal events (Figure 20.7).

C. Each neuron has a cell body, dendrites that transfer messages to the cell body, and axons that transfer messages away from the cell body (Figure 28.2).

D. Between neurons, signals are transferred by the diffusion of chemicals.

Module 20.8 Several tissues are organized to form an organ.

A. All animals except sponges have some organs.
Review: Sponges are discussed in greater detail in Module 18.3.

B. **Organs** consist of several tissues adapted to perform specific functions as a group. They perform functions that none of the component tissues can perform alone.

C. The heart consists of muscle (the major portion, providing the contractile, pumping force), epithelial tissue (providing a smooth, low-friction inner surface), connective tissue (tying all the tissues together into a strong, elastic structure), and nervous tissue (directing the contractions).

D. The stomach consists of muscle tissue (smooth muscle churns and moves the food), epithelial tissue (secretes digestive juices and protects other tissues from the juices' enzymatic functions), and connective tissue (binds all into an elastic structure that surrounds the lumen) (Figure 20.8). There are a few nerves to sense and regulate its function.

Module 20.9 The body is a cooperative of organ systems.

A. An **organ system** is a group of several organs that work together to perform a vital body function.

B. In vertebrates, there are twelve organ systems. Each one is introduced below, followed by the chapter in which it is covered.

C. **Digestive system.** Organs of the digestive tract ingest food, break it down into smaller chemical units, absorb these units, and eliminate the unused parts (Chapter 21; Figure 20.9A).

D. **Respiratory system.** The lungs and associated breathing tubes exchange gases with the environment (Chapter 22; Figure 20.9B).

E. **Circulatory system.** The heart and blood vessels supply nutrients and O_2 to the body and carry away wastes and CO_2 (Chapter 23; Figure 20.9C).

F. **Lymphatic and immune systems.** Lymph vessels and nodes supplement the work of the cardiovascular system, particularly as components of the immune system, a diffuse system of cells (including lymphocytes and macrophages, both of which are types of white blood cells) and processes that protect the body from foreign invasion (Chapter 24; Figure 20.9D). The lymphatic system supplements the function of the circulatory system. Lymph fluid that has leaked out of blood vessels and into the tissue is returned to the blood by the lymph vessels.

G. **Excretory system.** The kidneys, bladder, and urethra remove nitrogen-containing wastes from the blood and maintain osmotic balance (Chapter 25; Figure 20.9E).

H. **Endocrine system.** The endocrine glands secrete hormones into the blood that regulate most other activities (Chapter 26; Figure 20.9F).

I. **Reproductive systems.** There are two separate systems, one in females and one in males. Ovaries and testes and associated organs produce female and male gametes, and help in fertilization and embryo development (Chapter 27; Figure 20.9G).

J. **Nervous system.** The brain, spinal cord, nerves, and sense organs work together with the endocrine system to sense the outside environment, affect responses, and coordinate body activities (Chapters 28 and 29; Figure 20.9H).

K. **Muscular system.** All skeletal muscles provide movement as they work with the skeletal system (Chapter 30; Figure 20.9I).

L. **Skeletal system.** Bones and cartilage provide support and protection, and work with the muscular system to provide movement (Chapter 30; Figure 20.9J).

M. **Integumentary system.** Skin, hair, and nails protect the internal body parts from mechanical injury, infection, extreme temperatures, and drying out (Figure 8.11B and Figure 20.9J).

Module 20.10 Connection: New imaging technology reveals the inner body.

A. X-rays show shadows of hard structures but fail to image soft tissues; X-rays produce flat, two-dimensional images.

B. Computerized tomography (CT) uses computers to combine the images produced by many weak X-ray sources. This technology can detect small differences between normal and abnormal tissues in many organs (Figure 20.10A, B). A modified version of the CT scanner is the ultrafast CT that shows actual movements and volumes of the organs. This technique is very useful for the detection of heart disease.

C. Magnetic resonance imaging (MRI) measures changes in the magnetic signal when the hydrogen atoms in living materials are excited. MRI images soft tissues extremely well. A powerful application of MRI is MRM (magnetic resonance microscopy), which can create 3-D images of very small structures (Figure 20.10C). Functional MRI can track small changes in blood flow within the brain.

D. Positron-emission tomography (PET) yields information about metabolic processes by imaging the pattern of radioactivity from isotope-labeled glucose or other metabolic precursors. PET is most valuable for measuring metabolic activity in the brain (Figure 20.10D).

II. Exchanges with the External Environment

Module 20.11 Structural adaptations enhance exchange between animals and their environment.

A. Animals are not closed systems; from the cellular through the organismal level of organization they must obtain materials from the outside environment and excrete metabolic wastes into that same environment.

B. In simple animals with gastrovascular cavities (cnidarians and flatworms, Modules 18.4 and 18.6), virtually every cell has a plasma membrane exposed directly to an aqueous environment (Figure 20.11A).

C. Most other animals have relatively smaller outer surfaces compared to their volumes. They rely on specialized, inner surfaces for the exchange of materials (Figure 20.11B).

D. Surface areas of the lungs (Figure 20.11C), intestines, and kidneys provide for the exchange of materials between the outer environment and the blood. Bodies with greater numbers of cells to be serviced have correspondingly larger total surfaces of exchange.

E. The **interstitial fluid** mediates the exchange of materials between the blood and the body's inner cells.

Module 20.12 Animals regulate their internal environment.

A. **Homeostasis** is the maintenance of an organism's steady state in the face of environmental fluctuations (Figure 20.12B).
NOTE: The term "steady state" should not be taken to mean unchanging. Homeostasis maintains the body in a dynamic equilibrium.
Preview: The classic example of homeostasis is the regulation of blood sugar levels. After a meal, when blood sugar levels rise, the body releases insulin to lower blood sugar levels. Between meals, when blood sugar levels have fallen, the body releases glucagon to stimulate the release of sugar into the blood (Module 26.8).

B. An animal's homeostatic control systems maintain internal conditions within a range where life's metabolic processes can occur.

C. For example, our bodies maintain salt and water balance and also keep our internal fluids at about 37°C.

Module 20.13 Homeostasis depends on negative feedback.

A. A thermostat uses **negative feedback** control to keep the room temperature constant. When a sensor falls below a set temperature, the heat turns on. When the sensor rises above that point, the heat turns off (Figure 20.13A).
Review: Negative feedback with regard to cell metabolism is discussed in Module 5.8.

B. Maintenance of blood temperature in mammals (and most homeostatic mechanisms) functions by negative feedback. The brain's hypothalamus senses temperature and raises or lowers body temperature by sending nervous signals to two sets of structures in the skin: sweat glands and blood vessel networks (Figure 20.13B).
Preview: Thermoregulation (Module 25.2) and thermoreceptors (Module 29.3).
NOTE: Positive feedback mechanisms also have a role in homeostasis. Labor (Module 27.18) and blood clotting (Module 23.16) are regulated by positive feedback mechanisms.

Class Activities

1. Throughout this unit, the projection of material onto a monitor to illustrate structures seen under a dissecting or compound microscope can be used to great advantage. Your own internal cheek epithelial cells and blood cells (previously included in many laboratory exercises but now banned from most student labs because of AIDS) can be rapidly prepared and examined in front of a class. The arrangement of tissues in organs (lung, heart, striated muscle, kidney, brain, and other material from slaughterhouses) can be demonstrated under a dissecting microscope to very large classes. Combine a living surface view of human skin with the details seen under a prepared slide showing a cross section of skin. Activities such as feeding, responses to stimuli, various kinds of movement, and the circulation of blood can be demonstrated in invertebrates, or with fish, frogs, and small reptiles.
2. Have groups of students choose an organ and discover what tissues make up this organ and how these tissues contribute to the function of that organ.
3. Although negative feedback is important in the regulation of homeostasis, the human body also exhibits positive feedback. After describing positive feedback, see if your class can determine which human physiological processes are regulated by positive feedback mechanisms.

Transparency Acetates

Figure 20.1	The structure of a bird wing
Figure 20.2	A structural hierarchy in a zebra
Figure 20.4	Types of epithelium
Figure 20.5	Types of connective tissue
Figure 20.6	The three types of muscle
Figure 20.8	Tissue layers of the small intestine wall
Figure 20.9	Main components of vertebrate organ systems (Layer 1)
Figure 20.9	Main components of vertebrate organ systems (Layer 2)
Figure 20.11A	Direct exchange between the environment and the cells of a structurally simple animal (a hydra)
Figure 20.11B	Indirect exchange between the environment and the cells of a complex animal
Figure 20.12B	A model of homeostasis
Figure 20.13A	Control of room temperature
Figure 20.13B	Control of body temperature

Media

See the beginning of this book for a complete description of all media available for instructors and students. Animations and videos are available in the Campbell Image Presentation Library. Media Activities and Thinking as a Scientist investigations are available on the student CD-ROM and web site.

Activities and Thinking as a Scientist	Module Number
Web/CD Activity 20A: *Correlating Structure and Function of Cells*	20.1
Web/CD Activity 20B: *The Levels of Life Card Game*	20.2
Web/CD Activity 20C: *Overview of Animal Tissues*	20.3
Web/CD Activity 20D: *Epithelial Tissue*	20.4
Web/CD Activity 20E: *Connective Tissue*	20.5
Web/CD Activity 20F: *Muscle Tissue*	20.6
Web/CD Activity 20G: *Nervous Tissue*	20.7
Web/CD Activity 20H: *Regulation: Negative and Positive Feedback*	20.13