Chapter 10

Plants

10.1 Lesson 10.1: Introduction to Plants

Lesson Objectives

- Describe the major characteristics that distinguish the Plant Kingdom.
- Describe plants' major adaptations for life on land.
- Explain plants' reproductive cycle.
- Explain how plants are classified.

Check Your Understanding

- What are the major differences between a plant cell and an animal cell?
- What is photosynthesis?

Introduction

Plants have adapted to a variety of environments, from the desert to the tropical rain forest to our lakes and oceans. In each environment, plants have become crucial to supporting animal life. First, plants provide animals with food. In a forest, for example, caterpillars munch on leaves while birds eat berries and deer eat grass. Furthermore, plants make the atmosphere friendly for animals. Plants absorb animals' "waste" gas, carbon dioxide, and release the oxygen all animals need for cellular respiration. Finally, plants provide cover and shelter for animals. A bird can take refuge from predators in a shrub and use twigs to make a nest high in a tree (**Figure** 10.1). Without plants, animals would not be able to survive.

Figure 10.1: These bird eggs are benefiting from the cover of a plant; plant materials make up the nest, and when the eggs hatch, the young birds will eat plant products like seeds and berries. (33)

What Are Plants?

From tiny mosses to extremely large trees (**Figure** 10.2), the organisms classified into the Plant Kingdom have three main distinguishable features.

They are all:

- eukaryotic
- photosynthetic
- multicellular

Recall that eukaryotic organisms also include animals, protists, and fungi; eukaryotic cells have true nuclei that contain DNA and membrane-bound organelles such as mitochondria. As discussed in the *Cell Functions* chapter, photosynthesis is the process by which plants capture the energy of sunlight and use carbon dioxide from the air to make their own food. Lastly, plants must be multicellular. Recall that some protists, like diatoms, are eukaryotic and photosynthetic; however, diatoms are not considered plants. Diatoms are a major group of algae, and are mostly unicellular.

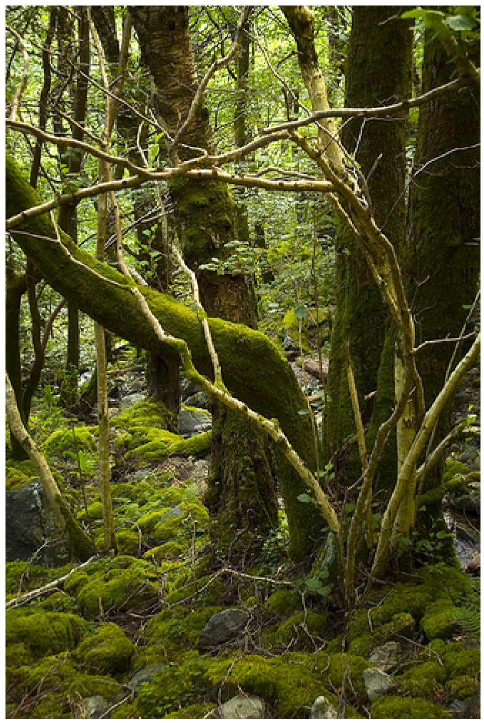

Figure 10.2: There is great diversity in the plant kingdom, from tiny mosses to huge trees. (12)

Adaptations For Life On Land

Much evidence suggests that plants evolved from freshwater green algae (**Figure** 10.3). For example, green algae and plants both have the carbohydrate cellulose in their cell walls and they share many of the same pigments. (For a review of plant cells, see the *Cells and Their Structures* chapter.) So what separates green algae, which are protists, from green plants?

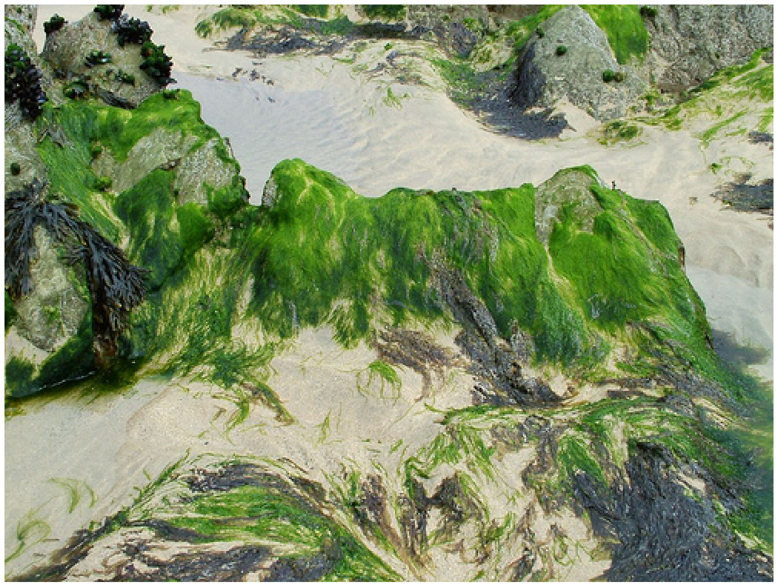

Figure 10.3: The ancestor of plants is green algae. This picture shows a close up of algae on the beach. (11)

One of the main features that distinguishes plants from algae is the retention of the embryo during development. In plants, the embryo develops and is nourished in the female reproductive structure after fertilization. Algae do not retain the embryo. This was the first feature to evolve that separated the plants from the green algae. Plant reproduction will be discussed in the following section.

Although the retention of the embryo is the only adaptation shared by all plants, over time other adaptations for living on land also evolved. In early plants, a waxy layer called a **cuticle** evolved to help seal water in the plant and prevent water loss. However, the cuticle also prevents gases from entering and leaving the plant easily. Recall that the exchange of gasses - taking in carbon dioxide and releasing oxygen - occurs during the process of photosynthesis. Therefore, along with the cuticle, small pores in the leaves called **stomata** also evolved (**Figure** 10.4). The stomata can open and close depending on weather conditions; when it's hot and dry the stomata can stay closed to conserve water. The stomata can open again to permit gas exchange when the weather cools down.

A later adaption for life on land was the evolution of vascular tissue. **Vascular tissue** is specialized tissue that transports water, nutrients, and food in plants. In algae, vascular

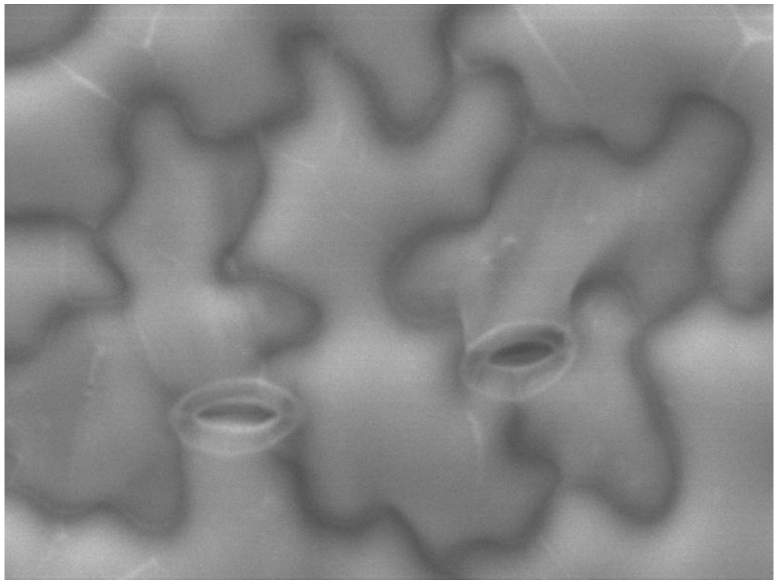

Figure 10.4: Stomata are pores in leaves that allow gasses to pass through, but they can be closed to conserve water. (1)

tissue is not necessary since the entire body is in contact with the water. But on land, water may only be present deep in the ground. Vascular tissue delivers water and nutrients from the ground up and food down into the rest of the plant. The two vascular tissues are xylem and phloem. **Xylem** is responsible for the transport of water and mineral nutrients from the roots throughout the plant. It is also used to replace water lost during transpiration and photosynthesis. **Phloem** mainly carries the sugars made during photosynthesis to the parts of the plant where it is needed.

Plant Reproduction and Life Cycle

Alteration of generations describes the lifecycle of a plant (**Figure** 10.5). In alternation of generations, the plant alternates between a **sporophyte** that has two sets of chromosomes (diploid) and a **gametophyte** that has one set of chromosomes (haploid). Briefly, alternation of generations can be summarized in the following four steps: follow along in **Figure** 10.5 as you read through the steps.

1. The gametophyte produces the **gametes,** sperm and egg, by mitosis. Remember, gametes are haploid.
2. Then the sperm fertilizes the egg, producing a diploid zygote that develops into the sporophyte.
3. The sporophyte produces haploid spores by meiosis.
4. The haploid spores undergo mitosis, developing into the gametophyte.

As we will see in the following lessons, the generation in which the plant spends most of its lifecycle differs between various plants. In the plants that first evolved, the gametophyte takes up the majority of the lifecycle of the plant. During the course of evolution, the sporophyte became the major stage of the lifecycle of the plant. In flowering plants, the female gametophyte is retained within the sporophyte and the male gametophyte is the pollen.

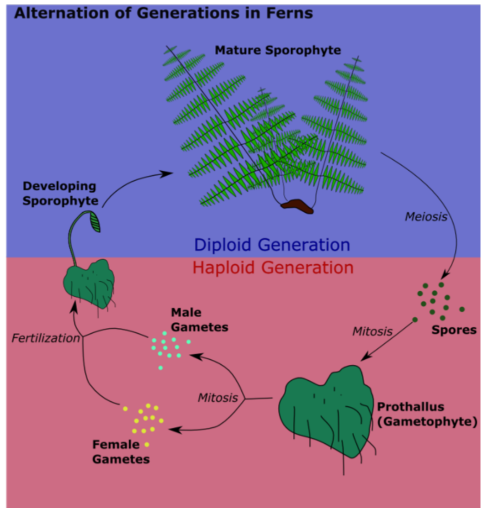

Figure 10.5: In ferns, the sporophyte is dominant and produces spores that germinate into a gametophyte; after fertilization the sporophyte is produced. Ferns will be discussed in further detail in the next lesson. (2)

Classification of Plants

The Plant Kingdom is formally divided into 12 phyla, and these phyla are subdivided into four groups:

1. nonvascular plants
2. seedless vascular plants
3. nonflowering plants
4. flowering plants

Portrayed in **Figure** 10.6 are some of the rich diversity of this kingdom. These four groups are based on the evolutionary history of significant features in plants. The first significant feature to evolve in the Plant Kingdom, after the retention of the embryo, was vascular tissue. Vascular tissue allowed the transport of water and food throughout the plant. The phyla that were around before the evolution of the vascular tissue are known as the **nonvascular plants** (without vascular tissue to move water, nutrients and food). The next significant step in the evolutionary history of plants was the development of the seed. Plants that evolved vascular tissue but do not have seeds are the **seedless vascular plants.** The final major evolutionary event in the Plant Kingdom was the evolution of flowers and fruits. Plants with vascular tissue and seeds but without flowers are the **gymnosperms.** The plants that have all these features and also fruits and flowers are the **angiosperms.** These four groups are the focus of the next two lessons.

Figure 10.6: The plant kingdom contains a diversity of organisms. Note that *Volvox* in the upper left is a protist, not a plant. (9)

Lesson Summary

- Plants are multicellular photosynthetic eukaryotes that evolved from green algae.
- Plants have several adaptive features for living on land, including a cuticle, stomata, and vascular tissue.
- Plants are informally divided into four groups: the nonvascular plants, the seedless vascular plants, the nonflowering plants (gymnosperms) and the flowering plants (angiosperms).

Review Questions

1. How are plants necessary for animal life?
2. Compare and contrast a typical plant to a photosynthetic protist like a diatom.
3. Plants evolved from green algae. How are they different from green algae?
4. What strategies have plants evolved for life on land?
5. What is the purpose of the stomata?
6. What term describes the plant life cycle?
7. What is the diploid stage of the alteration of generations?
8. Which generation of the alternation of generations is dominant in early plants?
9. What is the term for plants that lack vascular tissue?
10. What is the term for plants that have flowers and bear fruit?

Further Reading / Supplemental Links

- http://www.ucmp.berkeley.edu/plants/plantae.html
- http://www.bioedonline.org/slides/slide01.cfm?q=%22Plantae%22
- http://www.wisc-online.com/objects/index_tj.asp?objID=BIO804
- http://www.perspective.com/nature/plantae
- http://plants.usda.gov
- http://en.wikipedia.org/wiki

Vocabulary

alteration of generations The plant lifecycle, which alternates between a haploid gametophyte and a diploid sporophyte.

angiosperms Plants that flower and bear fruit.

cuticle Waxy layer that aids water retention in plants.

gamete Haploid sex cell; egg or sperm

gametophyte Haploid generation of the alteration of generations life cycle; produces gametes.

gymnosperms Seed plant where seeds are not enclosed by a fruit.

nonvascular plants Plants that do not have vascular tissue to conduct food and water.

sporophyte Diploid generation of the alteration of generations; produces haploid spores.

stomata Small pores on the underside of leaves that can regulate the passage of gasses and moisture.

vascular tissue Tissues that conduct food, water, and nutrients in plants.

Points to Consider

- Can you think of examples of plants that do not have seeds?
- If a plant does not have seeds, how can it reproduce?

10.2 Lesson 10.2: Seedless Plants

Lesson Objectives

- Name examples of nonvascular seedless plants.
- Name examples of vascular seedless plants.
- Explain the reproduction strategies of seedless plants.
- Describe the ways seedless plants impact humankind.

Check Your Understanding

- What is a plant?
- How are plants classified?

Introduction

What might you think a forest would have looked like millions of years ago? Or tens of millions of years ago? Or hundreds of millions of years ago? Probably very different than today. In this lesson the focus will be on the very first and most ancient plants: the nonvascular seedless plants and the vascular seedless plants. These plants have had a great impact on all our lives. Over 300 million years ago, during the Carboniferous period, forests looked very different than they do today. Seedless plants grew as tall as today's trees in vast swampy forests (**Figure** 10.7). The remains of these forests formed the fossil fuel coal that we depend on today. Although most of these giant seedless plants are now extinct, smaller relatives still remain.

Figure 10.7: Seedless plants were dominant during the Carboniferous period, as illustrated by this drawing. (30)

Nonvascular Seedless Plants

Since the nonvascular seedless plants lack vascular tissue, they also do not have true roots, stems, or leaves. Remember that vascular tissue moves water, food and nutrients throughout the plant. By definition, roots, stems and leaves must contain vascular tissue. However, nonvascular plants do often have a "leafy" appearance and can have stem-like and root-like structures. These plants must also remain very short in stature due to their lack of ability to conduct nutrients and water up a stem. The appearances of the nonvascular plants vary, however, and they are classified into three phyla: the mosses, the hornworts, and the liverworts.

The **mosses,** phylum Bryophyta, are most often recognized as the green "fuzz" on damp rocks and trees in a forest. If you look closely, you will see that most mosses have tiny stem-like and leaf-like structures. This is the gametophyte stage. Remember from lesson 1 that the gametophyte is haploid. The gametophyte produces the gametes that, after fertilization, develop into the diploid sporophyte. The sporophyte forms a distinctive capsule, called the sporangium, which releases spores (**Figure** 10.8).

Figure 10.8: Sporophytes sprout up on stalks from this bed of moss gametophytes. Notice that both the sporophytes and gametophytes exist at the same time. (31)

The **hornworts,** phylum Anthocerophyta, get their name from their distinctive hornlike sporophytes, and "wort" which comes from the Anglo-Saxon word for herb. The hornlike sporophytes grow from a base of flattened lobes, which are the gametophytes (**Figure** 10.9). They tend to grow in moist and humid areas.

Liverworts, phylum Hepatophyta, have two distinct appearances- they can either be leafy like mosses or flattened and ribbon-like. Liverworts get their name from the type with the flattened bodies which can resemble a liver (**Figure** 10.10). Liverworts can often be found along stream beds.

Vascular Seedless Plants

As their name implies, vascular seedless plants have vascular tissue but do not have seeds. Vascular tissue is specialized tissues which conduct water and nutrients throughout the plant. Vascular tissue allowed these plants to grow much taller than nonvascular plants, forming the ancient swamp forests mentioned previously. Most of these large vascular seedless plants

Figure 10.9: In hornworts, the “horns”, the sporophytes are rise up from the leaflike gametophyte. (5)

Figure 10.10: Liverworts with a flattened, ribbon-like body are called thallose liverworts. (8)

are now extinct, but their smaller relatives still remain. Seedless vascular plants include the club mosses, the ferns, the horsetails, and the whisk ferns.

Club mosses, in the phylum Lycophyta, are so named because they can look similar to mosses (**Figure** 10.11). Club mosses are not true mosses, though, because they have vascular tissue. The "club" part of the name comes from club-like clusters of sporangia in some types of club mosses. The resurrection plant is also a club moss. It shrivels and turns brown when it dries out, but then quickly recovers and turns green when watered again.

Figure 10.11: Club mosses can superficially resemble mosses, but they have vascular tissue. (29)

Ferns, in the phylum Pterophyta, are the most common seedless vascular plants (**Figure** 10.12). They typically have large divided leaves called fronds. In most ferns, fronds develop from a curled-up formation called a fiddlehead (**Figure** 10.13). The fiddlehead resembles the curled decoration on the end of a stringed instrument, such as a fiddle. Leaves unroll as the fiddleheads grow and expand. Ferns grow in a variety of habitats, ranging in size from tiny aquatic species to giant tropical plants.

The **horsetails,** the phylum Sphenophyta, have hollow, ribbed stems and are often found in marshes (**Figure** 10.14). Whorls of tiny leaves around the stem make the plant look like a horse's tail, but these soon fall off and leave the photosynthetic hollow stem. The stems are rigid and rough to the touch as they are coated with abrasive silicates. Because of their scratchy texture, these plants were once used as scouring pads for cleaning dishes.

The **whisk ferns,** the phylum Psilophyta, have green branching stems with no leaves, so they resemble a whisk broom (**Figure** 10.15). Another striking feature of the whisk ferns is their spherical yellow sporangia.

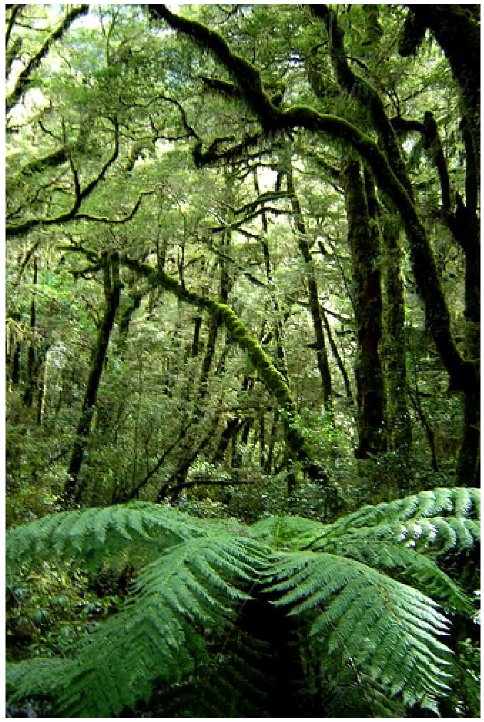

Figure 10.12: Ferns are common in the understory of the tropical rainforest. (14)

Figure 10.13: The first leaves of most ferns appear curled up into fiddleheads. (23)

Figure 10.14: Horsetails are common in marshes. (20)

Figure 10.15: Whisk ferns have no leaves and bear yellow sporangia. (21)

Reproduction of Seedless Plants

Seedless plants can reproduce asexually or sexually. Some seedless plants, like hornworts and liverworts, can reproduce asexually through fragmentation. When a small fragment of the plant is broken off, it can form a new plant.

Like all plants, nonvascular plants have an alternation of generations lifecycle. In the lifecycle of the nonvascular seedless plants, the gametophyte is dominant. The gametophyte is photosynthetic and normally described as the plant. The male gametophyte produces flagellated sperm that must swim to the egg formed by the female gametophyte. For this reason, sexual reproduction must happen in the presence of water; hence the nonvascular plants tend to live in moist environments. Following fertilization, the sporophyte forms. The sporophyte is connected to and dependent on the gametophyte. The purpose of the sporophyte is to produce spores that will develop into gametophytes and start the cycle over again.

For the seedless vascular plants, the sporophyte tends to be dominant. For example, in ferns the gametophyte is a tiny heart-shaped structure, and the leafy plant we recognize as a fern is the sporophyte (as shown in **Figure** 10.5). The sporangia of ferns are often on the underside of the fronds (**Figure** 10.16). Like the nonvascular plants, ferns also have flagellated sperm that must swim to the egg. But unlike the nonvascular plants, once fertilization takes place, the gametophyte will die and the sporophyte will thrive independently.

Figure 10.16: This fern is producing spores underneath its fronds. (17)

Why Seedless Plants Are Important

The greatest influence of seedless plants on human society was in the formation of the fossil fuel coal millions of years ago. Coal is burned to provide energy. But some seedless plants still have uses in society today. *Sphagnum,* also called peat moss, is commonly used by gardeners to improve soils since it has a great ability to absorb and hold water (**Figure** 10.17). Ferns are also a familiar fixture in many gardens. Besides being prized for their ornamental value, the fiddleheads of certain species of ferns are used in gourmet food. Some species of ferns, like the maidenhair fern, are believed by some people to have medicinal qualities.

Figure 10.17: *Sphagnum,* or peat moss, is commonly added to soil to aid water retention. (3)

Lesson Summary

- Nonvascular seedless plants include mosses, liverworts, and hornworts.
- Vascular seedless plants include club mosses, ferns, whisk ferns, and horsetails.
- Nonvascular seedless plants tend to have a dominant gametophyte while vascular seedless plants tend to have a dominant sporophyte.
- Mosses and ferns are used commonly in gardening.

Review Questions

1. What is vascular tissue?
2. What is an example of a nonvascular seedless plant?
3. What is an example of a vascular seedless plant?

4. Compare and contrast the fern gametophyte and sporophyte.
5. Compare and contrast the whisk fern (Psilophyta) and the ferns (Pterophyta).
6. Compare and contrast mosses and club mosses.
7. What are some uses of the seedless plants to gardeners?
8. What are some of the distinguishing features of horsetails?
9. What does the sporophyte of the hornwort look like?
10. Explain reproduction by fragmentation.

Further Reading / Supplemental Links

- http://www.cavehill.uwi.edu/FPAS/bcs/bl14apl/bryo1.htm
- http://www.microscopy-uk.org.uk/mag/indexmag.html
- http://www.microscopy-uk.org.uk/mag/artjul98/jpmoss.html
- http://www.biologycorner.com/bio2/notes_plants.html
- http://forestencyclopedia.com/p/p1893
- http://www.hiddenforest.co.nz/plants/clubmosses/clubmosses.htm
- http://www.washjeff.edu/greenhouse/Pnudum http://amerfernsoc.org/; http://www.washjeff.edu/greenhouse/Pnudum
- http://en.wikipedia.org/wiki

Vocabulary

club mosses Seedless vascular plants that resemble mosses.

ferns Seedless vascular plants that have large, divided fronds.

hornworts Seedless nonvascular plants with hornlike sporophytes.

horsetails Seedless vascular plants with hollow, rigid stems.

liverworts Seedless nonvascular plants that can have flattened bodies resembling a liver.

mosses Seedless nonvascular plants with tiny stem-like and stem-like structures.

whisk ferns Seedless vascular plants that have branching stems and yellow globular sporangium.

Points to Consider

- Can you think of examples of plants that have seeds?
- Can you think of a plant that has seeds but no flowers or fruits?
- Why do you think having flowers is beneficial to a plant?

10.3 Lesson 10.3: Seed Plants

Lesson Objectives

- Describe the importance of the seed.
- Explain the ways in which seeds are dispersed.
- Define and give examples of Gymnosperms.
- Define and give examples of Angiosperms.
- Explain some uses of seed plants.

Check Your Understanding

- What are the two types of seedless plants?
- How do seedless plants reproduce?

Introduction

If you've ever seen a plant grow from a tiny seed, then you might realize that seeds are rather amazing structures. The seed allows a plant embryo to survive droughts, harsh winters, and other conditions that would kill an adult plant. The tiny plant embryo can simply stay **dormant,** in a resting state, and wait for the perfect conditions for growth before it sprouts. In fact, some seeds can stay dormant for hundreds of years! Another impressive feature of the seed is that it provides stored food for the seedling after it sprouts. This greatly increases the chances that the tiny plant will survive. So being able to produce a seed is a very beneficial adaptation, and as a result, seed plants have been very successful. Although the seedless plants were here on Earth first, today there are many more seed plants than seedless plants. Recall that there are two different groups of seed plants: the Gymnosperms, which do not have flowers or fruits, and Angiosperms, which do have flowers and fruits.

Seeds and Seed Dispersal

For a seed plant species to be successful, the seeds must be dispersed, or scattered out in various directions. If the seed are distributed in a variety of areas, there is a better chance that some of the seeds will find suitable conditions for growth. Furthermore, for plants to establish themselves in new areas, such as areas formed after a glacier retreat, the seeds must somehow reach that new site. To aid with seed dispersal, some plants have evolved special features to encourage their seeds to move long distances.

One such strategy is to allow the wind to carry the seeds. With special adaptations in the seeds, the seeds can be carried long distances by the wind. For example, you might have noticed how the "fluff" of a dandelion moves swiftly in the breeze. Each piece of fluff carries a seed to a new location. Or if you look under the scales of pine cone, you would see tiny seeds with "wings" that allow these seeds to be carried away by the wind. Maple trees also have specialized fruits with wing-like extensions that aid in seed dispersal, as shown in **Figure** 10.18.

Figure 10.18: Maple trees have fruits with "wings" that help the wind disperse the seeds. (13)

Another common seed dispersal strategy that some flowering plants utilize is to produce a fleshy fruit around the seeds. Animals that eat the seeds aid in the dispersal of the seeds inside. Berries, citrus fruits, cherries, apples, and a variety of other types of fruits are all adapted to be attractive to animals (**Figure** 10.19). Some seeds can pass through an animal's digestive tract unharmed and germinate after they are passed out with the feces.

Some non-fleshy fruits are especially adapted for animals to carry them on their fur. You might have returned from a walk in the woods to find burrs stuck to your socks. These burs are actually specialized fruits that carry seeds to a new location.

Gymnosperms

Plants with "naked" seeds, meaning they are not enclosed by a fruit, are called **Gymnosperms.** Instead, the seeds of Gymnosperms are usually found in cones. There are four phyla of gymnosperms:

1. Coniferophyta, common name conifers

Figure 10.19: Fleshy fruits aid in seed dispersal since animals eat the fruits and carry the seeds to a new location. (26)

2. Cycadophyta, common name cycads
3. Ginkgophyta, Ginkgo trees
4. Gnetophyta, common name gnetophytes

The **Conifers,** members of the phylum Coniferophyta, are probably the gymnosperms that are most familiar to you. The conifers include pines, firs, spruces, cedars, and the coastal redwoods in California that are tallest living vascular plants. The name of this group signifies that the plants bear their reproductive structures in cones, but this is not a characteristic unique to this phylum (**Figure** 10.20). Conifer pollen cones are usually very small, while the seed cones are larger. **Pollen** contains gametophytes that produce the male gamete of seed plants. The pollen, which is a fine to coarse powder-like material, is carried by the wind to fertilize the seed cones (**Figure** 10.21).

The Conifers are important to humankind since they have many uses. They are important sources of lumber and are also used to make paper. Resins, the sticky substance you might see oozing out of a wound on a pine tree, are collected from conifers to make a variety of products, such as the solvent turpentine and the rosin used by musicians and baseball players. The sticky rosin improves the pitcher's hold on the ball or increases the friction between the bow and the strings to help create music from a violin or other stringed instrument.

The **Cycads,** in the phylum Cycadophyta, are also Gymnosperms. They have large, finely-divided leaves and grow as short shrubs and trees in tropical regions. Like the conifers, they produce cones, but the seed cones and pollen cones are always on separate plants (**Figure** 10.22). One type of cycad, the sago palm, is a popular landscape plant. During the Age of

Figure 10.20: A red pine, which bears seeds in cones, is an example of a conifer. (18)

Figure 10.21: The end of a pine tree branch bears the male cones that produce the pollen. (4)

the Dinosaurs (about 65 to 200 million years ago) the cycads were the dominant plants. So you can imagine dinosaurs grazing on cycad seeds and roaming through cycad forests.

Figure 10.22: Cycads bear their pollen and seeds in cones on separate plants. (28)

Ginkgo trees, in the phylum Ginkgophyta, are unique because they are the only species left in the phylum, although there are many other species in the fossil record that have gone extinct (**Figure** 10.23). Therefore, the Ginkgo tree is sometimes considered a "living fossil". The Ginkgo tree survived as it was widely cultivated in China, especially around Buddhist temples. The Ginkgo tree is also a popular landscape tree today in American cities because it is very tolerant of pollution. The Ginkgo tree, like the cycads, has separate female and male plants. The male trees are usually preferred for landscaping because the seeds produced by the female plants smell rather foul as they ripen.

The **Gnetophytes,** in the phylum Gnetophyta, are a very small and unusual group of plants. *Ephedra* is an important member of this group since this desert shrub produces the ephedrine used to treat asthma and other conditions. *Welwitschia* produces extremely long leaves and is found in the deserts of southwestern Africa (**Figure** 10.24). Overall, there are about 70 different species in this very diverse phylum.

Angiosperms

Angiosperms, in the phylum Anthophyta, are the most successful phylum of plants and vastly outnumber the individuals in other phyla (**Figure** 10.25). The feature that distinguishes the angiosperms is the evolution of the flower, so they are also called the flowering plants. Angiosperms inhabit a variety of environments; a water lily, an oak tree, and a barrel cactus are all angiosperms.

Figure 10.23: Ginkgo trees are gymnosperms with broad leaves. (10)

Figure 10.24: One type of gnetophyte is *Welwitschia*. (7)

Figure 10.25: Angiosperms are the flowering plants. (16)

Even though flowers may differ widely in their appearance, they do have some structures in common. The outermost structure is the **sepals,** collectively known as the **calyx,** which are usually green and protect the flower before it opens. The petals, collectively known as the **corolla,** are often bright and colorful to attract a particular pollinator, an animal that carries pollen from one flower to another. The next structure is the **stamens,** consisting of the stalk-like **filament** that holds up the **anther,** or the pollen sacs. The pollen is the male gametophyte. At the very center is the **carpel,** which is divided into three different regions: the sticky, knob-like **stigma** where the pollen lands, the slender tube of the **style,** and the enlarge base known as the **ovary.** The ovary is where the ovules, the female gametophytes, are found. When the ovules are fertilized, the ovule becomes the seed and the ovary becomes the fruit. Some flowers have all these parts and are known as **complete flowers** (**Figure** 10.26), while others may be missing one or more of these parts and are known as **incomplete flowers.**

Table 10.1:

Flower part	Definition
sepals	Outermost layer of the flower that is usually leaf-like and green.
calyx	The sepals collectively; outermost layer of the flower.
corolla	The petals of a flower collectively.
stamens	The part of the flower consisting of a filament and an anther that produces pollen.

Table 10.1: (continued)

Flower part	Definition
filament	Stalk that holds up the anther.
anther	The pollen-containing structure in a flower.
carpel	"Female" portion of the flower; consists of stigma, style, and ovary.
stigma	The knob-like section of the carpel where the pollen must land for fertilization to occur.
style	Slender tube that makes up part of the carpel.
ovary	Enlarged part of the carpel where the ovules are contained.

Many plants can self-pollinate, meaning that pollen falls on the stigma of the same flower. Cross-fertilization is often favored and occurs when the pollen from an anther is transferred to a stigma of another flower on another plant. This can be accomplished two ways, by wind or by animals. Flowers that are pollinated by animals such as birds, butterflies, or bees are often colorful and provide nectar, a sugary reward, for their animal pollinators.

Angiosperms are important to humankind in many ways, but the most significant role of angiosperms is as food. Wheat, rye, corn, and other grains are all harvested from flowering plants. Starchy foods, such as potatoes, and legumes, such as beans, are also angiosperms. And as mentioned previously, fruits are a product of angiosperms to increase seed dispersal and are also nutritious foods. There are also many non-food uses of angiosperms that are important to society; for example, cotton and other plants are used make cloth, and hardwood trees to make lumber. The flowering plants are dominant in the environment and are important resources for humans and all animals.

Lesson Summary

- Seeds consist of a dormant plant embryo and stored food.
- Seeds can be dispersed by wind or by animals that eat fleshy fruits.
- Gymnosperms, seed plants without flowers, include the Conifers, the Cycads, the Gingko tree, and the Gnetophytes.
- Angiosperms are flowering plants.
- Seed plants provide many foods and products for humans.

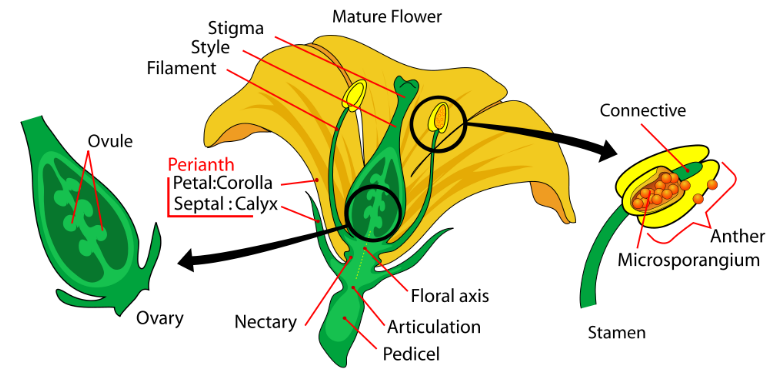

Figure 10.26: A complete flower has sepals, petals, stamens, and one or more carpels. (32)

Review Questions

1. Why are seeds an adaptive feature for seed plants?
2. What is the purpose of a plant developing a fruit?
3. What are two ways that plants disperse their seeds?
4. How do Gymnosperms and Angiosperms differ?
5. What are some examples of Gymnosperms?
6. What are some uses that seed plants have for humans?
7. Firs, spruces, and pines belong to what group of Gymnosperms?
8. Why is the Ginkgo tree considered a “living fossil”?
9. Where is the pollen stored in a flower?
10. How are plants pollinated?

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Vocabulary

angiosperms Another name for flowering plants.

anther The pollen-containing structure in a flower.

calyx The sepals collectively; outermost layer of the flower.

carpel "Female" portion of the flower; consists of stigma, style, and ovary.

complete flowers Flowers that contain all four structures: sepals, petals, stamens, and one or more carpels.

conifers Group of gymnosperms that bear cones; includes spruces, pine, and fir trees.

corolla The petals of a flower collectively are known as the corolla.

dormant Halting growth and development temporarily.

ginkgo Tree known as the "living fossil" because it is the only species left in the phylum Ginkgophyta.

gnetophytes Diverse group of gymnosperms that includes Ephedra and Welwitschia.

gymnosperms Seed plants in which the seeds are not encased in a fruit.

incomplete flowers Flowers that are missing one or more structures: sepals, petals, stamens, or carpels.

ovary Enlarged part of the carpel where the ovules are contained.

sepals Outermost layer of the flower that is usually leaf-like and green.

stamens The part of the flower consisting of a filament and an anther that produces pollen.

stigma The knoblike section of the carpel where the pollen must land for fertilization to occur.

Points to Consider

- Do you think plants can sense their environment? Why or why not?
- Can you think of an example of a hormone?
- Do you think that plants have hormones?
- How do you think trees know when it's time to lose their leaves?

10.4 Lesson 10.4: Plant Responses

Lesson Objectives

- List the major types of plant hormones and the main functions of each.
- Define tropism and explain examples of tropisms.
- Explain how plants detect the change of seasons.

Check Your Understanding

- Why do pants need sunlight?

Introduction

Plants may not move, but that does not mean they don't respond to their environment. Plants are constantly responding to their surroundings. Plants detect and respond to stimuli such as gravity, light, touch, and seasonal changes. For example, you might have noticed how a house plant bends towards a bright window. Plants must be able to detect and respond to changes in the direction of light. You probably also have noticed that some trees lose their leaves in the autumn, so plants must be able to detect the time of year. Plants are able to respond to stimuli through the help of special chemical messengers, called **hormones.** The various ways that plants respond to their environment and the hormones that control these responses will be the focus of this section.

Plant Hormones

In order for plants to respond to the environment, their cells must be able to communicate with other cells. The chemical signals that travel through cells to help them communicate are called hormones. You might be familiar with the term hormones since animals, including humans, also depend on hormones, such as testosterone or estrogen, to carry messages from cell to cell. Animal hormones will be discussed in the *Controlling the Body* chapter. In both plants and animals, hormones travel from cell to cell in response to a stimulus and also activate a specific response.

Table 10.2: **Each plant hormone has a specific function.**

Hormone	Function
Ethylene	Fruit ripening and abscission
Gibberellins	Break the dormancy of seeds and buds; promote growth

Table 10.2: (continued)

Hormone	Function
Cytokinins	Promote cell division; prevent senescence
Abscisic Acid	Close the stomata ; maintain dormancy
Auxins	Involved in tropisms and apical dominance

Ethylene is the plant hormone involved in ripening fruit and with **abscission,** the dropping of leaves, fruits and flowers. When a flower is done blooming or a fruit is ripe and ready to be eaten, ethylene stimulates the production of enzymes that allow the petals or fruit to separate from the plant (**Figures** 10.27 and 10.28). Ethylene is an unusual plant hormone because it is a gas. That means it can move through the air, and a ripening apple can cause another to ripen, or even over-ripen. That's why one rotten apple spoils the whole barrel!

Figure 10.27: The hormone ethylene is signaling these tomatoes to ripen. (25)

Gibberellins are growth-promoting hormones. When gibberellins are applied artificially to plants, the stems grow longer. Therefore, gibberellins can be used in horticulture to increase the growth of ornamental plants, whereas dwarf plants have low concentrations of gibberellins (**Figure** 10.29). Another function of gibberellins is to break the dormancy of

Figure 10.28: The hormone ethylene plays a role in signaling these flower petals to separate and drop, a process known as abscission. (24)

seeds and buds. Gibberellins signal that it's time for a seed to germinate or for a bud to open.

Figure 10.29: Dwarf plants like this bonsai tree often have unusually low concentrations of gibberellins. (22)

Cytokinins are hormones that promote cell division. Cytokinins were discovered from attempts to grow plant tissue in artificial media (**Figure** 10.30). Cytokinins also prevent **senescence,** the programmed aging process. As a result, florists sometimes apply cytokinins to cut flowers.

Figure 10.30: Cytokinins promote cell division and are necessary for growing plants in tissue culture; a small piece of a plant is placed in sterile conditions to regenerate a new plant. (15)

Abscisic Acid is misnamed because it was once believed to play a role in abscission (the dropping of leaves, fruits and flowers), but we now know abscission is regulated by ethylene. The actual role of abscisic acid is to close the stomata and maintain dormancy. When a plant is stressed due to lack of water, abscisic acid signals the stomata to close. This prevents excess water loss through the stomata. When conditions are not ideal for a seed to germinate or for a winter bud to put out its leaves, abscisic acid signals for dormancy to continue. When conditions improve, the levels of abscisic acid drop and the levels of gibberellins increase, signaling that is time to break dormancy (**Figure** 10.31).

Auxins are hormones that influence many different processes in plants. Auxins produced at the tip of the plant are involved in apical dominance, preventing the growth of side branches. In **apical dominance** the main central stem of the plant is dominant over other side stems; the main stem grows more strongly than other stems and branches. When the tip of the plant is removed, the auxins are no longer present and the side branches begin to grow. This is why pruning generally will help produce a fuller plant with more branches. Auxins are also involved in tropisms, which will be discussed in the next section.

Tropisms

Plants may not be able to move, but they are able to change their growth in response to a stimulus. Growth toward or away from a stimulus is known as a **tropism.** The ability of a plant to curve its growth in one direction is achieved with the signaling of auxin. The auxin moves to one side of the stem, where it starts a chain of events that elongate the cells on

Figure 10.31: A reduction in levels of abscisic acid allows these buds to break dormancy and put out leaves. (27)

Figure 10.32: These seedlings bending toward the sun are displaying phototropism. (6)

just that one side of the stem. With one side of the stem growing faster than the other, the plant begins to bend.

You might have noticed that plants tend to bend towards the light. This is an example of a tropism where light is the stimulus, known as **phototropism** (**Figure** 10.32). To obtain more light for photosynthesis, it's advantageous for leaves and stems to grow towards the light. On the other hand, roots are either insensitive to light or actually grow away from light. This is advantageous for the roots since their purpose is to obtain water and nutrients from deep within the ground.

A seed often starts out underground in the dark, yet the roots always grow downwards into the earth and not toward the surface. How do the roots know which way is up? **Gravitropism** is a growth towards or away from the pull of gravity. Shoots also exhibit gravitropism, but in the opposite direction. If you place a plant on its side, the stem and new leaves will curve upwards. Again, the hormone auxin is involved in this response. Auxin builds up on the lower side of the stem, elongating this side of the stem and causing it to bend upwards over time.

Plants also have a touch response, called **thigmotropism.** If you have ever seen a morning glory or the tendrils of a bean plant twist around a pole, then you know that plants must be able to detect the pole. Thigmotropism works much like the other tropisms. The plant grows straight until it comes in contact with the pole. Then the side of the stem in contact with the pole grows slower than the opposite side of the stem. This causes the stem to bend around the pole.

Table 10.3: **Tropisms**

Type of Tropism	Stimulus
Phototropism	light
Gravitropism	gravity
Thigmotropism	touch

Seasonal Changes

Along with detecting differences in light or gravity, plants also are able to detect the seasons. Leaves change color and drop each autumn in temperate climates (**Figure** 10.33). Certain flowers, like poinsettias, only bloom during the winter. And in the spring, the winter buds on the trees break open and the leaves start to grow. How do plants detect time of year?

Although you might detect the change of seasons by the change in temperature, this is not the primary way by which plants detect the change of seasons. Plants determine the time of year by the length of the day. Because of the tilt of the Earth, during winter days there are less hours of light than during summer days. That's why during the winter it may start getting dark very early during the evening and even stay dark while you're getting ready for

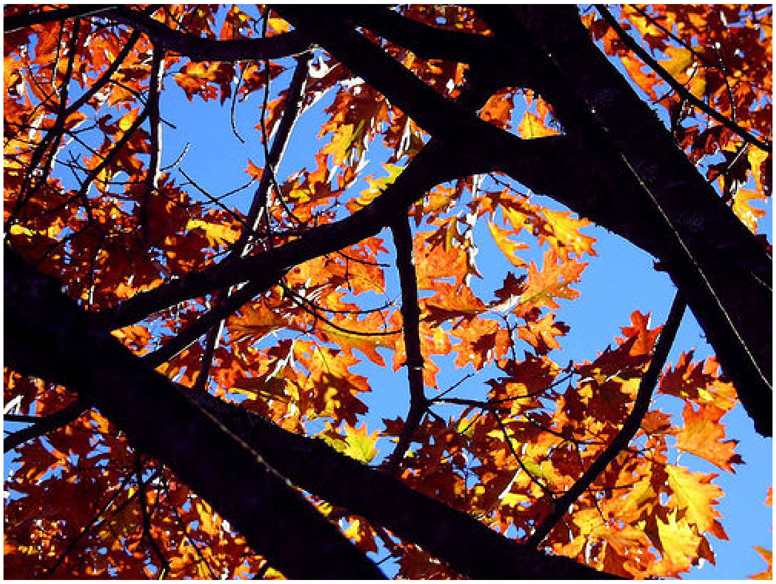

Figure 10.33: Leaves changing color is a response to the shortened length of the day in autumn. (19)

school the next morning. But in the summer it will be bright early in the morning and the sun may not set until late that night. Plants can detect the differences in day length and respond accordingly. For example, in the fall when the days start to get shorter, the trees sense it is time to begin the process of shedding their leaves.

Lesson Summary

- Plant hormones are chemical signals that regulate a variety of processes in plants.
- A plant tropism is growth towards or away from a stimulus such as light or gravity.
- Many plants undergo seasonal changes after detecting differences in day length.

Review Questions

1. What is the term for dropping fruits, flowers, or leaves?
2. What hormone is involved with fruit ripening?
3. How are hormones involved in seed germination?
4. What hormone is involved in tropisms?
5. What hormones promote cell division?
6. What hormone causes stems to elongate?
7. What is phototropism?
8. How does a tendril wind around a pole?
9. How do plants detect the change in seasons?

10. What are some seasonal responses in plants?

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Vocabulary

abscisic acid Plant hormone involved in maintaining dormancy and closing the stomata.

abscission The shedding of leaves, fruits, or flowers.

apical dominance Suppressing the growth of the side branches of a plant.

auxin Plant hormone involved in tropisms and apical dominance.

cytokinins Plant hormone involved in cell division.

ethylene Plant hormone involved in fruit ripening and abscission.

gibberellins Plant hormone involved in seed germination and stem elongation.

gravitropism Plant growth towards or away from the pull of gravity.

hormones Chemical messengers that signal responses to stimuli.

phototropism Plant growth towards or away from light.

senescence The programmed process of aging and eventual death.

thigmotropism Differential plant growth in response to contact with an object.

tropism Plant growth response towards or away from a stimulus.

Points to Consider

In the next chapter we will turn our attention to animals.

- List some ways animals are different from plants.
- What characteristics do you think define an animal?
- Can you think of examples of animals that do not have hard skeletons?

Image Sources

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Chapter 11

Introduction to Invertebrates

11.1 Lesson 11.1: Overview of Animals

Lesson Objectives

- List the characteristics that define the animal kingdom.
- Define and give examples of the invertebrates.

Check Your Understanding

- What are the main differences between an animal cell and a plant cell?
- How do animals get their energy?

Introduction

How are animals different from other forms of life? Recall that all animals are eukaryotic, meaning that they have cells with true nuclei and membrane-bound organelles. Another feature that distinguishes animals from animal-like protists is that animals are multicellular, while protists are often unicellular. Because animals are multicellular, animal cells can be organized into tissues, organs, and organ systems. Finally, animals are **heterotrophic**, meaning they must ingest some type of organic matter for nutrition and energy (**Figure** 11.1).

Eukaryotic, multicellular, and heterotrophic are features shared by all the millions of diverse types of animals on earth, from tiny ants and snails to giant whales and grizzly bears. In this chapter we will just focus on the invertebrates, the animals that do not have a backbone of bone or cartilage.

Figure 11.1: Animals are heterotrophs, meaning they must eat to get molecules necessary for their growth and energy. (9)

Classification of Animals

Recall that each kingdom of life, including the animal kingdom, is divided into smaller groups called phyla based on their shared characteristics. For example the phylum Mollusca largely consists of animals with shells like snails and clams. Although modern classification is also based on looking at molecular data, such as DNA sequencing, animals have long been classified in their current phyla largely by their physical characteristics.

One example of a physical characteristic used to classify animals is body symmetry. In **radially symmetrical** organisms, such as sea stars, the body is organized like a circle (**Figure** 11.2). Therefore, any cut through the center of the animal results in two identical halves. Other animals, such as humans and worms, are **bilaterally symmetrical,** meaning their left and right sides are mirror images.

Animals are also often classified by their body structure. For example, segmentation, the repetition of body parts, defines one phylum of worms (**Figure** 11.3). Animals that have a true body cavity, defined as a fluid-filled space, and internal organs are also classified in separate phyla from those animals that do not have a true body cavity. Finally, the structure of the digestive system of animals can also be used as a characteristic for classification. Animals with **incomplete digestive tracts** have only one opening in their digestive tracts, while animals with **complete digestive tract** have two openings, the mouth and anus.

Figure 11.2: Sea stars are radially symmetrical. (3)

Figure 11.3: A segmented body plan defines the phylum that includes the earthworms. (7)

What Are Invertebrates?

Besides being classified into phyla, animals are also often characterized as being invertebrates or vertebrates. This is an informal classification term based on the skeletons of the animals. **Vertebrates** have a backbone of bone or cartilage, while invertebrates have no **backbone**. All vertebrate organisms are in the phylum Chordata, while invertebrates make up several diverse phyla. As seen in **Figure** 11.4, the invertebrates include the insects, the earthworms, the jellyfish, the star fish, and a variety of other animals. In the next lessons we will discuss some of phyla within the animal kingdom that contain invertebrates.

Figure 11.4: Snails are an example of invertebrates, animals without a backbone. (18)

Table 11.1:

Phylum	Examples
Porifera	Sponges
Cnidaria	Jellyfish, corals
Platyhelminthes	Flatworms, tapeworms
Nematoda	Nematodes, heartworm
Mollusca	Snails, clams
Annelida	Earthworms, leeches
Arthropoda	Insects, crabs
Echinodermata	Sea stars, sea urchins

Lesson Summary

- Animals are multicellular, eukaryotic heterotrophs.

- Animals can be classified by both molecular data and physical characteristics such as symmetry.
- Invertebrates are animals without a backbone.

Review Questions

1. What are some key features that define the animal kingdom?
2. What does heterotrophic mean?
3. What defines the invertebrates?
4. What are some examples of invertebrates?
5. What is the difference between radially and bilaterally symmetrical animals?
6. What's an example of a bilaterally symmetrical animal?
7. What are some examples of a radially symmetrical animal?
8. What is a body cavity?
9. What is the difference between an incomplete and complete digestive system?
10. What is segmentation?

Further Reading

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- http://animals.nationalgeographic.com/animals/invertebrates.html
- http://en.wikipedia.com

Vocabulary

bilaterally symmetrical Body plan in which the left and right side are mirror images.

complete digestive tract A digestive tract that has two openings, the mouth and the anus.

heterotroph Organism that cannot make its own food, so it must ingest some type of organic matter.

invertebrates Animals without a backbone.

incomplete digestive tract A digestive tract that has only one opening.

radially symmetrical A body plan in which any cut through the center results in two identical halves.

segmentation Repetition of body parts or segments.

Points to Consider

- What do you think that jellyfishes and corals have in common?
- Think of some examples of animals that are bilaterally symmetrical, where the left side is a mirror image of the right?

11.2 Lesson 11.2: Sponges and Cnidarians

Lesson Objectives

- Describe the key features of the Sponges.
- Describe the key features of the Cnidarians.
- List examples of the Cnidarians.

Check Your Understanding

- How are animals classified?
- What is an invertebrate?

Introduction

The ocean is home to a variety of organisms. Phytoplankton, tiny photosynthetic organisms that float in the water, make their own food from the energy of the sun. Small aquatic animals, known as zooplankton, and larger animals, such as fish, use phytoplankton as a food source. These animals can in turn be eaten by larger aquatic animals, such as larger fish and sharks.

Among the various types of animals that live in the ocean, the **sponges** and **cnidarians** are important invertebrates. The Sponges are believed to be one of the most ancient forms of animal life on earth. The cnidarians, which include the jellyfish, also are among the oldest and most unusual animals on earth. In this lesson we will discuss the features that make these two types of invertebrates unique from other types of animals.

Sponges

Sponges are classified in the phylum **Porifera**, which derives its name from Latin words meaning "pore bearing." These pores allow the movement of water into the sponges' sac-like bodies (**Figure** 11.5). Sponges pump water through their bodies because they are **sessile filter feeders**, meaning they cannot move and must filter organic matter and tiny organisms out of the water to obtain food.

Figure 11.5: Sponges have tube-like bodies with many pores. (11)

Sponges are relatively primitive animals and do not have brains, stomachs, or other organs. In fact, sponges do not even have true tissues. Instead, their bodies are made up of specialized cells that each has specific functions. For example, the collar cells are flagellated and encourage water movement, while other types of cells regulate the water flow by increasing or decreasing the size of the pores.

Cnidarians

The cnidarians, in the phylum **Cnidaria**, include organisms such as the jellyfish (**Figure** 11.6) and sea anemones (**Figures** 11.7 and 11.8) that are found in shallow ocean water. You might recognize that these animals can give you a painful sting if you step on them. That's because cnidarians have stinging cells known as **nematocysts**. When touched, the nematocysts unleash long, hollow threads that are intended to trap prey, and sometimes toxins are also injected through these threads to paralyze the prey.

The body plan of cnidarians is unique because these organisms are radially symmetrical, meaning that they have a circular body plan so that any cut through the center of the animal leaves two equal halves. The cnidarians have two basic body forms, polyp and medusa. The **polyp** is a cup-shaped body with the mouth directed upward, such as a sea anemone (**Figure** 11.8). The **medusa** is a bell-shaped body with the mouth and tentacles directed downward, such as a jellyfish (**Figure** 11.7).

Unlike the sponges, the cnidarians are made up of true tissues. The inner tissue layer secretes digestive enzymes into the **gastrovascular cavity,** a large cavity that has both digestive and circulatory functions. The cnidarians also have nerve tissue organized into a net-like structure. Cnidarians do not have true organs, however.

Figure 11.6: Jellyfish have bell-shaped bodies with tenticles. (8)

Cnidarian Colonies

Some types of cnidarians are also known to form colonies. For example, the Portuguese man-of-war looks like a single organism but is actually a colony of polyps (**Figure** 11.9). One polyp is filled with air to help the colony float, while several feeding polyps hang below with tentacles full of nematocysts. Consequently, the Portuguese man-of-war is known to cause extremely painful stings to swimmers and surfers who accidentally brush up against these creatures in the water.

Figure 11.7: Sea anemones can sting and trap fish with their tentacles. (15)

Figure 11.8: One type of sea anemone is home to the clownfish. (6)

Figure 11.9: The Portuguese man-o-war can deliver debilitating stings with its tentacles. (13)

Coral reefs are built from colonial cnidarians called corals (**Figure** 11.10). The corals are sessile polyps that can extend their tentacles to feed on ocean creatures that pass by. Their skeletons are made up of calcium carbonate, which is also known as limestone. Over long periods of time, their skeletons can accumulate to produce massive structures known as coral reefs. Coral reefs are important habitats for diverse types of ocean life.

Figure 11.10: Corals are colonial cnidarians. (4)

Lesson Summary

- Sponges are sessile filter feeders without true tissues.
- The cnidarians, such as jellyfish, are radially symmetrical with true tissues.
- Colonial cnidarians include the Portuguese man-of-war and corals.

Review Questions

1. What is the only animal to lack true tissues?
2. In what phylum are the sponges?
3. How do sponges gain nutrition?
4. Cnidarians are radially symmetrical. What does this mean?
5. What are some examples of cnidarians?
6. How do cnidarians sting their prey?
7. Describe the nervous system of the cnidarians.
8. How is a jellyfish different from a Portuguese man-o-war?
9. How are coral reefs built?
10. Where are most cnidarians found?

Further Reading / Supplemental Links

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Vocabulary

corals Cnidarians that live on ocean reefs in colonies.

cnidarians Invertebrates that have radial symmetry and include the jellyfish.

filter feeders An organism that feeds by filtering organic matter out of water.

gastrovascular cavity A large cavity having both digestive and circulatory functions.

medusa Cnidarian with a bell-shaped body directed downward.

nematocysts Specialized cells in cnidarians that can release a small thread-like structure and toxins to capture prey.

porifera Filter-feeders with sac-like bodies; known as the sponges.

polyp Cnidarian with a cup-shaped body directed upward.

sessile Permanently attached and not freely moving.

Points to Consider

- How do you think that worms are different from sponges and cnidarians?
- How do you think that worms might be similar to sponges and cnidarians?

11.3 Lesson 11.3: Worms

Lesson Objectives

- Describe the major features of the flatworms.
- Describe the major features of the roundworms.
- Describe the major features of the segmented worms.

Check Your Understanding

- In terms of body structure, what does segmentation refer to?
- What is a body cavity?

Introduction

Calling an animal a worm is an informal, non-scientific classification for animals that have long bodies with no appendages. Worms are bilaterally symmetrical, meaning that the right side of their bodies is a mirror of the left. Worms live in a variety of environments, including in the ocean, in fresh water, on land, and as parasites of plants and animals.

In this chapter we will discuss three types of worms: the flatworms, the roundworms, and the segmented worms. These worms are distinguished from each other by their body plan. The flatworms have flat ribbon-like bodies with no body cavity. The roundworms have a body cavity but no segments. The segmented worms have both a body cavity and segmented bodies.

Flatworms

Worms in the phylum **Platyhelminthes** are called flatworms because they have flattened bodies. Some species of flatworms are free live-living organisms that feed on small organisms and decaying matter. These types of flatworms include marine flatworms and fresh-water flatworms such as *Dugesia* (**Figures** 11.11 and 11.12). Other types of flatworms are parasitic and rely on a host organism for energy. For example, **tapeworms** have a modified head region with tiny hooks that help the worm attach to the intestines of a animal host (**Figures** 11.13 and 11.14).

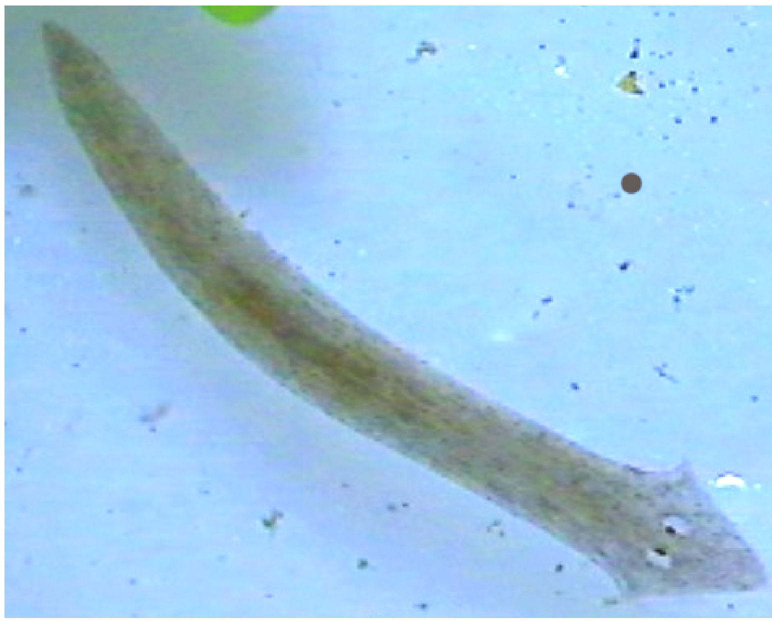

Figure 11.11: *Dugesia* is a type of flatworm with a head region and eyespots. (14)

Flatworms have no true body cavity and an **incomplete digestive system,** meaning that the digestive tract has only one opening. Flatworms do not have a respiratory system, so gas exchange occurs at surface of their bodies. Furthermore, there are no blood vessels or true circulatory system in the flatworms. Their **gastrovascular cavity** serves for both digestion and to distribute nutrients. The flatworms do have a ladder-like nervous system with a distinct head region with a concentration of nerve cells and sensory organs such as eyespots (**Figure** 11.11). The development of a head region, called **cephalization,** arose with the development of bilateral symmetry in animals.

Roundworms

The phylum **Nematoda** includes non-segmented worms known as nematodes or roundworms (**Figure** 11.15). Unlike the flatworms, the roundworms have a body cavity with internal

Figure 11.12: Marine flatworms can be brightly colored. (2)

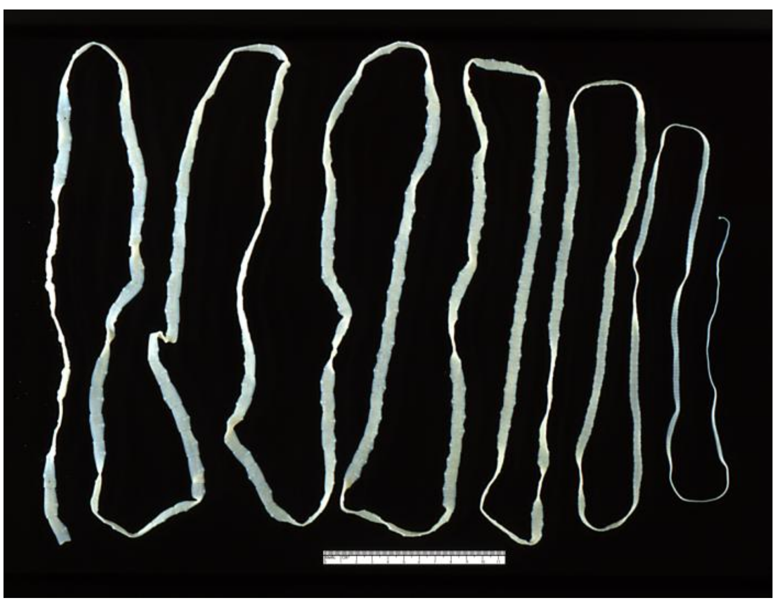

Figure 11.13: Tapeworms are parasitic flatworms that live in the intestines of their hosts. (17)

Figure 11.14: Tapeworms attach to the intestinal wall with a head region that has hooks and suckers. (12)

organs. A roundworm's **complete digestive tract**, meaning the digestive tract includes both a mouth and anus, includes a large digestive organ known as the gut. Roundworms also have a simple nervous system with a primitive brain. Both their anterior and posterior ends have specialized sensory nerves. These nerves are connected with a ventral and dorsal nerve cord that run the length of the body.

Roundworms can be free-living organisms, but they are probably best known for their role as significant plant and animal parasites. The heartworms, which cause serious disease in dogs while living in the heart and blood vessels, are a type of roundworm. Round worms can also cause disease in humans. Elephantiasis, a disease characterized by the extreme swelling of the limbs, is caused by infection with a type of roundworm (**Figure** 11.16).

Segmented Worms

The phylum **Annelida** includes the segmented worms such as the common earthworm, some marine worms, and leeches (**Figures** 11.17 and 11.18). These worms are known as the segmented worms because their bodies are **segmented**, or separated into repeating units. Most segmented worms feed on dead organic matter, while leeches can live in freshwater and suck blood from host organisms. Leeches can also be used medicinally to remove excess blood.

Segmented worms have a well-developed body cavity filled with fluid, which serves as a **hydroskeleton,** a supportive structure that aids in muscle contraction. Segmented worms also tend to have organ systems that are more developed than the roundworms or flatworms. Earthworms, for example, have a complete digestive tract including an esophagus

Figure 11.15: Nematodes can be parasites of plants and animals. (10)

Figure 11.16: One roundworm parasite causes elephantiasis, a disease characterized by the swelling of the limbs. (1)

Figure 11.17: Earthworms are segmented worms. (5)

Figure 11.18: Leeches are parasitic segmented worms. (16)

and intestines. The circulatory system consists of paired hearts and blood vessels, while the nervous system consists of the brain and a ventral nerve cord.

Table 11.2:

Type of Worm	Body Cavity	Segmented	Digestive System	Example
Flatworm	No	No	Incomplete	Tapeworm
Roundworm	Yes	No	Complete	Heartworm
Segmented	Yes	Yes	Complete	Earthworm

(*Source:* Jessica Harwood, *License:* CC-BY-SA)

Lesson Summary

- The flatworms have no true body cavity and include free-living *Dugesia* and parasitic tapeworms.
- The roundworms, which can also be parasitic or free-living, are non-segmented worms with a complete digestive tract and a primitive brain.
- The segmented worms include the common earthworm and leeches.

Review Questions

1. Are all worms classified into a single phylum?
2. Describe the respiratory system of the flatworms.
3. What is cephalization?
4. Name a parasitic flatworm.
5. How does the body plan of the roundworms differ from that of the flatworms?
6. Describe the digestive system of roundworms.
7. What features distinguish Phylum Annelida from the other worms?
8. Describe the skeletal system of a segmented worm.
9. Name a parasitic segmented worm.
10. Earthworms are in what phylum?

Further Reading / Supplemental Links

- http://animaldiversity.ummz.umich.edu/site/accounts/information/Annelida.html
- http://animaldiversity.ummz.umich.edu/site/accounts/information/Nematoda.html

- http://animaldiversity.ummz.umich.edu/site/accounts/information/Platyhelminthes.html
- http://www.ucmp.berkeley.edu/platyhelminthes/platyhelminthtml
- http://www.ucmp.berkeley.edu/phyla/ecdysozoa/nematoda.html
- http://www.ucmp.berkeley.edu/annelida/annelida.html
- http://animaldiversity.ummz.umich.edu
- http://en.wikipedia.org/wiki/Annelida

Vocabulary

annelida Invertebrate worms that have segmented bodies, such as earthworms.

cephalization Having a head region with a concentration of sensory organs and central nervous system.

complete digestive tract A digestive tract with two openings, a mouth and anus.

gastrovascular cavity A large cavity having both digestive and circulatory functions.

hydroskeleton Fluid-filled body cavity that provides support for muscle contraction.

incomplete digestive system A digestive tract with only one opening.

nematoda Invertebrate worms that include the roundworms.

platyhelmenthes Invertebrate worms that include the flatworms and tapeworms.

segmentation A body plan that has repeated units or segments.

tapeworms Intestinal parasites in the phylum Platyhelmenthes.

Points to Consider

- How might the vertebrates be different from the invertebrates?
- Can you think of some examples of animals with a backbone?

Lab

Survey of Some Invertebrates

In this lab you will observe some examples of the invertebrates, those animals that do not have a backbone. The hydras are in the phylum Cnidaria. The *Dugesia* are in the phylum Platyhelmenthes, the flatworms. The earthworm is in the phylum Annelida.

Materials:

- compound and dissecting microscopes
- slides and cover slips
- pipettes
- watch glass
- culture of living hydra
- *Dugesia*
- construction paper
- preserved earthworms
- dissection kits

Procedure:

1. **Hydra**
   (a) With a pipette, pull up some of the material from the bottom of the culture dish. Then squeeze a coupe drops onto a clean slide and cover with a cover slip. Observe your hydra under the microscope and sketch one below.
2. **Dugesia**
   (a) With a pipette, place a couple *Dugesia* on a clean watch glass. Observe under the **dissecting** microscope. Sketch below, labeling the eyespots, auricles, and gastrovascular cavity.
   (b) With a dark piece of paper, cover half the watch glass. Do the *Dugesia* seem to prefer the shade or the light? Movement in response to light is called **phytotaxis**.
3. **Earthworm**
   (a) Find the clitellum. What is its function?
   (b) Touch the ventral side of the worm to feel the setae. What are their function?
   (c) Lay the worm on the dissecting tray with the dorsal side up. Using the forceps and the scissors, carefully cut open the worm along a straight line from the clitellum to the mouth. Make sure to just cut the skin so you do not damage the internal organs. Sketch your worm below and label the following: aortic arches, crop, gizzard, pharynx, dorsal blood vessel, intestine, ventral nerve cord, and seminal vesicles.

Image Sources

(1) prep4md. http://www.flickr.com/photos/27920559@N05/2778292954/. CC-BY 2.0.

(2) Steve Childs. *Marine flatworms can be brightly colored.*. CC-BY 2.0.

(3) *Sea stars are radially symmetrical.*. CC-BY-SA 2.5.

(4) Laszlo Ilyes. *Corals are colonial cnidarians.*. CC-BY 2.0.

(5) Squeezyboy. *Earthworms are segmented worms.*. CC-BY 2.0.

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(16) Rob and Stephanie Levy. *Leeches are parasitic segmented worms.*. CC-BY 2.0.

(17) http://commons.wikimedia.org/wiki/Image:Taenia_saginata_adult_5260_lores.jpg. Public Domain.

(18) suika*2009. http://www.flickr.com/photos/14376024@N00/178810773/. CC-BY 2.0.

Chapter 12

Other Invertebrates

12.1 Lesson 12.1: Mollusks

Lesson Objectives

- Discuss what characteristics define mollusks.
- Describe the different types of mollusks.
- Explain why mollusks are important.

Check Your Understanding

- What is an invertebrate?
- How are animals classified?

Introduction

Perhaps the best example of a wide variety of attainable mollusks is along a walk on the beach (**Figure** 12.1). There you can find the calcified shells of many different types of mollusks, most typically clams, mussels, scallops, oysters, and snails. Another reminder of the treasures that mollusks yield up may be as close as a jewelry collection (**Figure** 12.2). There glossy pearls, mother of pearl (**Figure** 12.3), and abalone shells reveal some of the unique features of mollusks (**Figure** 12.4).

As you learn about the different types of mollusks and their characteristics, consider how these features help adapt the mollusks to their living conditions. Then also admire their features and see how people's ingenuity has used the mollusk's design and beauty for practical and decorative purposes.

Figure 12.1: The beach yields a wide variety of mollusks. (13)

Figure 12.2: Pearls being removed from oysters. (16)

Figure 12.3: The inside of a bivalve, one of the mollusk classes described in "Types of Mollusks," showing mother of pearl. (35)

Figure 12.4: Shells of marine mollusks, including abalone. (26)

What are Mollusks?

Mollusks belong to the phylum **Mollusca**. The mollusk body is often divided into a head with eyes or tentacles, a muscular foot, and a mass housing the organs. In most species, the muscular foot is used for locomotion. Mollusks also have a mantle, a fold of the outer skin lining the shell, which in most mollusks secretes a calcium carbonate external shell, just like the ones you find on the beach.

The majority of marine mollusks have a gill or gills to absorb oxygen from the water. All species have a complete digestive tract that begins at the mouth and runs to the anus. Many have a feeding structure, the **radula**, found only in mollusks. The radula is composed mostly of **chitin**, a tough, semitransparent substance that is the main component of the shells of crustaceans and the outer coverings of insects. Radulae range from structures used to scrape algae off rocks to the beaks of squid and octopuses.

Larval development suggests a close relationship between the mollusks and other groups, notably the annelids, any of various worms or worm-like animals, including the earthworm and leech, characterized by a cylindrical, elongated, and segmented body. Unlike the annelids, however, mollusks lack body segmentation and their body shape is usually quite different, as well.

The giant squid (**Figure** 12.5), which until recently had not been observed alive in its adult form, is one of the largest invertebrates. However, the colossal squid is even larger and can grow up to 46 ft. (14 m) long. The smallest mollusks are snails that are microscopic in size.

Figure 12.5: The colossal squid, one of the largest invertebrates, here measuring 30 ft (9 m) in length. (21)

Types of Mollusks

Within the phylum Mollusca, there are approximately 160,000 living species and an estimated 70,000 extinct species. Mollusks are typically divided into ten classes, of which two are extinct. Which classes are you most familiar with?

Table 12.1: **Living Molluscan Classes**

Molluscan Class	Number of Species	Habitat	Features of Class/Examples
Caudofoveata	70	Deep ocean	Worm-like organisms
Aplacophora	250	Deep ocean	Worm-like organisms
Polyplacophora	600	Rocky marine shorelines	Chitons (**Figure** 12.6)
Monoplacophora	11	Deep ocean	Limpet-like organisms
Gastropoda	150,000 (80% of living molluscan diversity)	Marine (some limpets live in deep ocean around hot hydrothermal vents), freshwater, and terrestrial	Abalone, limpets, conch, nudibranchs, sea hares, sea butterfly, snails, and slugs (**Figure** 12.7.)
Cephalopoda	786	Marine	Most neurologically advanced of all invertebrates; include squid, octopus, cuttlefish, and nautilus (**Figure** 12.8).

Table 12.1: (continued)

Molluscan Class	Number of Species	Habitat	Features of Class/Examples
Bivalvia	8,000	Marine (some clams live in deep ocean around hot hydrothermal vents) and freshwater.	Most bivalves are **filter feeders** (mechanism whereby suspended matter and food particles are strained from the water, typically by passing the water over a specialized filtering structure); bivalves include clams, oysters, scallops, and mussels.
Scaphopoda	350	Marine	Tusk shells

Figure 12.6: A chiton and sea anemones at a tide pool. (31)

As you can see, the majority of mollusk species live in marine environments, and many of them are found intertidally in the shallow subtidal zone and on the continental shelf. Freshwater species are represented in the bivalves and gastropods, and some gastropods, like land snails, and slugs, live on land.

Figure 12.7: An example of a gastropod species, the ostrich foot. (10)

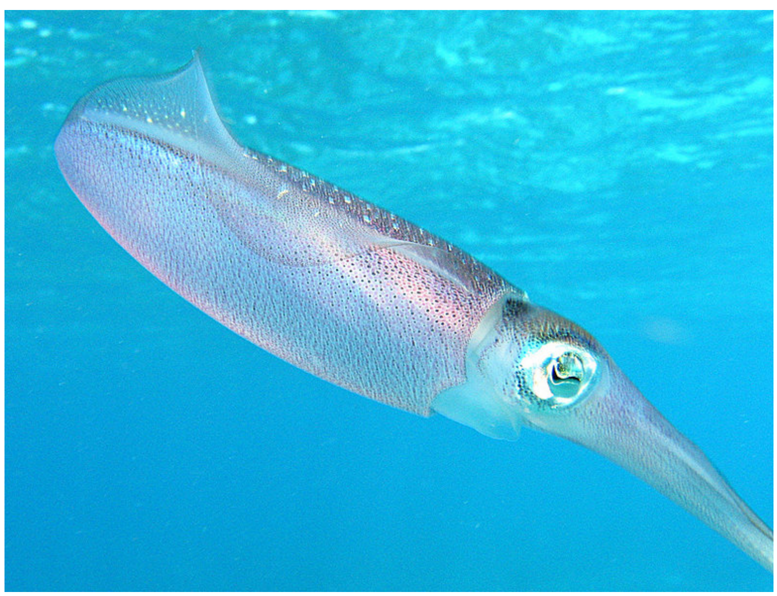

Figure 12.8: A Caribbean reef squid, an example of a cephalopod. (3)

Importance of Mollusks

Mollusks are important in a variety of ways, including as food, for decoration, in jewelry, and in scientific studies. They are even used as roadbed material and in calcium supplements.

Edible species of mollusks include numerous species of clams, mussels, oysters, scallops, marine and land snails, squid, and octopus. Many species of mollusks, such as oysters, are farmed in order to provide additional food sources (**Figure** 12.9).

Figure 12.9: An oyster harvest in France. (14)

Two natural products of mollusks used for decorations and jewelry are **pearls** and **nacre**, or mother of pearl. A pearl is the hard, round object produced within the mantle of a living shelled mollusk. Fine quality natural pearls have been highly valued as gemstones and objects of beauty for many centuries. The most desirable pearls are produced by oysters and river mussels.

Nacre is an iridescent inner shell layer produced by some bivalves, some gastropods, and some cephalopods, and has been used in sheets on floors, walls, counter tops, doors, and ceilings. It is also inserted into furniture; it can be found in buttons, watch faces, knives, guns, and jewelry; and is used as decorations on various musical instruments.

Several mollusks are ideal subjects for scientific investigation, especially in the area of neurobiology. The giant squid has a sophisticated nervous system and a complex brain for study. The California sea slug, also called the California sea hare, is used in studies of learning and memory, since it has a simple nervous system, consisting of just a few thousand large, easily identified neurons, but also a variety of learning tasks.

Lesson Summary

- The mollusk body often has a head with eyes or tentacles, a muscular foot, a mass housing the organs, and a mantle, which secretes the external shell.
- Other mollusk structures include a gill or gills for absorbing oxygen, a complete digestive tract, and a radula.
- Mollusks are divided into ten living classes, including the familiar gastropods, cephalopods, and bivalves.
- Mollusks live in marine and freshwater habitats, as well as on land.
- Mollusks are important as food, for decoration, and in scientific studies.

Review Questions

1. What are the main characteristics of mollusks?
2. What evidence shows that mollusks and annelids are related? How are they different?
3. What habitats do marine mollusks live in?
4. What makes the California sea slug ideal for studies of learning and memory?
5. Oysters, one of the bivalve filter feeders, filter up to five liters of water per hour. Sediment, nutrients, and algae can cause problems in local waters, but oysters filter these pollutants and either eat them or shape them into small packets that are deposited on the bottom where they are harmless. When there is a high concentration of bacteria in the water from sewage run-off, this can make filter feeders, like clams and mussels, risky to eat. What do you think happens to the pollutants in this case?

Further Reading / Supplemental Links

- http://www.centerofweb.com/scitech/bio_mollusks.htm
- http://www.manandmollusc.net/links_educational.html
- http://www.oceanicresearch.org/education/wonders/mollusk.html
- http://www.manandmollusc.net/links_medicine.html
- http://en.wikipedia.org

Vocabulary

chitin A tough, semitransparent substance that is the main component of the radula.

filter feeders A mechanism whereby suspended matter and food particles are strained from the water, typically by passing the water over a specialized filtering structure.

mollusca The phylum containing ten living classes of mollusks.

nacre The iridescent inner shell layer produced by some bivalves, some gastropods, and some cephalopods; also known as mother of pearl.

pearl The hard, round object produced within the mantle of a living shelled mollusk.

radula A molluscan feeding structure, composed mostly of chitin.

Points to Consider

- Many mollusks demonstrate bilateral symmetry. How do you think this differs from the radial symmetry evident in echinoderms, in the next lesson?
- As we have seen, some species of mollusks live in the deep ocean around hot hydrothermal vents. In the next lesson we will learn that many echinoderms also live in the deep sea. What adaptations do you think both groups might have for living in such a unique environment?
- Mollusks have an exoskeleton, which is primarily external and composed of calcium carbonate. As a result many of these are preserved in the fossil record. How do you think this compares to the type of skeleton that an echinoderm has and to its fossil record?

12.2 Lesson 12.2: Echinoderms

Lesson Objectives

- Discuss the traits of echinoderms.
- List the types of echinoderms.
- Explain the roles echinoderms play.

Check Your Understanding

- What is meant by body symmetry?
- What is radial symmetry?
- What is bilateral symmetry?

Introduction

We're all familiar with starfish (**Figure** 12.10), and also maybe sea urchins (**Figure** 12.11) and sand dollars (**Figure** 12.12). The radial symmetry is what hits us right away, a symmetry in which the body is arranged in five parts around a central axis. Much of the perceived beauty of this group resides in that design. Later in this lesson, learn how symmetry takes advantage of the animal's habitat.

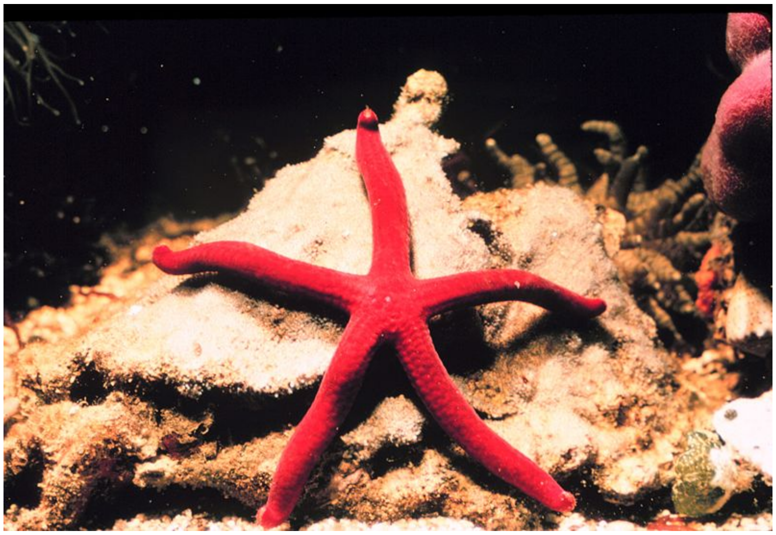

Figure 12.10: A starfish, showing the radial symmetry, characteristic of the echinoderms. (8)

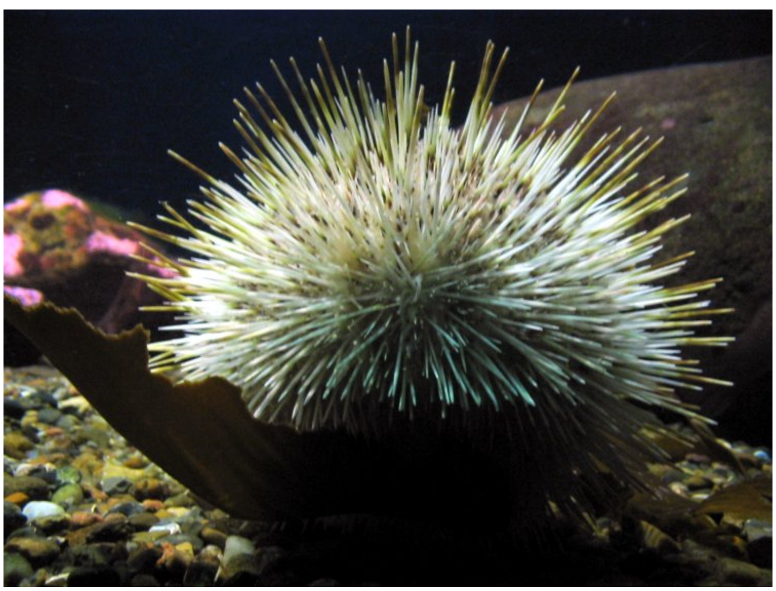

Figure 12.11: Another echinoderm. a sea urchin, showing its calcareous spines. (33)

The other things that stand out, quite literally, are the calcareous (containing calcium carbonate) spines of the sea urchin. If you've gone snorkeling or walked on a sandy beach you've learned to most likely watch out for those sharp spines. Think about how this adaptation might benefit the sea urchin in terms of predation and colonization by other organisms. Can you think of another use of these structures?

Figure 12.12: An echinoderm, the keyhole sand dollar. (18)

These and other adaptations will be explored in more detail as we examine this most fascinating group of invertebrates. Next time you take a walk on the beach, you'll have appreciation for these organisms and how they are adapted for their environment.

What are Echinoderms?

Echinoderms belong to the phylum **Echinodermata**, which contains marine animals living at all ocean depths. It consists of about 7,000 living species, the largest phylum without freshwater or terrestrial members. Also, few other groups are so abundant in the deep ocean as well as the shallower seas.

As mentioned earlier, echinoderms are radially symmetric. In spite of their appearance, they do not have an external skeleton. Instead, a thin outermost skin covers an internal endoskeleton made of tiny calcified plates and spines, contained within tissues of the organism, and which forms a rigid support. Some groups, such as the sea urchins (**Figure** 12.13), have calcareous spines, referred to earlier, which protect the organism from predation and colonization by encrusting (covering or coating) organisms. The sea cucumbers also use these spines for locomotion.

Echinoderms have a unique **water vascular system**, a network of fluid-filled canals, which function in gas exchange, feeding, and also in locomotion. This system allows them to function without gill slits found in other organisms. Echinoderms possess a very simple

Figure 12.13: An echinoderm, the giant California sea cucumber. (9)

digestive system, often leading directly from mouth to anus. They also possess an open and reduced circulatory system, but no heart. Their nervous system consists of a modified **nerve net** (interconnected neurons with no central brain).

In most species, eggs and sperm cells are released into open water, where fertilization takes place. The release of sperm and eggs is coordinated temporally (to occur at the same time) in some species and spatially (to occur within the same location) in others. Internal fertilization takes place in a few species. Some species even have parental care!

Many echinoderms have amazing powers of regeneration. Some sea stars are capable of regenerating lost arms, and in some cases, lost arms have been observed to regenerate a second complete sea star! Sea cucumbers often discharge parts of their internal organs if they perceive danger. The discharged organs and tissues are then quickly regenerated.

Feeding strategies vary greatly among the different groups of echinoderms. Some are passive filter-feeders, absorbing suspended particles from passing water; others are grazers; others are deposit feeders, which feed on particles of organic matter, usually in the top layer of soil, and still others are active hunters.

Types of Echinoderms

The echinoderms are subdivided into two major groups, the Eleutherozoa, which contains the more familiar, motile classes, and the Pelmatozoa, which contains the sessile (permanently attached and not freely moving) crinoids, including the feather stars (**Figure** 12.14), which have secondarily developed a free-living lifestyle.

Figure 12.14: This passion flower feather star is an echinoderm. (36)

The following table summarizes the four main classes of echinoderms present in the Eleutherozoa Group:

Table 12.2:

Echinoderm Class	Representative Organisms
Asteroidea	Starfish and sea daisies
Ophiuroidea	Brittle stars (**Figure** 12.15)
Echinoidea	Sea urchins and sand dollars
Holothuroidea	Sea cucumbers

Figure 12.15: The giant red brittle star, an ophiuroid echinoderm. (28)

Echinoderms are distributed all over the world at almost all depths, latitudes, and environments in the ocean. They are in highest diversity in reefs but are also widespread on shallow shores, around the poles (where crinoids are at their most abundant) and throughout the deep ocean, where bottom dwelling and burrowing sea cucumbers are common, sometimes dollar and sea cucumber burrowing provides more oxygen at greater depths of the sea floor, thus allowing a more complex ecological community to develop. In addition, starfish and brittle stars prevent the growth of algal mats on coral reefs, so that the coral can more effectively filter-feed.

Echinoderms are also the staple diet of many organisms, including the otter. Many sea cucumbers provide a habitat for parasites, including crabs, worms, and snails. The extinction of large quantities of echinoderms appears to have caused a subsequent overrunning of ecosystems by seaweed, causing the destruction of entire reefs.

Economically, in some countries echinoderms are regarded as delicacies. Around 50,000 tons of sea urchins are captured each year, and certain parts are consumed mostly in Japan, Peru, and France. Sea cucumbers are considered a delicacy in some southeastern Asian countries.

Some sea cucumber toxins slow down the growth rate of tumor cells, so there is an interest in using these in cancer research. The calcareous external covering of echinoderms is used as a source of lime by farmers in some areas where limestone is unavailable and 4,000 tons of the animals are used each year for this purpose.

Lesson Summary

- Echinoderms belong to the phylum Echinodermata, the largest phylum without freshwater or terrestrial members.
- Echinoderms are radially symmetric, they have an endoskeleton, some have calcareous spines they have a unique water vascular system, a simple digestive system, an open and reduced circulatory system and a modified nerve net.
- Fertilization is generally external; regeneration is fairly common among echinoderms; feeding strategies vary greatly.
- Echinoderms consist of two main subdivisions, the motile Eleutherozoa and the sessile Pelmatazoa.
- Echinoderms are distributed all over the world at almost all depths, latitudes, and marine environments.
- Echinoderms play an important role in the ecological community. Economically, they are eaten as delicacies in different countries, they play a role in cancer research, and they are used as a source of lime.

Review Questions

1. What are the characteristic features of echinoderms?
2. What feeding strategies are represented in the echinoderms?
3. What protection do echinoderms have against predation?
4. Chemical elements within the skeleton makes it stronger and more resistant. How could this be an advantage in grazing echinoderms?

5. The larvae of many echinoderms, especially starfish and sea urchins, are **pelagic** (of or pertaining to the open ocean). How does this relate to the fact that echinoderms are distributed globally?

Further Reading / Supplemental Links

- http://dictionary.reference.com
- http://www.oceanicresearch.org/education/wonders/echinoderm.html
- http://www.junglewalk.com/info/echinoderm-information.htm
- http://invertebrates.si.edu/echinoderm/http://en.wikipedia.org

Vocabulary

echinodermata The phylum of the echinoderms; contains about 7,000 living species, the largest phylum without freshwater or terrestrial members.

nerve net Interconnected neurons that send signals in all directions.

pelagic Of, or pertaining to, the open ocean.

sessile Permanently attached and not freely moving.

water vascular system A network of fluid-filled canals; functions in gas exchange, feeding, and also in locomotion.

Points to Consider

- Echinoderms' water vascular system functions in gas exchange via a network of fluid-filled canals. Terrestrial arthropods have internal surfaces that are specialized for gas exchange, via air sacs. How might these systems compare and differ?

- Echinoderms possess an open and reduced circulatory system, consisting of a central ring and five radial vessels but no heart. Arthropods also have an open circulatory system but the blood is propelled by a series of hearts into the body cavity where it comes in direct contact with the tissues. Why might there be an advantage to having a heart as part of the circulatory system?

12.3 Lesson 12.3: Arthropods

Lesson Objectives

- Explain what arthropods are.
- Describe the features of crustaceans.
- Describe the characteristics of centipedes and millipedes.
- List the features of arachnids.
- Describe why arthropods are important.

Check Your Understanding

- What is an invertebrate?
- What do mollusks and echinoderms have in common?

Introduction

With over a million described species in the phylum containing arthropods, chances are you encounter one of these organisms every day, even without leaving your house. As much as we would like to eliminate all insect pests from our dwellings, for example, there is a great probability you will see an ant, a spider, a fly, or a moth inside. Even if you don't, you will most likely see such creatures in your yard or on a walk around your neighborhood.

Wherever you observe these animals, you will see a tremendous amount of diversity and adaptations. You will also learn, despite how you feel about how annoying some of these organisms may be, how beneficial in fact they are both ecologically and economically.

What are Arthropods?

Arthropods belong to the phylum **Arthropoda**, which means "jointed feet," and includes four living subphyla. These are chelicerates, including spiders (**Figure** 12.16), mites, scorpions (**Figure** 12.17) and related organisms; myriapods, comprising centipedes (**Figure** 12.18) and millipedes (**Figure** 12.19) and their relatives, who are hexapods, including insects and three small orders of insect-like animals; and crustaceans, including lobsters (**Figure** 12.20), crabs (**Figure** 12.21), barnacles (**Figure** 12.22), crayfish (**Figure** 12.23), and shrimp.

Arthropods are characterized by the possession of a segmented body with appendages on at least one segment. Arthropod appendages are used for feeding, sensory reception, defense, and locomotion. Their heart is on the dorsal side and the nervous system on the ventral. They are covered by a hard exoskeleton made of chitin, which provides physical protection and among terrestrial species resistance to drying out. In order to grow, arthropods shed

Figure 12.16: A species of spider in its web. (7)

Figure 12.17: A species of scorpion. (4)

Figure 12.18: A centipede, from the subphyla of myriapods. (34)

Figure 12.19: A species of millipede found in Hawaii. (1)

Figure 12.20: The blue American lobster illustrates the segmented body plan of the arthropods. (22)

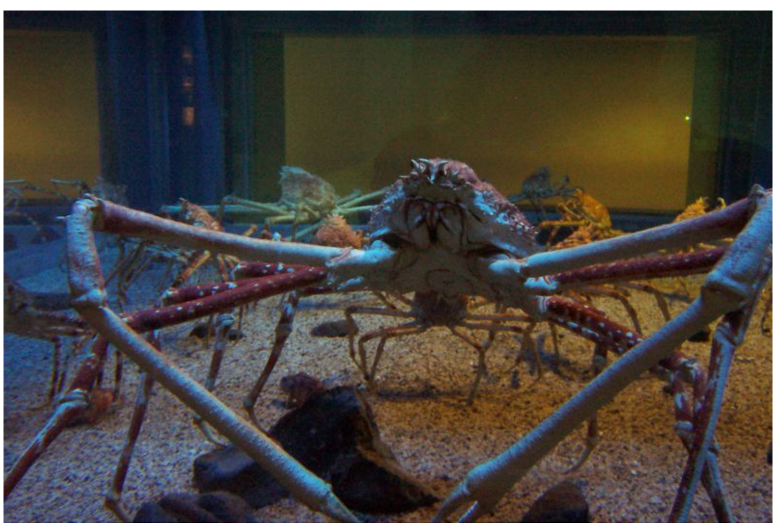

Figure 12.21: Giant spider crabs. (25)

Figure 12.22: The sessile barnacles shown here feeding. (32)

Figure 12.23: A crayfish. (27)

this covering in a process called **molting**.

It is the largest phylum in the Animal Kingdom with more than a million described species making up more than 80% of all described living species. They are found commonly throughout marine, freshwater, terrestrial, and even aerial environments, in addition to various forms that are **parasitic** and **symbiotic**. They range in size from microscopic plankton (approximately ¼ mm) up to the largest living arthropod, the Japanese spider crab, with a leg span up to 12 feet (3.5 m).

Aquatic arthropods use gills to exchange gases. These gills have an extensive surface area in contact with the surrounding water. Terrestrial arthropods have internal surfaces that are specialized for gas exchange. Insects and most other terrestrial species have a **tracheal system**, where air sacs lead into the body from pores in the exoskeleton, for oxygen exchange. Others use **book lungs**, or gills modified for breathing air, as seen in species like the coconut crab. Some areas of the legs of soldier crabs are covered with an oxygen absorbing membrane. Terrestrial crabs sometimes have two different structures: one that is gilled, which is used for breathing underwater, and another adapted to take up oxygen from the air.

Arthropods have an open circulatory system with **haemolymph**, a blood-like fluid, which is propelled by a series of hearts into the body cavity where it comes in direct contact with the tissues. Arthropods have a complete digestive system with a mouth and anus.

Crustaceans

The crustaceans are a large group of arthropods, consisting of almost 52,000 species. The majority of them are aquatic, living in either marine or freshwater habitats. A few groups have adapted to living on land, such as terrestrial crabs, terrestrial hermit crabs, and woodlice (**Figure** 12.24).

Crustaceans are among the most successful animals and are as abundant in the oceans as insects are on land. The majority of crustaceans are motile, although a few groups are parasitic and live attached to their hosts. Adult barnacles live a sessile life, where they are attached headfirst to the substrate and cannot move independently.

Various parts of the crustacean exoskeleton may be fused together, such as in the **carapace**, the thick dorsal shield seen in many crustaceans that often forms a protective chamber for the gills. The main body cavity is an expanded circulatory system, through which blood is pumped by a heart located near the dorsal surface. The digestive system consists of a straight tube that often has a gizzard-like **gastric mill** for grinding food and a pair of digestive glands that absorb food.

Structures that function as kidneys are located near the antennae. A brain exists in the form of **ganglia** (connections between nerve cells) close to the antennae and a collection of major ganglia below the gut. Most crustaceans have separate sexes. Many terrestrial crustaceans, such as the Christmas Island red crab, mate seasonally and return to the sea to release the

Figure 12.24: A terrestrial arthropod, a species of woodlice. (20)

eggs. Others, such as woodlice, lay their eggs on land, although in damp conditions. In other crustaceans, the females keep the eggs until they hatch into free-swimming larvae.

Six classes of crustaceans are generally recognized:

Table 12.3:

Class	Information
Branchiopoda	Includes brine shrimp
Remipedia	A small class restricted to deep caves connected to salt water
Cephalocarida	The horseshoe shrimp
Maxillopoda	Includes barnacles and copepods
Ostracoda	Small animals with bivalve shells
Malacostraca	The largest class, with the largest and most familiar animals: crabs, lobsters, shrimp, krill, and woodlice

Centipedes and Millipedes

Centipedes and millipedes belong to the subphylum **Myriapoda**, which contains 13,000 species, all of which are terrestrial, and which are divided among four classes. They range from having over 750 legs (a species of millipede) to having fewer than ten legs. They have a single pair of antennae and simple eyes.

They are most abundant in moist forests, where they help to break down decaying plant material, although a few live in grasslands, semi-arid habitats, or even deserts. The majority are herbivores, but centipedes are chiefly nocturnal predators.

Although not generally considered dangerous to humans, many from this group produce noxious secretions, which can cause temporary blistering and discoloration of the skin. Centipedes are fast, predatory, and venomous. There are around 3,300 described species, ranging

Arachnids

Arachnids are a class of joint-legged invertebrates in the subphylum **Chelicerata**. They are mainly terrestrial, but are also found in freshwater and in all marine environments, except for the open ocean. They comprise over 100,000 named species, including spiders (**Figure** 12.25), scorpions (**Figure** 12.26), daddy-long-legs, ticks, and mites (**Figure** 12.27) and there may be up to 600,000 species in total, including unknown ones.

Figure 12.25: A daddy-long-legs with a captured woodlouse. (24)

It is commonly understood that arachnids have four pairs of legs and that they may be easily distinguished from insects on this basis (insects have three pairs of legs). Arachnids also have two additional pairs of appendages, the first pair, the **chelicerae**, serve in feeding and defense. The next pair, the **pedipalps**, are adapted for feeding, locomotion, and/or reproductive functions. Arachnids are further distinguished by the fact they have no antennae and no wings. Their body is organized into the **cephalothorax**, derived from the fusion of the head and thorax, and the abdomen.

Arachnids are also well adapted for a terrestrial existence. They have internal respiratory surfaces in the form of trachea or a book lung. They also have appendages modified for more efficient locomotion on land, internal fertilization, special sensory organs, and structures for water conservation, such as more efficient excretory structures and a waxy layer covering the outer layer of the exoskeleton.

Arachnids are mostly carnivorous, feeding on the pre-digested bodies of insects and other small animals. Several groups are largely venomous and they secrete venom from specialized glands to kill prey or enemies. Several mites are parasitic and some of those are carriers of disease. Arachnids usually lay eggs, which hatch into immature arachnids that resemble the adults. Scorpions, however, bear live young.

Figure 12.26: Various diseases are caused by species of bacteria that are spread to humans by "hard" ticks, like the one shown here. (12)

Figure 12.27: A female crab spider sharing its flower with velvet mites. (6)

The arachnids are divided into eleven subgroups. **Table** (12.4) shows the four most familiar subgroups, with a description of each.

Table 12.4:

Subgroup of Arachnid	Representative Organisms	Approximate Number of Species	Description
Araneae	Spiders	40,000	Found all over the world, ranging from tropics to the Arctic, some in extreme environments; All produce **silk**, used for many functions, including trapping insects in webs, aiding in climbing, forming smooth walls for burrows, producing egg sacs, and wrapping prey Nearly all spiders inject venom to protect themselves or to kill prey; only about 200 species have bites that can be harmful to humans

Table 12.4: (continued)

Subgroup of Arachnid	Representative Organisms	Approximate Number of Species	Description
Opiliones	Daddy-long-legs	6,300	Known for exceptionally long walking legs; no silk nor poison glands Many are omnivores, eating small insects, plant material and fungi; some are scavengers, eating decaying animal and other matter Mostly nocturnal, colored in hues of brown; a number of diurnal species have vivid patterns of yellow, green, and black

Table 12.4: (continued)

Subgroup of Arachnid	Representative Organisms	Approximate Number of Species	Description
Scorpiones	Scorpions	2,000	Characterized by a tail with six segments, the last bearing a pair of venom glands and a venom-injecting barb Predators of small arthropods and insects, they use pincers to catch prey, then either crush it or inject it with a fast-acting venom, which is used to kill or paralyze the prey; only a few species are harmful to humans Nocturnal; during the day find shelter in holes or under rocks Unlike the majority of arachnids, scorpions produce live young, which are carried about on the mother's back until they have molted at least once; they reach an age of between four to 25 years

Table 12.4: (continued)

Subgroup of Arachnid	Representative Organisms	Approximate Number of Species	Description
Acarina	Mites and ticks	30,000	Most are minute to small (no more than 1.0 mm in length), but some ticks and one species of mite may reach lengths of 10-20 mm Live in nearly every habitat, including aquatic and terrestrial Many are parasitic, affecting both invertebrates and vertebrates, and may be vectors of human and other mammalian disease; those that feed on plants may damage crops

Why Arthropods are Important

Many species of crustaceans, especially the familiar crabs, lobsters, shrimp, prawn, and crayfish, are consumed by humans, and nearly 10,000,000 tons were produced in 2005. Over 70% by weight of all crustaceans caught for consumption are shrimp and prawns, and over 80% is produced in Asia, with China producing nearly half the world's total.

Some mites prey on undesirable arthropods and are used in pest control, while others control weed growth. Populations of whip scorpions are valuable in controlling populations of cockroaches and crickets. Finally, an unquantified, but major positive contribution of the mites and ticks, as well as the centipedes and millipedes, is their role in ecosystems, especially their roles as decomposers and the resulting enriching of the soil due to the release of the nutrients during decomposition.

In the next lesson, we will discuss the diversity of insects. As we will see, insects, also arthropods are beneficial in many ways, both to the ecosystems of which they are part, as well as to humans.

Lesson Summary

- The phylum Arthropoda includes four living subphyla; chelicerates, including spiders, mites, and scorpions; myriapods, including centipedes and millipedes; hexapods, including insects; and crustaceans. Arthropods are characterized by a segmented body; appendages used for feeding, sensory structures, defense, and locomotion; a dorsal heart and a ventral nervous system; and a hard exoskeleton. Arthropods are the largest phylum in the Animal Kingdom with more than a million described species; they are found in all environments. There are a variety of respiratory systems in arthropods, including gills, tracheal system, book lungs, and oxygen absorbing membranes; arthropods have an open circulatory system and a complete digestive system.
- Crustaceans consist of almost 52,000 species, the majority of which are aquatic; they are among the most successful animals. There are six classes of crustaceans, including brine shrimp, barnacles and copepods, and the malacostracans, including crabs, lobsters, and shrimp. Centipedes and millipedes belong to the myriapods, where they occur most abundantly in moist forests; they are chiefly nocturnal predators.
- Arachnids are mainly terrestrial and comprise over 100,000 named species; adaptations for a terrestrial existence include specialized respiratory structures, appendages modified for locomotion on land, internal fertilization, special sensory organs, and structures for water conservation. Arachnids are divided into eleven subgroups, the most familiar being spiders; spiders produce silk, which is used in a variety of ways. Many species of crustaceans are used for food; some species of mites are used in pest control and for controlling weeds; and centipedes, millipedes, and the acarines play a valuable role as decomposers, enriching the soil as a result.

Review Questions

1. What are arthropod appendages used for?
2. What respiratory systems do terrestrial arthropods use?
3. Arachnids have several adaptations for living on land. For each adaptation you list, explain how it is beneficial for a terrestrial existence.

4. How does the scorpions' method of producing young differ from most other arachnids?

Further Reading / Supplemental Links

- http://cybersleuth-kids.com/sleuth/Science/Animals/Arthropods/index.htm
- http://www.oceanicresearch.org/education/wonders/arthropods.htm
- http://www.biokids.umich.edu/critters/Crustacea
- http://www.nps.gov/archive/yell/kidstuff/Alphabet/a.htm

Vocabulary

acarina The group of arachnids containing the mites and ticks.

araneae The arachnid group containing the spiders.

arthropoda The phylum meaning "jointed feet;" includes four living subphyla of arthropods.

book lungs Gills modified for breathing air.

carapace The thick dorsal shield seen in many crustaceans; often forms a protective chamber for the gills.

cephalothorax The anterior part of the arachnid body, derived from the fusion of the head and thorax.

chelicerae The first pair of arachnid appendages; used in feeding and defense.

chelicerata An arthropod subphylum containing the arachnids.

ganglia A compact group of nerve cells having a specific function.

gastric mill A gizzard-like structure for grinding food.

haemolymph A blood-like fluid, which is propelled by a series of hearts into the body cavity, where it comes in direct contact with the tissues.

molting The process by which arthropods shed their hard exoskeleton in order to grow.

myriapoda An arthropod subphylum containing the centipedes and millipedes.

opiliones The arachnid group containing daddy-long-legs.

parasitic Living on or in an organism of another species; harmful to the host species.

pedipalps The second pair of arachnid appendages used for feeding, locomotion, and/or reproductive functions.

scorpiones The group of arachnids containing the scorpions.

silk A thin, strong, protein strand extruded from the spinnerets; most commonly found on the end of the abdomen of spiders.

symbiotic The living together of two dissimilar organisms.

Points to Consider

- Arthropods are characterized by the possession of a segmented body with appendages on at least one segment and they are covered by a hard exoskeleton made of chitin. How is the general arthropod body plan specialized in the insects?
- Insects are the only group of invertebrates to have developed flight. Compare this mode of locomotion to those discussed in the groups of arthropods already discussed. What advantages might there be to using flight for a method of locomotion?

12.4 Lesson 12.4: Insects

Lesson Objectives

- Describe the characteristics of insects.
- Explain how insects obtain food.
- Describe reproduction and the life cycle of insects.
- Explain how insects are important.
- Describe how insect pests are controlled.

Check Your Understanding

- What is an arthropod?
- Is a spider an insect? Why or why not?

Introduction

Insects, with over a million described species, are the most diverse group of animals on Earth. They may be found in nearly all environments on the planet. That would explain that no matter where you travel, you are bound to see representatives from this group and probably lots of different kinds as well. Even if you were not partial to bees, wasps, and ants perhaps, it would be difficult to not admire the beauty of a butterfly, moth, or even a dragonfly!

As you learn about the amazing diversity within this group and some of the fascinating behaviors, you may begin to look upon some of the insects you come upon with a bit more interest! Perhaps you will even learn to appreciate some of the species you may dislike now, such as bees and wasps, when you realize how beneficial they are to humans and especially necessary for the continued presence of some of the beautiful flowers or delicious fruits that may grace your yard or nearby park.

What Are Insects?

Insects are a major group of arthropods and the most diverse group of animals on the planet, with over a million described species and more than half of all known living organisms. They are found in nearly all environments on Earth, although only a few species occur in the oceans. Adults range in size from a minuscule fairy fly to a 21.9 in (55.5 cm) long stick insect (**Figure** 12.28).

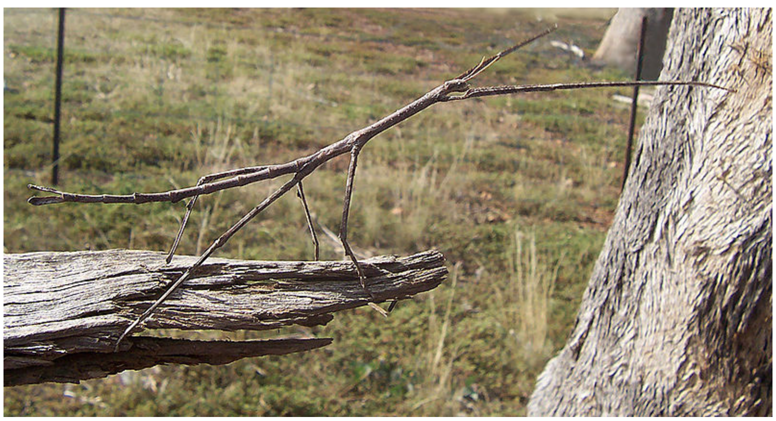

Figure 12.28: A stick insect, showing how well it blends in to its environment. (29)

Insects have segmented bodies with an exoskeleton. The outer layer of the exoskeleton, the **cuticle,** is made up of two layers, a thin and waxy water resistant outer layer (the **exocuticle**), and an inner, much thicker layer. The exocuticle is greatly reduced in many soft-bodied insects and especially in larval stages, such as caterpillars (**Figure** 12.29).

The segments of the body are organized into three distinctive but joined units: a head, a thorax, and an abdomen (**Figure** 12.30).

Figure 12.29: Caterpillars feeding on a host plant. (23)

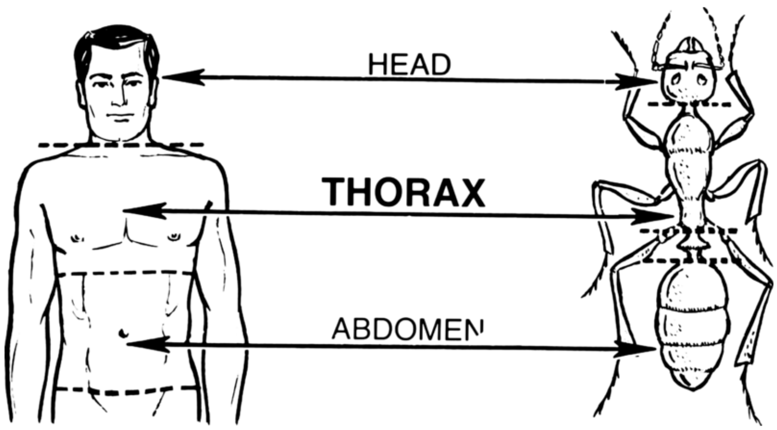

Figure 12.30: A diagram of a human and an insect, comparing the three main body parts: head, thorax, and abdomen. (2)

Table 12.5: **shows the structures present in each body segment.**

Head	Thorax	Abdomen
A pair of sensory antennae, a pair of compound eyes, one to three simple eyes, and three sets of variously modified appendages that form the mouthparts	Six segmented legs and two or four wings	Has most of the digestive, respiratory, excretory, and reproductive structures

The nervous system is divided into a brain and a ventral nerve cord. Air is taken in through the **spiracles**, openings on the sides of the abdomen. Insect respiration occurs without lungs, with a system of internal tubes and sacs through which oxygen is delivered directly to the adjoining body tissues. Since oxygen is delivered directly, the circulatory system is therefore greatly reduced and consists of only a single dorsal tube with openings. The tube pulses and circulates blood-like fluids inside the body cavity.

Insect locomotion includes flight, walking, and swimming. Insects are the only invertebrates to have developed flight and this has played an important role in their success. Insect flight is not very well understood. Primitive insect groups use muscles that act directly on the wing structure. More advanced groups have foldable wings and their muscles act on the wall of the thorax and give power to the wings indirectly. These muscles are able to contract multiple times for each single nerve impulse, allowing the wings to beat faster than would ordinarily happen.

Many adult insects use six legs for walking and have adopted a gait that uses the legs in alternate triangles touching the ground. This gait allows for rapid walking at the same time as having a stable stance. A few insects have evolved to walk on the surface of the water, especially the water striders (**Figure** 12.31).

A large number of insects live either parts of or their whole lives underwater. Water beetles and water bugs have legs adapted to paddle in the water. Dragonfly young use jet propulsion, forcibly expelling water out of the rectal chamber.

Insects use a wide variety of senses for both communicating and receiving information. Many insects have very sensitive and/or specialized sensory organs. **Table** (12.6) summarizes five types of communication that are used by various insects and sometimes for different purposes.

Figure 12.31: A pair of water striders mating, showing how water surface tension allows for them to stand on the water. (17)

Table 12.6: **Insect Communication**

Types of Communication	Representative Organisms	Description
Visual Ultraviolet wavelengths Polarized light Bioluminescence	Bees Bees Fireflies	Perceive ultraviolet wavelengths Detect polarized light Reproduction and Predation Some species produce flashes to attract mates; other species to lure prey.

Table 12.6: (continued)

Types of Communication	Representative Organisms	Description
Sound Production Mostly by mechanical action of appendages Ultrasound clicks Hearing	Cicadas Moths Moths Some predatory and parasitic insects	Loudest sounds among insects; have special modifications of body and musculature to produce and amplify sounds. Predation Produced mostly by unpalatable moths to warn bats; other moths make similar sounds in order to mimic distasteful moths so they will be avoided by bats as well. Predation Some nocturnal species can hear the ultrasonic emissions of bats, which help them avoid predation. Can detect sounds made by prey or hosts.

Table 12.6: (continued)

Types of Communication	Representative Organisms	Description
Chemical Wide range of insects have evolved chemical communication; chemicals often derived from plant metabolites and are used to attract, repel, or provide other kinds of information; chemicals may be targeted at individuals of same or different species; use of scents is especially well developed in social insects.	Moths	Antennae of males can detect **pheromones** (chemicals secreted by animals, especially insects, that influence the behavior or development of others within the same species) of female moths over distances of many kilometers (**Figure** 12.32).
Infrared	Blood-sucking insects	Have specialized sensory structures that can detect infrared emissions in order to find their hosts.

Table 12.6: (continued)

Types of Communication	Representative Organisms	Description
"Dance Language" – a system of abstract symbolic communication	Honey bees	Thought that various species of honey bees are only invertebrates to have evolved this type of communication; angle at which bee dances represents direction relative to sun, length of dance represents distance to be flown.

Figure 12.32: A yellow-collared scape moth, showing the feathery antennae. (37)

Social insects, such as the termites (**Figure** 12.33), ants, and many bees and wasps (**Figure** 12.34), are the most familiar social species. They live together in large well-organized colonies. Only those insects which live in nests or colonies show any true capacity for homing. This allows an insect to return to a single hole among a mass of thousands of apparently identical holes, after a trip of up to several kilometers and as long as a year after last seeing the area, as when an insect hibernates. A few insects migrate, but this is a larger-scale form of navigation and involves only a large general region, such as the overwintering of the monarch butterfly (**Figure** 12.35).

Figure 12.33: Damage to this nest, brings the workers and soldiers of this social insect, the termite, to repair it. (5)

Figure 12.34: A wasp building its nest. (30)

Figure 12.35: Monarch butterflies in an overwintering cluster. (11)

Insects are divided into two major groups, the wingless and the winged insects. The wingless consists of two orders: the bristle tails and the silverfish. The winged orders of insects include the mayflies; dragonflies and damselflies; stoneflies; webspinners; angel insects; earwigs; grasshoppers, crickets, and katydids; stick insects; ice-crawlers and gladiators; cockroaches and termites; mantids; lice; thrips; true bugs, aphids, and cicadas; wasps, bees, and ants; beetles; twisted-winged parasites; snakeflies; alderflies and dobsonflies; lacewings and antlions; Scorpios and hangingflies (including fleas); true flies; caddisflies; and butterflies, moths, and skippers.

How Insects Obtain Food

Insects have a wide variety of appendages adapted for capturing and feeding on prey. In addition, as already discussed, they have sensory capabilities, which help them detect prey.

Insects have a wide range of mouthparts used for feeding. Specialized parts are mostly for piercing and sucking, as in mosquitoes and aphids. A number of insect orders have mouthparts that pierce food items to enable sucking of internal fluids. Some are herbivorous, like aphids and leafhoppers, while others are insectivorous, like assassin bugs and mosquitoes (females only).

Examples of chewing insects include dragonflies, grasshoppers, and beetles. Some larvae have chewing mouthparts, as in moths and butterflies.

Some insects use siphoning, as if sucking through a straw, as in moths and butterflies, where some of the mouthparts are adapted into an elongated sucking tube. You have probably seen a butterfly or moth poised at a flower while it siphons the nectar of the flower. Some moths, however, have no mouthparts at all.

Some insects are capable of sponging, as in the housefly. One of the mouthparts is specialized for this function, where liquid food is channeled to the esophagus. The housefly is able to eat solid food by secreting saliva and dabbing it over the food item. As the saliva dissolves the food, the sponging mouthpart absorbs the liquid food.

Reproduction and Life Cycle of Insects

Most insects have a high reproductive rate and can rapidly reproduce within a short period of time. With a short generation time, they evolve faster and can adjust to environmental changes faster. Although there are many forms of reproductive organs in insects, there is a basic design and function for each reproductive part. These parts may vary in shape (gonads), position, and number (glands), with different insect groups.

Most insects reproduce via sexual reproduction. The female produces eggs, which are fertilized by the male, and then the eggs are usually deposited in a precise microhabitat at or near the required food. Most insects are **oviviparous**, where the young hatch after the eggs have been laid. In some insects, there is asexual reproduction and in the most common type, the offspring are essentially identical to the mother. This is most often seen in aphids and scale insects.

An insect can have one of three types of metamorphosis and life cycle:

Table 12.7:

Type of Metamorphosis	None	Incomplete	Complete
Characteristics	Only difference between adult and larvae is size	Young, called **nymphs** (**Figure** 12.36), usually similar to adult, wings then appear as buds on nymphs or early forms; when last molt is completed wings expand to full adult size	Insects have different forms in immature and adult stages, have different behaviors, and live in different habitats; immature form is called larvae and remains similar in form but increases in size; they usually have chewing mouthparts even if adult mouthparts are sucking ones; at last larval stage of development insect forms into pupa (**Figure** 12.37), doesn't feed and is inactive; here wing development is initiated, and adult emerges
Example	Silverfish	Dragonflies	Butterflies and Moths

Importance of Insects

Many insects are considered to be pests by humans. In spite of this, insects are also very important. In the environment, some insects pollinate flowering plants, as in wasps, bees, butterflies, and ants. Many insects, especially beetles, are scavengers, feeding on dead animals and fallen trees, and insects are responsible for much of the process by which topsoil is created.

Insects also produce useful substances as honey, wax, lacquer, and silk. Honeybees have been cultured by humans for thousands of years for honey. The silkworm has greatly affected

Figure 12.36: Heteroptera nymphs and egg cases. (15)

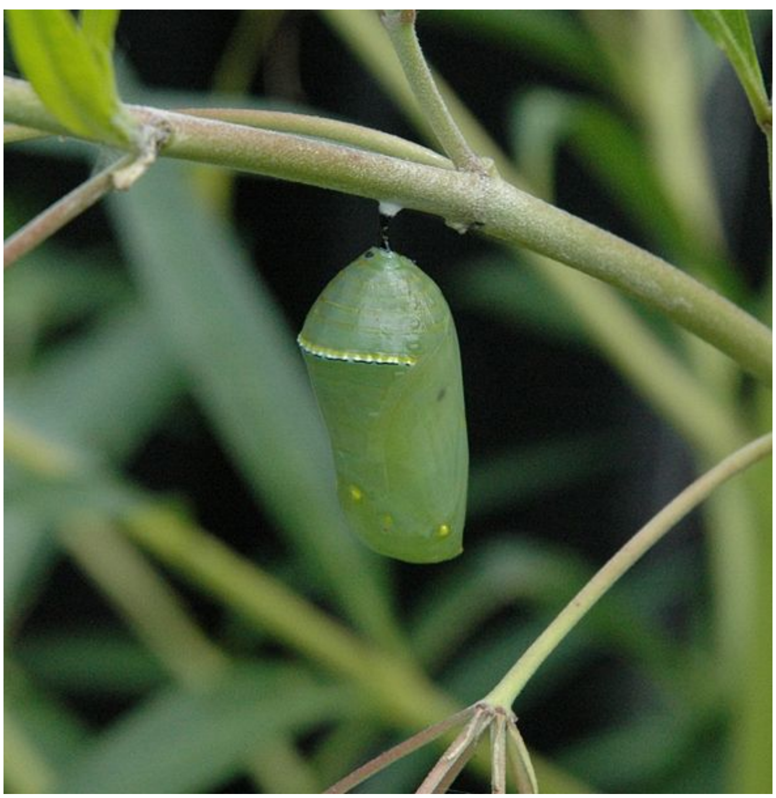

Figure 12.37: The chrysalis (pupal stage) of a monarch butterfly. (19)

human history, as silk-driven trade established relationships between China and the rest of the world.

Fly larvae (maggots) were formerly used to treat wounds to prevent or stop gangrene, as they would only consume dead flesh. This treatment is finding modern usage in some hospitals. Adult insects such as crickets, and insect larvae of various kinds, are also commonly used as fishing bait.

In some parts of the world, insects are used for human food, while being a taboo in other places. Some people support this idea to provide a source of protein in human nutrition. Insects also have a role in controlling insect pests, as we will see in the next section.

Controlling Insect Pests

Insects commonly regarded as pests include those that are parasitic (mosquitoes, lice, bed bugs), transmit diseases (mosquitoes, flies), damage structures (termites), or destroy agricultural products (locusts, weevils). Many entomologists are involved in various forms of pest control, often using insecticides, but more and more relying on methods of biocontrol.

Biological control of pests in agriculture is a method of controlling pests that relies on predation, parasitism, herbivory, or other natural mechanisms. Insect predators, such as lady beetles and lacewings, are mainly free-living species that consume a large number of prey during their lifetime.

Parasitoids are species whose immature stage develops on or within a single insect host, ultimately killing the host. Most have a very narrow host range. Many species of wasps and some flies are parasitoids. Both of these types of predators and parasitoids are used to control insect pests. Pathogens are disease-causing organisms including bacteria, fungi, and viruses, which kill or debilitate their host and are specific to certain insect groups.

Most of the insecticides now applied are long-lasting synthetic compounds that affect the nervous system of insects on contact. Agricultural pesticides prevent a monetary loss of about $9 billion each year in the U.S. These benefits, however, must be weighed against the costs to society of using pesticides, which include human poisonings, fish kills, honeybee poisonings, and the contamination of livestock products.

Lesson Summary

- Insects are the most diverse group of animals on Earth; they are found in nearly all environments. They have segmented bodies with an exoskeleton; the nervous, respiratory, and circulatory systems are fairly simple. Insects are the only invertebrates to have developed flight. Insects have very sensitive and/or specialized organs of perception, including visual, chemical, heat-sensitive, and auditory. Some insects, like termites, ants, and many bees and wasps, are social and live together in large well-organized colonies.

- Insect locomotion includes flight, walking, and swimming. There are two major groups of insects, the wingless and the winged, and these are further subdivided into various orders. Insects obtain food with the use of specialized appendages for capturing and eating the prey. Most insects have a high reproductive rate and can rapidly reproduce within a short period of time. An insect can have one of three types of metamorphosis and life cycle. Insects are beneficial both environmentally and economically. Insect pests can be controlled with chemical or with natural means, some of which are insects themselves; even though agricultural pesticides prevent a major monetary loss, they have major drawbacks, too.

Review Questions

1. What are the main characteristics of insects?
2. Why is the insect's circulatory system greatly reduced?
3. Give an example of mimicry in insects.
4. How do female accessory glands aid in the development of eggs?
5. What makes parasitoids especially effective against pests?

Further Reading / Supplemental Links

- http://homeschooling.gomilpitas.com/explore/bugs.htm
- http://rusinsects.com/links/view.php?id=20
- http://www.kidsolr.com/science/page18.html
- http://pestworldforkids.org/learninggames.html

Vocabulary

cuticle The outer layer of the exoskeleton.

exocuticle The thin and waxy water resistant outer layer of the cuticle.

nymphs A developmental stage of insects, where the young is usually similar to the adult.

oviviparous A method of reproduction where the young hatch after the eggs have been laid.

parasitoids Species whose immature stages develop on or within a single insect host, ultimately killing the host.

pheromones Chemicals secreted by animals, especially insects, that influence the behavior or development of others within the same species.

spiracles Openings on the sides of the insect abdomen, through which air is taken in.

Points to Consider

- Some of the adaptations that insects have evolved for a terrestrial existence are also displayed in amphibians and reptiles. What could be some of these? How are they similar and different?
- Insects have some very specialized sensory capabilities. How do you think these compare to those found in fish, amphibians, and reptiles?

Image Sources

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(24) Daniel Ullrich. *A daddy-long-legs with a captured woodlouse.*. GNU-FDL.

(25) Chris Gladis. *close.jpg Giant spider crabs.*. CC-BY 2.0.

(26) Mila Zinkova. *Shells of marine mollusks, including abalone.*. GNU-FDL.

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Chapter 13

Fishes, Amphibians, and Reptiles

13.1 Lesson 13.1: Introduction to Vertebrates

Lesson Objectives

- Describe the general features of chordates.
- List the three groups of chordates with their characteristics.
- List the general features of vertebrates.
- Describe the classification of vertebrates.

Check Your Understanding

- What is the function of the notochord in lower vertebrates?
- What happens to the notochord in higher vertebrates?

Introduction

It is hard to believe that some of the organisms that are chordates are closely related to us and vertebrates like us - everything from fish to amphibians and reptiles, to birds and mammals. **Chordates** are a group of animals that includes the vertebrates, as well as several closely related invertebrates. Some chordates, as we will soon see, appear to be nothing more than animals resembling marine invertebrates, like the tunicates in **Figure** 13.1. Chordates also include the lancelets, which appear as mostly featureless and simplified swimming animals (**Figure** 13.2). What these all have in common, though, are certain characteristics appearing either in the larval or adult forms, and which we will explore further in the first section.

Vertebrates all have backbones or spinal columns as well as some other defining characteristics. About 58,000 species have been described and contain many familiar groups of large land animals.

Chordates

Chordates (phylum **Chordata**), including the vertebrates and several closely related invertebrates, are united by having, at some time in their life cycle, a **notochord,** a hollow dorsal nerve cord); pharyngeal slits (vertical slits in the pharynx wall, which help to filter out food particles); an **endostyle** (ciliated groove or grooves located in the pharynx), and a post-anal tail. The phylum is broken down into three subphyla: Urochordata (represented by tunicates), Cephalochordata (represented by lancelets) and Vertebrata (the vertebrates).

Urochordates have a notochord and nerve cord only during the larval stage and **cephalochordates** have a notochord and nerve cord but no vertebrae (bones in the backbone). In all vertebrates, except for hagfish, the notochord is generally reduced and the dorsal hollow nerve cord is surrounded with cartilaginous (made of cartilage, not bone) or bony vertebrae.

The urochordates consist of 3,000 species of tunicates (sessile (permanently attached) marine animals, with saclike bodies having thick membranes and siphons for water movement) and the cephalochordates consist of 30 species of lancelets (burrowing marine animals). The vertebrates encompass 57,739 species, including jawless and jawed vertebrates.

The origin of chordates is currently unknown. The first clearly identifiable chordates appear in the Cambrian Period (about 542 - 488 million years ago) as lancelet-like specimens.

Figure 13.1: Tunicate colonies of *Botrylloides violaceus* (subphylum urochordata), showing oral tentacles at openings of oral siphons, which take in food and water, and expel waste and water. (14)

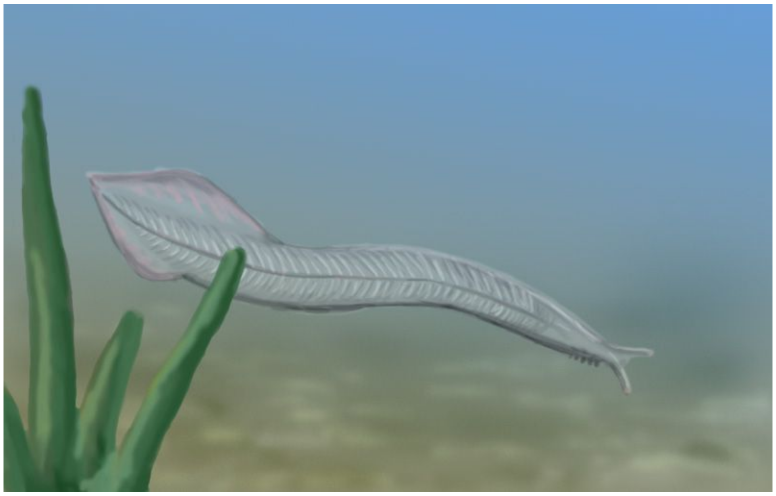

Figure 13.2: *Pikaia gracilens* (subphylum cephalochordates), perhaps the oldest known ancestor of modern vertebrates, resembled a living chordate, known as a lancelet, and perhaps swam much like an eel. *Pikaia* is thought to have had a very primitive, proto-notochord. Its "tentacles" may be related to those in present-day hagfish, a jawless chordate. (29)

What are Vertebrates?

Vertebrates, belonging to the subphylum **Vertebrata**, are chordates with a backbone or spinal column. Other characteristics are a braincase, or **cranium**, and an internal skeleton (the latter feature is present in all vertebrates except for lampreys). All vertebrates are most easily distinguished from all other chordates by having a defined head with pronounced cephalization. **Cephalization** is the concentration of nervous tissue towards one end of the organism. Vertebrates have sensory organs, especially eyes, concentrated at the front (anterior) end of the body. How do you think this type of body design is an advantage?

Typical vertebrate traits include:

- a backbone or spinal column
- braincase
- internal skeleton
- defined head with pronounced cephalization
- sensory organs, especially eyes

The vertebrate muscular system mostly consists of paired masses, as well as a central nervous system, partly located inside the backbone, when a backbone is present. Extant (living) vertebrates range in size from a carp species (**Figure** 13.3), at as little as 7.9 mm (0.3 in), to the blue whale, as large as 110 ft (**Figure** 13.4).

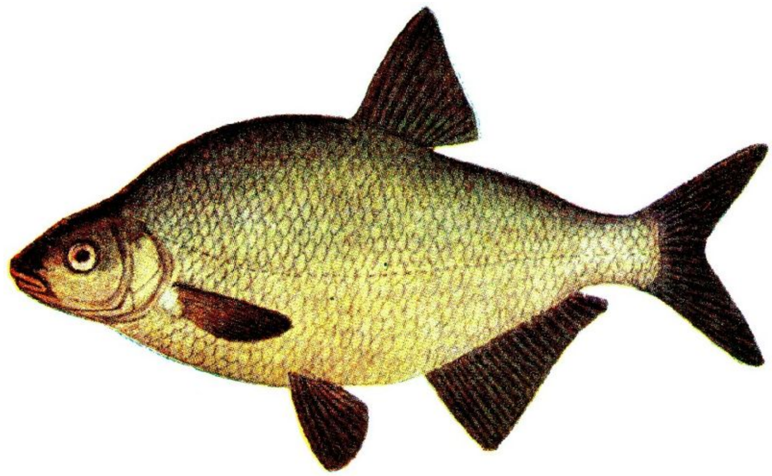

Figure 13.3: A species of carp, carp bream (*Abramis brama*). (10)

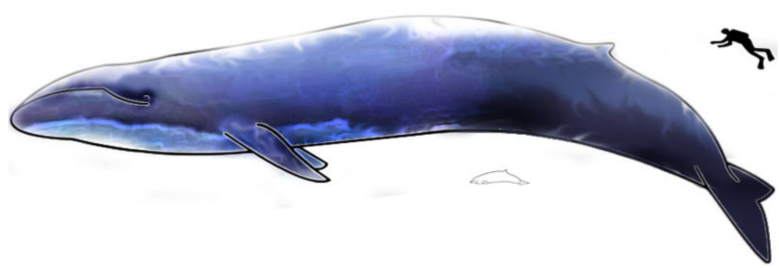

Figure 13.4: An image of the blue whale, the largest living vertebrate, reaching up to 33 m (110 ft) long. Shown below it is the smallest whale species, Hector's dolphin (about 1.4 m (5 ft) in length), and beside it, a human. (24)

Classification of Vertebrates

Vertebrates consist of both jawless and jawed vertebrates. The jawless vertebrates consist of more than 100 species including 65 species of hagfish, the conodonts, and the lampreys. The jawed vertebrates include over 900 species of cartilaginous fish, over 30,000 species of bony fish and over 18,000 species of tetrapods, or four-legged (or leg-like) vertebrates.

The bony fish are further divided into ray-finned and lobe-finned fish. The tetrapods consist of amphibians, reptiles, birds, mammal-like reptiles, and mammals.

Table 13.1: **Species of the Main Groups of Tetrapods**

Type of Tetrapod	Number of Species
Amphibians	6,000
Reptiles	8,225
Birds	10,000
Mammal-like Reptiles	4,500
Mammals	5,800

Lesson Summary

- Chordates are characterized by a notochord, pharyngeal slits, an endostyle, and a post-anal tail.
- There are three main groups of chordates, including tunicates, lancelets and vertebrates.
- Vertebrates are distinguished by having a backbone or spinal column.
- Vertebrates are classified into two major groups: those without jaws and those with jaws.

Review Questions

1. What features characterize the chordates?
2. What are the main features of vertebrates?
3. The first clearly-identifiable chordates are lancelet-like (small, burrowing marine animals with a lancet shape) specimens. List three ways in which these first chordates could have evolved into a swimming-like animal.
4. Which two structures that all chordates possess sometime during their life cycle are used for food gathering, and how are these structures used?
5. Why, do you think, cephalization is not necessary in urochordates and cephalochordates? Explain how this is illustrated in tunicates.

Further Reading / Supplemental Links

- http://www.ucmp.berkeley.edu/chordata/Chordata.html
- http://www.ucmp.berkeley.edu/vertebrates/vertintro.html
- http://en.wikipedia.org/wiki

Vocabulary

cephalization The placement of important sensory organs near or in the head.

cephalochordates A group of chordates with a notochord and nerve cord but no vertebrae.

chordata The phylum of chordates, containing the vertebrates and several closely related invertebrates.

cranium The braincase or skull.

endostyle A groove or pair of grooves having cilia; located in the pharynx; functions are to gather food particles and transport them along the digestive tract.

notochord A hollow dorsal nerve cord.

urochordates A group of chordates having a notochord and nerve cord present only during the larval stage.

vertebrata The subphylum of vertebrates, distinguished by having backbones or spinal columns.

Points to Consider

- The notochord's stiffness in many chordates may have evolved to facilitate the effectiveness of swimming in S-shaped movements. Think about the advantages this may have for water-living vertebrates.
- Unlike chordates with cephalization, cephalochordates (lancelets)have a mouth, but not a well-developed head, and have light-sensitive areas along their entire back, instead of at the anterior end of the body.
- How do you think cephalization could be an advantage in movement and feeding in fish?

13.2 Lesson 13.2: Fishes

Lesson Objectives

- List the general traits of fish.
- Describe the features of jawless fish.
- List the general features of the cartilaginous fish.
- Describe the features of bony fish and the significance of this superclass.
- List some of the reasons why fish are important.

Check Your Understanding

- What are the unique characteristics of vertebrates?
- What are the two main groups of vertebrates?

Introduction

So what exactly is a fish? You probably think the answer is obvious. You may say that a fish is an animal that swims in the ocean or a lake. But there is lots more to fish than that. Fish are aquatic vertebrates, which through evolution became a dominant form of sea life and eventually branched to create land vertebrates. They have a number of characteristic traits and are classified into two major groups: jawless and jawed fish. Jawed fish are further divided into those with bones and those with just cartilage. Fish, in general, are important in many ways to humans - economically, recreationally and culturally. Perhaps you can think of some of these ways?

Characteristics of Fish

Fish are vertebrates that are typically ectothermic, are covered with scales, have jaws and have two sets of paired fins and several unpaired fins. A typical fish has a streamlined body that allows it to swim rapidly, extracts oxygen from the water using gills or an accessory breathing organ to enable it to breathe atmospheric oxygen, and lays eggs that are fertilized internally or externally (**Figure** 13.5). Fish range in size from the 16 m (51 ft) whale shark to the 8 mm (just over ¼ of an inch) stout infantfish.

Traits of a typical fish include:

- Vertebrate
- Ectothermic
- Scales

- Jaws
- Two sets of paired fins
- Several unpaired fins
- Streamlined body
- Gills or an accessory breathing organ
- Lays eggs that are fertilized internally or externally

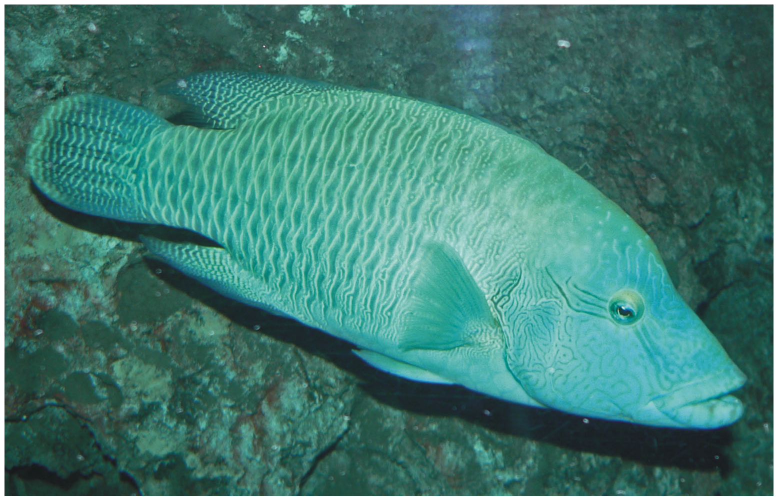

Figure 13.5: The humphead or Napoleon wrasse (*Cheilinus undulates*), showing some of the general traits of fish, including scales, fins and a streamlined body. (23)

There are exceptions to many of these traits. For example, tuna, swordfish, and some species of sharks show some warm-blooded adaptations, and are able to raise their body temperature significantly above that of the water around them. Some species of fish have a slower, but more maneuverable, swimming style, like eels and rays (**Figure** 13.6). Body shape and the arrangement of fins are highly variable, and the surface of the skin may be naked, as in moray eels, or covered with scales. Scales can be of a variety of different types.

Although most fish live in aquatic habitats, such as the ocean, lakes, and rivers, there are some that spend considerable time out of water. Mudskippers, for example, feed and interact with each other on mudflats for up to several days at a time and only go underwater when occupying burrows (**Figure** 13.7). They breathe by absorbing oxygen across the skin, similar to what frogs do.

Agnatha: Jawless Fishes

Agnatha is a superclass of jawless fish belonging to the phylum Chordata, subphylum Vertebrata (agnath means *jawless*). There are two extant (living) groups of jawless fish, the lampreys and the hagfish, with about 100 species in total. Although hagfish belong to the subphylum Vertebrata, they do not technically have vertebrae.

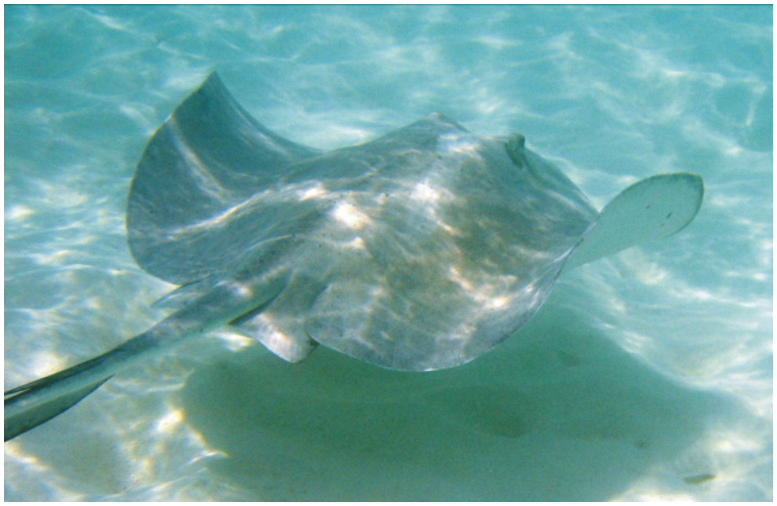

Figure 13.6: One of the cartilaginous fish, a stingray, showing very flexible pectoral fins connected to the head. (21)

Figure 13.7: A mudskipper, shown on the mudflats, where it spends time feeding and interacting with other individuals. (4)

In addition to the absence of jaws, Agnatha are characterized by absence of paired fins, the presence of a notochord both in larvae and adults, and seven or more paired gill pouches. The branchial arches (a series of arches that support the gills of aquatic amphibians and fishes) lie close to the body surface.

Agnatha have a light sensitive pineal eye (an eye-like structure that develops in some cold-blooded vertebrates) and do not have an identifiable stomach. They reproduce using external fertilization. They are ectothermic, have a cartilaginous skeleton, and a heart with two chambers.

Many agnathans from the fossil record were armored with heavy bony-spiky plates. The first armored agnathans - the Ostracoderms – were precursors to the bony fish and hence to the tetrapods, including humans.

What advantages would the advent of jaws have for fish? Such an adaptation would allow fish to eat a much wider variety of food, including plants and other organisms. In the next two sections you will be introduced to two groups of fish with jaws: those with a cartilaginous skeleton and those with a bony skeleton.

Cartilaginous Fishes

The cartilaginous fishes, or **Chondrichthyes**, are jawed fish with paired fins, paired nostrils, scales, two-chambered hearts, and skeletons made of cartilage rather than bone. The approximate 1,000 species are subdivided into two subclasses: Elasmobranchii (sharks, rays and skates) and Holocephali (chimaera, sometimes called ghost sharks). Fish from this group range in size from the dwarf lanternshark, at 16 cm (6.3 in), to the whale shark, up to sizes of 13.6 m (45 ft) (**Figure** 13.8).

Figure 13.8: One of two male whale sharks at the Georgia Aquarium. Whale sharks are the largest cartilaginous fish. (5)

Animals from this group generally have ratio of brain weight to body size that is close to that of mammals, and about ten times that of bony fishes. One of the explanations for their relatively large brains is that the density of nerve cells is much lower than in the brains of bony fishes, making the brain less energy demanding and allowing it to be bigger.

Since they do not have bone marrow (as they have no bones), red blood cells are produced in the spleen, in special tissue around the gonads, and in an organ called Leydig's Organ, only found in cartilaginous fishes. The tough skin of this group is covered with dermal teeth, or **placoid** scales, although they are mostly lost in adult Holocephali, making it feel like sandpaper. It is assumed that their oral teeth evolved from these dermal teeth, which migrated into the mouth.

The sharks, rays and skates are further broken into two superorders, one containing the rays and skates, and the other containing the sharks (**Figure** 13.9). There are eight orders of sharks within the superorder. They are distinguished by such features as:

- Number of gill slits
- Numbers and types of fins
- Type of teeth
- Body shape
- The sawsharks, with an elongate, toothed snout used for slashing the fish that they eat.
- The bullhead sharks, with teeth used for grasping and crushing shellfish.
- Carpet sharks with **barbels**
- Nocturnal habits
- The groundsharks, with an elongated snout.
- The mackerel sharks, with large jaws and ovoviviparous reproduction, where the eggs develop inside the mother's body after internal fertilization, and the young are born alive.

Figure 13.9: A spotted Wobbegong shark (*Orectolobus maculatus*), at Shelly Beach, Sydney, Australia, showing skin flaps around the mouth and cryptic coloration. (1)

Bony Fishes

The **Osteichthyes,** or bony fish, contain almost 27,000 species, which are divided into two classes: the ray-finned fish (Actinopterygii) and the lobe finned fish (Sarcopterygii). Most

Figure 13.10: One of the only eight living species of lobe finned fish, the lungfish. (30)

Figure 13.11: One of the eight living species of lobe finned fish, the coelacanth. (26)

bony-fish belong to the Actinopterygii; there are only eight living species of lobe finned fish, including the lungfish (**Figure** 13.10) and coelacanths (**Figure** 13.11).

The vast majority of fish are osteichthyes, and this group is the most various of vertebrates, making them the largest group of vertebrates in existence today. They are characterized by a relatively stable pattern of cranial bones, and the head and pectoral girdles (arches supporting the forelimbs) are covered with large dermal bones (bones derived from the skin). They have a lung or swim bladder, which helps the body create a neutral balance between sinking and floating, by either filling up with or emitting such gases as oxygen; have bone fin rays (jointed, segmented rods) supporting the fins; have an operculum (a cover over the gill), which helps them to breathe without having to swim; and are able to see in color, unlike most other fish.

One of the best-known innovations of this group is the ability to produce endochondral or "replacement" bone, by replacing cartilage from within, with bone. This is in addition to the production of perichondral or "spongy bone." The effect is to create a relatively lightweight, flexible, "spongy" bone interior, surrounded by an outline of dense bone. This is still much heavier and less flexible than cartilage.

The ocean sunfish is the most massive bony fish in the world, up to 3.33 m (11 ft) in length and weighing up to 2,300 kg (5,070 lb) (**Figure** 13.12). Other very large bony fish include the Atlantic blue marlin, the black marlin, some sturgeon species, the giant grouper and the goliath grouper. In contrast, the dwarf pygmy goby measures only 1.5 cm (0.6 in).

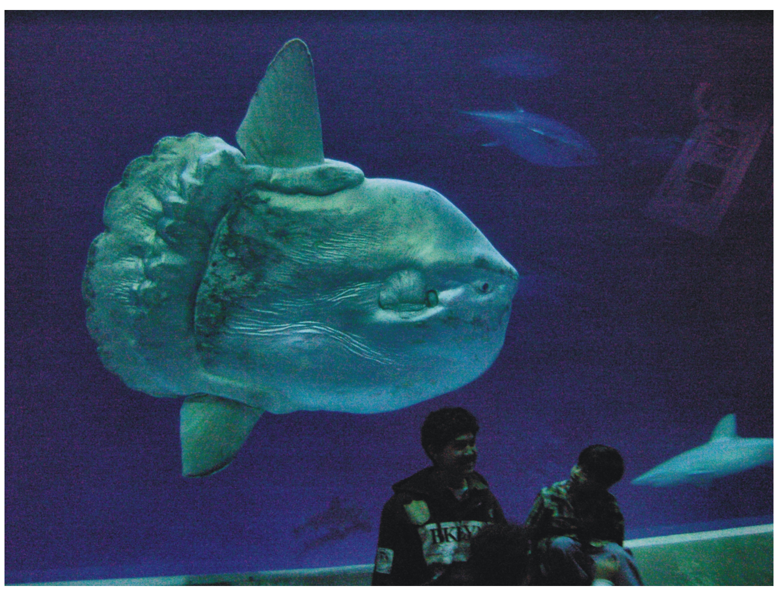

Figure 13.12: An ocean sunfish, the most massive bony fish in the world, up to 11 ft in length and 5,070 lb in weight! (16)

Why Fish are Important

Now that you have some understanding of the general features of fish, you might come up with some ways in how fish are important. Of course, what comes to mind right away is their use for food (**Figure** 13.13). In fact, people from around the world either fish them from the wild or farm them in much the same way as cattle or chickens (**aquaculture**). Fish are also exploited for recreation, through angling and fishkeeping, and are commonly exhibited in public aquaria.

Figure 13.13: Workers harvest catfish from the Delta Pride Catfish farms in Mississippi. (25)

Fish also have an important role in many cultures and art through the ages, ranging as widely as deities and religious symbols to subjects of books and popular movies(**Figure** 13.14). For example, such deities that take the form of a fish are Ikee-Roa of the Polynesians, Dagon of various ancient Semitic peoples, and Matsya of the Dravidas of India. Fish have been used figuratively in many different ways, for example the ichthys used by early Christians to identify themselves and the fish as a symbol of fertility among Bengalis.

In literature, legends of half-human, half-fish mermaids are featured in stories of Hans Christian Anderson and fish feature prominently in *The Old Man and the Sea.* Fish and other fanciful fish also play a major role in such movies as *Splash, Jaws, Shark Tale,* and *Finding Nemo.*

Figure 13.14: Fish play an important role in many cultures, including art, through the ages. Here is a still life of fish, eels, and fishing nets, by Johannes Fabritius. (17)

Lesson Summary

- The general traits of fish help adapt them for living in an aquatic environment, mostly for swimming, and also for extracting oxygen.
- Fish are typically ectothermic, although some show warm-blooded adaptations.
- Jawless fish, the Agnatha, also have some other common features.
- Fish with jaws comprise both the cartilaginous fish and the bony fish.
- The cartilaginous fishes, or Chondrichthyes, include the sharks, rays, skates and chimaera.
- The bony fish, or Osteichthyes, is the largest group of vertebrates in existence today and have certain traits in common.
- Fish are important economically, recreationally and culturally.

Review Questions

1. What are the general traits of fish?
2. What are some exceptions to the general traits of fish?
3. Mudskippers are an example of a fish species that must absorb oxygen across the skin, instead of via gills, since they spend much of their time out of water. Describe an environmental situation in which air breathing would be of great use to a fish species.
4. What are the characteristics of jawless fish?
5. What is one structure only found in cartilaginous fishes and what is its function?
6. What are some reasons why it would be an advantage for fish to be endothermic?

7. List some ways that fish are important.

Further Reading / Supplemental Links

- Unabridged Dictionary, Second Edition. Random House, New York, 1998.
- http://kids.nationalgeographic.com/Animals
- http://www.fws.gov/educators/students.html
- http://www.igfa.org/kidshome.asp
- http://www.pbs.org/emptyoceans/educators/activities/fish-youre-eating.html
- http://en.wikipedia.org

Vocabulary

agnatha A superclass of jawless fish, belonging to the phylum Chordata, subphylum Vertebrata.

aquaculture The raising of aquatic plants and animals, especially seaweed, shellfish and other fish, in environments either natural or with controlled freshwater or marine conditions.

barbels A thin structure on the external part of the head, such as the jaw, mouth or nostrils, of certain fishes.

chondrichthyes The group of cartilaginous fishes, containing sharks, rays, skates and chimaeras.

ectothermic Cold-blooded

osteichthyes Contains all the bony fish, divided into the ray-finned and lobe finned fish.

ovoviviparous reproduction The eggs develop inside the mother's body after internal fertilization, and depend on the yolk for most of the nutrition; the young are born alive.

placoid Plate-like, as in the scales of sharks.

Points to Consider

- Juvenile bichirs, a type of fish, have external gills, a very primitive feature that they hold in common with larval amphibians. Think about how the external gills could be a transition between internal gills and lungs?
- Lungfish and bichirs have paired lungs similar to those of tetrapods and must rise to the water's surface to gulp fresh air through the mouth and pass spent air out though the gills. Discuss how lungfish could be similar to and different from tetrapods in the way they breathe?
- The structure, the pineal body, located in the brain, performs many different functions including detecting light, maintaining circadian rhythms and controlling color changes. What structures could perform similar functions in amphibians, as a result of living on land?

13.3 Lesson 13.3: Amphibians

Lesson Objectives

- Describe amphibian traits.
- List the features of salamanders.
- Compare and contrast frogs and toads with other amphibians.
- Describe the roles of amphibians.

Check Your Understanding

- What are some adaptations that amphibians, like fish, have for living in the water?
- What are the characteristics that amphibians share with all other vertebrates?

Introduction

What group of animals begins its life in the water, but then spends most of its life on land? You were right, if you guessed amphibians. Amphibians are a group of vertebrates that has adaptations for both aquatic and terrestrial lifestyles. Evolutionarily, their ancestors made the transition from the sea to land. They comprise approximately 6,000 species of various body types, physiology, and habitats, ranging from tropical to subarctic regions.

Characteristics of Amphibian

Amphibians are ectothermic vertebrates, belonging to the class Amphibia and consist of three orders: Urodela, containing the salamanders and newts; Manure, consisting of frogs and toads; and Apoda, containing the caecilians. The larvae are typically aquatic and breathe using gills. The adults are typically semiterrestrial and breathe both through moist skin and by lungs.

For the purposes of reproduction, most amphibians are bound to fresh water. Although there are no true seawater amphibians, a few tolerate brackish (slightly salty) water. Some species do not need any water whatsoever, and several species have also adapted to arid and semi-arid environments, but most still need water to lay their eggs.

In general, the life cycle of amphibians begins with a shell-less egg stage, usually laid the previous winter in a pond. A larval stage follows in which the organism is legless, fully aquatic and breathes with exterior gills. After hatching, the larvae start to transform gradually (metamorphosis) into the adult's appearance, including loss of gills, growth of four legs, and the ability to live in a terrestrial environment.

Adaptations for living in a terrestrial environment include replacement of gills with another respiratory organ, such as lungs; a development of glandular (containing cells, a group of cells, or an organ producing a secretion) skin to avoid dehydration, and the development of eyelids and adaptation to vision outside the water. An eardrum also develops that separates the external ear from the middle ear and, in frogs and toads, the tail disappears.

Salamanders

This is a group of approximately 500 species of amphibians, typically characterized by slender bodies, short legs, and long tails, and most closely related to the caecilians, little known legless amphibians (**Figure** 13.16). Having moist skin, salamanders (**Figure** 13.15) rely on habitats in or near water or under some protection on moist ground, often in a swamp. Some species are aquatic throughout life, some are aquatic intermittently and some are entirely terrestrial as adults.

Respiration varies among the different species of salamanders; in those that retain lungs, respiration occurs through the gills as water passes over the gill slits. Some terrestrial species have lungs that are used in respiration in a similar way as in mammals. Other terrestrial salamanders lack both lungs and gills and exchange gases through their skin. This is known as **valarian respiration,** in which the capillary beds are spread throughout the epidermis.

Hunting prey is another unique aspect of salamanders. Muscles surrounding the **hyoid bone** contract to create pressure and "shoot" the hyoid bone out of the mouth along with the tongue. The tip of the tongue has mucus which creates a sticky end to which the prey is attached and captured. Muscles in the pelvic region are then used to bring the tongue and hyoid back to their original positions. Another trait, unique among vertebrates, is the

Figure 13.15: The marbled salamander, *Ambystoma opacum*, shows the typical salamander body plan: slender body, short legs, long tail and moist skin. (27)

Figure 13.16: A species of African caecilian, *Boulengerula taitanus*, a legless amphibian, most closely related to the salamanders. (13)

ability to regenerate lost limbs, as well as other body parts, in a process known as **ecdysis.**

Salamanders are found in most moist or arid habitats in the northern hemisphere. They are generally small, but some can reach 30 cm (a foot) or more, as in the mudpuppy of North America. In Japan and China, the giant salamander reaches 1.8 m (6 ft) and weighs up to 30 kg (66 lb) (**Figure** 13.17).

Figure 13.17: The Pacific giant salamander can reach up to 6 ft in length and 66 lb in weight. (12)

The order Urodela, containing the salamanders and newts, is divided into three suborders. These consist of the giant salamanders (including the hellbender and Asiatic salamanders), advanced salamanders (including lungless salamanders, mudpuppies, and newts), and sirens.

Frogs and Toads

Frogs and toads (**Figure** 13.18) are amphibians in the order Anura. A distinction is often made between frogs and toads on the basis of their appearance, caused by the **convergent adaptation** among so-called toads to dry environments (leathery skin for better water retention and brown coloration for camouflage), but this distinction has no taxonomic basis. One family, *Bufonidae,* is exclusively given the common name "toad," but many species from other families are also called "toads."

Frogs are distributed from the tropics to subarctic regions, but most species are found in tropical rainforests. Consisting of more than 5,000 species (about 88% of amphibian species are frogs), they are among the most diverse groups of vertebrates. Frogs range in size from 10 mm (less than ½ in) in species in Brazil and Cuba to the 300 mm (1 ft) goliath frog of

Figure 13.18: A species of toad, showing typical characteristics of leathery and warty skin, and brown coloration. (9)

Cameroon.

Adult frogs are characterized by long hind legs, a short body, webbed digits, protruding eyes and no tail. They also have a three-chambered heart, which they share with all tetrapods except birds and mammals. Most frogs have a semi-aquatic lifestyle, but move easily on land by jumping or climbing. They typically lay their eggs in puddles, ponds or lakes, and their larvae, or tadpoles, have gills and develop in water.

The reliance of frogs on an aquatic environment for the egg and tadpole stages gives rise to a variety of mating behaviors that include the calls used by the males of most species to attract females to the bodies of water chosen for breeding. Frogs are most noticeable by these calls, which can occur during the day or night.

Frogs are usually well suited to jumping with long hind legs and elongated ankle bones. They have a short vertebral column, with no more than ten free vertebrae, followed by a fused tailbone. Skin hangs loosely on the body because of the lack of loose connective tissue(tissue that surrounds, supports, or connects organs, other tissues, etc.). Skin texture varies, either smooth, warty or folded.

Frogs have three eyelid membranes: one is transparent to protect the eyes underwater, and two vary from translucent to opaque. Frogs have a **tympanum,** involved in hearing, on each side of the head, and in some species, is covered by skin.

Adult frogs are carnivorous and eat mostly arthropods, annelids and gastropods. Adults have a ridge of very small cone teeth, called maxillary teeth, around the upper edge of the jaw and they have what are called vomerine teeth on the roof of the mouth. Since they don't have teeth on their lower jaw, frogs usually swallow their food whole, and use the teeth they do have to hold the prey in place. Toads do not have any teeth, and so they must swallow their prey whole.

Roles of Amphibians

Frogs are raised commercially as a food source (frog legs are a delicacy in China, France, the Philippines, northern Greece and the American south, especially Louisiana). They are used in cloning research and other branches of embryology, because they lack egg shells, and therefore facilitate observations of early development. The African clawed frog or platanna (*Xenopus laevis*) is used as a **model organism** (a species that is extensively studied to understand certain biological phenomena) in developmental biology, because it is easy to raise in captivity and has a large and easily manipulated embryo. Many Xenopus genes have been identified, isolated, and cloned as a result.

Many environmental scientists believe that amphibians, including frogs, are excellent biological indicators of broader ecosystem health because of their intermediate position in food webs, their permeable skins, and typically biphasic life (aquatic larvae and terrestrial adults).

Amphibians also figure prominently in folklore, fairy tales and popular culture. Numerous legends have developed over the centuries around the salamander (its name originates from the Persian, for "fire" and "within) , many related to fire. This connection likely originates from the tendency of many salamanders to dwell inside rotting logs. When placed into the fire, salamanders would escape from the logs, lending to the belief that the salamander was created from flames.

Associations of the salamander with fire appear in the Talmud (a collection of Jewish law and tradition) and the Hadith (a traditional account of things said or done by Muhammad or his companions), as well as in the writings of Conrad Lycosthenes (a sixteenth century humanist and encyclopedist), Benvenuto Cellini (a sixteenth century Italian goldsmith, painter, sculptor, musician, and soldier), science fiction authors Ray Bradbury and David Weber, Paracelsus (a fifteenth century alchemist, physician, and astrologer) and Leonardo da Vinci.

In other representations in popular culture, salamanders are known as minor snake demons according to some folklore; they, and frogs, appear as some characters in video games; salamanders appear in anime series, and they were even the focus of a dance craze (the Salamander Homp) in the early 1980's. Frogs tend to be portrayed as benign, ugly, and clumsy, but with hidden talents. Examples include Michigan J. Frog, *The Frog Prince,* and Kermit the Frog.

The Moche people of ancient Peru worshiped animals and often depicted frogs and toads in their art. The toad also appears as symbol and in story in Vietnamese culture.

Lesson Summary

- Amphibians have adaptations for both aquatic, including gills, and terrestrial, including lungs and moist skin, lifestyles.
- Most amphibians are bound to water for reproduction.
- Development includes a shell-less egg, larval stage and adult.
- Salamanders have some unique features, including the use of the hyoid bone in hunting prey, and the process of ecdysis.
- Adult frogs and toads have features for living in the water (such as webbed digits) and for living on the land (such as long hind legs for jumping).
- Frogs are well known for their mating calls, which are used to attract females to aquatic breeding grounds.
- Amphibians play a role economically as a food source; are used in various types of biological research, can serve as indicators of ecosystem health, and figure prominently in folklore and popular culture.

Review Questions

1. Describe the general traits of amphibians.
2. Describe the life cycle of amphibians.
3. What are some adaptations of amphibians for living in a terrestrial environment?
4. A frog's skin must remain moist at all times in order for oxygen to pass through the skin and into the blood. Why does this fact make frogs susceptible to many toxins in the environment?
5. The permeability of a frog's skin can result in water loss. What adaptations would benefit a frog by counteracting this water loss?
6. Name how one feature of frog development lends itself to research applications.
7. Amphibians have a number of adaptations which make it easy for them to avoid predation. Describe some of these.

Further Reading / Supplemental Links

- Unabridged Dictionary, Second Edition. Random House, New York, 1998.
- http://en.wikipedia.org/wiki
- http://kids.nationalgeographic.com/Animals
- http://amphibiaweb.org
- http://helpafrog.org
- http://www.amphibianark.org/yearofthefrog.htm
- http://www.epa.gov/gmpo/education/photo/amphibians.html

Vocabulary

convergent adaptation The appearance of similar traits in groups of animals that are evolutionarily unrelated to each other.

ecdysis The ability to regenerate lost limbs, as well as other body parts.

hyoid bone A U-shaped bone at the root of the tongue; in salamanders it is used to help catch prey.

tympanum Equivalent to the middle ear; used in hearing.

valarian respiration Respiration in which the capillary beds are spread throughout the epidermis, so that gases can be exchanged through the skin.

Points to Consider

- Future studies of molecular genetics should soon provide further insights to the evolutionary relationships among frog families. These studies will also clarify relationships among families belonging to the rest of vertebrates as well.
- Toxins obtained from some frog species may have potential as therapeutic drugs. The alkaloid epibatidine, a painkiller 200 times more potent than morphine, is found in some species of poison dart frogs. Other chemicals isolated from frog skin may offer resistance to HIV infection. As we will see in the next lesson, reptiles also possess chemicals and unique genes that are useful for medical purposes.
- Although care of offspring is poorly understood in frogs, it is estimated that up to 20% of amphibian species care for their young, and that there is a great diversity of parental behaviors. As you begin to examine the reproductive system of reptiles in the next lesson, think about what kinds of parental behaviors reptiles might have and how they compare to that of amphibians.

13.4 Lesson 13.4: Reptiles

Lesson Objectives

- List reptile traits.
- Describe the general features of lizards and snakes.
- List the characteristics of alligators and crocodiles.
- Describe the traits of turtles.
- Explain the importance of reptiles.

Check Your Understanding

- What are some adaptations for living on land that are present in the amphibians?
- What features present in amphibians are also useful to reptiles for an aquatic lifestyle?

Introduction

While some types of reptiles, like snakes, alligators, and crocodiles, often have a bad reputation due to their venom, as in snakes, or their aggressive behavior, as in all three groups, reptiles are important both ecologically and economically, as we will see later in this lesson. They also possess some unique traits and interesting behaviors, which we will also explore in greater detail.

Reptiles are tetrapods and **amniotes,** whose embryos are surrounded by an amniotic membrane. Modern reptiles inhabit every continent with the exception of Antarctica, and are represented by four living orders: Squamata (lizards, snakes and amphisbaenids or "worm-lizards"), Crocodilia (crocodiles, gharials (**Figure** 13.19), caimans, and alligators) Testudines (turtles and tortoises) and Sphenodontia (tuatara) (**Figure** 13.20).

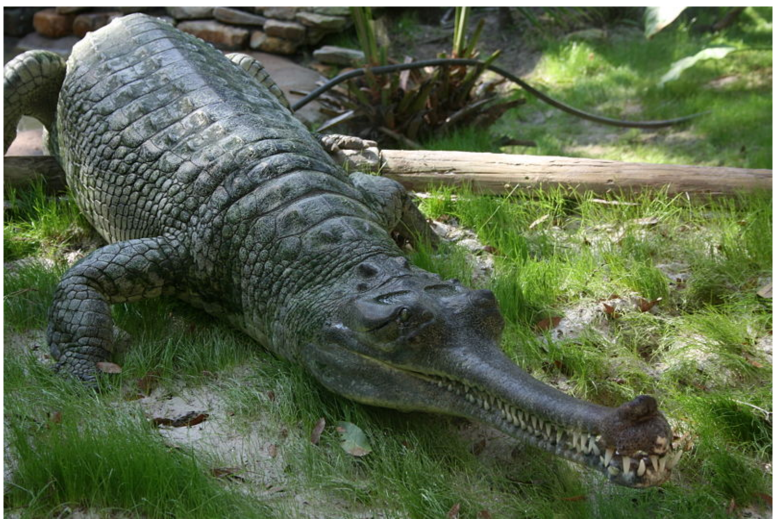

Figure 13.19: An Indian gharial crocodile. (3)

Traits of Reptiles

Reptiles are air-breathing, cold-blooded vertebrates that have skin covered in scales. The majority of species are **oviparous** (egg-laying) although certain species of squamates are capable of giving birth to live young. This is achieved, either by ovoviviparity (egg retention within the female until birth), or viviparity (offspring born without use of calcified eggs).

Figure 13.20: A tuatara. (19)

Many of the viviparous species feed their fetuses through various forms of placenta, similar to those of mammals, with some providing initial care for their hatchlings. The degree of viviparity varies: some species simply retain the eggs until just before hatching, others provide maternal nourishment to supplement the yolk, while still others lack any yolk and provide all nutrients via a placenta.

All reproductive activity occurs with the cloaca, the single exit/entrance at the base of the tail, where waste is also eliminated. Most reptiles lay amniotic eggs covered with leathery or calcareous shells. An amnion (the innermost of the embryonic membranes), chorion (the outermost of the membranes surrounding the embryo) and allantois (a vascular embryonic membrane) are present during embryonic life. There are no larval stages of development.

Most reptiles reproduce sexually, although six families of lizards and one snake are capable of asexual reproduction. In some species of squamates, a population of females is able to produce a nonsexual diploid clone of the mother. This asexual reproduction called **parthenogenesis** occurs in several species of gecko, and is particularly widespread in the teiids and lacertids.

Extant reptiles range in size from the newly-discovered Jaragua Sphaero, at 1.6 cm (0.6 in), to the saltwater crocodile, at up to 7 m (23 ft).

Most reptiles have a closed circulatory system with a three-chambered heart consisting of two atria and one ventricle. All reptiles breathe using lungs, although aquatic turtles have developed more permeable skin, and some species have modified their cloacas to increase the area for gas exchange. Excretion is performed mainly by two small kidneys.

The reptilian brain is similar to that of amphibians, except the cerebrum and cerebellum are slightly larger. Most typical sense organs are well developed with certain exceptions most notably the snakes lack of external ears (middle and inner ears are present). All reptilians have advanced visual depth perception compared to other animals.

Lizards and Snakes

Lizards and snakes belong to the largest recent order of reptiles (Squamata). Members of the order are distinguished by their skin, which bears horny scales or shields. They also possess movable quadrate bones, making it possible to move the upper jaw relative to the braincase. This is particularly visible in snakes, which are able to open their mouths very widely to accommodate comparatively large prey (**Figure** 13.21).

Figure 13.21: A corn snake swallowing a mouse. (20)

Lizards are a large and widespread group of reptiles, with nearly 5,000 species, ranging across all continents except Antarctica. Most lizards have four limbs, external ears, movable eyelids, a short neck, a long tail, and are insectivores. Many can shed their tails in order to escape from predators.

Vision, including color vision, is particularly well developed in lizards, and most communicate with body language, bright colors, or **pheromones.** Adults range from a few cm (1 in) in length (some Caribbean geckos) to nearly 3 m (10 ft) (**Figure** 13.22), although most species are less than 220 g (0.5 lb).

Encompassing 40 families, there is tremendous variety in color, appearance and size of lizards. Most lizards are oviparous, although a few species are viviparous. Many are also capable of regeneration of lost limbs or tails. Almost all lizards are carnivorous, although most are so small that insects are their primary prey. A few species are omnivorous or herbivorous,

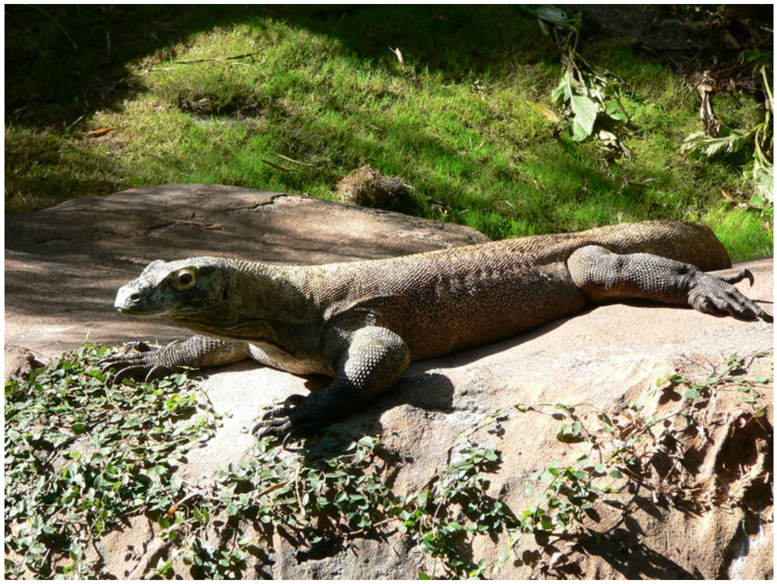

Figure 13.22: A Komodo dragon, the largest of the lizards, attaining a length of 10 ft. (28)

and others have reached sizes where they can prey on other vertebrates, such as birds and mammals.

Many lizards are good climbers or fast sprinters. Some can run bipedally, such as the collared lizard, and some, like the basilisk, can even run across the surface of water to escape. Many lizards can change color in response to their environments or in times of stress (**Figure** 13.23). The most familiar example is the chameleon, but more subtle color changes occur in other lizard species, such as the anole, as well.

Some lizard species, including the glass lizard and flap-footed lizards, have lost their legs or reduced them to the point they are non-functional. However, some vestigial structures remain. While some legless lizards, like flap-footed lizards, are similar in appearance to snakes, they can be distinguished by such features as their external ears.

All snakes are carnivorous and can be distinguished from legless lizards by lack of eyelids, limbs, external ears, and vestiges of forelimbs. The 2,700+ species of snakes occur in every continent except Antarctica and range in size from the tiny, 10 cm (4 in) long thread snake to pythons and anacondas over 5 m (17 ft) long (**Figure** 13.24). In order to accommodate snakes' narrow bodies, paired organs (such as kidneys) appear one in front of the other instead of side by side.

While venomous snakes comprise a minority of the species, some possess potent venom capable of causing painful injury or death to humans. However, snake venom is primarily for killing and subduing prey rather than for self-defense. All snakes are strictly carnivorous, eating small animals including lizards, other snakes, small mammals, birds, eggs, fish, snails or insects.

Figure 13.23: A species of lizard, showing general body form and camouflage against background. (8)

Figure 13.24: A species of anaconda, one of the largest snakes, getting as long as 17 ft. (7)

Because snakes cannot bite or tear their food to pieces, prey must be swallowed whole. The body size of a snake has a major influence on its eating habits. The snake's jaw is one of the most unique jaws in the animal kingdom. Snakes have a very flexible lower jaw, the two halves of which are not rigidly attached, and numerous other joints in their skull, allowing them to open their mouths wide enough to swallow their prey whole.

Some snakes have a venomous bite, which they use to kill their prey before eating it; others kill their prey by constriction, and still others swallow their prey whole and alive. After eating, snakes become dormant while the process of digestion takes place. The process is highly efficient, with the snake's digestive enzymes dissolving and absorbing everything but the prey's hair and claws.

Most snakes use specialized belly scales to travel, gripping surfaces. The body scales may be smooth, keeled or granular (**Figure** 13.25). Snakes' eyelids are transparent "spectacle" scales which remain permanently closed. In the shedding of scales, or molting, the complete outer layer of skin is shed in one layer (**Figure** 13.26). Molting replaces old and worn skin, allows the snake to grow and helps it get rid of parasites such as mites and ticks.

Figure 13.25: A close up of snake scales of a banded krait, *Bungarus fasciatus*, showing Black and yellow alternating bands and spaces between scales. (6)

Although a wide range of reproductive modes are used by snakes, all snakes employ internal fertilization, accomplished by means of paired, forked hemipenes, which are stored inverted in the male's tail. Most species of snakes lay eggs and most species abandon them shortly after laying.

Figure 13.26: A northern water snake shedding its skin. (2)

Alligators and Crocodiles

Crocodilia, containing both alligators and crocodiles, is an order of large reptiles. Reptiles belonging to Crocodilia are the closest living relatives of birds, as the two groups are the only known living descendants of the Archosauria, a subclass of reptiles, including the dinosaurs. The basic crocodilian body plan (**Figure** 13.27) is a very successful one that has changed little over time; modern species closely resemble their Cretaceous ancestors of 84 million years ago. Crocodilians have a flexible semi-erect (semi-sprawled) posture. They can walk in low, sprawled "belly walk," or hold their legs more directly underneath them to perform the "high walk." Most other reptiles can only walk in a sprawled position.

All crocodilians have, like humans, **thecodont dentition**, (teeth set in bony sockets), but unlike mammals, they replace their teeth throughout life. Crocodilians also have a secondary bony palate that enables them to breathe when partially submerged, even if the mouth is full of water. Their internal nostrils open in the back of their throat, where a special part of the tongue called the "palatal valve" closes off their respiratory system when they are underwater, allowing them to breathe when submerged.

Crocodiles and gharials (large crocodilians having elongated jaws) have modified salivary glands on their tongue (salt glands), which are used for excreting excess salt ions from their bodies. Crocodilians are often seen lying with their mouths open, a behavior called gaping. One of its functions is probably to cool them down, but it may also have a social function.

Like mammals and birds and unlike other reptiles, crocodiles have a four-chambered heart; however, unlike mammals, oxygenated and deoxygenated blood can be mixed. Crocodilians

Figure 13.27: Two Nile crocodiles, showing the basic crocodilian body plan. (11)

are known to swallow stones, known as gastroliths, which act as a ballast in addition to aiding post-digestion processing of their prey. The crocodilian stomach is divided into two chambers, the first is powerful and muscular, like a bird gizzard, where the gastroliths are found. The other stomach has the most acidic digestive system of any animal and can digest mostly everything from their prey: bones, feathers and horns.

The sex of developing crocodilians is determined by the incubation temperature of the eggs. This means crocodilians do not have genetic sex determination, but instead have a form of environmental sex determination, which is based on the temperature that embryos are subjected to early in their development.

Like all reptiles, crocodilians have a relatively small brain, but the crocodilian brain is more advanced than those of other reptiles. As in many other aquatic or amphibian tetrapods, the eyes, ears, and nostrils are all located on the same plane. They see well during the day and may even have color vision, plus the eyes have a vertical, cat-like pupil, which gives them excellent night vision. A third transparent eyelid, the **nictitating membrane,** protects their eyes underwater.

While birds and most reptiles have a ring of bones around each eye which supports the eyeball (the sclerotic ring), the crocodiles lack these bones, just like mammals and snakes. The eardrums are located behind the eyes and are covered by a movable flap of skin. This flap closes, along with the nostrils and eyes, when they dive, preventing water from entering their external head openings. The middle ear cavity has a complex of bony air-filled passages and a branching Eustachian tube. Eustachian tubes will be discussed in the chapter titled *Controlling the Body.*

The upper and lower jaws are covered with sensory pits, which encase bundles of nerve fibers that respond to the slightest disturbance in surface water. Thus they can detect vibrations and small pressure changes in water, making it possible for them to detect prey, danger and intruders even in total darkness.

Turtles

Turtles are reptiles of the order Testudines, most of whose body is shielded by a special bony or cartilaginous shell developed from their ribs. About 300 species are alive today and some are highly endangered. Turtles cannot breathe in water, but can hold their breath for various periods of time. Like other reptiles, turtles are **poikilothermic** (or "of varying temperature"). Like other amniotes, they breathe air and don't lay eggs underwater, although many species live in or around water.

The largest chelonian (all living species) is the great leatherback sea turtle (**Figure** 13.28), which reaches a shell length of 200 cm (7 ft) and can reach a weight of over 900 kg (2,000 lb). Freshwater turtles are generally smaller, but the largest species, the Asian softshell turtle, has been reported up to 200 cm (7 ft). The only surviving giant tortoises are on the Seychelles and Galapagos Islands and can grow to over 130 cm (4 ft) in length and weigh about 300 kg (670 lb) (**Figure** 13.29).

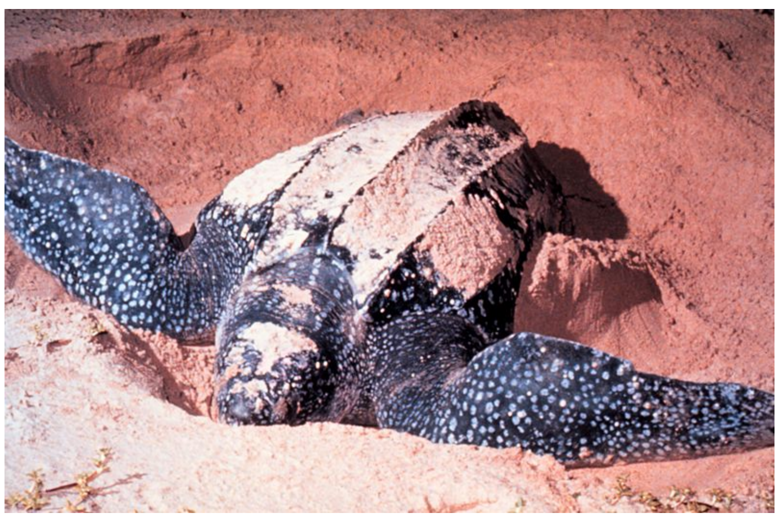

Figure 13.28: The largest living chelonian, the leatherback turtle, which can reach up to 7 ft in length and over 2,000 lb. (15)

The smallest turtle is the speckled padloper tortoise of South Africa, measuring no more than 8 cm (3 in) in length, and weighing about 140 g (5 oz). Turtles are broken down into two groups, according to how they evolved a solution to the problem of withdrawing their neck into the shell: the Cryptodira, which can draw their neck in while contracting it under their spine, and the Pleurodira, which contract their neck to the side.

Figure 13.29: A Galapagos giant tortoise, pictured here, can grow to over 4 ft in length and weigh about 670 lb. (18)

Most turtles that spend most of their life on land have their eyes looking down at objects in front of them. Some aquatic turtles, such as snapping turtles and soft-shelled turtles, have eyes closer to the top of the head. These species of turtles can hide from predators in shallow water where they lie entirely submerged except for their eyes and nostrils. Sea turtles (**Figure** 13.30) possess glands near their eyes that produce salty tears that rid their body of excess salt taken in from the water they drink.

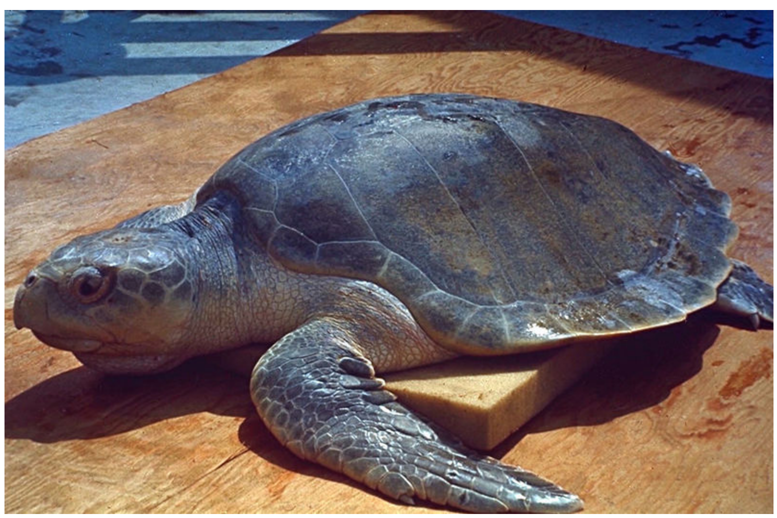

Figure 13.30: A species of sea turtle, showing placement of eyes, shell shape, and flippers. (22)

Turtles are thought to have exceptional night vision due to the unusually large number of rod cells in their retinas. Turtles have color vision with a wealth of cone subtypes with sensitivities ranging from the near ultraviolet to red. (For a description of rods and cones, see chapter titled *Controlling the Body*). Turtles have a rigid beak and use their jaws to cut and chew food. Instead of teeth, the upper and lower jaws of the turtle are covered by horny ridges. Carnivorous turtles usually have knife-sharp ridges for slicing through their prey. Herbivorous turtles have serrated-edged ridges that help them cut through tough plants.

Although many turtles spend large amounts of their lives underwater, all turtles and tortoises breathe air, and must surface at regular intervals to refill their lungs. They can also spend much of their lives on dry land. Turtles lay eggs, like other reptiles, and which are slightly soft and leathery. The eggs of the largest species are spherical, while the eggs of the rest are elongated. In some species, temperature determines whether an egg develops into a male or female. Large numbers of eggs are deposited in holes dug into mud or sand. They are then covered and left to incubate by themselves. When the turtles hatch, they squirm their way to the surface and head toward the water.

Importance of Reptiles

The chief impact of reptiles, such as lizards, on humans is positive as they are significant predators of pest species. Snakes are also very useful rat exterminators, for example, in the Irula villages of India.

Reptiles can be important as food sources: green iguanas are eaten in Central America, the tribals of “Irulas” from Andhra Pradesh and Tamil Nadu in India are known to eat some of the snakes they catch, Cantonese snake soup is consumed by local people in the fall to prevent colds, cooked rattlesnake meat is commonly consumed in parts of the Midwestern United States, and turtle soup is widely consumed.

Reptiles also make good pets. Numerous lizard species are prominent in the pet trade. In the Western world, some snakes, especially docile species such as the ball python and corn snake, are kept as pets. Turtles, particularly small terrestrial and freshwater turtles, are also commonly kept as pets. Among the most popular are the Russian tortoises, Greek spur-thighed tortoises and red-ear sliders (or terrapin).

For medical and scientific research, snake venom collected by the “Irulas” is used for producing life-saving antivenin and for other medicinal products. Observations about turtle longevity (the liver, lungs and kidneys of a centenarian turtle are virtually indistinguishable from those of its immature counterpart) have inspired genetic researchers to begin examining the turtle genome for longevity genes.

Finally, reptiles play a significant role in folklore, religion and popular culture. Lizard symbology plays important, though rarely predominant roles in some cultures (e.g. Tarrotarro in Australian mythology). The Moche people of ancient Peru worshipped animals and often depicted lizards in their art. Crocodilians have starred in several science fiction movies such as Lake Placid and DinoCroc. There are also many cultural depictions of turtles and tortoises.

Snakes or serpents (the latter usually referring to a mythic or symbolic snake) are associated with healing in the Bible (the account of the brass serpent of Moses) as well as with the devil (the Biblical account of Adam and Eve). The periodic renewal, as in the shedding of snake skin, has led to the snake being a symbol of healing and medicine, as pictured in the Rod of Asclepius (**Figure** 13.31). In Egyptian history, the snake occupies a primary role with the Nile cobra adorning the crown of the pharaoh in ancient times. It was worshipped as one of the gods and was also used for sinister purposes, such as murder of the adversary and ritual suicide by the Egyptian queen Cleopatra. Snakes also play a role in Greek mythology, in Indian tradition and religion, and in other religions and customs.

Lesson Summary

- Reptiles are air-breathing, cold-blooded vertebrates characterized by a scaly skin.
- Reptiles have a variety of reproductive systems, with different strategies for providing nutrition to developing young.
- Lizards and snakes are distinguished by a unique type of scaly skin and movable quadrate bones.
- There is a tremendous variety in color, appearance and size of lizards, and they have some unique adaptations, including regeneration of lost limbs or tails and changing color.
- Snakes are distinguished by lack of eyelids, limbs, external ears and vestiges of forelimbs.
- Snakes have various adaptations for killing and eating their prey.
- Crocodilia have a flexible semi-erect posture, thecodont dentition, replacement of teeth, and a secondary bony palate.
- The sex of developing crocodilians is determined by the incubation temperature of the eggs.
- Other crocodilian traits, such as salt glands, nictitating membranes, ear flaps and sensory pits, are adaptations for aquatic living.
- Turtles are characterized by a special bony or cartilaginous shell; have specialized adaptations for aquatic living, such as eye placement and salt glands, and adaptations for terrestrial living as well (placement of eyes and protection of eggs).
- Reptiles play important roles as predators of pest species, food sources, pets, in medical and scientific research, and in folklore, religion and popular culture.

Review Questions

1. Describe the general traits of reptiles.
2. Describe the different types of reproduction in reptiles.
3. How are snakes distinguished from legless lizards?

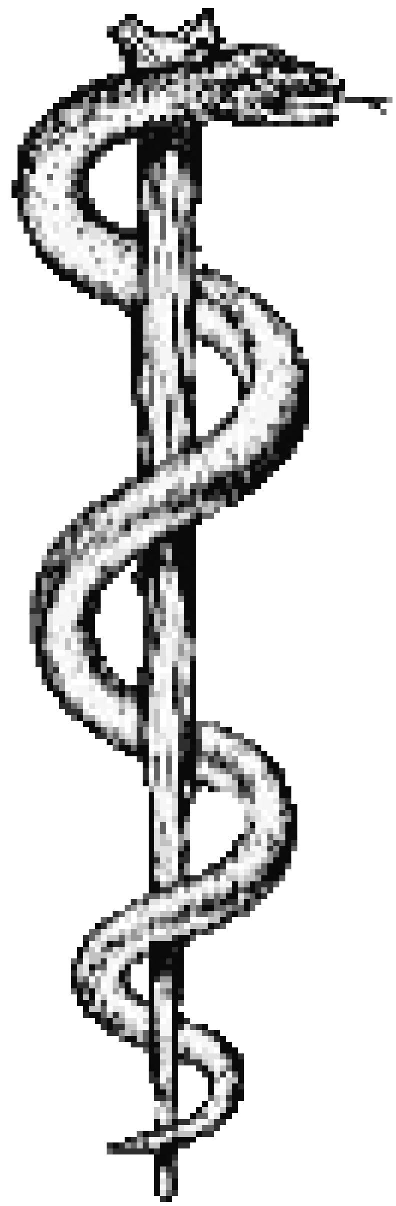

Figure 13.31: The Rod of Asclepius, where the snake is a symbol of healing and medicine. (31)

4. Pit vipers, pythons and some boas have infrared-sensitive receptors in deep grooves between the nostril and eye. What role might such receptors play?
5. Name two adaptations of a crocodilian stomach which help it in digestion.
6. The shape and structure of a turtle's shell can give its inhabitant advantages for avoiding predators, aid in swimming and diving, and for walking on land. Given what you know about a turtle's shell, explain how the structure and shape could help the turtle in the above situations.

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Vocabulary

amniotes Vertebrates whose embryos are surrounded by an amniotic membrane.

nictitating membrane A third transparent eyelid.

oviparous Reproduction involving the laying of eggs.

parthenogenesis A form of asexual reproduction, where the egg develops without fertilization.

pheromones Chemicals released by an animal that influence the behavior or physiology of other individuals of the same species.

poikilothermic Cold-blooded; without the ability to independently warm the blood.

the codont Where teeth are set in bony sockets.

Points to Consider

- Some lizards have a dewlap, a brightly colored patch of skin on the throat, which is used in displays. What colorful displays do you think are used for courtship in birds and mammals?
- Lizards and snakes use smell to track their prey, using the Jacobson's or vomeronasal organ in the mouth, as well as a forked tongue. How do you think this compares to the sense of smell in birds and mammals and the structures used for smelling in these groups?
- Like the scales comprising the shell of a turtle, or the cross-section of a tree trunk, crocodile osteoderms (small plates of bone under the scales) have annual growth rings, and by counting them it is possible to tell their age. Can we determine age in the same way in either birds or mammals?

Image Sources

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(3) Jonathan Zander. *An Indian gharial crocodile.*. GNU-FDL.

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Chapter 14

Birds and Mammals

14.1 Lesson 14.1: Birds

Lesson Objectives

- List and describe general traits of birds.
- Explain how birds are adapted for flight.
- List different breeding systems in birds and describe nesting, incubation and parental care.
- Illustrate the diversity of birds with examples of some of the varied groups.
- Explain how birds are important, both economically and ecologically.

Check Your Understanding

- Birds and reptiles have some traits in common. For example, birds are egg-layers and most reptiles are also oviparous. What do the eggs of both groups have in common?
- What traits are there in birds as a result of them being warm-blooded?

Introduction

We all think we know what a bird is. It seems fairly obvious. But if you were to really stop and think about birds, you would be amazed at the diversity of these organisms. From hummingbirds to ostriches, and countless varieties in between, birds are amazing creatures.

It is pretty easy to be aware of birds all around us. From pet birds in our houses to those seen flying and perching in the out-of-doors, birds constantly remind us of their diversity in both appearance and habits. Birds have special adaptations for flight, including feathers and a lightweight skeleton. They also have a wide variety of reproductive strategies among the different types of birds. Let us examine some of their principle traits so we can get a better appreciation of what birds can do.

Characteristics of Birds

Birds (class Aves) are warm-blooded, vertebrate animals with two legs (bipedal), who lay eggs. They range in size from the tiny 2 in (5 cm) Bee Hummingbird to the 9 ft (2.7 m) ostrich (**Figure** 14.1). With approximately 10,000 living species, birds are the most numerous vertebrates with four limbs (tetrapod). They occur in diverse habitats across the globe, ranging from the Arctic to the Antarctic.

Figure 14.1: The ostrich can reach a height of 9 feet! Pictured here are ostriches with young in Namibia, Africa. (4)

Defining characteristics of modern birds include:

- feathers
- high metabolism
- a four-chambered heart
- a beak with no teeth
- a lightweight but strong skeleton
- production of hard-shelled eggs

The digestive system of birds is unique, with a crop for storage and a gizzard that contains swallowed stones for grinding food to compensate for the lack of teeth. Birds have forelimbs modified as wings and nearly all can fly. Which of the above traits do you think might be of importance to flight?

Adaptations for Flight

In comparing birds with other vertebrates, what do you think distinguishes them the most? Of course, in most birds flight is the most obvious difference (**Figure** 14.2), and birds have adapted their body plan for this function. Their skeleton is especially lightweight, with large pneumatic (air-filled) cavities connecting to the respiratory system. Cervical, or neck, vertebrae are especially flexible and in birds with flight the sternum has a keel, or longitudinal ridge, for the attachment of two large flight muscles: the pectoralis, which encompasses 15% of the bird's total mass, and the supracoracoideus, the primary upstroke muscle for flight.

What other traits do you think might be important for flight? Of course, feathers are lightweight too and a forelimb modified as a wing serves as an aerofoil**.** This surface is designed to aid in lifting or controlling by making use of the air currents through which it moves. A bird's wing shape and size will determine how a species flies. For example, many birds have powered, flapping flight at certain times, while at other times they soar, using up less energy

Figure 14.2: One bird's flight, as seen in a tern species. (32)

About 60 living bird species are flightless, such as penguins, as were many extinct birds. Flightlessness often arises in birds on isolated islands, probably due to limited resources and the absence of land predators.

Reproduction in Birds

How do birds reproduce? We are all familiar with the classic chicken egg. So what is involved in the process of a bird laying an egg? It all starts with courtship. Courtship involves some type of courtship display, usually performed by the male, leading up to the breeding. Most displays involve a type of song and some displays are very elaborate and may include dancing, aerial flights, or wing or tail drumming.

One of the most distinguishing features of bird reproduction is internal fertilization and the laying of eggs. The hard-shelled eggs have a fluid-filled amnion, a thin membrane forming a closed sac around the embryo. Eggs are usually laid in a nest. How do you think where a bird lays an egg might influence the egg color? If an egg is hidden in a hole or burrow, away from predators, then the eggs are most often pale or white. Nests in the open have eggs that are camouflaged, thus giving protection against predation (**Figure** 14.3). However, some species like the ground-nesting nightjars, have pale eggs, but the birds themselves provide the camouflage with their feathers.

Figure 14.3: Nest and eggs of the common moorhen (*Gallinula chloropus*), showing camouflaged eggs. (30)

The shape of birds' nests varies quite a lot too. Most create somewhat elaborate nests, consisting of such structures as cups, domes, plates, mounds or burrows. The albatross, however, makes a nest that is simply a scrape on the ground. Still others, like the common guillemot, do not use nests, instead they lay their eggs on bare cliffs. The male emperor penguins are even more elaborate in the care of their eggs: they incubate the eggs between their body and feet.

How else might a bird help protect its young from predators? Most species locate their nests in areas that are hidden, in order to avoid predators. Other birds that are large or nest in colonies may build nests in the open, since they are more capable of defending their young.

Young Birds and Parental Care

Parent birds usually incubate their eggs after the last one has been laid. In the 95% of species which are **monogamous,** (the species pair for the duration of the breeding season or sometimes for a few years or until one mate dies) the parents take turns incubating. In **polygamous** species, where there is more than one mate, one parent does all the incubating.

Brood parasitism, in which an egg-layer leaves her eggs in another individual's nest, is more common among birds than any other type of animal. The host bird often accepts and raises the parasite's eggs, at the expense of the host's own offspring.

Some precocial chicks, like those of the Ancient Murrelet (*Synthliboramphus antiquus*), follow their parents out to sea the night after they hatch, in order to avoid land predators. In most species, however, the young leave the nest just before, or right after, they can fly, sometimes making it necessary for them to walk until they have mastered flying.

The length and type of parental care varies widely amongst different species of birds. At one extreme in a group of birds called the magapodes, parental care ends in hatching. In this case, the newly-hatched chick digs itself out of the nest mound without parental help and can take care of itself right away. At the other extreme, many seabirds care for their young for extended periods of time, the longest being that of the Great Frigatebird, whose chicks take up to six months to fledge (getting parental care until they are ready to fly) and then an additional 14 months of being fed by the parents (**Figure** 14.4).

Although male parental care is rare among most groups of animals, in birds it is quite common, more so than in any other class of vertebrates. Often, the tasks of defense of territory and nest site, incubation, and feeding of chicks are shared between the parents; sometimes one parent undertakes all or most of a particular duty.

Given all the information so far about birds, what would you say is true about bird diversity?

Diversity of Birds

If you guessed that there is a lot of diversity in birds, you guessed correctly. About 10,000 bird species belong to 29 different orders, or groups, within the class Aves. They live and breed in most terrestrial habitats and on all seven continents. The greatest biodiversity of birds occurs in the tropics.

There is enormous diversity and a wide range of adaptations of various body parts, such as beaks and feet, to the specific habitats of the birds. There is also enormous diversity in the feeding habits of birds. The feeding habits of birds is related to the beak shape and size,

Figure 14.4: The Great Frigatebird (*Fregata minor*) adults are known to care for their young for up to 20 months after hatching, the longest in a bird species. Here, a young bird is begging for food. (12)

as well as the foot shape. Birds can be carnivores, insectivores, or **generalists**, which feed on a variety of foods. Some feed on nectar, such as hummingbirds. Can you think of some examples of beak shape and size that are adapted to the type of food a bird eats?

Beaks

For example, parrots and their allies have down-curved, hooked bills, which are well-adapted for cracking seeds and nuts, and eating the meat inside (**Figure** 14.5). Hummingbirds, on the other hand, have long, thin and pointed bills, which are ideal for probing tubular flowers for nectar (**Figure** 14.6). Can you also think of some different types of bird feet, which might be adapted for different types of habitats?

Feet

Webbed feet used for swimming or floating, as in waterfowl or gulls and terns, may come to mind (**Figure** 14.7). Other birds, for example, herons, gallinules and rails have four long spreading toes, which are ideal for walking delicately in the wetland in which they live (**Figure** 14.8). You can now see that you could come up with your own ideas for how a particular bird trait is adapted to a specific habitat, food, or other specialized requirement. That might even make going out for an outdoor hike more of an adventure!

Figure 14.5: The down-curved, hooked bill of a scarlet macaw, a large colorful parrot (*Ara macao*). (1)

Figure 14.6: A long, thin and pointed bill of the Swallow-tailed Hummingbird (*Eupetomena macroura*). (6)

Figure 14.7: The webbed feet of a great black-backed gull (*Larus marinus*). (33)

Figure 14.8: The long spreading toes of an American purple gallinule (*Porphyrio martinica*). (8)

Why Birds are Important

Now that you have some general knowledge about birds, you may want to make a list yourself of how you think birds are important. Just think about your daily living and how birds play a role. Do you eat chicken or turkey at meals? Do you have pet birds? Do you enjoy going out in your backyard or for a walk and listen to the beauty of birdsong or see the iridescent plumage of a bird in the sun?

What are some other economic uses of birds? One is the harvesting of guano (droppings) for use as fertilizer. Another is the use of chickens as an early warning system of diseases, such as West Nile Virus, that affect humans. In the latter example, mosquitoes carry the West Nile Virus, bite young chickens and other birds, and infect them with the virus. The first human cases of the virus usually follow the first appearance of infected birds within three months. Blood samples from young chickens can be tested for the presence of antibodies to the virus, and if detected, then this is an early warning that human infection can follow.

What about how birds can be important ecologically? For example, some nectar-feeding birds are important pollinators, and many frugivores, or fruit-eating birds, help disperse seeds. Birds are often important to island ecology, since they can easily reach islands. In New Zealand, the Kereru and Kokako are important browsers (animals that eat or nibble on leaves, tender young shoots, or other vegetation) and seabirds enrich the soil and water with their production of guano (**Figures** 14.9 and 14.10).

Figure 14.9: The Kereru is an important browser species in New Zealand. (15)

Finally, let's not forget that birds have had a relationship with humans since the dawn of humanity. Sometimes, as in the cooperative honey-gathering among honeyguides and African peoples such as the Borana, these relationships are mutualistic, where both benefit. Birds also play prominent and diverse roles in folklore, religion, and popular culture, and

Figure 14.10: The Kokako, another important browser species of New Zealand. (14)

have been featured in art since prehistoric times, as in early cave paintings. Perhaps their beauty and diversity will always capture the imagination of humans.

Lesson Summary

- Most of birds' traits are related to their being warm-blooded or their adaptations for flight.
- Adaptations for flight involve features that are lightweight, flexible, strong and that take advantage of air currents.
- The components of reproduction usually involve a courtship display, nest production, egg-laying, incubation and parental care. There is much diversity demonstrated in adaptations for predator avoidance.
- With 10,000 bird species there is a lot of diversity. Specialized structures are adapted for specific habitats or living requirements.
- Birds are important economically, ecologically and in human culture.

Review Questions

1. List five traits which are important for flight.
2. Describe how a bird's breeding system can be adapted to avoid predation.
3. Explain how the absence of land predators on islands would result in flightlessness in birds.
4. You detect the presence of antibodies to the West Nile Virus in young chickens. How did the chickens get the virus? When would the first human cases of the virus most likely occur?

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Vocabulary

aerofoil A surface which is designed to aid in lifting or controlling by making use of the air currents through which it moves.

altricial A reproductive system in birds in which the newly hatched young are small, naked, immobile and blind.

monogamous A mating system in birds where the couple pair for the duration of the breeding season or sometimes for a few years or until one mate dies.

polygamous A mating system in birds where there is more than one mate.

precocial A reproductive system in birds in which the newly hatched young are feathered and mobile.

Points to Consider

- Birds and mammals are the only warm-blooded vertebrates. As in birds, mammals also have lots of diversity and live in varied habitats. Based on what you know about adaptations in birds, how do you think mammalian limbs are adapted for locomotion in different habitats?
- Mammals also have specialized diets, as in birds. Instead of beaks, mammals have different kinds of teeth. How do you think different kinds of teeth in mammals are adapted for different kinds of diets in this group?

14.2 Lesson 14.2: Mammals

Lesson Objectives

- List and describe general traits of mammals.
- Compare reproduction in monotremes, marsupials and placental mammals.
- Describe how mammals can be grouped according to their anatomy and their habitats.
- Explain how non-human mammals can benefit people and how they play an ecological role.

Check Your Understanding

- What traits are there in mammals as a result of them being warm-blooded?

Answer: They have fur to decrease heat loss; their diets contain high energy foods and methods of feeding help to maintain a high metabolism; and they conserve energy both by being inactive at certain times of day and sometimes by hibernation.

- Describe courtship displays in birds. As you learn about mammals, think about how their courtship is similar or different to that of birds.

Answer: Males usually perform courtship displays in birds. Most displays involve a type of song and some displays are very elaborate and may include dancing, aerial flights, or wing or tail drumming.

Introduction

What's a mammal? It is easy to forget about the biodiversity of mammals, but these animals range from bats and cats and rats to dogs and monkeys and whales. They walk and run and swim and fly. They live in the ocean, they fly in the sky, they walk on the prairies and run in the savannah. What allows them to live in such diverse environments? Well, mammals have some specialized traits which no other group of animals has. There is a tremendous amount of diversity within the group in terms of reproduction, habitat, and adaptation for living in their different habitats. It is because of some of their traits that mammals have been of benefit to people and also play an important ecological role.

Characteristics of Mammals

Mammals (class Mammalia) are warm-blooded, vertebrate animals with a number of unique characteristics. In most mammals, these include:

- The presence of hair
- Sweat glands
- Glands specialized to produce milk (**mammary glands**)
- Three middle ear bones
- A **neocortex** region in the brain
- Specialized teeth
- A four-chambered heart

All mammals, except for the **monotremes** (the most primitive order of mammals, with certain birdlike and reptilian characteristics, such as laying eggs, and a single opening for the urinary, genital, and digestive organs), produce live young (known as **vivipary**) instead of laying eggs.

There are approximately 5,400 mammalian species, ranging in size from the tiny 1-2 in (30-40mm) bumblebee bat to the 1,083ft (330m) blue whale. These are distributed in about 1,200 genera, 153 families and 29 orders. (see http://users.tamuk.edu/kfjab02/Biology/mammalogy/mammal_classification.htm).

Reproduction in Mammals

Keep in mind what you have learned about reptiles and birds and see how mammals might be both similar and different to these groups. The egg-laying monotremes, such as echidnas (**Figure** 14.11) and platypuses (**Figure** 14.12), use one opening, the cloacae, to urinate, deficate and reproduce, just as lizards and birds do. They lay leathery eggs, similar to those of lizards, turtles and crocodilians. Monochromes feed their young by "sweating" milk from patches on their bellies, since they lack nipples, unlike other mammals.

Figure 14.11: The echidna is a member of the monotremes, the most primitive order of mammals. (25)

All other mammals give birth to live young and are either marsupial or placental. The females of most **marsupials** have an abdominal pouch or skin fold within which are mammary glands and a place for raising the young (**Figure** 14.13). **Placental** mammals have a placenta that nourishes the fetus and removes waste products.

Some mammals are solitary except for brief periods when the female comes into **estrus,** the optimal time for a female to get pregnant. Others form social groups where a pronounced difference between sexes (sexual dimorphism) is frequently extreme. Dominant males are often those that are largest or best-armed. These males usually have an advantage in mating or may exclude other males from access to females within a group, such as in elephant seals (**Figure** 14.14). This group of females forms a **harem.** Think back to what you learned about courtship displays in birds. How are such systems in mammals similar or different?

Figure 14.12: Another monotreme, the platypus, like other mammals in this order, lays eggs and has a single opening for the urinary, genital, and digestive organs. (7)

Groups of Mammals

Mammal groups, as is true for most animal groups, can be characterized a number of ways. They can be characterized according to their anatomy, the habitats in which they live, and their feeding habits.

Most mammals belong to the placental group. Within this group are several subgroups including lagomorphs (i.e. hares and rabbits) and rodents (rats, mice and other small, gnawing mammals); carnivores (cats, dogs, bears and other mammals that are primarily meat eaters) (**Figure** 14.15); insectivores (including moles and shrews) (**Figure** 14.16); a group including bats and primates; and ungulates (hoofed animals, including deer, sheep, goats, buffalo and elephants, and also whales and manatees) (**Figure** 14.17).

Why do you think the above groups of animals are placed together? Can you think of some examples of tooth type that are adapted for a mammals' diet and types of limbs that are adapted for living in different types of habitats?

Mammals can also be grouped according to the habitat they live in and with adaptations for living in that habitat. Terrestrial mammals with saltatory (leaping) locomotion, as in some marsupials and in lagomorphs, is typically found in mammals living in open habitats. Other terrestrial mammals are adapted for running, such as dogs or horses. Still others, such as elephants, hippopotamuses and rhinoceroses, have a cumbersome (and hefty) mode of locomotion known as "graviportal."

Other mammals are adapted for living in trees (arboreal), such as many New World monkeys (**Figure** 14.18). Others are fully aquatic, such as manatees, whales, dolphins and seals, and others are adapted for flight, as are bats, or gliding (some marsupials and rodents).

Figure 14.13: A marsupial mammal, this Eastern grey kangaroo has a joey (young kangaroo) in its abdominal pouch. (28)

Figure 14.14: A mating system with a harem of many females and one male, as seen in the seal species, *Callorhinus ursinus*. (18)

Figure 14.15: A Caracal, hunting in the Serengeti. (11)

Figure 14.16: One of the subgroups of placental mammals is the insectivores, including moles and shrews. Pictured here is the Northern short-tailed shrew. (10)

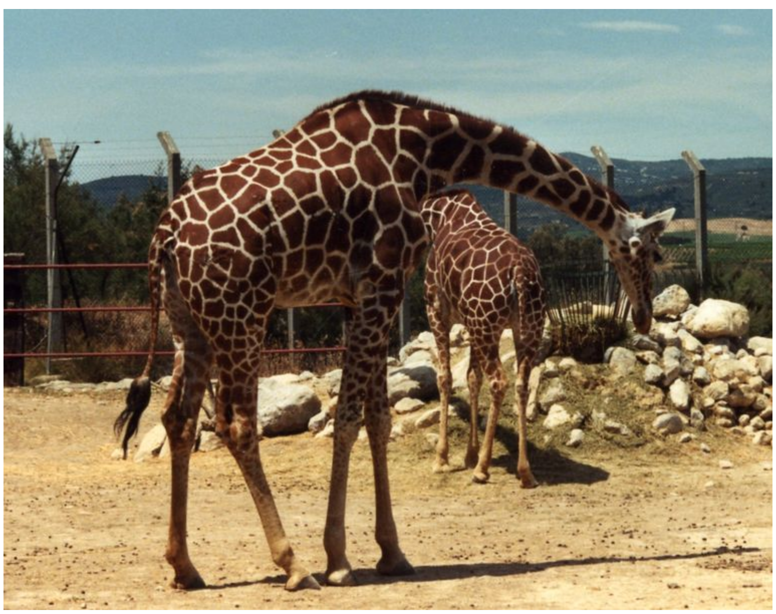

Figure 14.17: The ungulates (hoofed animals) like the giraffe here, is another of the subgroups belonging to the placental mammals. (20)

Figure 14.18: This howler monkey shows adaptations for an arboreal existence. (9)

Significance of Mammals

Mammals are thought to be significant both in terms of how they benefit people and also of their importance ecologically. Given what you know about mammals so far, how do you think they may be important to people? Just examining our daily lives we see examples of mammals (other than people!) serving our needs everywhere. We have pets that are mammals, most commonly dogs and cats; if we live in rural areas or visit another country we will probably see lots of examples of mammals used for transport (horses, donkeys, mules and even camels), being raised for food (cows and goats), and used for work (dogs (**Figure** 14.19), horses, and elephants).

The special capabilities of some mammal species have been used in practical situations and also to increase our knowledge. Can you think of how they have been used? For example, the United State and Russian militaries have trained and employed oceanic dolphins to rescue lost divers or to locate underwater mines. Mammals' more highly developed brain has made them ideal for use by scientists in studying such things as learning, as seen in maze studies of mice and rats. The ability of young mammals to learn from the experience of their elders has allowed a behavioral plasticity unknown in any other group of organisms and has been a primary reason for the evolutionary success of mammals. See if you can come up with some other examples.

Mammals have also played a significant role in different cultures' folklore and religion. For example, the grace and power of the cougar have been widely admired in the cultures of the indigenous peoples of the Americas. The Inca city of Cusco is reported to have been designed in the shape of a cougar and the sky and thunder god of the Inca, Viracocha, has been associated with the animal. In North America, mythological descriptions of the cougar have appeared in stories of a number of Native American tribes.

Figure 14.19: A Labrador Retriever working as an assistance dog. (17)

Ecologically, nectar-feeding and fruit-eating bats (**Figure** 14.20) play an important role in plant pollination and seed dispersal, respectively. Can you think of a type of bird that has a similar ecological role?

Mammals are also the only animal group that has made a complete transition to aquatic habitats. Some, such as cetaceans (whales, dolphins and porpoises) have undergone profound adaptations for swimming and life, even reproduction, in the water. Cetaceans depend on water for mechanical support and thermal insulation. Because they are buoyed by their aquatic environment, whales have evolved into the largest mammals and the largest animals ever recorded.

Micro-Lab: Matching Adaptations of Teeth and Limbs in Mammals with their respective Diets and Habitats

Estimated time: 15 minutes

Materials:

1. Tray of actual, or illustrations of, various mammal teeth, numbered, and Pictures of animals eating:

- Incisors – cutting and nipping (herbivores, like cows, have well-developed incisors for cutting grass)

Figure 14.20: Bats, like this Egyptian fruit bat, belong to another subgroup of placental mammals. Ecologically, fruit bats play an important role in seed dispersal. (24)

- Premolars – shearing and grinding (herbivores, like cows, have flat premolars and molars for grinding vegetation)
- Canines – piercing (carnivores, like lions, have long and strong canines.)

2. Tray of actual, or illustrations of, various mammalian limbs, numbered (for feet, could also show cast of track, to see if students can match the track with the actual foot type) and pictures of habitats or actual animals, lettered:

- Toe ending in claws – tiger (climbing and running)
- Toes with hooves – horses and cows (running)
- Fins – aquatic mammals (swimming)
- Wings – bats (flying)
- Highly mobile limbs – monkeys (climbing in trees)

3. Answer sheets, listing numbered mammal teeth and limbs

Directions:

One group of students examines the tray of mammal teeth and pictures of diets and indicates on the answer sheet the correct matches. The other group of students examines the tray of mammal limbs and pictures of habitats and similarly matches these up with the correct answers.

Links to websites with pictures of mammal teeth and/or limbs: Teeth:

http://www.vinsweb.org/education/elf/units/tas.html

http://www.teachersdomain.org/resources/tdc02/sci/life/stru/jaws/index.html

Teeth and Limbs:

http://www.acornnaturalists.com/Mammal-Activities-C227.aspx

Lesson Summary

- The class Mammalia is distinguished by the presence of hair, sweat glands, three middle ear bones and a neocortex area in the brain.
- There is a lot of variation in mammalian reproductive systems. Mammals consist of both the egg-laying monotremes and those that are viviparous. The latter group includes marsupial and placental mammals. Diversity can also be found in mammalian mating systems.
- The 5,400 species of mammals can be grouped according to anatomical features as well as the type of habitat found in. Mammals have specific adaptations for living on land, in trees, in water and for flight.
- Non-primate mammals have an important relationship with people as well as fulfilling necessary ecological functions.

Review Questions

1. What are two ways in which monotremes differ from viviparous mammals?
2. With respect to characteristics of feet, limbs and tails, what features would you expect mammals to have for

    (a) jumping?
    (b) living in trees?

3. Give examples of three different adaptations of limbs for locomotion in mammals, naming a mammal species, a structure and how it is adapted.
4. Instead of beaks, as in birds, mammals have different kinds of teeth. Incisors are specialized for cutting and nipping, premolars for shearing and grinding, and canines for piercing. Based on what you know of diets in mammals, name two mammal species, the kind of diet they eat, and one type of specialized teeth that would be best adapted for the diet.
5. In order to maintain a high constant body temperature, mammals need a nutritious and plentiful diet. What are some ways that mammals have adapted to meet their dietary requirements? How might size determine diet type, and why?

Further Reading / Supplemental Links

- Unabridged Dictionary, Second Edition. Random House, New York, 1998.
- http://en.wikipedia.org
- http://kids.nationalgeographic.com/Animals
- http://kids.yahoo.com/animals/mammals
- http://nationalzoo.si.edu/Animals/SmallMammals/ForKids
- http://www.ucmp.berkeley.edu/mammal/mammal.html
- http://www.americazoo.com/goto/index/mammals/classification.htm

Vocabulary

estrus A period of time when the female has maximum sexual receptivity.

harem A group of females followed or accompanied by a fertile male; this male excludes other males access to the group.

mammary glands Specialized sweat glands that produce milk.

marsupial A type of mammal where the female has an abdominal pouch or skin fold within which are mammary glands and a place for raising the young.

monotremes A group of mammals that lays eggs and feeds their young by "sweating" milk from patches on their bellies.

neocortex Site of the cerebral cortex where most of higher brain functions occur.

placental A type of mammal that has a placenta that nourishes the fetus and removes waste products.

vivipary A reproductive system in most mammals and some reptiles and fish, in which living young are produced rather than eggs laid.

Points to Consider

- Rats are considered to be highly intelligent as they can learn and perform new tasks, an ability that may be important when they first colonize a fresh habitat. Think about what kind of increased learning takes place with an increased brain size, as we will see in primates.
- Think of some significant similarities between the mammals you read about in this lesson with those in the next lesson, particularly human beings.
- What are some significant adaptations in the evolution of primates?

14.3 Lesson 14.3: Primates and Humans

Lesson Objectives

- List and describe general traits of primates.
- Summarize mating systems of primates.
- Review the types of habitats primates can be found in.
- Describe the three main groupings of primates.
- List the traits of the hominids, their diet, reproduction and social system.

Check Your Understanding

- What are general traits of mammals?
- Describe the mating systems in mammals.

Introduction

If primates are mammals, what makes them seem so different? Primates, including humans, have several unique features only belonging to this group of mammals. Some of these adaptations are obvious, others not so obvious. Some of these features give primates advantages such that allow them to live in certain habitats, such as arboreal habitats, such as trees. Other features have allowed them to adapt to complex and new social and cultural situations.

What are Primates?

The biological order Primates, mostly **omnivorous** (eating both plant and animal material) mammals, contains all the species commonly related to the lemurs (**Figure** 14.21), monkeys (**Figure** 14.22) and apes ((**Figure** 14.23), the latter including humans ((**Figure** 14.24). All primates have five fingers (**pentadactyl**), a generalized dental pattern, a primitive (nonspecialized) body plan and certain eye orbit characteristics, such as a postorbital bar (a bone, which runs around the eye socket). While an opposable thumb (the only digit on the hand able to turn back against the other four fingers, thereby refining the grip in order to hold objects) are a characteristic feature of this group, other orders, such as opossums, also have this feature.

In intelligent mammals, such as primates, the cerebrum is larger relative to the rest of the brain. Indications of intelligence in primates include the ability to learn and complex behavioral flexibility, involving much social interaction, such as fighting and play.

Old World species (apes and some monkeys as seen in **Figure** 14.25) tend to have signifi-

Figure 14.21: A ring tailed lemur and twins. Lemurs belong to the prosimian group of primates. (22)

Figure 14.22: One of the New World monkeys, a squirrel monkey. (2)

Figure 14.23: Chimpanzees, pictured here, belong to the great apes, one of the groups of primates. (27)

cant **sexual dimorphism,** characterized mostly as size differences, with males being slightly more than twice as heavy as females. This dimorphism may be a result of a polygamous mating system where males attract and defend multiple females. New World species (including tamarins((**Figure** 14.26) and marmosets(**Figure** 14.27)) form pair bonds, which is a partnership between a mating pair that lasts at least one season. The pair cooperatively raise the young, and thus generally do not show significant size difference between the sexes.

Non-human primates occur mostly in Central and South America, Africa and South Asia. Since primates evolved from arboreal animals, many modern species live mostly in trees. Other species are partially terrestrial, such as baboons (**Figure** 14.28) and the Patas monkey. Only a few species are fully terrestrial, for example, the gelada and humans.

Primates live in a diverse number of forested habitats, including rain forests, mangrove forests and mountain forests to altitudes of over 9,800 ft (3,000 m). The combination of opposable thumbs, short fingernails and long, inward-closing fingers has, in part, allowed some species to develop brachiation, locomotion of swinging by arms from one branch to another (**Figure** 14.29). Another feature for climbing – expanded digits – as in tarsiers improves grasping (**Figure** 14.30).

A few species, such as the proboscis monkey, De Brazza's monkey and Allen's swamp monkey, the latter having small webbing between its fingers, are fine swimmers and occur in swamps and other aquatic habitats. Some species, such as the rhesus macaque and the Hanuman langur, can exploit human-altered environments and even live in cities.

Figure 14.24: Reconstruction of a Neanderthal man, belonging to an extinct subspecies of *Homo sapiens*, humans, who are part of the great apes. This subspecies lived in Europe and western and central Asia from about 100,000 – 40,000 B.C. (26)

Figure 14.25: An Old World monkey, a species of macaque, in Malaysia. (21)

Figure 14.26: A New World species of monkey, a tamarin. (13)

Figure 14.27: Another New World species of monkey, the common marmoset. (3)

Figure 14.28: Baboons are partially terrestrial. Pictured here is a mother baboon and her young, in Tanzania. (19)

Figure 14.29: A gibbon shows how its limbs are modified for hanging from trees. (5)

Figure 14.30: A species of tarsier, with expanded digits used for grasping branches. (31)

Primate Classification

The primate order is divided informally into three main groupings: prosimians, New World monkeys, and Old World monkeys and the apes. The prosimians are species whose bodies most closely resemble that of the early proto-primates, the earliest examples of primates (**Figure** 14.31). Prosimians include the lemurs, located in Madagascar and to a lesser extent on the Comoro Islands, a group of islands in the Indian Ocean.

Figure 14.31: One of the prosimians, a greater bush baby, Kenya. (23)

The New World monkeys include the capuchin, howler and squirrel monkeys, who live exclusively in the Americas. The Old World monkeys and the apes (all except for humans, who inhabit the entire earth) inhabit Africa and southern and central Asia.

A few new species of primates are discovered each year and the evaluation of current populations varies as to the number of species; estimates over the last several years range from 350 to 405 species. In New World monkeys alone there are thought to be 128 species; of Old World monkeys, 135 species; of gibbons or "lesser apes," 13 species and of humans and other great apes, seven species. But there is only one species of humans, which will be discussed below.

The Human Family

The great apes are the members of the biological family Hominidae, which includes seven species, making up humans, two species each of chimpanzees, gorillas and orangutans. Hominids are large, tailless primates, ranging in size from the pygmy chimpanzee, at 66-88 lbs (30-40 kg) in weight, to the gorilla, at 309-397 lbs (140-180 kg) (**Figure** 14.32). In all species, the males are, on average, larger and stronger than the females, although the degree of sexual dimorphism varies greatly. Most living species are predominantly **quadrupedal** (four-footed), but all are able to use their hands for gathering food or nesting materials, and in some cases, for using tools, such as gorillas using sticks to gauge the depth of water and chimpanzees sharpening sticks to use as spears in hunting and using sticks to gather food and to "fish" for termites (**Figure** 14.33).

Figure 14.32: A gorilla mother and baby, members of the great apes, at Volcans National Park, Rwanda. The gorilla is the largest of the hominids, getting up to 309-397 lbs. (29)

Most species are omnivorous (eat both plants and meat), but fruit is the preferred food among all but humans. In contrast, humans consume a large proportion of highly processed, low fiber foods, unusual proportions of grains and vertebrate meat, as well as a wide variety of other foodstuffs. Human teeth and jaws are markedly smaller for our size than those of other apes, perhaps as adaptations to eating cooked food. Humans may have been eating cooked food for possibly as long as a million years or more.

Gestation lasts 8-9 months and usually results in the birth of a single offspring. The young are born helpless, and thus they need parental care for long periods of time. Compared with most other mammals, great apes have a long adolescence and become fully mature not until 8-13 years in most species (longer in humans). Thus, females typically give birth only once every few years.

Gorillas and chimpanzees live in family groups of approximately five to ten individuals, although larger groups are sometimes observed. The groups include at least one dominant male, and females leave the group at maturity. Orangutans, however, are generally solitary. Human social structure is complex and highly variable. Can you think of any that are similar to those of other great apes?

Gorillas, chimpanzees and humans are all lumped together in the subfamily, the Homininae,

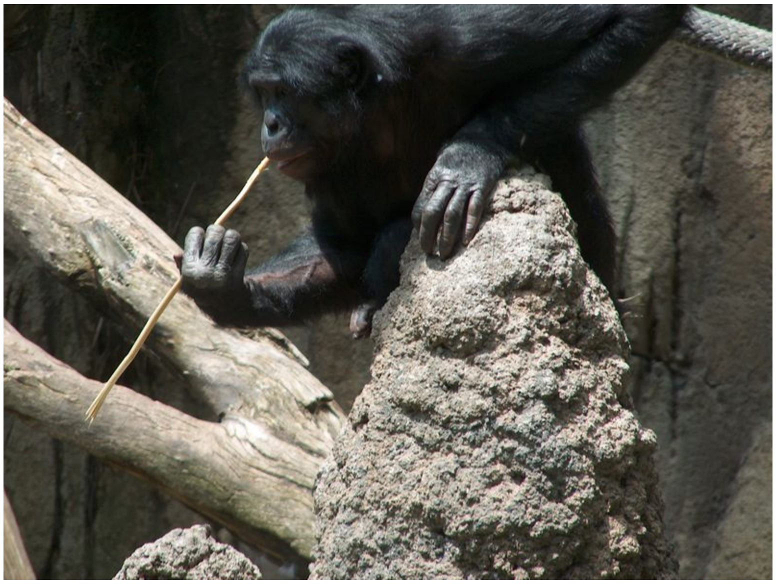

Figure 14.33: Tool using in a primate. A chimpanzee uses a stick to "fish" for termites, and then, pictured here, extracts the insects. (16)

because they generally share more than 97% of their DNA with each other, and exhibit a capacity for language or for simple culture beyond the family or band, a group of animals functioning together. A proposed theory including such faculties as empathy is a controversial criterion distinguishing the adult human alone among the hominids. Can you think of other human attributes that are unique to humans?

Lesson Summary

- Primates are characterized by pentadactyly, a generalized dental pattern, a nonspecialized body plan and certain eye orbit features. Primates also have opposable thumbs and a large cerebrum relative to the rest of the brain.
- Old World species tend to have significant sexual dimorphism, whereas New World species generally do not show significant sexual differences.
- Many primates live in a variety of forested habitats, whereas others are partially terrestrial, and some, like the gelada and humans, are fully terrestrial. A few species are adapted for living in aquatic habitats.
- There are three subgroups within the primates order: prosimians, including the lemurs; New World monkeys, and the Old World monkeys and the apes. There are estimated to be somewhere between 350 to 405 species of primates.
- The great apes, consisting of seven species, are large, tailless primates, with sexual dimorphism. Most species are quadrupedal, but all are able to use their hands.
- Most great apes are omnivorous, but fruit is the preferred food among all species but

humans.

- The great apes have unique reproductive and parental care features, especially when compared with most other mammals. There is a variety of social structure among the great apes.
- Gorillas, chimpanzees and humans share some common characteristics.

Review Questions

1. What characteristics distinguish the biological order Primates?
2. What theory might explain why human teeth and jaws are markedly smaller for our size than those of other apes?
3. Opposable thumbs are a characteristic primate feature. List two ways in which non-human primates might use opposable thumbs.
4. Various hybrid monkeys are produced in captivity when different species or subspecies are housed together. In what situation in the wild would hybrids be produced?
5. Primates are thought to have developed several of their traits and habits initially while living in trees. What primate features might be an advantage in an arboreal habitat?
6. Gorillas and chimpanzees live in family groups of around five to 10 individuals. What are two possible strategies for feeding, when fruit is hard to find?

Further Reading / Supplemental Links

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- http://kids.nationalgeographic.com/Animals
- http://nationalzoo.si.edu/Animals/Primates
- http://www.ucmp.berkeley.edu/mammal/eutheria/primates.html
- http://pslc.ws/macrog/paul/lemurs.htm
- http://www.wikipedia.org

Vocabulary

hybrid The offspring of different species, genera, varieties or breeds.

omnivorous Eating both plant and animal material.

pentadactyl Having five fingers or toes.

quadrupedal Four-footed

sexual dimorphism A condition in which the males and females of a species are different in form and structure.

Points to Consider

- Forward-facing color binocular vision was useful for human ancestors who swung by their arms from one branch to another. Recent studies suggest this type of vision was more useful in courtship. What other groups of animals might vision also be important in courtship?
- Thousands of primates are used every year around the world in scientific experiments because of their psychological and physiological similarity to humans. What kinds of behavioral experiments do you think might be conducted in primates?

Image Sources

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(2) Linda de Volder. http://commons.wikimedia.org/wiki/File:Squirrel_monkey_2.JPG. GNU-FDL.

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(21) Luxo. http://commons.wikimedia.org/wiki/Image:Langschwanzmakak_in_tioman.jpg. GNU-FDL.

(22) Sannse. http://commons.wikimedia.org/wiki/Image:Ring_tailed_lemur_and_twins.jpg. GNU-FDL.

(23) Buecherfresser. http://commons.wikimedia.org/wiki/Image:Greater_Bush_Baby.jpg. GNU-FDL.

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Chapter 15

Behavior of Animals

15.1 Lesson 15.1: Understanding Animal Behavior

Lesson Objectives

- Give examples of animal behavior.
- Explain why animal behavior is important.
- Describe innate behavior and how it evolves.
- List ways that behavior can be learned.

Check Your Understanding

- What is an animal?
- Give examples of a wide variety of animals.

Do you have a dog or a cat? If you don't, you probably know someone that does. Think about how these animals act. Does the dog bark when it's excited? Does the cat purr when it's happy? Do they both play with toys?

Examples of Animal Behavior

Barking, purring, and playing are just some of the ways that dogs and cats behave. These are examples of animal behavior. **Animal behavior** is any way that animals act, either alone or with other animals. Can you think of other examples of animal behavior? What about insects and birds? How do they behave? The pictures in **Figures** 15.1, 15.2, 15.3, 15.4, 15.5, 15.6 and 15.7 show some of the ways that these and other animals act. Look at the pictures and read about the behaviors.

All of the animals pictured in the **Figures** here are busy doing something important. Read about what each animal is doing. Think about why the animal is behaving that way. These are just a few of the many ways that animals behave.

Figure 15.1: This cat is stalking a mouse. It is a hunter by nature. (16)

Importance of Animal Behavior

Why do animals behave in these ways? The answer to this question depends on what the behavior is. A cat chases a mouse to catch it. A spider spins its sticky web to trap insects. A mother dog nurses her puppies to feed them. All of these behaviors have the same purpose: getting or providing food. All animals need food for energy. They need energy to move around. In fact, they need energy just to stay alive. Baby animals also need energy to grow and develop.

Birds and wasps build nests to have a safe place to store their eggs and raise their young. Many other animals build nests for the same reason. Animals protect their young in other

Figure 15.2: This spider is busy spinning a web. If you have ever walked into a spider web, you know how sticky a spider web can be. Why do spiders spin webs? (4)

Figure 15.3: This mother dog is nursing her puppies. In what other ways do mother dogs care for their puppies? (7)

Figure 15.4: This bird is using its beak to add more grass to its nest. What will the bird use its nest for? (5)

Figure 15.5: This wasp is starting to build a nest. Have you seen nests like this on buildings where you live? Why do wasps build nests? (14)

Figure 15.6: This rabbit is running away from a fox. Did you ever see a rabbit run? Do you think you could run that fast? (20)

Figure 15.7: This lizard is perched on a rock in the sun. Lizards like to lie on rocks and “sun” themselves. Do you know why? (24)

ways, as well. For example, a mother dog not only nurses her puppies. She also washes them with her tongue and protects them from strange people or other animals. All of these behaviors help the young survive and grow up to be adults.

Rabbits run away from foxes and other predators to stay alive. Their speed is their best defense. Lizards sun themselves on rocks to get warm because they cannot produce their own body heat. When they are warmer, they can move faster and be more alert. This helps them escape from predators, as well as find food.

All of these animal behaviors are important. They help the animals get food for energy, make sure their young survive, or ensure that they survive themselves. Behaviors that help animals or their young survive increase the animals' fitness. You read about fitness in the *Evolution* chapter. Animals with higher fitness have a better chance of passing their genes to the next generation. If behaviors that increase fitness are controlled by genes, the behaviors become more common in the species. This is called evolution by natural selection.

Innate Behavior

All of the behaviors shown in **Figures** 15.1, 15.2, 15.3, 15.4, 15.5, 15.6 and 15.7 are ways that animals act naturally. They don't have to learn how to behave in these ways. Cats are natural-born hunters. They don't need to learn how to hunt. Spiders spin their complex webs without learning how to do it from other spiders. Birds and wasps know how to build nests without being taught. Behaviors such as these are called innate.

An **innate behavior** is any behavior that occurs naturally in all animals of a given species. An innate behavior is also called an **instinct**. The first time an animal performs an innate behavior, the animal does it well. The animal does not have to practice the behavior in order to get it right or become better at it. Innate behaviors are also predictable. All members of a species perform an innate behavior in the same way. From the examples described above, you can probably tell that innate behaviors usually involve important actions, like eating and caring for the young.

There are many other examples of innate behaviors. For example, did you know that honey bees dance? The honey bee in **Figure** 15.8 has found a source of food. When the bee returns to its hive, it will do a dance, called the waggle dance. The way the bee moves during its dance tells other bees in the hive where to find the food. Honey bees can do the waggle dance without learning it from other bees, so it is an innate behavior.

Besides building nests, birds have other innate behaviors. One example occurs in gulls. A mother gull and two of her chicks is shown in **Figure** 15.9. One of the chicks is pecking at a red spot on the mother's beak. This innate behavior causes the mother to feed the chick. In many other species of birds, the chicks open their mouths wide whenever the mother returns to the nest. This is what the baby birds in **Figure** 15.10 are doing. This innate behavior, called gaping, causes the mother to feed them.

Figure 15.8: When this honey bee goes back to its hive, it will do a dance to tell the other bees in the hive where it found food. (27)

Figure 15.9: This mother gull will feed her chick after it pecks at a red spot on her beak. Both pecking and feeding behaviors are innate. (2)

Figure 15.10: When these baby birds open their mouths wide, the mother instinctively feeds them. This innate behavior is called gaping. (15)

Another example of innate behavior in birds is egg rolling. It happens in some species of water birds, like the graylag goose shown in **Figure** 15.11 . Graylag geese make nests on the ground. If an egg rolls out of the nest, a mother goose uses her bill to push it back into the nest. Returning the egg to the nest helps ensure that the egg will hatch.

Drawback of Innate Behavior

Innate behaviors such as these usually help animals or their offspring survive. Therefore, they increase fitness. This is why the behaviors evolved. However, innate behaviors have a drawback. The trouble with innate behaviors is that they are not flexible. An innate behavior is always performed exactly the same way.

The example of the graylag goose shows how this can be a problem. The sight of any nearby egg-shaped object will cause a graylag goose to push the object into her nest. She will push the object even if it isn't an egg. For example, if the mother goose sees a golf ball nearby, she will push it into her nest. This wastes time and energy that could be spent on the real eggs. From this example, you can see that innate behavior is not always helpful. It does not always increase fitness.

Figure 15.11: This female graylag goose is a ground-nesting water bird. Behind her are two of her young chicks. Before the chicks hatch, the mother protects the eggs. She will use her bill to push eggs back into the nest if they roll out. This is an example of an innate behavior. How could this behavior increase the mother goose's fitness? (8)

Innate Behavior in Human Beings

All animals have innate behaviors, even human beings. Can you think of human behaviors that do not have to be learned? Chances are, you will have a hard time thinking of any. The only truly innate behaviors in humans are called **reflex behaviors**. They occur mainly in babies. Like innate behaviors in other animals, reflex behaviors in human babies may help them survive.

An example of a reflex behavior in babies is the sucking reflex. Newborns instinctively suck on a nipple that is placed in their mouth. It is easy to see how this behavior evolved. It increases the chances of a baby feeding and surviving.

Another example of a reflex behavior in babies is the grasp reflex. This behavior is shown in **Figure** 15.12. Babies instinctively grasp an object placed in the palm of their hand. Their grip may be surprisingly strong. How do you think this behavior might increase a baby's chances of surviving?

Learned Behavior

Just about all other human behaviors are learned and not innate. **Learned behavior** is behavior that occurs only after experience or practice. Learned behavior has an advantage over innate behavior. It is more flexible. Learned behavior can be changed if conditions change. For example, you probably know the route from your house to your school. Assume that you moved to a new house in a different place, so you had to take a different route to school. What if following the old route was an innate behavior? You would not be able to adapt. Fortunately, it is a learned behavior. You could learn the new route just as you learned the old one.

Although most animals can learn, animals with greater intelligence are better at learning and have more learned behaviors. Humans are the most intelligent animals. They depend on learned behaviors more than any other species. Other highly intelligent species include the apes, our closest relatives in the animal kingdom. You read about apes in the previous chapter. They include chimpanzees and gorillas. Both are also very good at learning behaviors.

You may have heard of a gorilla named Kook. Koko was raised by the psychologist Dr. Francine Patterson. Dr. Patterson wanted to find out if gorillas could learn human language. Starting when Koko was just one year old, Dr. Patterson taught her to use sign language. Koko learned to use and understand more than 1,000 signs. Koko showed how much gorillas can learn.

Think about some of the behaviors you have learned. They might include riding a bicycle, using a computer, and playing a musical instrument or sport. You probably did not learn all of these behaviors in the same way. Perhaps you learned some behaviors on your own, just by practicing. Other behaviors you may learned from other people. Humans and other

Figure 15.12: One of the few innate behaviors in human beings is the grasp reflex. It occurs only in babies. (10)

animals can learn behaviors in several different ways. Some common ways of learning are habituation, observational learning, conditioning, play, and insight learning.

Habituation

Habituation is learning to get used to something after being exposed to it for awhile. Habituation usually involves getting used to something that is annoying or frightening but not dangerous. Habituation is one of the simplest ways of learning. It occurs in just about every species of animal.

You have probably learned through habituation many times. For example, maybe you were reading a book when someone turned on a television in the same room. At first, the sound of the television may have been annoying. After awhile, you may no longer have noticed it. If so, you had become habituated to the sound.

Another example of habituation is shown in **Figure** 15.13. Crows and most other birds are usually afraid of people. They avoid coming close to people, or they fly away when people come near them. The crows landing on this scarecrow have gotten used to a "human" in this place. They have learned that the scarecrow poses no danger. They are no longer afraid to come close. They have become habituated to the scarecrow.

Can you see why habituation is useful? It lets animals ignore things that will not harm them. Without habituation, animals might waste time and energy trying to escape from things that are not really dangerous.

Observational Learning

Observational learning is learning by watching and copying the behavior of someone else. Human children learn many behaviors this way. When you were a young child, you may have learned how to tie your shoes by watching your dad tie his shoes. More recently, you may have learned how to dance by watching a pop star dancing on TV. Most likely you have learned how to do math problems by watching your teachers do problems on the board at school. Can you think of other behaviors you have learned by watching and copying other people?

Other animals also learn through observational learning. For example, young wolves learn to be better hunters by watching and copying the skills of older wolves in their pack. Another example of observational learning is how some monkeys have learned how to wash their food in the ocean. They learned by watching and copying the behavior of other monkeys.

Figure 15.13: This scarecrow is no longer scary to these crows. They have gotten used to it being in this spot and learned that it is not dangerous. This is an example of habituation. (11)

Conditioning

Conditioning is a way of learning that involves a reward or punishment. Did you ever train a dog to fetch a ball or stick by rewarding it with treats? If you did, you were using conditioning. Another example of conditioning is shown in **Figure** 15.14. This lab rat has been taught to "play basketball" by being rewarded with food pellets. Conditioning also occurs in wild animals. For example, bees learn to find nectar in certain types of flowers because they have found nectar in those flowers before.

Figure 15.14: This rat has been taught to put the ball through the hoop by being rewarded with food for the behavior. This is an example of conditioning. What do you think would happen if the rat was no longer rewarded for the behavior? (28)

Humans learn behaviors through conditioning, as well. A young child might learn to put away his toys by being rewarded with a bedtime story. An older child might learn to study for tests in school by being rewarded with better grades. Can you think of behaviors you learned by being rewarded for them?

Did you ever hear the saying, "You can't teach an old dog new tricks?" Don't believe it. Older dogs—like older people—are capable of learning new behaviors. They may learn more slowly, but they can still learn to behave in new ways.

Conditioning does not always involve a reward. It can involve a punishment instead. A toddler might be punished with a time-out each time he grabs a toy from his baby brother. After several time-outs, he may learn to stop taking his brother's toys. A dog might be scolded each time she jumps up on the sofa. After repeated scolding, she may learn to stay off the sofa. A bird might become ill after eating a poisonous insect. The bird may learn from this "punishment" to avoid eating the same kind of insect in the future.

Learning by Playing

Most young mammals—including humans—like to play. Play is one way they learn skills they will need as adults. Think about how kittens play. They pounce on toys and chase each other. This helps them learn how to be better predators when they are older. Big cats also play. The lion cubs in **Figure** 15.15 are playing and practicing their hunting skills at the same time. The dogs in **Figure** 15.16 are playing tug-of-war with a toy. What do you think they are learning by playing together this way? Other young animals play in different ways. For example, young deer play by running and kicking up their hooves. This helps them learn how to escape from predators.

Human children learn by playing, as well. For example, playing games and sports can help them learn to follow rules and work with others. The baby in **Figure** 15.17 is playing in the sand. She is learning about the world through play. What do you think she might be learning?

Insight Learning

Insight learning is learning from past experiences and reasoning. It usually involves coming up with new ways to solve problems. Insight learning generally happens quickly. An animal has a sudden flash of insight.

Insight learning requires relatively great intelligence. Human beings use insight learning more than any other species. They have used their intelligence to solve problems ranging from inventing the wheel to flying rockets into space. Think about problems you have solved. Maybe you figured out how to solve a new type of math problem or how to get to the next level of a video game. If you relied on your past experiences and reasoning to do it, then

Figure 15.15: These two lion cubs are playing. They are not only having fun. They are also learning how to be better hunters. (31)

Figure 15.16: They are really playing. This play fighting can help them learn how to be better predators. (1)

Figure 15.17: Playing in a sandbox is fun for young children. It can also help them learn about the world. For example, this child may be learning that sand is soft. (23)

you were using insight learning.

One type of insight learning is making tools to solve problems. Scientists used to think that humans were the only animals intelligent enough to make tools. In fact, being able to make tools was thought to be one of the most important human traits. Tool making was believed to set humans apart from all other animals. Then, in 1960, chimpanzee expert Jane Goodall discovered that chimpanzees also make tools. She saw a chimpanzee strip leaves from a twig. Then he poked the twig into a hole in a termite mound. After termites climbed onto the twig, he pulled the twig out of the hole and ate the insects clinging to it (**Figure** 15.18). The chimpanzee had made a tool to "fish" for termites. He had used insight to solve a problem.

Figure 15.18: This chimpanzee was the first nonhuman primate ever observed to make tools. He was studied by Jane Goodall. He is eating termites from the "fishing pole" he made from a twig. (22)

Since then, chimpanzees have been seen making several different types of tools. For example, they sharpen sticks and use them as spears for hunting. They use stones as hammers to crack open nuts. Scientists have also observed other species of animals making tools to solve problems. A crow was seen bending a piece of wire into a hook. Then the crow used the hook to pull food out of a tube. An example of a gorilla using a walking stick is shown in **Figure** 15.19. Behaviors such as these show that other species of animals—not just humans—can use their experience and reasoning to solve problems. They can learn through insight.

Figure 15.19: This gorilla is using a branch as a tool. She is leaning on it to keep her balance while she reaches down into swampy water to catch a fish. (17)

Lesson Summary

- Animal behavior is any way that animals act, either alone or with other animals.
- Behaviors that increase fitness can evolve through natural selection.
- Innate behavior is behavior that occurs naturally in all members of a species.
- Learned behavior is behavior that occurs only after experience or practice.

Review Questions

Knowledge and Comprehension

1. Give two examples of animal behavior.
2. Define innate behavior.
3. Identify one drawback of innate behavior.
4. What is learned behavior?
5. State three ways that behavior can be learned.

Critical Thinking

1. Explain how egg rolling by graylag geese is likely to have evolved.
2. Describe how the grasp reflex might help a baby survive.
3. Explain how you could use conditioning to teach a dog to sit.
4. Why is play important for baby animals?
5. A crow was seen dropping nuts on a rock to crack the shells and then eating the nut meats. No other crows in the flock were ever observed cracking nuts in this way. What type of learning could explain the behavior of this crow?

Further Reading / Supplemental Links

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- http://www.unmc.edu/Physiology/Mann/mann19.html

Vocabulary

animal behavior Any way that animals act, either alone or with other animals.

innate behavior Any behavior that occurs naturally in all animals of a given species.

instinct Another term for an innate behavior.

reflex behaviors The only truly innate behaviors in humans, occurring mainly in babies.

learned behavior Behavior that occurs only after experience or practice.

habituation Learning to get used to something that is not dangerous after being exposed to it for awhile.

observational learning Learning by watching and copying the behavior of someone else.

conditioning Way of learning that involves a reward or punishment.

insight learning Learning from past experiences and reasoning.

Points to Consider

Did you ever watch a long line of ants marching away from their ant hill? What were they doing? How were they able to work together? What explains group behaviors such as this?

15.2 Lesson 15.2: Types of Animal Behavior

Lesson Objectives

- List ways that animals communicate.
- Describe social behavior in animals.
- Explain the purpose of mating behavior.
- Describe how animals defend their territory.
- Identify animal behaviors that occur in cycles.

Check Your Understanding

- What is an animal?
- Give examples of a wide variety of animals.
- List some "behaviors" animals, such as spiders and rabbits, have in common.

Introduction

What is reproduction? (Reproduction is the production of offspring. Animals reproduce asexually or sexually. Reproduction is related to fitness because fitness depends in part on the ability to reproduce. Do all animals talk to each other? Probably not, but many do communicate. Like human beings, many other animals live together in groups. Some insects, including ants and bees, are well known for living in groups. In order for animals to live together in groups, they must be able to communicate with each other. Animal communication, like most other animal behaviors, increases fitness. Fitness is the ability to survive and have offspring. Communication increases fitness by helping animals find food, defend themselves from predators, mate, and care for offspring.

Communication

What does the word *communication* make you think of? Talking on a cell phone? Texting? Writing? Those are just a few of the ways that human beings communicate. Most other animals also communicate. **Communication** is any way that animals share information, and they do this in many different ways.

Ways That Animals Communicate

Some animals communicate with sound. Most birds communicate this way. Birds use different calls to warn other birds of danger or to tell them to flock together. Many other animals also use sound to communicate. For example, monkeys use warning cries to tell other monkeys in their troop that a predator is near. Frogs croak to attract female frogs as mates. Gibbons use calls to tell other gibbons to stay away from their area.

Another way some animals communicate is with sight. By moving in certain ways or "making faces," they show other animals what they mean. Most primates communicate in this way. For example, a male chimpanzee may raise his arms and stare at another male chimpanzee. This warns the other chimpanzee to keep his distance. The chimpanzee in **Figure** 15.20 may look like he is smiling. However, he is really showing fear. He is communicating to other chimpanzees that he will not challenge them. Look at the peacock in **Figure** 15.21. Why is he raising his beautiful tail feathers? He is also communicating. He is showing females of his species that he would be a good mate.

All of the animals pictured here are busy doing something important. Read about what each animal is doing then think about why the animal is behaving that way. These are just a few of the many ways that animals behave.

Figure 15.20: This chimpanzee is communicating with his face. His expression is called a "fear grin." It tells other chimpanzees that he is not a threat. (29)

Some animals communicate with scent. They secrete chemicals that other animals of their species can smell or detect in some other way. Ants secrete many different chemicals. Other ants detect the chemicals with their antennae. This explains how ants are able to work together. The different chemicals that ants secrete have different meanings. Some of the chemicals signal all the ants in a group to come together. Other chemicals warn of danger. Still other chemicals mark trails to food sources. When an ant finds food, it marks the trail

Figure 15.21: This peacock is using his tail feathers to communicate. What is he "saying"? (3)

back to the nest by secreting a chemical on the ground. Other ants follow the chemical trail to the food.

Many other animals also use chemicals to communicate. You have probably seen male dogs raise their leg to urinate on a fire hydrant or other object. Did you know that the dogs were communicating? They were marking their area with a chemical in their urine. Other dogs can smell the chemical. The scent of the chemical tells other dogs to stay away.

Human Communication

Like other animals, humans communicate with one another. They mainly use sound and sight to share information. The most important way that humans communicate is with language. **Language** is the use of symbols to communicate. In human languages, the symbols are words. They stand for many different things. Words stand for things, people, actions, feelings, or ideas. Think of several common words. What does each word stand for?

Another important way that humans communicate is with facial expressions. Look at the faces of the young children in **Figure** 15.22. Can you tell from their faces what the children are feeling? Humans also use gestures to communicate. What are people communicating when they shrug their shoulders? When they shake their head? These are just a few examples of the ways that humans share information without using words.

Social Behavior

Why is animal communication important? Without it, animals would not be able to live together in groups. Animals that live in groups with other members of their species are called **social animals**. Social animals include many species of insects, birds, and mammals. Specific examples of social animals are ants, bees, crows, wolves, and humans. To live together with one another, these animals must be able to share information.

Highly Social Animals

Some species of animals are very social. In these species, members of the group depend completely on one another. Different animals within the group have different jobs. Therefore, group members must work together for the good of all. Most species of ants and bees are highly social animals.

Ants, like those in **Figure** 15.23, live together in large groups called colonies. A colony may have millions of ants. All of the ants in the colony work together as a single unit. Each ant has a specific job. Most of the ants are workers. Their job is to build and repair the colony's nest. Worker ants also leave the nest to find food for themselves and other colony members. The workers care for the young, as well. Other ants in the colony are soldiers. They defend

Figure 15.22: What does this girl's face say about how she is feeling? (18)

the colony against predators. Each colony also has a queen. Her only job is to lay eggs. She may lay millions of eggs each month. A few ants in the colony are called drones. They are the only male ants in the colony. Their job is to mate with the queen.

Figure 15.23: The ants in this picture belong to the same colony. They have left the colony's nest to search for food. (21)

Honeybees and bumblebees also live in colonies. A colony of honeybees is shown in **Figure** 15.24. Each bee in the colony has a particular job. Most of the bees are workers. Young worker bees clean the colony's hive and feed the young. Older worker bees build the waxy honey comb or guard the hive. The oldest workers leave the hive to find food. Each colony usually has one queen that lays eggs. The colony also has a small number of male drones. They mate with the queen.

Cooperation

Ants, bees, and other social animals must cooperate. **Cooperation** means working together with others. Members of the group may cooperate by sharing food. They may also cooperate by defending each other. Look at the ants in **Figure** 15.25. They show clearly why cooperation is important. A single ant would not be able to carry this large insect back to the nest to feed the other ants. With cooperation, the job is easy.

Animals in many other species cooperate. For example, lions live in groups called prides. A lion pride is shown in **Figure** 15.26. All the lions in the pride cooperate. Male lions work together to defend the other lions in the pride. Female lions work together to hunt. Then they share the meat with other pride members.

Meerkats are small mammals that live in Africa. They also live in groups and cooperate with one another. For example, young female meerkats act as babysitters. They take care

Figure 15.24: All the honeybees in this colony work together. Each bee has a certain job to perform. The bees are gathered together to fly to a new home. How do you think they knew it was time to gather together? (26)

Figure 15.25: These ants are cooperating. By working together, they are able to move this much larger insect prey back to their nest. At the nest, they will share the insect with other ants that do not leave the nest. (6)

Figure 15.26: Members of this lion pride work together. Males cooperate by defending the pride. Females cooperate by hunting and sharing the food. (13)

of the baby meerkats while their parents are away looking for food.

Mating Behavior

Some of the most important animal behaviors involve mating. **Mating** is the pairing of an adult male and female to produce young. Adults that are most successful at attracting a mate are most likely to have offspring. Traits that help animals attract a mate and have offspring increase their fitness. If the traits are controlled by genes, they will become more common in the species through natural selection.

Courtship Behaviors

In many species, females choose the male they will mate with. For their part, males try to be chosen as mates. They show females that they would be a better mate than the other males. To be chosen as a mate, males may perform **courtship behaviors**. These are special behaviors that help attract a mate. Male courtship behaviors get the attention of females and show off a male's traits. Different species have different courtship behaviors. Remember the peacock raising his tail feathers in Figure 1b? This is an example of courtship behavior. The peacock is trying to impress females of his species with his beautiful feathers.

Another example of courtship behavior in birds is shown in **Figure** 15.27. This bird is called a blue-footed booby. He is doing a dance to attract a female for mating. During the dance, he spreads out his wings and stamps his feet on the ground. You can watch a video of a blue-footed booby doing his courtship dance at: http://www.travelpod.com/travel-photo/harryandnorah/the_other_way/1199840760/blue-footed-booby-courting-dance.avi/tpod.html.

Courtship behaviors occur in many other species. For example, males in some species of whales have special mating songs to attract females as mates. Frogs croak for the same reason. Male deer clash antlers to court females. Male jumping spiders jump from side to side to attract mates. To see a video of a jumping spider courting a mate, go to: http://video.aol.com/video-detail/courtship-and-mating-of-the-jumping-spider-lyssomanes-viridis-araneae-2837652909.

Courtship behaviors are one type of display behavior. A **display behavior** is a fixed set of actions that carries a specific message. Although many display behaviors are used to attract mates, some display behaviors have other purposes. For example, display behaviors may be used to warn other animals to stay away, as you will read below.

Figure 15.27: This blue-footed booby is a species of sea bird. The male pictured here is doing a courtship "dance." He is trying to attract a female for mating. (12)

Caring for the Young

In most species of birds and mammals, one or both parents care for their offspring. Caring for the young may include making a nest or other shelter. It may also include feeding the young and protecting them from predators. Caring for offspring increases their chances of surviving. When parents help their young survive, they increase their own fitness.

Birds called killdeers have an interesting way to protect their chicks. When a predator gets too close to her nest, a mother killdeer pretends to have a broken wing. The mother walks away from the nest holding her wing as though it is injured. This is what the killdeer in **Figure** 15.28 is doing. The predator thinks she is injured and will be easy prey. The mother leads the predator away from the nest and then flies away.

In most species of mammals, parents also teach their offspring important skills. For example, meerkat parents teach their pups how to eat scorpions without being stung. A scorpion sting can be deadly, so this is a very important skill. Teaching the young important skills makes it more likely that they will survive.

Defending Territory

Some species of animals are territorial. This means that they defend their area. The area they defend usually contains their nest and enough food for themselves and their offspring. A species is more likely to be territorial if there is not very much food in their area.

Figure 15.28: This mother killdeer is pretending she has a broken wing. She is trying to attract a predator's attention in order to protect her chicks. This behavior puts her at risk of harm. How can it increase her fitness? (30)

Animals generally do not defend their territory by fighting. Instead, they are more likely to use display behavior. The behavior tells other animals to stay away. It gets the message across without the need for fighting. Display behavior is generally safer and uses less energy than fighting.

Male gorillas use display behavior to defend their territory. They pound on their chests and thump the ground with their hands to warn other male gorillas to keep away from their area. The robin in **Figure** 15.29 is also using display behavior to defend his territory. He is displaying his red breast to warn other robins to stay away.

Some animals deposit chemicals to mark the boundary of their territory. This is why dogs urinate on fire hydrants and other objects. Cats may also mark their territory by depositing chemicals. They have scent glands in their face. They deposit chemicals by rubbing their face against objects.

Cycles of Behavior

Many animal behaviors change in a regular way. They go through cycles. Some cycles of behavior repeat each year. Other cycles of behavior repeat every day.

Yearly Cycles

An example of a behavior with a yearly cycle is **hibernation**. Hibernation is a state in which an animal's body processes are slower than usual and its body temperature falls. An

Figure 15.29: The red breast of this male robin is easy to see. The robin displays his bright red chest to defend his territory. It warns other robins to keep out of his area. (19)

animal uses less energy than usual during hibernation. This helps the animal survive during a time of year when food is scarce. Hibernation may last for weeks or months. Animals that hibernate include species of bats, squirrels, and snakes.

Most people think that bears hibernate. In fact, bears do not go into true hibernation. In the winter, they go into a deep sleep. However, their body processes do not slow down very much. Their body temperature also remains about the same as usual. Bears can be awakened easily from their winter sleep.

Another example of a behavior with a yearly cycle is **migration**. Migration is the movement of animals from one place to another. Migration is an innate behavior that is triggered by changes in the environment. For example, animals may migrate when the days get shorter in the fall. Migration is most common in birds, fish, and insects. In the Northern Hemisphere, many species of birds, including robins and geese, travel south for the winter. They migrate to areas where it is warmer and where there is more food. They return north in the spring. A flock of migrating geese is shown in **Figure** 15.30.

Figure 15.30: These geese are flying south for the winter. Flocks of geese migrate in V-shaped formations. (9)

Some animals migrate very long distances. The map in **Figure** 15.31 shows the migration route of a species of hawk called Swainson's hawk. About how many kilometers do the hawks travel from start to finish? Are you surprised that birds migrate that far? Some species of birds migrate even farther.

Birds and other migrating animals follow the same routes each year. How do they know where to go? It depends on the species. Some animals follow landmarks, such as rivers or coastlines. Other animals are guided by the position of the sun, the usual direction of the wind, or other clues in the environment.

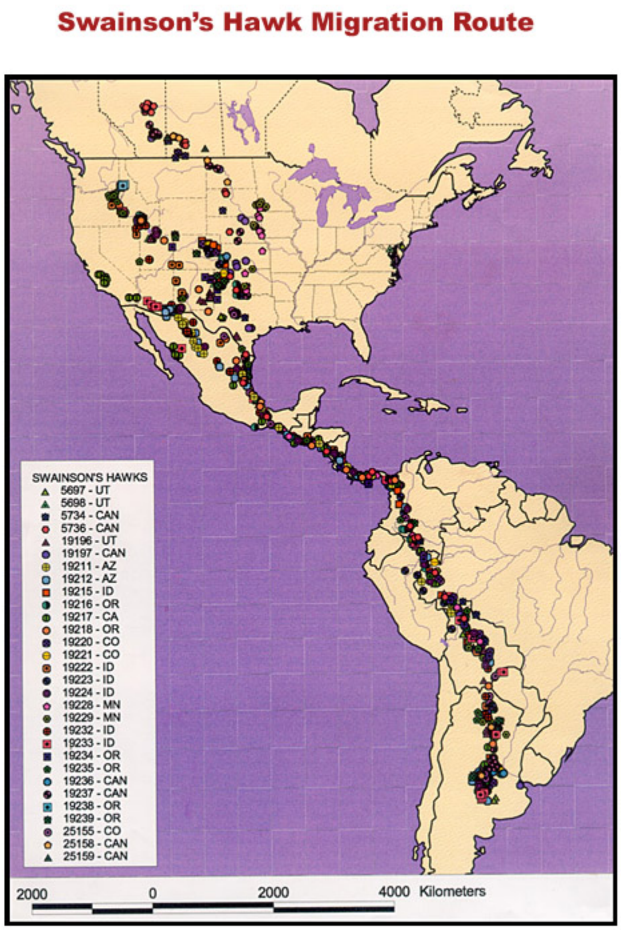

Figure 15.31: The migration route of Swainson's hawk starts in North America and ends in South America. Scientists learned their migration route by attaching tiny tracking devices to the birds. The birds were then tracked by satellite. On the migration south, the hawks travel about 8,000 kilometers from start to finish. (25)

Daily Cycles

Many animal behaviors change at certain times of day, day after day. For example, most animals go to sleep when the sun sets and wake up when the sun rises. Animals that are active during the daytime are called diurnal. Some animals do the opposite. They sleep all day and are active during the night. These animals are called nocturnal. Animals may eat and drink at certain times of day, as well. Humans have daily cycles of behavior, too. Most people start to get sleepy after dark and have a hard time sleeping when it is light outside. Daily cycles of behavior are called **circadian rhythms**.

In many species, including humans, circadian rhythms are controlled by a tiny structure called the **biological clock**. This structure is located in a gland at the base of the brain. The biological clock sends signals to the body. The signals cause regular changes in behavior and body processes. The amount of light entering the eyes controls the biological clock. That's why the clock causes changes that repeat every 24 hours.

Lesson Summary

- Communication is any way that animals share information.
- Social animals live together in groups and cooperate with one another.
- Some of the most important animal behaviors involve attracting mates and caring for offspring.
- Some animals defend the area where they live from other animals.
- Many animal behaviors occur in cycles that repeat yearly or daily.

Review Questions

1. List two ways that animals communicate.
2. Describe how ants in a colony cooperate.
3. What is courtship behavior?
4. Why do male dogs urinate on fire hydrants and other objects?
5. Give an example of a circadian rhythm.
6. How do ants use chemicals to communicate?
7. Explain how courtship behaviors could evolve.
8. How do adult animals increase their own fitness by teaching skills to their young?
9. What is the advantage of animals using display behavior instead of fighting to defend their territory?
10. What is migration, and why do animals migrate?

Further Reading / Supplemental Links

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Vocabulary

biological clock Tiny structure in the brain that controls circadian rhythms.

circadian rhythms An organism's daily cycles of behavior.

communication Any way that animals share information.

cooperation Working together with others.

courtship behaviors Special behaviors that help attract a mate.

display behavior Fixed set of actions that carries a specific message.

hibernation State in which an animal's body processes are slower than usual.

language Use of symbols (or sounds) to communicate.

mating Pairing of an adult male and female to produce young.

migration Movement of animals from one place to another; often seasonal.

social animals Animals that live in groups with other members of their species.

Points to Consider

- The biological clock located just below the human brain controls behaviors such as the sleep-wake cycle.
- The brain is part of the nervous system. What other body system are found in humans?
- Which body system includes the bones? Which system includes the muscles? What do bones and muscles do?

Image Sources

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Chapter 16

Skin, Bones, and Muscles

16.1 Lesson 16.1: Organization of Your Body

Lesson Objectives

- List the levels of organization in the human body.
- Identify the four types of tissues that make up the body.
- Identify 12 organ systems.
- Describe how organs and organ systems work together to maintain homeostasis.

Check Your Understanding

- What is a cell?
- What are some of the differences between a prokaryotic cell and an eukaryotic cell?
- What are some of the basic functions of animal cells?

Introduction

The men in **Figure** 16.1 have just jumped into freezing icy water. They are having fun, but imagine how cold they must feel! One minute their bodies were wrapped in warm clothes, the next, they were dunked in freezing water. Their bodies are now working hard to adapt to the sudden great change in temperature. The ability of the body to maintain a stable internal environment in the response to change is called *homeostasis*. **Homeostasis** allows your body to adapt to change, such as jumping into cold water, running in hot weather, or not getting enough food when you are hungry. Homeostasis is an important characteristic of living things.

Figure 16.1: The bodies of these swimmers are working hard to maintain homeostasis while they are in the icy pool water. Otherwise, their life processes would stop working as soon as they got into the water. (5)

Cells, Tissues, and Organs

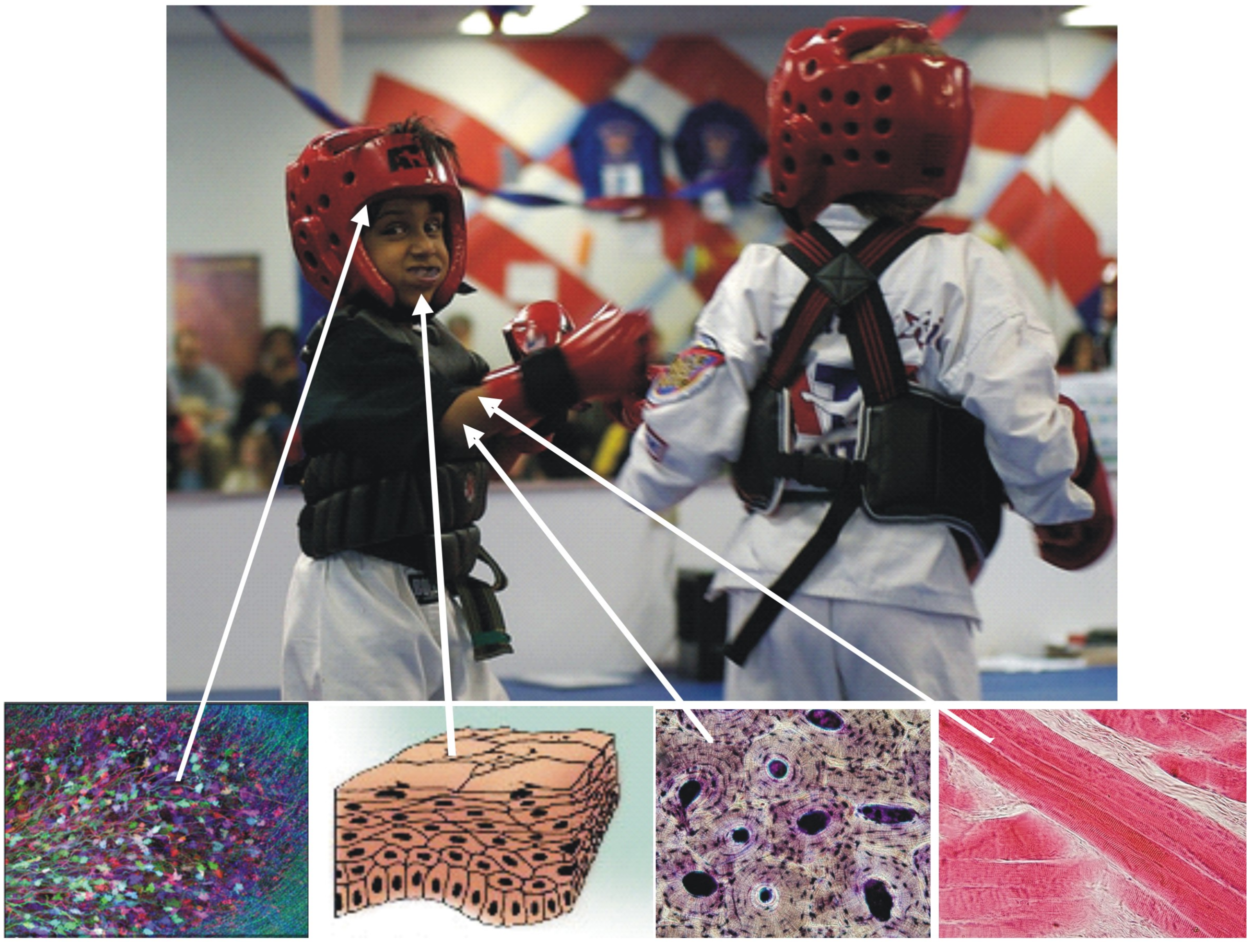
Cells are the most basic units of life in your body. They must do many jobs to maintain homeostasis, but each cell does not have to do every job. Cells have specific jobs to maintain homeostasis. For example, nerve cells move electrical messages around the body, and white blood cells patrol the body and attack invading bacteria. There are many additional different types of cells. Other cells include red blood cells, skin cells, cells that line the inside of your stomach, and muscle cells.

Groups of Cells Form Tissues

Cells are grouped together to carry out specific functions. A group of cells that work together is called a tissue. Your body has four main types of tissues, as do the bodies of other animals. These tissues make up all structures and contents of your body. An example of each tissue type is shown in **Figure** 16.2.

- **Epithelial tissue** is made up of layers of tightly packed cells that line the surfaces of the body. Examples of epithelial tissue include the skin, the lining of the mouth and nose, and the lining of the digestive system.

- **Connective tissue** is made up of many different types of cells that are all involved in structure and support of the body. Examples include blood, cartilage, and bone.



Nervous (brain) Epithelial (skin) Connective (bone) Muscle (skeletal muscle)

Figure 16.2: Your body has four main types of tissue; nervous tissue, epithelial tissue, connective tissue, and muscle tissue. They are found throughout your body. (17)

- **Muscle tissue** is made up of cells that have filaments that move past each other and change the size of the cell. There are three types of muscle tissue: smooth muscle, skeletal muscle, and cardiac muscle.

- **Nervous tissue** is made up of the nerve cells that together form the nervous system. Nervous tissue is found in nerves, the spinal cord, and the brain.

Groups of Tissues Form Organs

A single tissue alone cannot do all the jobs that are needed to keep you alive and healthy. Two or more tissues working together can do a lot more. An **organ** is a structure made of two or more tissues that work together. The heart, shown in **Figure** 16.3, is made up of four types of tissues.

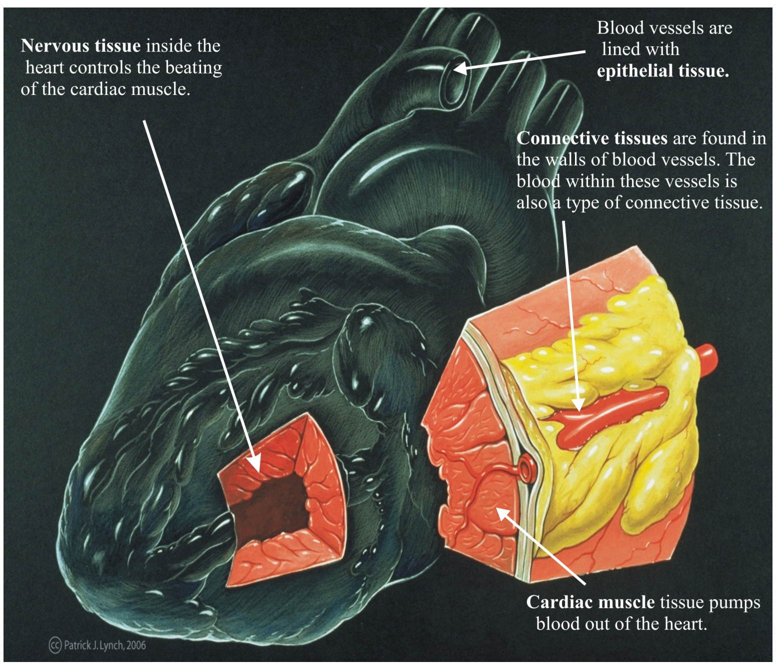


Figure 16.3: The four different tissue types work together in the heart as they do in the other organs. (27)

Groups of Organs Form Organ

Systems Your heart pumps blood around your body. However, your heart needs to be able to get blood to and from every cell in your body in order to do its job. So, your heart is connected to blood vessels such as veins and arteries. Organs that work together form an

organ system. Together, your heart, blood, and blood vessels form your *cardiovascular system*.

Organ Systems Work Together

Your body's 12 organ systems are shown in **Table** 16.1. Your organ systems do not work alone in your body. They must all be able to work together to maintain homeostasis. For example, when the men in **Figure** 16.1 jumped into the cold water, their integumentary systems (skin, hair, nails), cardiovascular systems, muscular systems, and nervous systems work quickly together to ensure the icy-cold water did not cause harm to their bodies. The nervous system sent nerve messages from the skin to tell the cardiovascular system to reduce the blood flow to the skin. Blood flow is then increased to the internal organs and large muscles to help keep them warm and supply them with oxygen. The nervous system also sent messages to the respiratory system to breathe faster. This allows for more oxygen to be delivered by the blood to the muscular system which is shivering and moving about to keep the body warm. **Feedback loops** in the nervous and endocrine systems regulate conditions in the body. A feedback loop is a path that leads from the initial generation of the signal to the subsequent modification of the initial event. For example, the men that jumped into the cold water do not need to continue to breathe faster and faster. Feedback loops return the respiratory system to "normal." One of the most important functions of organ systems is to provide cells with oxygen and nutrients and removes toxic waste products such as carbon dioxide. A number of organ systems, including the cardiovascular and respiratory systems, work together to do this.

Table 16.1: **Major Organ Systems of the Human Body**

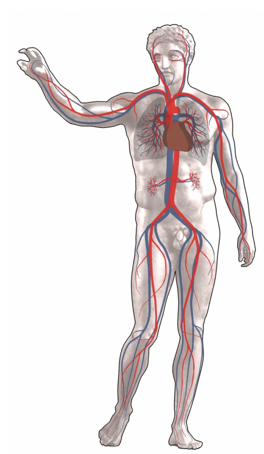
Organ System	Major Tissues and Organs	Function	Example
Cardiovascular	Heart; blood vessels; blood	Transports oxygen, hormones and nutrients to the body cells, and wastes and carbon dioxide away from cells	

Table 16.1: (continued)

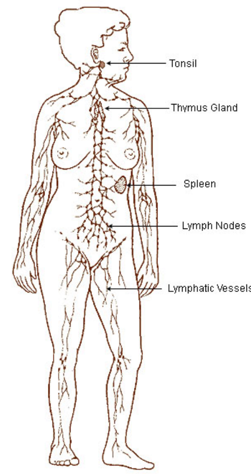
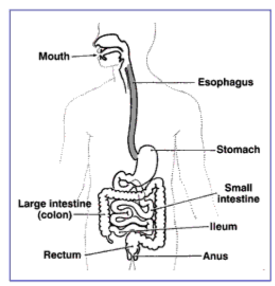
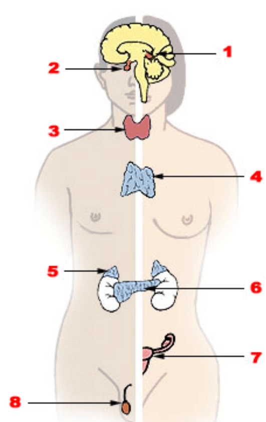
Organ System	Major Tissues and Organs	Function	Example
Lymphatic	Lymph nodes; lymph vessels	Defense against infection and disease, transfer of lymph between tissues and the blood stream	
Digestive	Esophagus; stomach; small intestine; large intestine	Processing of foods and absorption of nutrients, minerals, vitamins, and water	
Endocrine	Pituitary gland, hypothalamus; adrenal glands; Islet of Langerhans; ovaries; testes	Communication within the body with hormones; directing long-term change over other organ systems to maintain homeostasis	

Table 16.1: (continued)

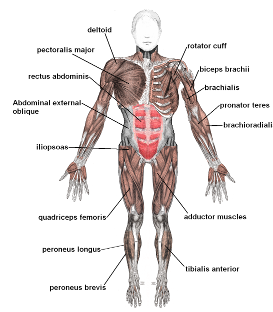
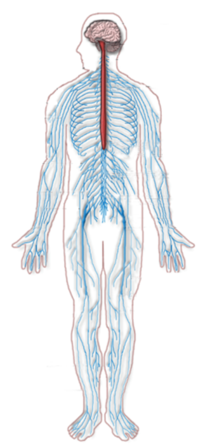
Organ System	Major Tissues and Organs	Function	Example
Integumentary	Skin, hair, nails	Protection from injury and fluid loss; physical defense against infection by microorganisms; temperature control	
Muscular	Cardiac (heart) muscle; skeletal muscle; smooth muscle; tendons	Movement, support, heat production	
Nervous	Brain, spinal cord; nerves	Collecting, transferring and processing information; directing short-term change over other organ systems in order to maintain homeostasis	
Reproductive	Female: uterus; vagina; fallopian tubes; ovaries Male: penis; testes; seminal vesicles	Production of gametes (sex cells) and sex hormones; production of offspring	

Table 16.1: (continued)

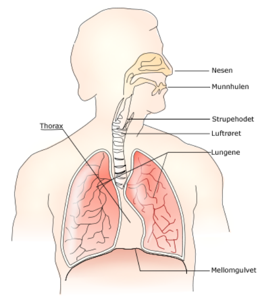
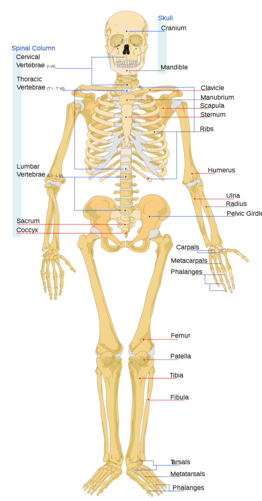
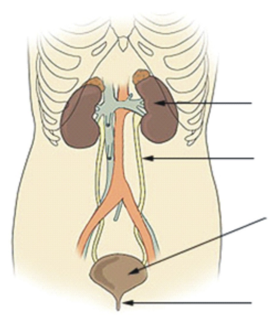
Organ System	Major Tissues and Organs	Function	Example
Respiratory	Trachea, larynx, pharynx, lungs	Delivery of air to sites where gas exchange can occur between the blood and cells (around body) or blood and air (lungs)	
Skeletal	Bones, cartilage; ligaments	Support and protection of soft tissues of body; movement at joints; production of blood cells; mineral storage	
Urinary	Kidneys; urinary bladder	Removal of excess water, salts, and waste products from blood and body; control of pH; regulates water and electrolyte balance	

Table 16.1: (continued)

Organ System	Major Tissues and Organs	Function	Example
Immune	Skin; bone marrow; spleen; white blood cells	Defending against microbial pathogens (disease-causing agents) and other diseases	

Figures in table above: Each body system works together to maintain homeostasis of other systems and of the entire organism. No system of the body works alone, and your well-being depends upon the well-being of all the body systems. A problem in one system usually affects other body systems.

Homeostasis and Feedback Regulation

Homeostasis refers to stability, balance, or equilibrium within a cell or the body. It is an organism's ability to keep a constant internal environment. Homeostasis is an important characteristic of living things. Keeping a stable internal environment requires constant adjustments as conditions change inside and outside the cell. Because the internal and external environments of a cell are constantly changing, adjustments must be made continuously to stay at or near the set point (the normal level or range).

The endocrine system plays an important role in homeostasis because **hormones**, which are the messengers of the endocrine system, regulate the activity of body cells. The release of hormones into the blood is controlled by a stimulus, or signal. For example, the stimulus either causes an increase or a decrease in the amount of hormone released. Then, the response to the signal changes the internal conditions and may itself become a new stimulus. This self-adjusting mechanism is called feedback regulation.

Feedback regulation occurs when the response to a stimulus has an effect of some kind on the original stimulus. The type of response determines what the feedback is called. **Negative feedback** occurs when the response to a stimulus reduces the original stimulus. **Positive feedback** occurs when the response to a stimulus increases the original stimulus.

Thermoregulation: A Negative Feedback Loop

Negative feedback is the most common feedback loop in the body. The system acts to reverse the direction of change, keeping things constant. For instance, when the concentration of carbon dioxide in the human body increases, the lungs are signaled to increase their activity and exhale more carbon dioxide, so your breathing rate increases. **Thermoregulation** is another example of negative feedback. When body temperature rises, receptors in the skin and the brain sense the temperature change. The temperature change (signal) triggers a command from the brain. This command, causes a response (the skin makes sweat and blood vessels near the skin surface dilate), which helps decrease body temperature. **Figure** 16.4 shows how the response to a stimulus reduces the original stimulus in another of the body's negative feedback mechanisms.

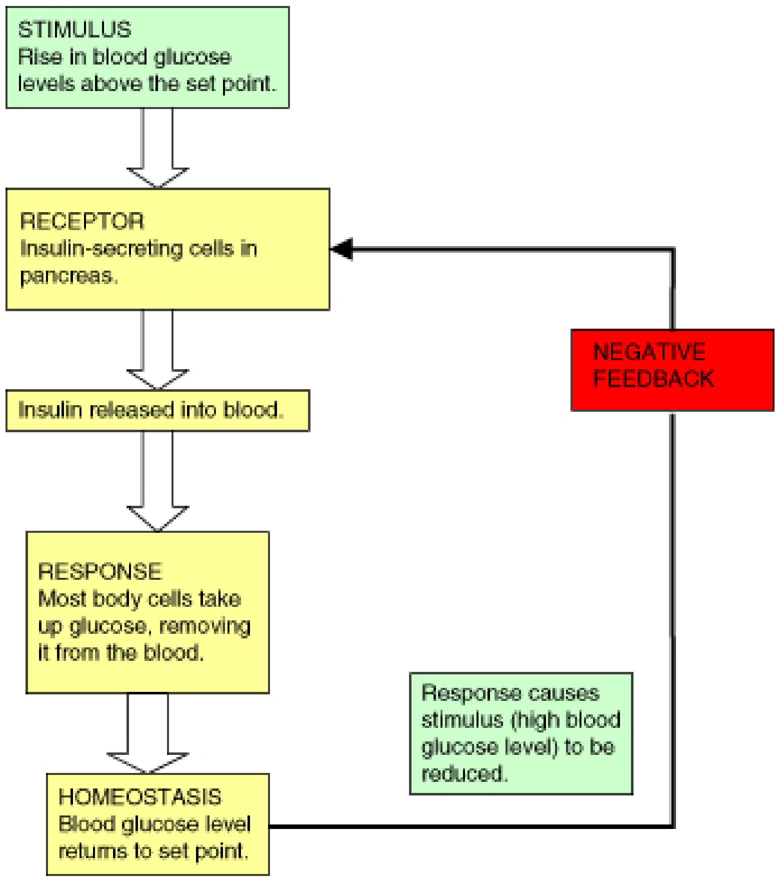


Figure 16.4: Control of blood glucose level is an example of negative feedback. Blood glucose concentration rises after a meal (the stimulus). The hormone insulin is released by the pancreas, and it speeds up the transport of glucose from the blood and into selected tissues (the response). Blood glucose concentrations then decrease, which then decreases the original stimulus. The secretion of insulin into the blood is then decreased. (24)

Positive feedback is less common in biological systems. Positive feedback acts to speed up the direction of change. An example of positive feedback is lactation (milk production). As the baby drinks its mother's milk, nerve messages from the mammary glands cause a hormone, prolactin, to be released. The more the baby suckles, the more prolactin is released, which stimulates further milk production.

Not many feedback mechanisms in the body are based on positive feedback. Positive feedback speeds up the direction of change, which leads to increasing hormone concentration, a state that moves further away from homeostasis.

Lesson Summary

- The levels of organization in the human body include: cells, tissues, organs, and organ systems. A tissue is a group of cells that work together. An organ is made of two or more tissues that work together. Organs that work together make up organ systems.
- There are four tissue types in the body: epithelial tissue, connective tissue, muscle tissue, and nervous tissue. There are 12 major organ systems in the body. Organs and organ systems work together to maintain homeostasis.

Review Questions

1. What is homeostasis?
2. What are the four levels of organization in an organism?
3. What is the difference between a tissue and an organ?
4. List the four types of tissues that make up the human body.
5. A classmate says that all four tissue types are never found together in an organ.
6. Why do you think an organ is able to do many more jobs than a single tissue can?
7. Identify the organ system to which the following organs belong: skin, stomach, brain, lungs, and heart.
8. Give an example of how two organ systems work together to maintain homeostasis.

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki/Tissue_%28biology%29

Vocabulary

cardiovascular system The body system that include the heart, blood, and blood vessels.

connective tissue Tissue that is made up of different types of cells that are involved in structure and support of the body; includes blood, bone, and cartilage.

epithelial tissue A tissue that is composed of layers of tightly packed cells that line the surfaces of the body; examples of epithelial tissue include the skin, the lining of the mouth and nose, and the lining of the digestive system.

homeostasis The ability of the body to maintain a stable internal environment in the response to external changes.

muscular tissue Tissue that is composed of cells that have filaments that move past each other and change the size of the cell. There are three types of muscle tissue: smooth muscle, skeletal muscle, and cardiac muscle.

nervous tissue Composed of nerve cells and related cells.

organ A structure made of two or more tissues that work together.

organ system A group of organs that work together.

tissue SA group of cells that work together for a common purpose.

Points to Consider

- What are the levels of organization of the integumentary system?
- What other body systems does the integumentary system work with to maintain homeostasis?

16.2 Lesson 16.2: Integumentary System

Lesson Objectives

- List the functions of skin.
- Describe the structure of skin.
- Describe the structure of hair and nails.
- Identify two types of skin problems.
- Describe two ways to take care of your skin.

Check Your Understanding

- What is homeostasis?
- What is epithelial tissue?

Introduction

Did you know that you see the largest organ in your body every day? You wash it, dry it, cover it up to stay warm or uncover it to cool off. In fact, you see it so often it is easy to forget the important role your skin plays in keeping you healthy. Your skin is part of your **integumentary system** (**Figure** 16.5), which is the outer covering of your body. The integumentary system is made up of your skin, hair, and nails.

Figure 16.5: Skin acts as a barrier that stops water and other things, like soap and dirt, from getting into your body. (6)

Your Skin and Homeostasis

Your integumentary system has many roles in homeostasis, including protection, the sense of touch, and regulating body temperature. Keeping water out of the body is an important role for your integumentary system. If this were not so, the man in Figure 1 would not be able to bathe. All of your body systems work together to maintain stable internal conditions. Each of the parts that make up your integumantary system has a special role in maintaining homeostasis which we will explore a little later.

Functions of Skin

Your skin covers the entire outside of your body. Your skin is your body's largest organ yet it is only about 2 mm thick. It has many important functions, some of these include:

- It acts as a barrier. It keeps organisms that could harm the body out. It stops water from leaving the body, and stops water from getting into the body.
- It helps regulate body temperature. It does this by making sweat, a watery substance which cools the body when it evaporates.
- It helps you to gather information about your environment. Special nerve endings in your skin sense heat, pressure, cold and pain.
- It helps the body get rid of some types of waste, which are removed in sweat.
- It acts as a sun block. A chemical called *melanin* is made by certain skin cells when they are exposed to sunlight. Melanin blocks sun light from getting to deeper layers of skin cells, which are easily damaged by sun light.

Structure of Skin

Your skin is always exposed to your external environment so it gets cut, scratched, and worn down. You also naturally shed many skin cells every day. Your body replaces damaged or missing skin cells by growing more of them. The layer of skin that you can see is actually dead. The dead cells are filled with a tough, waterproof protein called **keratin**. As the dead cells are shed or are removed from the upper layer, they are replaced by the skin cells below them.

As you can see in **Figure** 16.6, two different layers make up the skin. These layers are the **epidermis** and the **dermis**. A fatty layer, called **subcutaneous tissue**, lies under the dermis, but it is not part of your skin. The layers that make up your skin are shown in **Figure** 16.6.

The color, thickness and texture of skin vary over the body. There are two general types of skin; thin and hairy, which is the most common type on the body, and thick and hairless, which is found on parts of the body that experience a lot of friction, such as the palms of the hands or the soles of the feet.

Epidermis

Epidermis is the outermost layer of the skin. It forms the waterproof, protective wrap over the body's surface and is made up of many layers of *epithelial* cells (discussed in lesson 1). The epidermis is divided into several layers where epithelial cells are formed by mitosis in the lowest layer. The epithelial cells move up through the layers of the epidermis, changing shape and composition as they divide and become filled with keratin. The skin cells at the

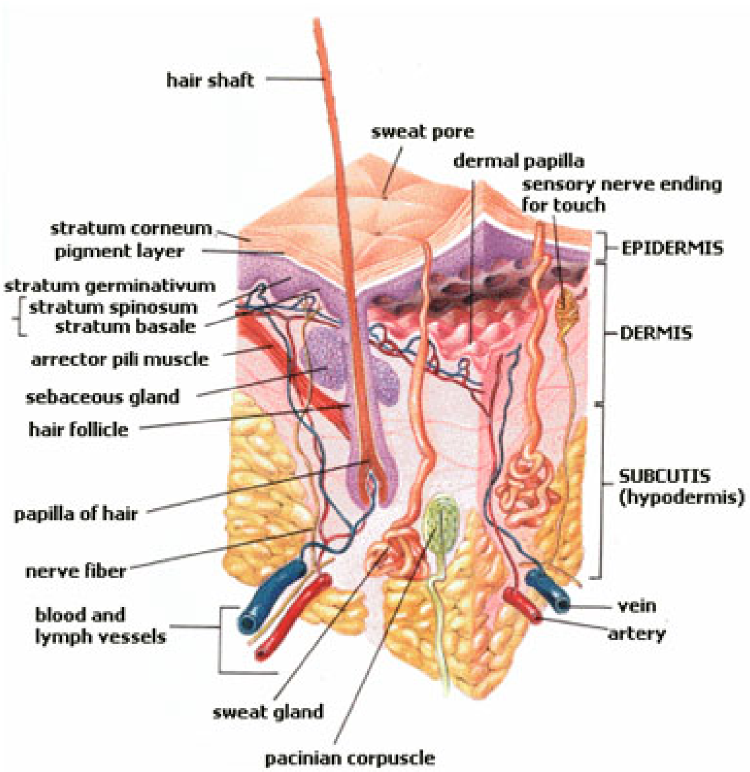


Figure 16.6: Skin is made up of two layers, the epidermis on top, and the dermis below. The tissue below the dermis is called the hypodermis, but it is not part of the skin. (20)

surface of the epidermis form a thin layer of flattened, dead cells. Although the top layer of epidermis is only about as thick as a sheet of paper, it is made up of 25 to 30 layers of cells.

The epidermis also contains cells that produce *melanin*. **Melanin** is the brownish pigment that gives skin and hair their color. Melanin-producing cells are found in the bottom layer of the epidermis. The epidermis does not have any blood vessels. The lower part of the epidermis is fed by diffusion from the blood vessels of the dermis.

Dermis

The **dermis** is the layer of skin directly under the epidermis. It is made of a tough connective tissue that contains the protein *collagen*. **Collagen** is a long, fiber-like protein that is very strong. The dermis is tightly connected to the epidermis by a membrane made of collagen fibers. As you can see in **Figure** 16.6, the dermis contains the hair follicles, sweat glands, oil glands, and blood vessels. It also holds many nerve endings that give you your sense of touch, pressure, heat, and pain. Tiny muscles in the dermis pull on hair follicles which cause hair to stand up. This can happen when you are cold or afraid. The resulting little "bumps" in the skin are commonly called *goosebumps*, shown in **Figure** 16.7.

Figure 16.7: Goose bumps are caused by tiny muscles in the dermis that pull on hair follicles, which causes the hairs to stand up straight. (23)

Oil Glands and Sweat Glands

Glands and follicles open out into the epidermis, but they start in the dermis. **Oil glands** secrete an oily substance, called *sebum*, into the hair follicle. An oil gland is shown in **Figure** 16.6. Sebum "waterproofs" hair and the skin surface to prevent them from drying out. It can also stop the growth of bacteria on the skin. Sebum is the cause of the oily appearance of skin and hair. It is odorless, but the breakdown of sebum by bacteria can cause odors. If an oil gland becomes plugged and infected, it develops into a pimple, also called *acne*.

Sweat glands open to the skin surface through skin pores. They are found all over the body. Evaporation of sweat from the skin surface helps to lower the skin temperature, which in turn helps to control body temperature. The skin also releases excess water, salts, and other wastes in sweat. A sweat gland is shown in **Figure** 16.6.

Nails and Hair

Nails and hair are made of the same types of cells that make up skin. Hair and nails contain the tough protein *keratin*. Both hair and nails are important parts of your integumentary system.

Fingernails and toenails both grow from nail beds. A nailbed is thickened to form a lunula (or little moon), which you can see in **Figure** 16.8. Cells forming the nail bed are linked together to form the nail. As the nail grows more cells are added at the nail bed. Older cells get pushed away from the nail bed and the nail grows longer. There are no nerve endings in the nail, which is a good thing, otherwise cutting you nails would hurt a lot!

Nails act as protective plates over the fingertips and toes. Fingernails also help in sensing the environment. The area under your nail has many nerve endings, which allow you to receive more information about objects you touch. Nails are made up of many different parts, as shown in **Figure** 16.8.

Hair sticks out from the epidermis, although it grows from hair follicles deep in the dermis, as shown in **Figure** 16.9. Hair is made of keratin, the same protein that makes up skin and nails. Hair grows from inside the hair follicle. New cells grow in the bottom part of the hair, called the *bulb*. Older cells get pushed up, and the hair grows longer. Similar to nails and skin, the cells that make up the hair strand are dead and filled with keratin. Hair color is the result of different types of melanin in the hair cells. In general, the more melanin in the cells, the darker the hair color; the less melanin, the lighter the hair color.

Hair helps to keep the body warm. When you feel cold, your skin gets a little bumpy. These bumps are caused by tiny muscles that pull on the hair, causing the hair to stick out. The erect hairs help to trap a thin layer of air that is warmed by body heat. In mammals that have much more hair than humans, the hair traps a layer of warm air near the skin and acts like warm blanket. Hair also protects the skin from ultraviolet radiation (UV radiation) from the sun. Hair also acts as a filter. Nose hair helps to trap particles in the air that may

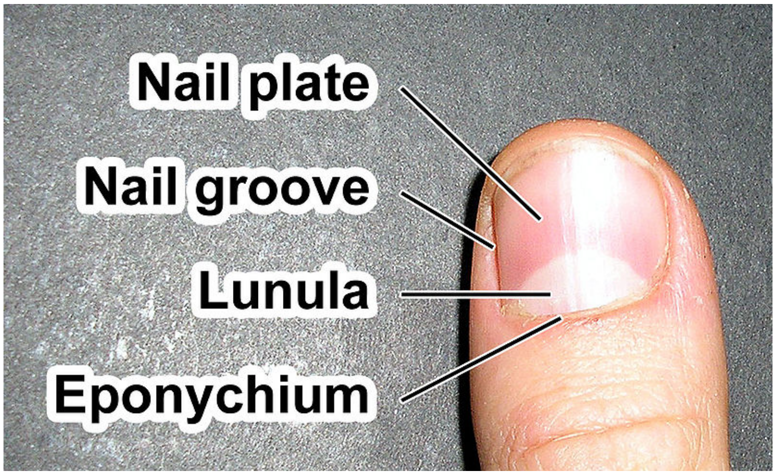


Figure 16.8: The structure of fingernails is similar to toenails. The *free edge* is the part of the nail that extends past the finger, beyond the nail plate. The *nail plate* is what we think of when we say "nail," the hard portion made of the tough protein keratin. The *lunula* is the crescent shaped whitish area of the nail bed. The *cuticle* is the fold of skin at the end of the nail. (16)

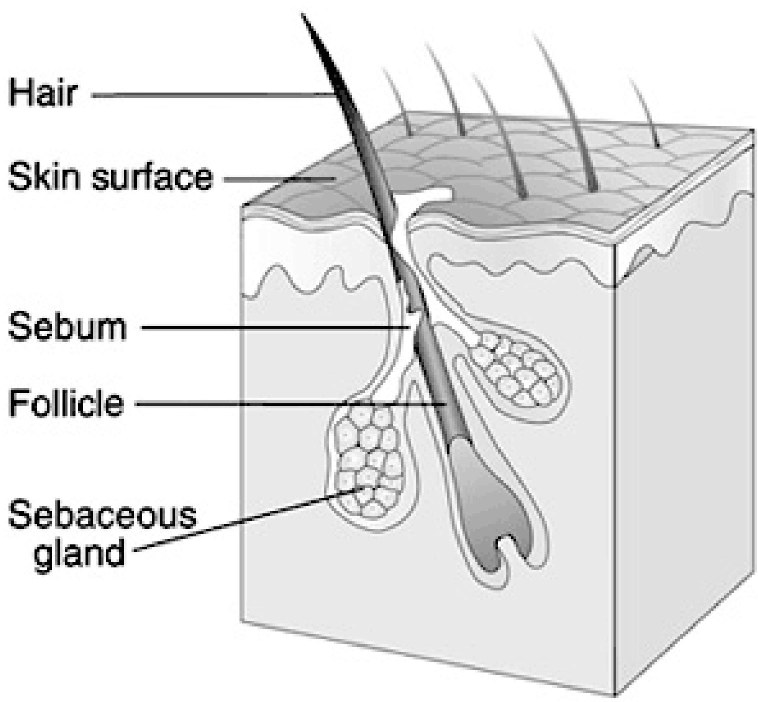


Figure 16.9: Hair, hair follicle, and oil glands. The oil, called sebum, helps to prevent water loss from the skin. (14)

otherwise travel to the lungs. Eyelashes shield eyes from dust and sunlight. Eyebrows stop salty sweat and rain from flowing into the eye.

Keeping Skin Healthy

Some sunlight is good for health. Vitamin D is made in the skin when it is exposed to sunlight. But, getting too much sun can be unhealthy. A **sunburn** is a burn to the skin that is caused by overexposure to UV radiation from the sun's rays or tanning beds. Light-skinned people, like the girl in **Figure** 16.10, get sunburned more quickly than people with darker skin do. This is because melanin in the skin acts as a natural sunblock that helps to protect the body from UV radiation. When exposed to UV radiation, certain skin cells make melanin, which causes skin to tan. Children and teens who have gotten sunburned are at a greater risk of developing skin cancer later in life than children and teens who have not.

Long-term exposure to UV radiation is the leading cause of skin cancer. About 90 percent of skin cancers are linked to sun exposure. UV radiation damages the genetic material of skin cells. This damage can cause the skin cells to grow out of control and form a tumor. Some of these tumors are very difficult to cure. For this reason you should always wear sunscreen with a high sun protection factor (SPF), a hat, and clothing when out in the sun. As people age, their skin gets wrinkled. Wrinkles are caused mainly by UV radiation and by the loosening of the connective tissue in the dermis due to age.

Figure 16.10: Sunburn is caused by overexposure to UV rays. Getting sunburned as a child or a teen, especially sunburn that causes blistering, increases the risk of developing skin cancer later in life. (29)

Because some types of skin cancer are easy to cure, the dangers of too much sunlight are not always taken seriously by people. It is important to remember that a more serious form of skin cancer, called **melanoma**, is also associated with long-term sun exposure.

Melanomas are difficult to treat, and potentially deadly tumors. The best way to avoid skin cancer is to cover up when outside in the sun, and to wear sunscreen.

Bathing and Skin Hygiene

During the day, your skin can collect many different things. Sweat, oil, dirt, dust, and dead skin cells can build up on the skin surface. If not washed away, the mix of sweat, oil, dirt, and dead skin cells can encourage the excess growth of bacteria. These bacteria feed on these substances and cause a smell that is commonly called *body odor*. Dirty skin is also more prone to infection. Bathing every day helps to remove dirt, sweat and extra skin cells, and helps to keep your skin clean and healthy.

Acne

Hormones can affect your skin. Certain hormones cause oil glands in the skin to make an oil called *sebum*. When too much sebum is made by oil glands, it can cause the hair follicles to get blocked with dead skin cells. Within these blocked pores bacteria and yeast begin to multiply. In response to the growth of the bacteria and yeast, the skin inflames. This skin inflammation produces the red bumps that are called *acne*. Up to 85% of teenagers get acne. Acne usually goes away by adulthood. Frequent washing can help reduce the amount of sebum and dead skin cells on the skin. But washing cannot prevent the excessive sebum production that leads to acne.

Injury

Your skin can heal itself even after a large cut. Cells that are damaged or cut away are replaced by cells that grow in the bottom layer of the epidermis and the dermis. These new cells will eventually replace the damaged tissues.

When an injury is deep enough through the epidermis into the dermis, bleeding occurs. A blood clot and scab soon forms. After the scab is formed, cells in the base of the epidermis begin to divide by and move to the edges of the scab. A few days after the injury, the edges of the wound are pulled together. If the cut is large enough, the production of new skin cells will not be able to heal the wound. Stitching the edges of the injured skin together can help the skin to repair itself. The person in **Figure** 16.11 had a large cut that needed to be stitched together. When the damaged cells and tissues are replaced, the stitches will be removed.

Lesson Summary

- Skin acts as a barrier that keeps particles and water out of the body.

Figure 16.11: Sewing the edges of a large cut together allows the body to repair the damaged cells and tissues, and heal the tear in the skin. (9)

- The skin helps to cool the body in hot temperatures, and keep the body warm in cool temperatures. It also help you to sense your surroundings.
- Skin is made up of two layers, the epidermis and the dermis. Hair and nails are made of the same type of protein as skin is.
- Nails grow from nail beds and hairs grow from hair follicles in the skin.
- Acne is a skin problem that happens when the skin makes too much sebum.
- Skin cancer can be caused by excess exposure to ultraviolet light from the sun or tanning beds.
- Bathing frequently helps keep the skin clean and healthy.
- Wearing sunblock and a hat when outdoors can help prevent skin cancer.

Review Questions

1. Identify two functions of skin.
2. How does the integumentary system help maintain homeostasis?
3. Describe the structure of skin.
4. Identify the layer of skin from which hair grows.
5. In what way are hairs and nails similar to skin?
6. Name two functions of nails.
7. Name two functions of hair.
8. What type of skin problem happens when the skin makes too much sebum?
9. The World Health Organization recommends that no person younger than 18 years old use a tanning bed. Why do you think using a tanning bed is not recommended?
10. How does washing your skin help to keep you healthy?
11. Why are stitches sometimes needed if a person gets a deep or long cut in their skin?

Further Reading / Supplemental Links

- http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5540a9.htm
- http://www.cdc.gov/Features/SkinCancer
- http://en.wikipedia.org/wiki

Vocabulary

body odor Smell that is produced by the breakdown of sweat by bacteria that live on the skin.

dermis The layer of skin directly under the epidermis; made of a tough connective tissue that contains the protein collagen.

epidermis The outermost layer of the skin; forms the waterproof, protective wrap over the body's surface; made up of many layers of epithelial cells.

integumentary system The outer covering of the body; made up of the skin, hair, and nails.

keratin Tough, waterproof protein that is found in epidermal skin cells, nail, and hair.

melanin The brownish pigment that gives skin and hair their color.

melanocyte Melanin-producing cells; found in the bottom layer of the epidermis.

melanoma Cancer of melanin-containing cells (melanocytes); mostly linked to long-term exposure to UV radiation.

oil gland Skin organ that secretes an oily substance, called sebum, into the hair follicle.

subcutaneous tissue Fatty layer of tissue that lies under the dermis, but is not part of the skin.

sunburn A burn to the skin that is caused by overexposure to UV radiation from the sun's rays or tanning beds.

sweat gland Gland that opens to the skin surface through skin pores; found all over the body; secretes sweat.

Points to Consider

- How might what you eat affect your bones?
- What do you think is the most important function of your skeletal system?

16.3 Lesson 16.3: Skeletal System

Lesson Objectives

- Identify the main tissues and organs of the skeletal system.
- List four functions of the skeletal system.
- Describe three movable joints.
- Identify two nutrients that are important for a healthy skeletal system.
- Describe two skeletal system injuries.

Check Your Understanding

- What is an organ system?
- What is connective tissue?

Introduction

How important is your skeleton? Can you imaging your body without it? You would be a wobbly pile of muscle and internal organs, and you would not be able to move around much. You will learn about these functions in this lesson. Your skeleton is important for many different things. Bones are the main organs of the skeletal system. They are made up of living tissue. If you think you have broken a bone it's important to visit a healthcare professional. A broken bone may not heal properly by itself. A sprain can be bandaged up properly to reduce swelling and discomfort. A doctor or other healthcare professional can also give you advice on how to manage such an injury at home.

Your Skeleton

Humans are vertebrates, which are animals that have a backbone. The sturdy scaffolding of bones and cartilage that is found inside vertebrates is called a **skeleton**. The adult human skeleton has about 206 bones, some of which are named in **Figure** 16.12. The skeletons of babies and children have many more bones and more cartilage than adults have. As a child grows, these "extra" bones grow into each other, and cartilage gradually hardens to become bone tissue.

You may think that bones are dry and lifeless, but they are very much alive. The white, hard bones that you might see in a museum or science book, are only the hard mineral remains of the bone tissue. Living bones are full of life. They contain many different types of tissues.

Cartilage is found at the end of bones and is made of tough protein fibers called *collagen*. Cartilage creates smooth surfaces for the movement of bones that are next to each other, like the bones of the knee. **Ligaments** are made of tough protein fibers and connect bones to each other. Your bones, cartilage, and ligaments make up your **skeletal system**.

Functions of Bones

Your skeletal system gives shape and form to your body, but it is also important in other homeostatic functions. The main functions of the skeletal system are:

- **Support** The skeleton supports the body against the pull of gravity. The large bones of the lower limbs support the trunk when standing.

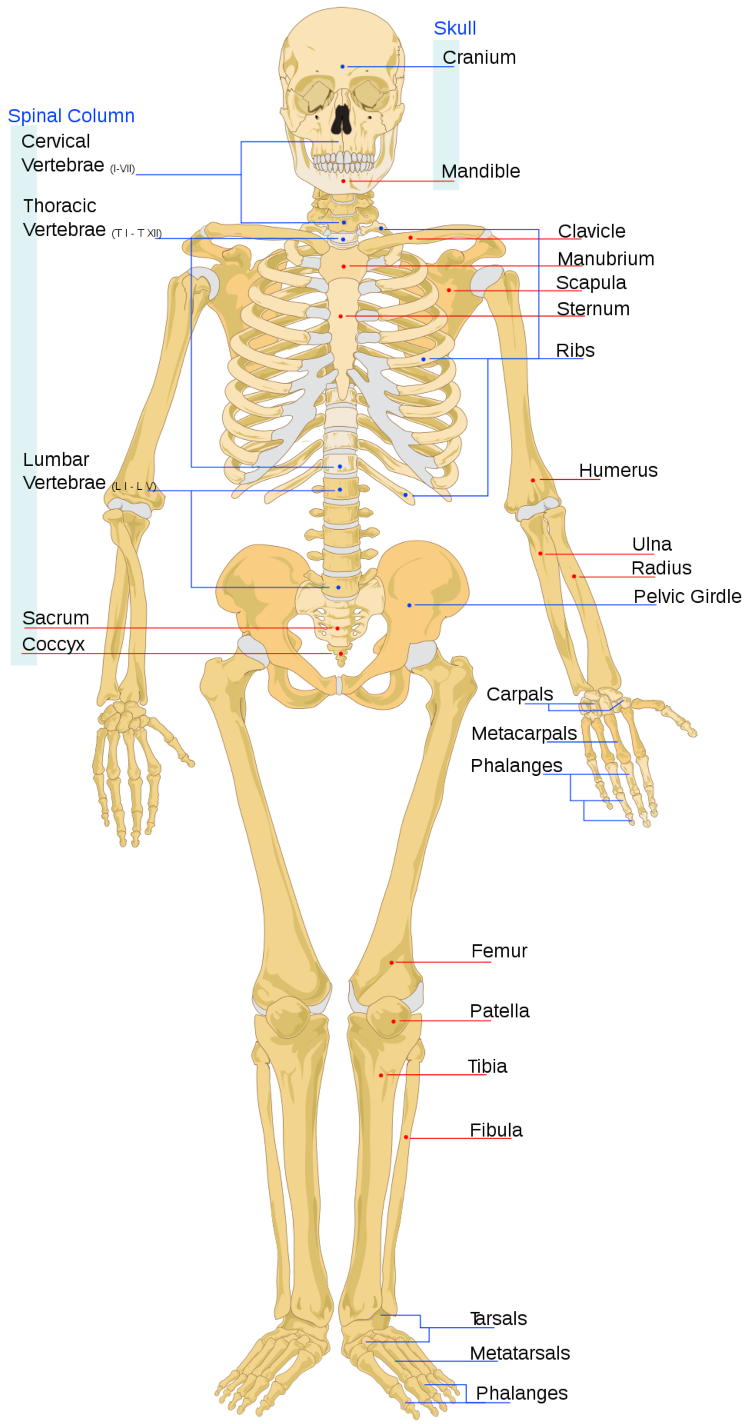


Figure 16.12: The skeletal system is made up of bones, cartilage, and ligaments. The skeletal system has many important functions in your body. (3)

- **Protection** The skeleton provides a framework that supports and protects the soft organs of the body. For example, the skull surrounds the brain to protect it from injury. The bones of the rib cage help protect the heart and lungs.
- **Movement** Bones work together with muscles as simple mechanical lever systems to move the body.
- **Making Blood Cells** Blood cells are made mostly inside certain types of bones.
- **Storage** Bones store calcium. They contain more calcium than any other organ does. Calcium is released by the bones when blood levels of calcium drop too low. The mineral phosphorus is also stored in bones.

Structure of Bones

Bones are *organs*. Recall that organs are made up of two or more types of tissues. Bones come in many different shapes and sizes, but they are all made of the same materials. The two main types of bone tissue are *compact bone* and *spongy bone*. **Compact bone** makes up the dense outer layer of bones. **Spongy bone** is lighter and less dense than compact bone, and is found toward the center of the bone. **T**he tough, shiny, white membrane that covers all surfaces of bones is called the *periosteum.*

Many bones also contain a soft connective tissue called **bone marrow**. There are two types of bone marrow: *red marrow* and *yellow marrow*. Red marrow makes red blood cells, platelets, and most of the white blood cells for the body (discussed in the *Diseases and the Body's Defenses* chapter). Yellow marrow makes white blood cells. The bones of newborn babies contain only red marrow. As children get older, their red marrow is replaced by yellow marrow. In adults, red marrow is found mostly in the bones of the skull, the ribs, and pelvic bones. Bone come in four main shapes. They can be *long, short, flat, or irregular*. Identifying a bone as long, short, flat, or irregular is based on the shape of the bone not the size of the bone. For example, both small and large bones can be classified as long bones. The small bones in your fingers and the largest bone in your body, the femur, are long bones. The structure of a long bone is shown in **Figure** 16.13.

How Bones Develop and Grow

Your skeleton began growing very early in your development. After only eight weeks of growth from a fertilized egg, your skeleton was formed by cartilage and other connective tissues. At this point your skeleton was quite bendy and flexible. After a few more weeks of growth, the cells that form hard bone began growing in the cartilage, and your skeleton began to harden. However, not all of the cartilage is replaced by bone. Cartilage remains in many places in your body including your joints, your rib cage, your ears, and the tip of your nose.

A baby is born with zones of cartilage in its bones that allow growth of the bones. These

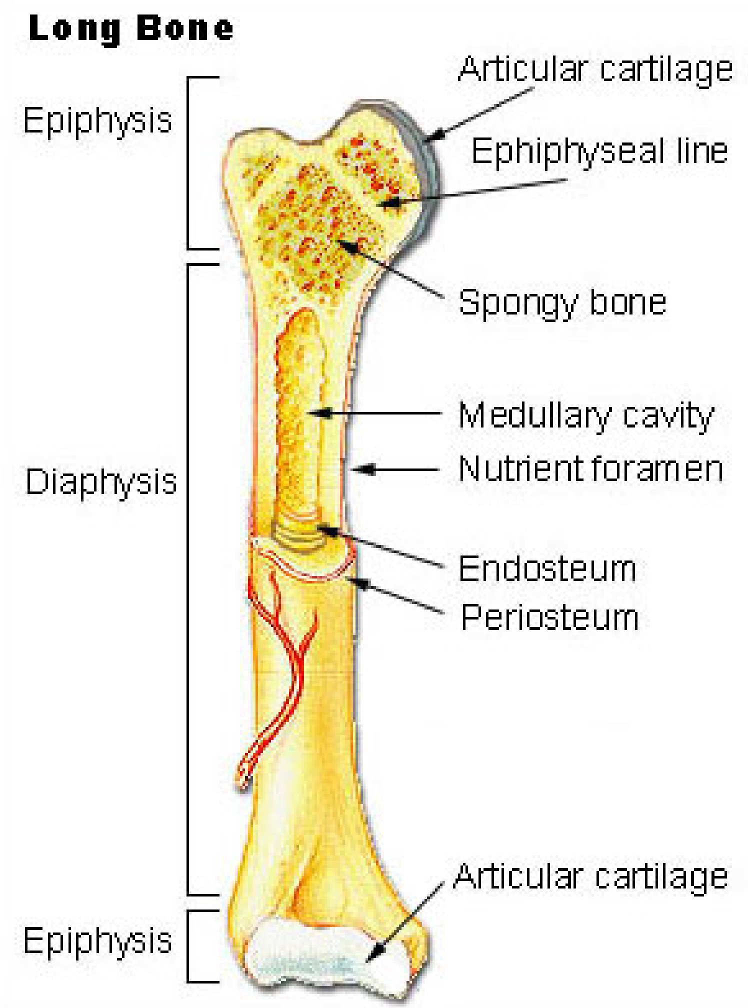


Figure 16.13: Bones are made up of different types of tissues. (12)

areas, called *growth plates*, allow the bones to grow longer as the child grows. When the child reaches an age of about 18 to 25 years, all of the cartilage in the growth plate is replaced by bone. This stops the bone from growing any longer.

Even though bones stop growing in length in early adulthood, they can continue to increase in thickness throughout life. This thickening can be in response to stress from increased muscle activity or to weight-bearing exercise.

Joints and How They Move

A **joint** is a point at which two or more bones meet. There are three types of joints in the body: *fixed, partly movable*, and *movable*. Fixed joints do not allow any bone movement. Many of the joints in your skull are fixed (**Figure** 16.14). Partly movable joints allow only a little movement. Your backbone has partly movable joints between the vertebrae (**Figure** 16.15). Movable joints allow movement and provide mechanical support for the body. Joints are a type of *lever*, which is a rigid object that is used to increase the mechanical force that can be applied to another object. Can openers and scissors are examples of levers. Joints reduce the amount of energy that is spent moving the body around. Just imagine how difficult it would be to walk about if you did not have knees!

Figure 16.14: The skull has fused joints. Fused joints do not allow any movement of the bones, which protects the brain from injury. (8)

Movable Joints

Movable joints are the most mobile joints of all. They are also the most common type of joint in your body. Your fingers, toes, hips, elbows, and knees all have movable joints. The surfaces of bones at movable joints are covered with a smooth layer of cartilage. The space

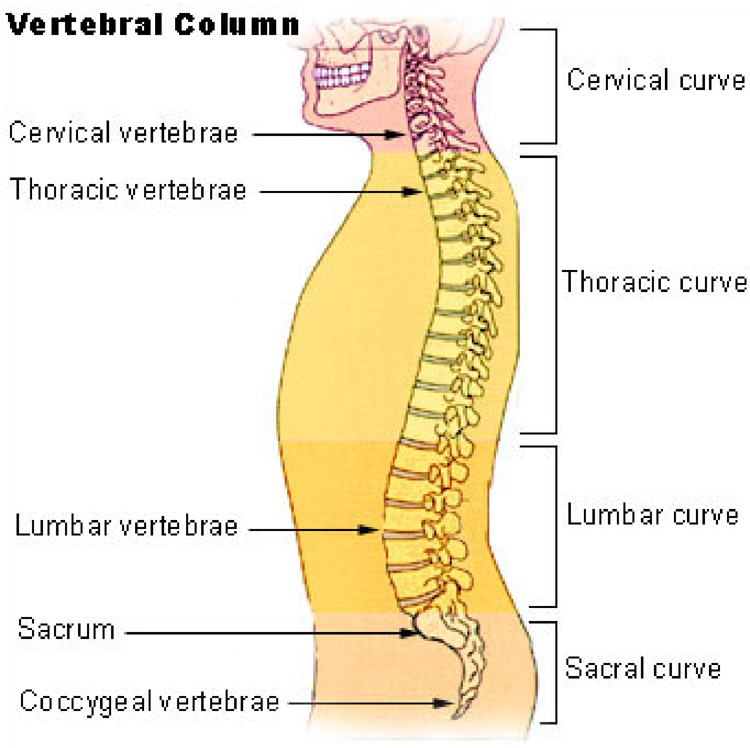


Figure 16.15: The joints between your vertebrae (b) are partially movable. (1)

between the bones in a movable joint is filled with a liquid called *synovial fluid*. Synovial fluid is a thick, stringy fluid that looks a lot like egg white. The fluid lubricates and cushions the bones when they move at the joint. There are many different types of movable joints, and many different examples. Four types of movable joints are shown in **Figures** 16.16, 16.17 and 16.18.

In a **ball and socket joint** the ball-shaped surface of one bone fits into the cup-like shape of another. Examples of a ball and socket joint include the hip, shown in **Figure** 16.16, and the shoulder.

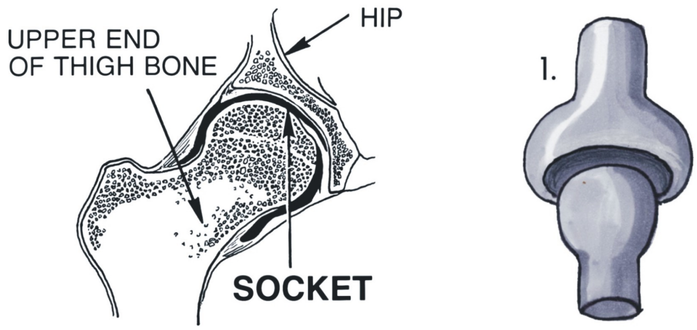


Figure 16.16: Your hip joint is a ball and socket joint. The "ball" end of one bone fits into the "socket" of another bone. These joints can move in many different directions. (13)

In a **hinge joint**, the ends of the bones are shaped in a way that allows motion only in two directions, forward and backward. Examples of hinge joints are the knees and elbows. A knee joint is shown in **Figure** 16.17.

The **pivot joint** is formed by a process that rotates within a ring, the ring being formed partly of bone, and partly of ligament. An example of a pivot joint is the joint between the radius and ulna that allows you to turn the palm of your hand up and down. A pivot joint is shown in **Figure** 16.18.

A **gliding joint** is a joint which allows only gliding movement. The gliding joint allows one bone to slide over the other. The gliding joint in your wrist allows you to flex your wrist. It also allows you to make very small side-to-side motions. There are also gliding joints in your ankles.

Keeping Bones and Joints Healthy

Just like a houseplant depends on you taking good care of it by watering it and giving it plant food, so too does your body depend on you! You can help keep your bones and skeletal system healthy by eating well and getting enough exercise. Weight-bearing exercises help keep bones strong. *Weight-bearing* exercises work against gravity; such activities include basketball, tennis, gymnastics, karate, running, and walking. When the body is exercised

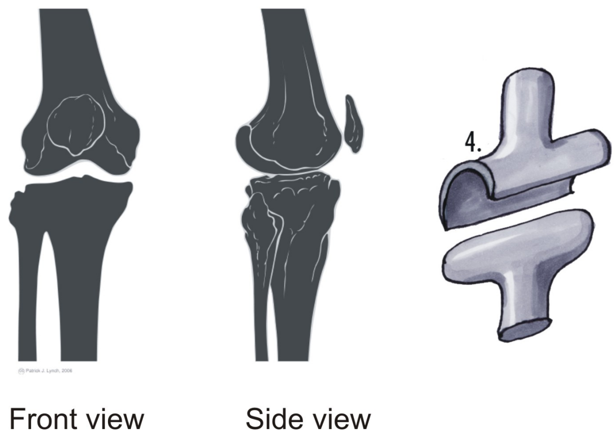


Figure 16.17: The knee joint is a hinge joint. Like a door hinge, a hinge joint allows backward and forward movement. (25)

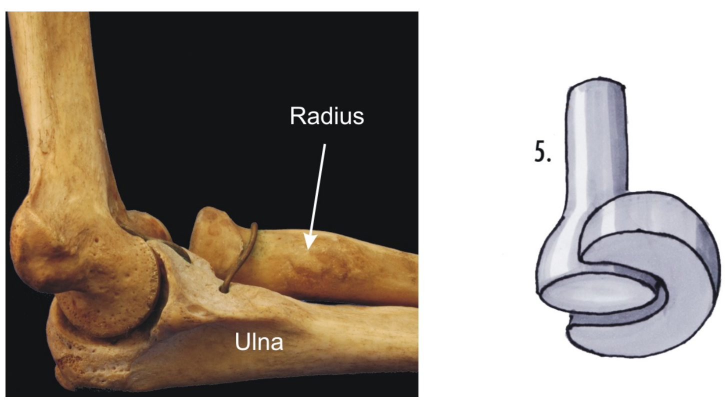


Figure 16.18: Pivot Joint The joint at which the radius and ulna meet is a pivot joint. Movement at this joint allows you to flip your palm over without moving your elbow joint. (28)

regularly by doing a weight-bearing activity, bones respond by adding more bone cells making the bones denser.

Eating Well

Did you know that what you eat now, as a teenager, can affect how healthy your skeletal system will be in 30, 40, and even 50 years from now? Calcium and vitamin D are two of the most important nutrients for a healthy skeletal system. Your bones need calcium to grow properly. If you do not get enough calcium in your diet as a teenager, your bones may become weak and break easily later in life. **Osteoporosis** is a disease in which bones become lighter and more porous than they should be. Light and porous bones are more likely to break, which can cause pain and prevent a person from walking. Being immobile can cause more bone loss which can make the disease worse.

Older women are most likely to develop osteoporosis because it is linked to the decrease in production of sex hormones. However, poor nutrition, especially diets that are low in calcium and vitamin D, increase the risk of osteoporosis in later life. Not doing regular weight-bearing exercises is also linked to having thinner, weaker bones. Two of the easiest ways to prevent osteoporosis is to eat a healthful diet that has the right amount of calcium and vitamin D, and to do weight-bearing exercise day.

Foods that are a good source of calcium include: milk, yogurt, and cheese. Non-dairy sources of calcium include Chinese cabbage, kale, and broccoli. Many fruit juices, fruit drinks, tofu, and cereals have calcium added into them. These foods are also an important source of calcium.

Teenagers are recommended to get 1300 mg of calcium every day. One cup of milk provides about 300 mg of calcium, which about 30% of your daily requirement for calcium. Other sources of calcium are shown in **Figure** 16.19.

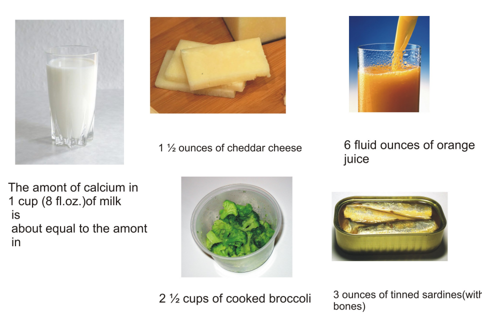


Figure 16.19: There are many different sources of calcium. Getting enough calcium in your daily diet is important for good bone health. How many ounces of cheddar cheese would provide your recommended daily intake of calcium? (2)

Your skin makes vitamin D when exposed to sunlight. The pigment melanin in the skin acts like a filter that can prevent the skin from making vitamin D. As a result, people with darker skin need more time in the sun than people with lighter skin to make the same amount of vitamin D.

Fish is naturally rich in vitamin D. Vitamin D is added to other foods including milk, soy milk and breakfast cereals. Teenagers are recommended to get 5 micrograms (200 IU/day) of vitamin D every day. A 3 ½ ounce portion of cooked salmon provides 360 IU of vitamin D.

Lack of vitamin D, or *deficiency*, can be caused by two different things: not enough sunlight exposure, and lack of vitamin D in the diet. Vitamin D deficiency results in problems with bone growth and hardening. This leads to bone softening diseases such as rickets in children and osteomalacia in adults. Osteomalacia is a bone disease in which the bones do not harden properly and they can break easily. Rickets is a type of osteomalacia. An X-ray of a child that has rickets is shown in **Figure** 16.20. Lack of vitamin D may also be related to osteoporosis.

Bone Fractures

Even though they are very strong, bones can fracture, or break. Fractures can happen at different places on a bone. They are usually due to excess bending stress on the bone. Bending stress is what causes a pencil to break if you were to bend it too far. Soon after a fracture, the body begins to repair the break. The area becomes swollen and sore. Within a few days bone cells travel to the break site and begin to rebuild the bone. It takes about 2 to 3 months before compact and spongy bone form at the break site.

Sometimes the body needs extra help in repairing a broken bone. In such a case a surgeon will piece a broken bone together with metal pins. Moving the broken pieces together will help keep the bone from moving, and give the body a chance to repair the break. A broken ulna has been repaired with pins in **Figure** 16.21.

Cartilage Injuries

Osteoarthritis is a condition in which the cartilage at the ends of the bones breaks down. The break down of the cartilage leads to pain and stiffness in the joint. Decreased movement of the joint because of the pain may lead to muscles that are attached to the joint to become weaker, and ligaments may become looser. Osteoarthritis is the most common form of arthritis. It has many causes, some of the more common causes include old age, sport injuries to the joint, bone fractures, and overweight and obesity. Total hip replacement is a common treatment for osteoarthritis.

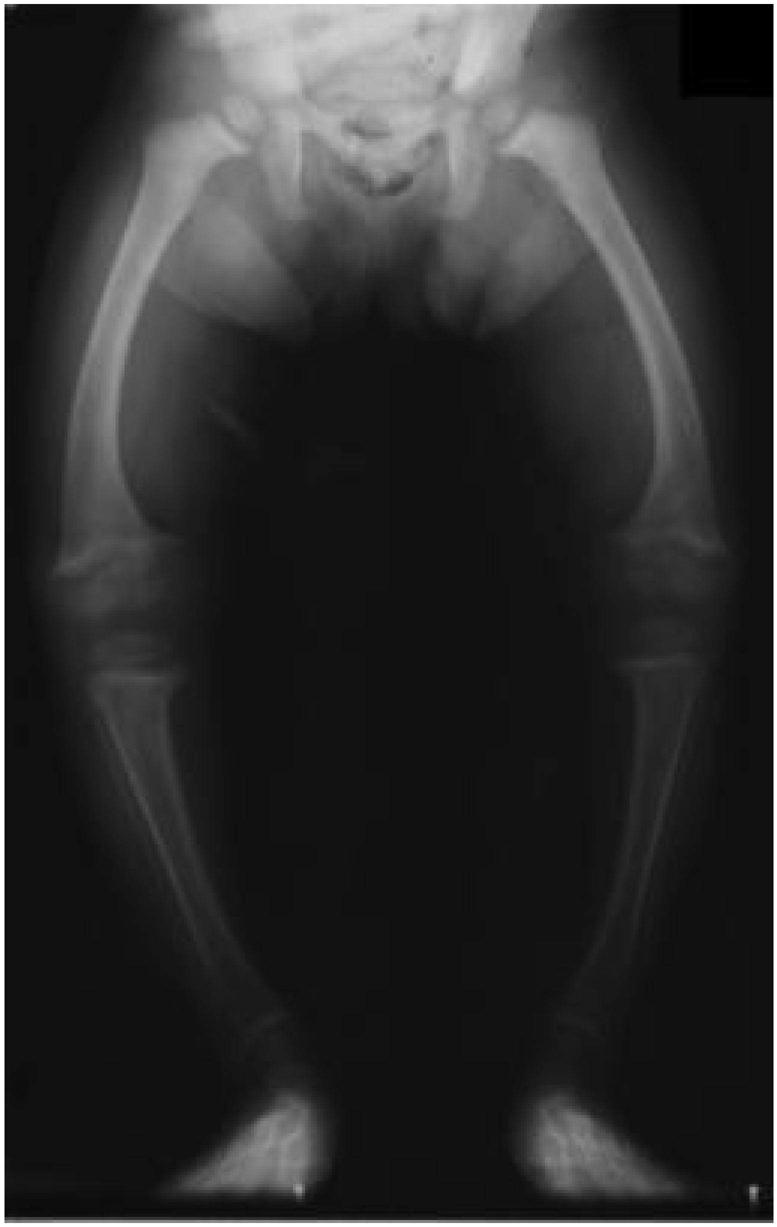


Figure 16.20: Rickets is a softening of the bones in children that may cause fractures and bending of the bones, especially of the legs. The bones have not hardened properly because of lack of vitamin D, and bend under the weight of the body. (7)

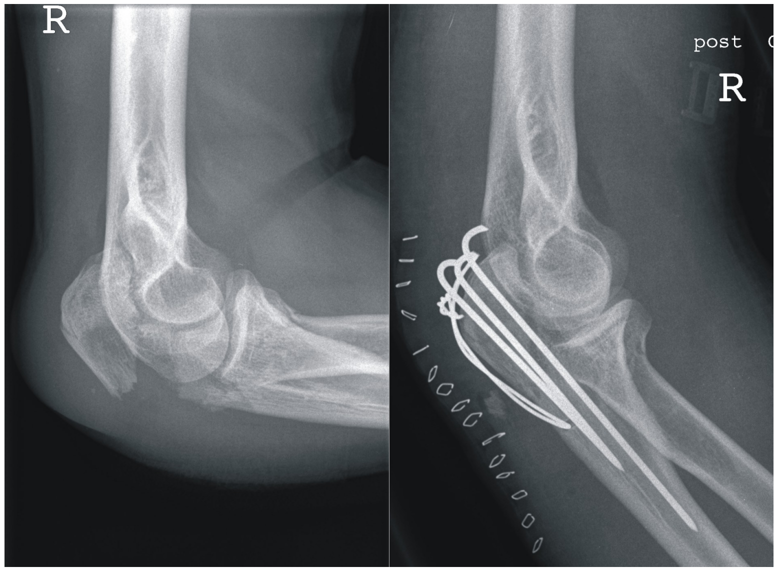


Figure 16.21: The upper part of the ulna, at the elbow is broken, as you can see in the X-ray at left. The x-ray at right was taken after a surgeon inserted pins into the joint to keep the two pieces of the ulna together. The two pieces of bone were reattached with metal pins. The line of staples is closing the skin wound. (21)

Ligament Injuries

Recall that a ligament is a short band of tough connective tissue that connects bones together to form a joint. Ligaments can get injured when a joint gets twisted or bends too far. The protein fibers that make up a ligament can get strained or torn, causing swelling and pain. Injuries to ligaments are called **sprains**. Ankle sprains are a common type of sprain. A small ligament in the knee, called the *anterior cruciform ligament* (ACL), is a common site of injury in athletes. Ligament injuries can take a long time to heal. Treatment of the injury includes rest and special exercises that are developed by a physical therapist.

Preventing Injuries

Preventing injuries to your bones and ligaments is easier and much less painful than treating an injury. Wearing the correct safety equipment when doing activities that require safety equipment can help prevent many common injuries. For example, wearing a bicycle helmet can help prevent a skull injury if you fall. Warming up and cooling down properly can help prevent ligament and muscle injuries. Torn ligaments and fractured bones are common sport injuries. Such injuries need to be treated by a doctor. Overuse injuries such as ligament strains and tears are common injuries for teenage athletes. Correct conditioning and enough rest can help prevent overuse injuries.

Stretching after activity may help prevent injuries. Regular stretching improves the flexibility of muscles and tendons. It also improves the range of mobility of your joints. Stretching can also improve your posture, and may help prevent some aches and pains caused by tight muscles.

Lesson Summary

- Bones, cartilage, and ligaments make up the skeletal system. The skeleton supports the body against the pull of gravity. The skeleton provides a framework that supports and protects the soft organs of the body. Bones work together with muscles as simple mechanical lever systems to move the body. Blood cells are made mostly inside the bone marrow. Bones store calcium.
- There are three types of joints in the body: *fixed, partly movable*, and *movable*. Fixed joints do not allow any bone movement. Partly movable joints allow only a little movement. Movable joints allow movement and provide mechanical support for the body. Joints are a type of lever, which is a rigid object that is used to increase the mechanical force that can be applied to another object. Joints reduce the amount of energy that is spent moving the body around. Calcium and vitamin D are two of the most important nutrients for a healthy skeletal system.
- Bones need calcium to grow properly. Vitamin D deficiency results in problems with bone growth and hardening. Osteoporosis is a disease in which bones become lighter and more porous than they should be. Light and porous bones are more likely to break than dense bones. Osteomalacia is a bone disease in which the bones do not harden properly and they can break easily. Osteoarthritis is a condition in which the cartilage at the ends of the bones breaks down. The break down of the cartilage leads to pain and stiffness in the joint. A sprain is an injury to a ligament. A fracture is a break or crack in a bone.

Review Questions

1. What are the organs of the skeletal system?
2. Name one tissue of the skeletal system.
3. List four functions of the skeletal system.
4. Name three types of movable joints.
5. "All joints in the body are movable." Do you agree with this statement? Explain why or why not. **(Intermediate**
6. How are the joints in your body similar to levers?
7. Why is calcium important for a healthy skeletal system?
8. The recommended daily amount of calcium for teenagers is 1300 mg. If a person gets only 1000 mg a day, what percentage of the recommended daily amount are they getting?

9. Name two things you can do to keep your skeletal system healthy.
10. What part of the skeletal system does osteoarthritis affect?
11. Why might a doctor need to insert pins into a broken bone?

Further Reading / Supplemental Links

- http://www.girlshealth.gov/bones
- [http://www.cdc.gov/nccdphp/dnpa/nutrition/nutrition_for_everyone/basics/calcium.htm http://www.cdc.gov/nccdphp/dnpa/nutrition/nutrition_for_everyone/basics/calcium.htm
- http://en.wikipedia.org/wiki

Vocabulary

ball and socket joint Joint structure in which the ball-shaped surface of one bone fits into the cuplike depression in another bone; examples include the shoulder and hip joints.

bone marrow Soft connective tissue found inside many bones; site of blood cell formation.

cartilage Smooth covering found at the end of bones; made of tough collagen protein fibers; creates smooth surfaces for the easy movement of bones against each other.

compact bone The dense, hard outer layer of a bone.

fracture Bone injury, often called a "break;" usually caused by excess bending stress on bone.

gliding joint Joint structure that allows one bone to slide over the other; examples includes the joints in the wrists and ankles.

hinge joint Joint structure in which the ends of bones are shaped in a way that allows motion in two directions only (forward and backward); examples include the knees and elbows.

joint Point at which two or more bones meet.

ligaments Fibrous tissue that connects bones to other bones; made of tough collagen fibers.

movable joint Most mobile type of joint; the most common type of joint in the body.

osteoarthritis A condition in which the cartilage at the ends of the bones breaks down.

osteoporosis Disease in which bones become lighter and more porous than normal.

periosteum Tough, shiny, white membrane that covers all surfaces of bones.

pivot joint Joint structure in which the end on one bone rotates within a ring-type structure which can be made partly of bone and partly of ligament; example includes the joint between the radius and ulna.

skeletal system Body system that is made up of bones, cartilage, and ligaments.

skeleton Sturdy scaffolding of bones and cartilage that is found inside vertebrates.

spongy bone Lighter and less dense than compact bone; found toward the center of the bone.

sprain A ligament injury; usually caused by the sudden overstretching of a joint which causes tearing.

Points to Consider

- How does your skeletal system interact with your muscular system?
- How might a broken bone affect the functioning of the muscular system?
- How do tendons differ from ligaments? How are they similar?

16.4 Lesson 16.4: The Muscular System

Lesson Objectives

- Identify the three muscle types in the body.
- Describe how skeletal muscles and bones work together to move the body.
- Describe how exercise affects the muscular system.
- Identify two types of injuries to the muscular system.

Check Your Understanding

- What is muscle tissue?
- What is the function of the muscular system?

Introduction

The **muscular system** is the body system that allows us to move. You depend on many muscles to keep you alive. Your heart, which is mostly muscle, pumps blood around your body. Muscles are always moving in your body. Certain muscle movements happen without you thinking about them, while you can control other muscle movements. In this lesson you will learn about the different types of muscles in your body and how your muscular system works with the other body systems to keep you alive and healthy. You will also learn how and why regular physical activity is important for good health.

Types of Muscles

Each muscle in the body is made up of cells called muscle fibers. **Muscle fibers** are long, thin cells that can do something that other cells cannot do—they are able to get shorter. Shortening of muscle fibers is called *contraction*. Nearly all movement in the body is the result of muscle contraction.

You are aware of and can control certain muscle movements. Other muscle movements you are not aware of and cannot control. Muscles that you can control are called *voluntary muscles*. Muscles that you cannot control are called *involuntary muscles*. There are three different types of muscles in the body (**Figure** 16.22): *skeletal, smooth*, and *cardiac* muscle. Skeletal muscle is voluntary muscle. Smooth muscle and cardiac muscle are involuntary muscles.

- **Skeletal muscle** is usually attached to the skeleton. Skeletal muscles move the body. They usually contract voluntarily, but they can contract involuntarily by reflexes. For example, you can choose to move your arms, but your arm would move automatically if you were to burn your finger on a stove top.
- **Smooth muscle** is found within the walls of organs and structures such as the esophagus, stomach, intestines, and blood vessels. Unlike skeletal muscle, smooth muscle is involuntary muscle which means it not under your control.
- **Cardiac muscle** is also an involuntary muscle but is a specialized kind of muscle found only in the heart.

Figure 16.22: There are three types of muscles in the body: cardiac, skeletal, and smooth. Everyone has the same three types of muscle tissue, no matter their age. (15)

Muscles, Bones, and Movement

Skeletal muscles are attached to the skeleton by tendons. A **tendon** is a tough band of connective tissue that connects a muscle to a bone. Tendons are similar to ligaments except that ligaments join bone to each other. Muscles move the body by contracting against the skeleton. When muscles contract they get shorter, when they relax, they get longer. By contracting and relaxing, muscles pull on bones and allow the body to move. Muscles work together in pairs. Each muscle in the pair works against the other to move bones at the joints of the body. The muscle that contracts to cause a joint to bend is called the **flexor**. The muscle that contracts to cause the joint to straighten is called the **extensor**.

For example, the biceps and triceps muscles work together to allow you to bend and straighten your elbow. Your biceps muscle, shown in **Figure** 16.23, contracts, and at the same time the triceps muscle relaxes. The contracting biceps pull on the radius bone and the elbow bends. To straighten the arm, the biceps muscle relaxes and the triceps on the opposite side of the elbow joint contracts. The biceps is the flexor and the triceps is the extensor of your elbow joint. In this way the joints of your body act like levers. This lever action of your joints reduces the amount of energy you have to spend to make large body movements.

Muscles and the Nervous System

Muscles are controlled by the nervous system (see the *Controlling the Body* chapter). Nerves send messages to the muscular system from the brain. Nerves also send messages to the brain from the muscles. Remember that smooth and cardiac muscles are involuntary muscles. This means that you cannot control the nerve messages that get sent to and from these muscles.

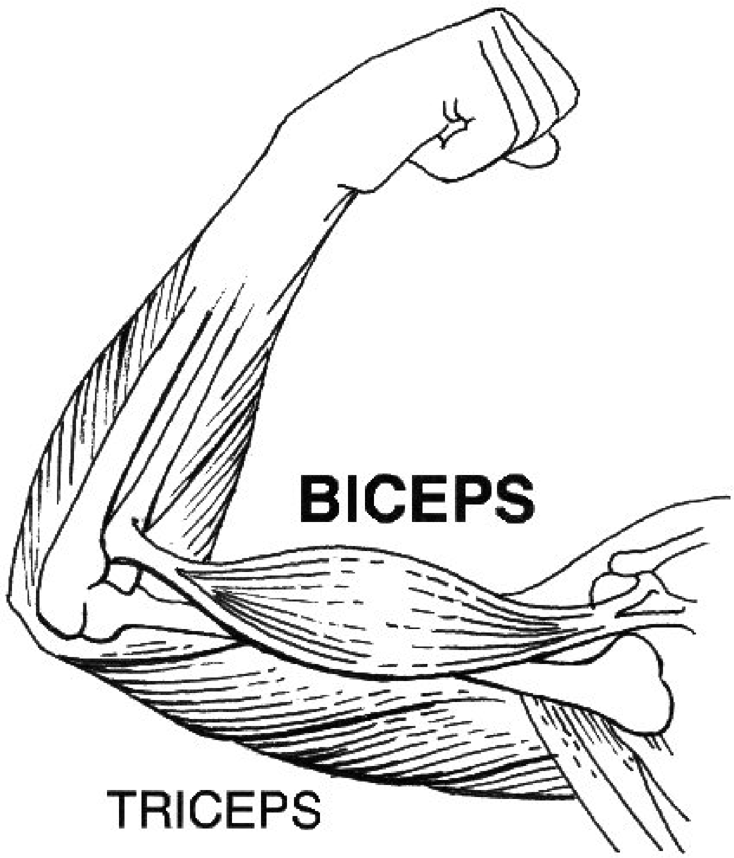


Figure 16.23: The biceps and triceps act against one another to bend and straighten the elbow joint. To bend the elbow, the biceps contract and the triceps relax. To straighten the elbow, the triceps contract and the biceps relax. (30)

For example, you cannot make your heart muscle stop beating. Likewise, you cannot make food stop moving through your intestines. You can however control the movement of your skeletal muscle. When you want to move your foot, electrical messages called *impulses* move along nerve cells from your brain to the muscles of your foot. At the point at which the nerve cell and muscle cells meet, the electrical message is converted to a chemical message. The muscle cells receive the chemical message, which causes tiny protein fibers inside the muscle cells to get shorter. The muscles contract, pulling on the bones, and your foot moves.

Contraction

A **muscle contraction** occurs when a **muscle fiber**, which is a muscle cell, generates tension through the movement of **actin** and **myosin**, two of the proteins involved in this process (see below).

Each muscle fiber contains cellular proteins and hundreds or thousands of myofibrils. Each **myofibril** is a long, cylindrical organelle that is made up of two types of protein filaments: actin and myosin. The actin filament is thin and threadlike, while the myosin filament is thicker. Myosin has a "head" region that uses energy from ATP to "walk" along the actin thin filament (**Figure** 16.24). The overlapping arrangement of actin and myosin filaments gives skeletal muscle its striated appearance. The actin and myosin filaments are organized into repeating units called sarcomeres, which can be seen in **Figure** 16.24. The sarcomeres stretch from one Z-line to the next, with thin actin filaments anchored to these Z lines. When each end of the myosin thick filament moves along the actin filament, the two actin filaments at opposite sides of the sacromere are drawn closer together and the sarcomere shortens, as shown in **Figure** 16.25. When a muscle fiber contracts, all sarcomeres contract at the same time, which pulls on the fiber ends.

The Sliding Filament Theory

The widely accepted theory of how muscles contract is called the **sliding-filament model** (also known as the **sliding filament theory**), which is shown in **Figure** 16.26. The presence of calcium ions (Ca^{2+}) allows for the interaction of actin and myosin. In the resting state, these two proteins are prevented from coming into contact. Two other proteins, troponin and tropomyosin, act as a barrier between the actin and myosin, preventing contact between them. When Ca^{2+} binds to the actin filament, the shape of the troponin-tropomyosin complex changes, allowing actin and myosin to contact with each other. Below is an outline of the sliding filament theory.

1. Once an action potential (see the *Controlling the Body* chapter) reaches a muscle fiber, the action potential spreads through the muscle fiber's network, activating specialized storage sites throughout the muscle, called the **sarcoplasmic reticulum**, to release

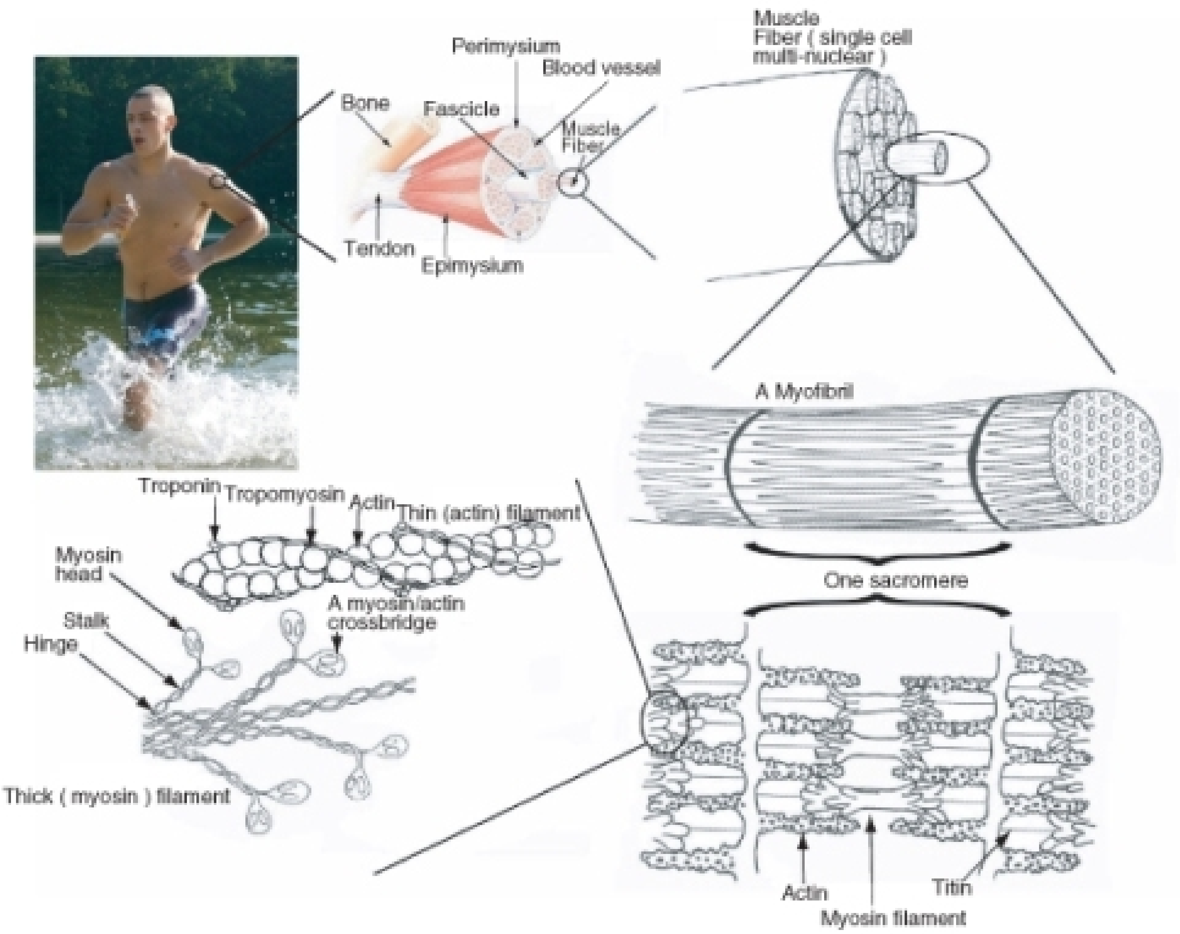


Figure 16.24: The components of muscle contraction. The **sacromere** is the functional unit of muscle contraction; it reaches from one Z-line to the next (labeled Z-disk in **Figure** 16.25). In a relaxed muscle, the actin (thin filament) and myosin (thick filament) overlap. In a muscle contraction, the filaments slide past each other, shortening the sacromere. This model of contraction is called the sliding filament model. (4)

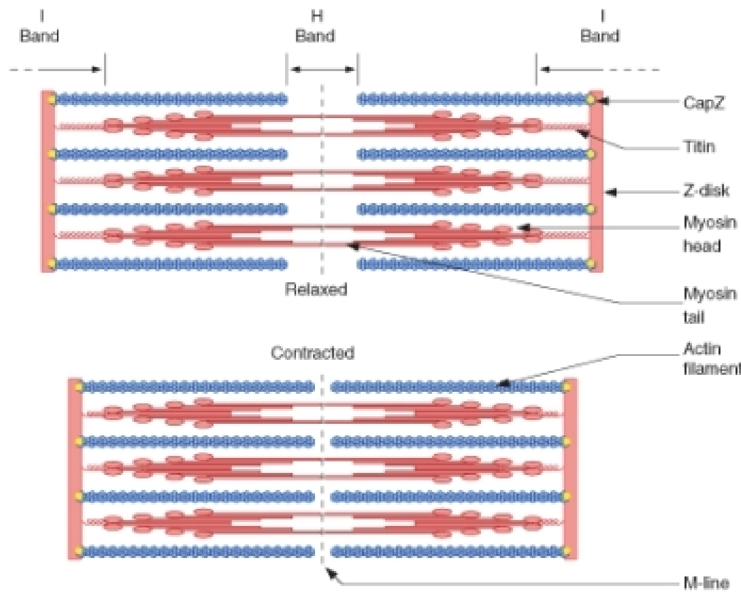


Figure 16.25: When each end of the myosin thick filament moves along the actin filament, the two actin filaments at opposite sides of the sacromere are drawn closer together and the sarcomere shortens. (10)

calcium ions (Ca^{++}). The sarcoplasmic reticulum is a special type of smooth endoplasmic reticulum found in smooth and skeletal muscle that contains large amounts of Ca^{++}.

2. The calcium ions bind to actin filaments of the myofibrils and activate the actin for attachment by the myosin heads filaments.
3. Activated myosin binds strongly to the actin filament. Upon strong binding, myosin rotates at the myosin-actin junction, which bends a region in the "neck" of the myosin "head," as shown in the **Figure** below.
4. Shortening of the muscle fiber occurs when the *bending neck* of the myosin region pulls the actin and myosin filaments across each other. Meanwhile, the myosin heads remain attached to the actin filament, as shown in **Figure** 16.26.
5. The binding of ATP allows the myosin heads to detach from actin. While detached, ATP breaks down to adenosine diphosphate and an inorganic phosphate (ADP + Pi). The breaking of the chemical bond in ATP gives energy to the myosin head, allowing it to bind to actin again.
6. Steps 4 and 5 repeat as long as ATP is available and Ca^{++} is present on the actin filament. The collective bending of numerous myosin heads (all in the same direction) moves the actin filament relative to the myosin filament which causes a shortening of the sacromere. Overall, this process results in muscle contraction. The sarcoplasmic reticulum actively pumps Ca^{++} back into itself. Muscle contraction stops when Ca^{++} is removed from the immediate environment of the myofilaments.

Figure 16.26: The process of actin and myosin sliding past one another is called crossbridge cycling, and it occurs in all muscle types. Myosin is a molecular motor that moves along the passive actin. Each thick myosin filament has little extensions or "heads," that "walk" along the thin actin filaments during contraction. In this way the thick filament slides over thin filament. The actin filaments transmit the force generated by myosin to the ends of the muscle, which causes the muscle to shorten. (22)

Muscles and Exercise

Your muscles are important for carrying out everyday activities. The ability of your body to carry out your daily activities without getting out of breath, sore, or overly tired is called **physical fitness**. Physical fitness also describes the body's ability to respond to emergencies and to avoid getting sick. A person can have a good level of physical fitness or a poor level of fitness. For example, a person who becomes breathless and tired after climbing a flight of stairs is not physically fit.

Physical exercise is any activity that maintains or improves physical fitness and overall health. Regular physical exercise is important in preventing lifestyle diseases such as heart disease, cardiovascular disease, Type 2 diabetes, and obesity.

Regular exercise improves the health of the muscular system. Muscles that are exercised are bigger and stronger than muscles that are not exercised. Exercise improves both muscular strength and muscular endurance. **Muscular strength** is the ability of a muscle to exert force during a contraction. **Muscular endurance** is the ability of a muscle to continue to contract over a long time without getting tired. Two types of exercises help improve the fitness of muscles, *anaerobic exercise* and *aerobic exercise.*

Exercises are grouped into three types depending on the effect they have on the body:

- **Aerobic exercises** such as cycling, walking, and running, increase muscular endurance.
- **Anaerobic exercises** such as weight training, or sprinting increase muscle strength.
- **Flexibility exercises** such as stretching, improve the range of motion of muscles and joints. Regular stretching helps avoid activity-related injuries.

Anaerobic Exercise and Muscular Strength

Anaerobic exercises cause muscles to get bigger and stronger. Anaerobic exercises use a resistance against which the muscle has to work to lift or push away. The resistance can be a weight or a person's own body weight, as shown in **Figure** 16.27. As a result of repeated muscle contractions, muscle fibers build up larger energy stores and the muscle tissue gets bigger. The larger a muscle is the greater the force it can apply to lift a weight or move a body joint. The muscles of weight lifters are large, and are therefore strong.

Figure 16.27: Anaerobic exercises involve the muscles working against resistance. In this case the resistance is the person's own body weight. (11)

Aerobic Exercise and Muscular Endurance

Aerobic exercises are exercises that cause your heart to beat faster and allow your muscles to use oxygen to contract. Aerobic exercise causes many different changes in skeletal muscle. Muscle energy stores are increased, the ability to use oxygen improves, and more capillaries surround the muscle fibers. These changes result in the ability of the muscle to avoid getting tired, and to use oxygen and food more efficiently. Aerobic exercise also helps improve cardiac muscle. It results in the heart being able to pump a larger volume of blood with each beat due to an increase in the size of the heart's ventricles. Examples of an aerobic exercise are shown in **Figure** 16.28.

Both aerobic and anaerobic exercises also improve the ability of the heart to pump blood around the body. Aerobic exercise causes the heart to get bigger, and anaerobic exercise causes the walls of the heart to get thicker. These changes allow the heart to push more blood throughout the body with every heartbeat.

Keeping Muscles Healthy

Being physically active for 60 minutes a day for at least five days a week improves your physical fitness. Being physically active can also help you to reduce your risk of developing

Figure 16.28: When done regularly, aerobic activities such as cycling, make the heart stronger. (26)

diseases such as cardiovascular disease, Type 2 diabetes, obesity, and certain forms of cancer. Being physically active does not mean you have to do boring workouts. You do not have to join a gym or be in a sports team to be physically active. Physical activities can include everyday things such as walking your dog, vacuuming or sweeping, cycling to school, skating, or climbing a flight of stairs (**Figure** 16.29).

Figure 16.29: Adding more physical activity in your daily life does not mean boring or expensive activities, it can be fun! Local and community pools often run swim classes that do not cost a lot, and are designed for beginners. (19)

Muscle Injuries

Sometimes muscles and tendons get injured when a person starts doing an activity before they have warmed up properly. A **warm up** is a slow increase in the intensity of a physical activity that prepares muscles for an activity. Warming up increases the blood flow to the muscles and increases the heart rate. Warmed-up muscles and tendons are less likely to get injured. For example, before running or playing soccer, a person might jog slowly to warm muscles and increase their heart rate. It is important that warm ups prepare the muscles that are to be used in the activity. Even elite athletes need to warm up, as shown in **Figure** 16.30. Some injuries are caused by overuse. An overuse injury happens if the muscle or joint is not rested enough between activities.

A **strain** is an injury to a muscle in which the muscle fibers tear because the muscle contracts too much or contracts before the muscle is warmed up. Strains are also known as *pulled muscles*. Overuse injuries often involve tendons. Overuse of tendons can cause tiny tears within the protein fibers of the tendon, which gradually weakens the tissue. These tiny tears lead to swelling, pain, and stiffness; a condition called **tendinitis**. Tendinitis can affect any tendon that is overused. Strains and tendinitis are usually treated with rest, cold compresses, and stretching exercises that a physical therapist designs for each patient.

Figure 16.30: Warming up before the game helps the players avoid injuries. Some warm-ups may include stretching exercises. Some researchers believe stretching before activities may help prevent injury. (18)

Proper rest and recovery are also as important to health as exercise is. If you do not get enough rest, your body will become injured and will not improve or react well to exercise. It is important to remember to allow enough recovery time for muscles and tendons to rest between exercise sessions. You can rest muscles by doing a different activity to what you normally do. For example, if you run, you can rest your running muscles and joints by swimming. This type of rest is called *active rest*.

Anabolic steroids are hormones that cause the body to build up more protein in its cells. Muscle cells, which contain a lot of protein, get bigger when exposed to anabolic steroids. Your body naturally makes small amounts of anabolic steroids. They help your body repair from injury, and help to build bones and muscles. Anabolic steroids are used as medicines to treat people that have illnesses that affect muscle and bone growth. However, some people who do not need anabolic steroid as medicine try to increase their muscle size by taking these steroids. When taken in this way, anabolic steroids can have long-term affects other body systems. They can damage the person's kidneys, heart, liver, and reproductive system. If taken by adolescents, anabolic steroids can cause bones to stop growing, resulting in stunted growth.

Lesson Summary

- The body has three types of muscle tissue: skeletal, cardiac, and smooth. Muscles move the body by contracting against the skeleton. Muscles are controlled by the nervous system.
- Nerves send messages to the muscular system from the brain. Nerves also send messages to the brain from the muscles. Regular exercise improves the health of the muscular system. Muscles that are exercised are bigger and stronger than muscles that are not exercised.
- Exercise improves both muscular strength and muscular endurance. Muscular strength is the ability of a muscle to exert force during a contraction. Muscular endurance is the ability of a muscle to continue to contract over a long time without getting tired. Identify two types of injuries to the muscular system.
- A strain is an injury to a muscle in which the muscle fibers tear because the muscle contracts too much or contracts before the muscle is warmed up. Tiny tears and swelling in a tendon results in tendinitis.

Review Questions

1. Name the three types of muscle tissue in the body.
2. Which of the three types of muscles in the body are voluntary?
3. What is another name for muscle cells?
4. Describe how skeletal muscles and bones work together to move the body.
5. What is a tendon?
6. How does aerobic exercise affect the heart?
7. How does aerobic exercise affect skeletal muscle?
8. How does anaerobic exercise affect skeletal muscle?
9. What is a muscle strain?

10. Why is warming up before exercise a good idea?
11. Why are taking anabolic steroids a dangerous way to try to build up muscles?

Further Reading / Supplemental Links

- http://www.hmc.psu.edu/healthinfo/m/musclestrain.htm
- http://www.cdc.gov/nccdphp/dnpa/physical/everyone/index.htm
- http://en.wiki.org

Vocabulary

aerobic exercises Types of exercises that cause the heart to beat faster and allow the muscles to obtain energy to contract by using oxygen.

anabolic steroids Hormones that cause the body to build up more protein in its cells.

anaerobic exercise Types of exercises that involve short bursts of high-intensity activity; forces the muscles to obtain energy to contract without using oxygen.

cardiac muscle An involuntary and specialized kind of muscle found only in the heart.

contraction Shortening of muscle fibers.

extensor The muscle that contracts to cause a joint to straighten.

flexibility exercises Stretching exercises that improve the range of motion of muscles and joints.

flexor The muscle that contracts to cause a joint to bend.

involuntary muscle A muscle that a person cannot consciously control; cardiac muscle and smooth muscle are involuntary.

muscle cells Long, thin cells that can contract; also called muscle fibers.

muscle fibers Long, thin cells that can contract; also called muscle cells.

muscular endurance The ability of a muscle to continue to contract over a long time without getting tired.

muscular strength The ability of a muscle to exert force during a contraction.

muscular system The body system that allows movement.

physical exercise Any activity that maintains or improves physical fitness and overall health.

physical fitness The ability of your body to carry out your daily activities without getting out of breath, sore, or overly tired.

skeletal muscle The muscle that is usually attached to the skeleton.

smooth muscle Involuntary muscle found within the walls of organs and structures such as the esophagus, stomach, intestines, and blood vessels.

strain An injury to a muscle in which the muscle fibers tear because the muscle contracts too much or contracts before the muscle is warmed up.

tendinitis A condition in which tiny tears form in the protein fibers of the tendon and gradually weaken the tissue.

tendon A tough band of connective tissue that connects a muscle to a bone.

voluntary muscle A muscle that a person can consciously control; skeletal muscle is voluntary.

warm-up A slow increase in the intensity of a physical activity that prepares muscles for an activity.

Points to Consider

- How does your muscular system depend on your digestive system?
- How does what you choose to eat affect your muscular system and your skeletal system?

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Chapter 17

Food and the Digestive System

17.1 Lesson 17.1: Food and Nutrients

Lesson Objectives

- Explain why the body needs food.
- Identify the roles of carbohydrates, proteins, and lipids.
- Give examples of vitamins and minerals, and state their functions.
- Explain why water is a nutrient.

Check Your Understanding

- What are the four types of organic compounds?
- What do all cells need in order to function?
- What are muscles made of?

Introduction

Did you ever hear the old saying "An apple a day keeps the doctor away"? Do apples really prevent you from getting sick? Probably not, but eating apples and other fresh fruits can help keep you healthy. The girl shown in **Figure** 17.1 is eating fresh vegetables as part of a healthy meal. Why do you need foods like these for good health? What roles does food have in the body?

Figure 17.1: This girl is eating a salad of tomatoes and leafy green vegetables. Fresh vegetables such as these are excellent food choices for good health. (14)

Why We Need Food

Your body needs food for three reasons:

- Food gives your body energy. You need energy for everything you do.
- Food provides building materials for your body. Your body needs building materials so it can grow and repair itself.
- Food contains substances that help control body processes. Your body processes must be kept in balance for good health. For example, your body needs the right balance of water and salts.

For all these reasons, you must have a steady supply of nutrients. **Nutrients** are chemicals in food that your body needs. There are six types of nutrients: carbohydrates, proteins, lipids, vitamins, minerals, and water. Carbohydrates, proteins, and lipids give your body energy. Proteins provide building materials. Proteins, vitamins, and minerals help control body processes.

Nutrients that Provide Energy

Molecules of carbohydrates, proteins, and lipids contain energy. When your body digests food, it breaks down the molecules of these nutrients. This releases the energy so your body can use it. The energy in food is measured in units called **Calories.**

Carbohydrates

Carbohydrates are nutrients that include sugars, starches, and fiber. How many grams of carbohydrates you need each day are shown in **Figure** 17.2. It also shows some foods that are good sources of carbohydrates.

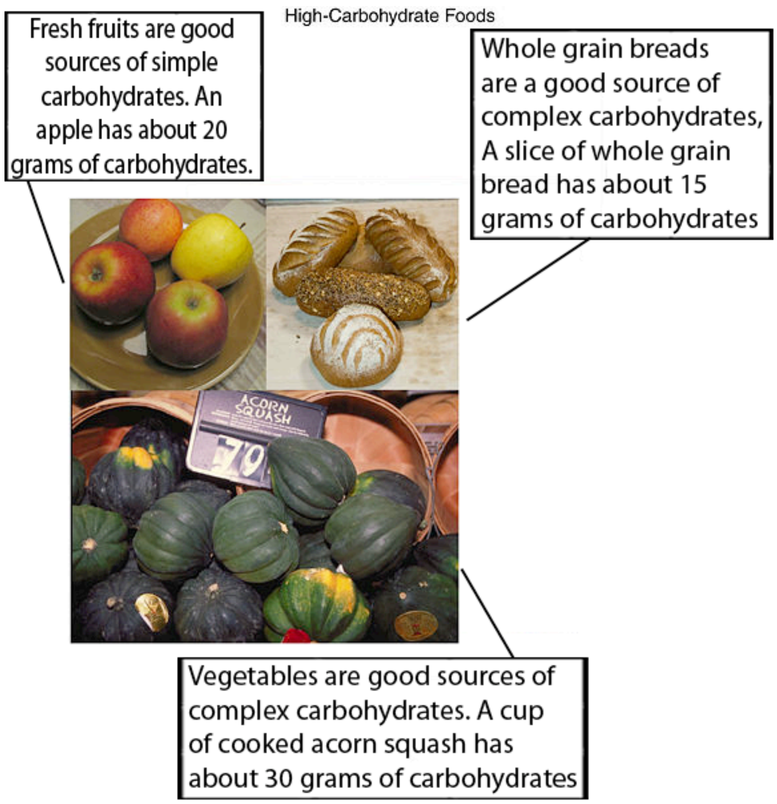

Figure 17.2: Up to the age of 13 years, you need about 130 grams of carbohydrates a day. Most of the carbohydrates should be complex. They are broken down by the body more slowly than simple carbohydrates. Therefore, they provide energy longer and more steadily. What other foods do you think are good sources of complex carbohydrates? (6)

Sugars are small, simple carbohydrates that are found in foods such as fruits and milk. The sugar found in fruits is called fructose. The sugar found in milk is called lactose. These sugars are broken down by the body to form glucose, the simplest sugar of all. Glucose is used by cells for energy. Remember the discussion of cellular respiration in the *Cell Functions* chapter? Cellular respiration turns glucose into the usable form of chemical energy, ATP. One gram of sugar provides your body with four Calories of energy.

Some people cannot digest lactose, the sugar in milk. This condition is called lactose intolerance. If people with this condition drink milk, they may have cramping, bloating, and gas. To avoid these symptoms, they should not drink milk, or else they should drink special, lactose-free milk.

Starches are large, complex carbohydrates. They are found in foods such as vegetables and grains. Starches are broken down by the body into sugars that provide energy. Like sugar, one gram of starch provides your body with four Calories of energy.

Fiber is another type of large, complex carbohydrate. Unlike sugars and starches, fiber does not provide energy. However, it has other important roles in the body. There are two types of fiber found in food: soluble fiber and insoluble fiber. Each type has a different role.

- Soluble fiber dissolves in water. It helps keep sugar and fat at normal levels in the blood.
- Insoluble fiber does not dissolve in water. As it moves through the large intestine, it absorbs water. This helps keep food waste moist so it can pass easily out of the body.

Eating foods high in fiber helps fill you up without providing too many Calories. Most fruits and vegetables are high in fiber. Some examples are shown in **Figure** 17.3.

Proteins

Proteins are nutrients made up of smaller molecules called amino acids. As discussed in the *Introduction to Living Things* chapter, the amino acids are arranged like "beads on a string." These amino acid chains then fold up into a three-dimensional molecule. Proteins have several important roles in the body. For example, proteins:

- Make up muscles.
- Help control body processes.
- Help the body fight off bacteria and other "foreign invaders."
- Carry substances in the blood.

If you eat more proteins than you need for these purposes, the extra proteins are used for energy. One gram of protein provides four Calories of energy. This is the same amount as one gram of sugar or starch. How many grams of proteins you need each day are shown in **Figure** 17.4. It also shows some foods that are good sources of proteins.

There are many different amino acids, the building blocks of proteins, but your body needs only 20 of them. Your body can make ten of these amino acids from simpler substances. The other ten amino acids must come from the proteins in foods. These ten are called essential amino acids. Only animal foods, such as milk and meat, contain all ten essential amino acids in a single food. Plant foods are missing one or more essential amino acids. However, by eating a combination of plant foods, such as beans and rice, you can get all ten essential amino acids.

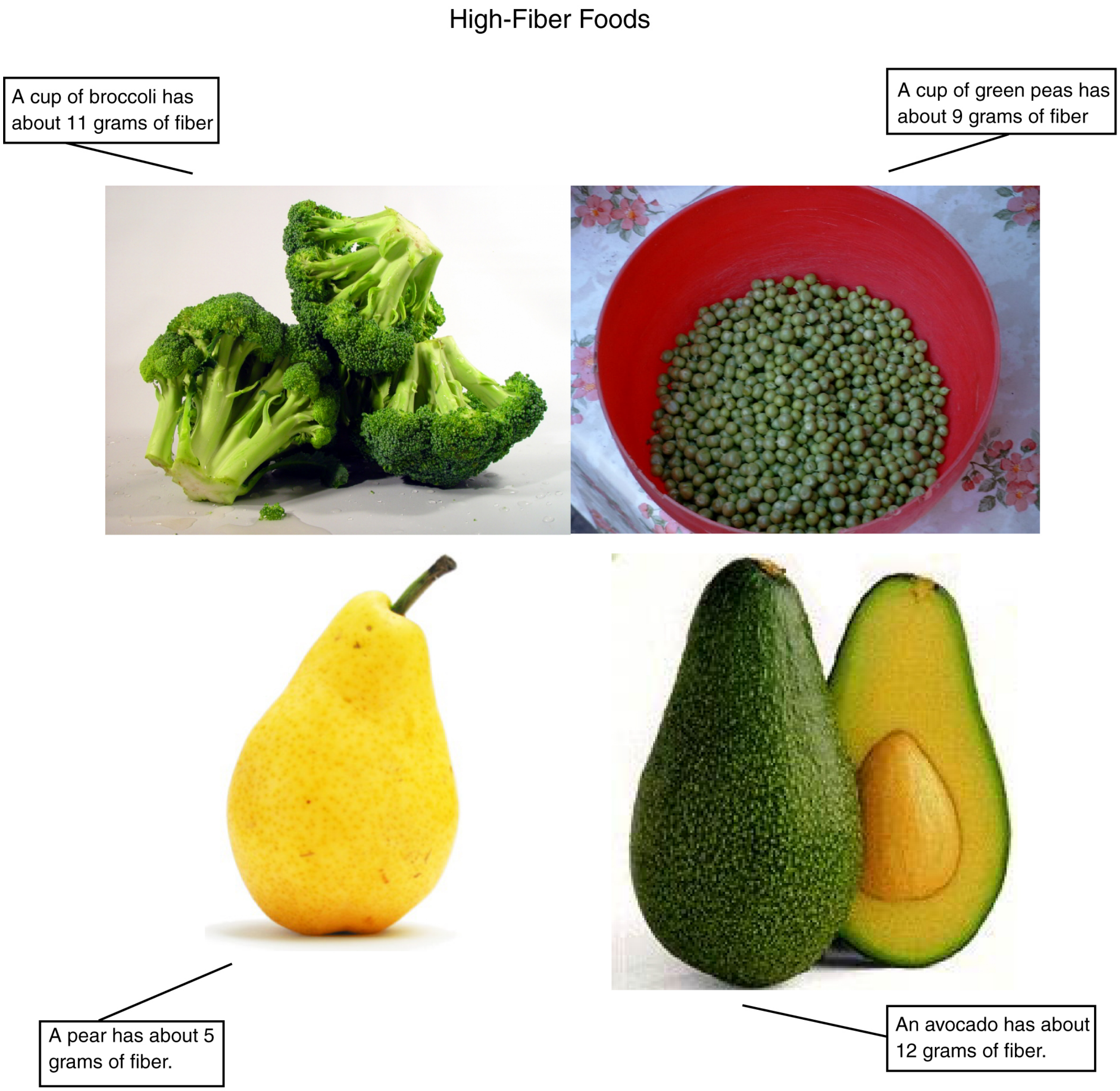

Figure 17.3: Between the ages of 9 and 13 years, girls need about 26 grams of fiber a day, and boys need about 31 grams of fiber a day. Do you know other foods that are high in fiber? (10)

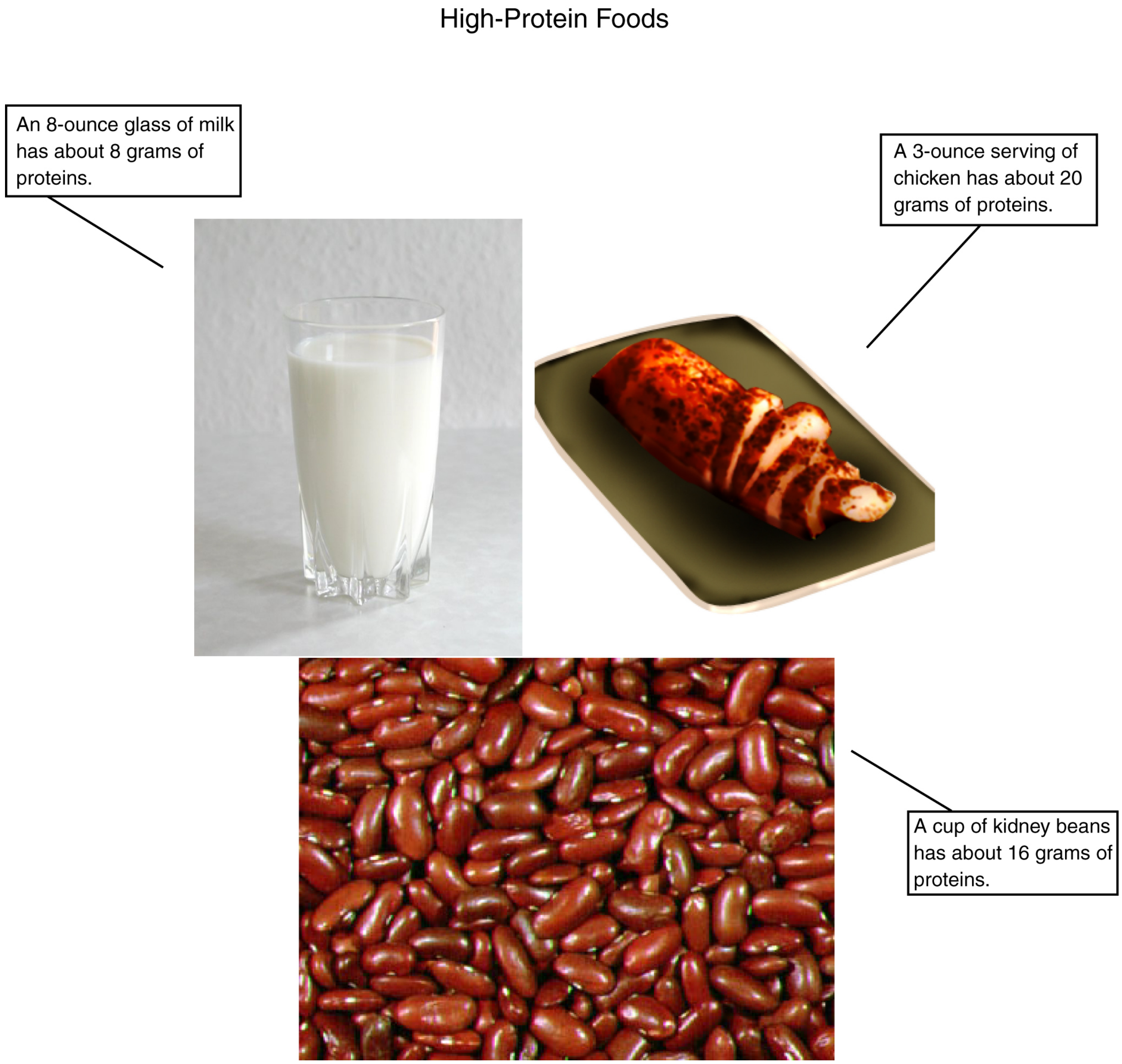

Figure 17.4: Between the ages of 9 and 13 years, you need about 34 grams of proteins a day. What other foods do you think are good sources of proteins? (5)

Lipids

Lipids are nutrients such as fats that store energy. The heart and skeletal muscles rely mainly on lipids for energy. One gram of lipids provides nine Calories of energy. This is more than twice the amount provided by carbohydrates or proteins. Lipids have several other roles in the body. For example, lipids:

- Protect nerves.
- Help control blood pressure.
- Help blood to clot.
- Make up the membranes that surround cells.

Fats are one type of lipid. Fat is the main form in which the body stores energy. Stored fat gives your body an energy reserve. It's like having money in a savings account. It's there in case you need it. Stored fat also cushions and protects internal organs. In addition, it insulates the body. It helps keep you warm in cold weather.

Fats and other lipids are necessary for life. However, they can be harmful if you eat too much of them, or the wrong type of fats. Fats can build up in the blood and damage blood vessels. This increases the risk of heart disease. There are two types of lipids: saturated lipids and unsaturated lipids.

- Saturated lipids are harmful even in very small amounts. They should be avoided as much as possible. Saturated fats are found mainly in animal foods, such as meats, whole milk, and eggs. Saturated fats increase cholesterol levels in the blood. Cholesterol is a fatty substance that is found naturally in the body. Too much cholesterol in the blood can lead to heart disease. It is best to limit the amount of saturated fats in your diet.
- Unsaturated lipids are found mainly in plant foods, such as vegetable oil, olive oil, and nuts. Unsaturated lipids are also found in fish such as salmon. Unsaturated lipids are needed in small amounts for good health because your body cannot make them. Most lipids and fats in your diet should be unsaturated.

Another type of lipid is called **trans fat**. Trans fat is manufactured and added to certain foods to keep them fresher for longer. Foods that contain trans fats include cakes, cookies, fried foods, and margarine. Eating foods that contain trans fats increases the risk of heart disease. You should do your best to eat fewer foods that contain it. Beginning in 2010, California will ban trans fats from restaurant products, and, beginning in 2011, from all retail baked goods.

Vitamins and Minerals

Vitamins and minerals are also nutrients. They do not provide energy. However, they are needed for good health.

Vitamins

Vitamins are substances that the body needs in small amounts to function properly. Humans need 13 different vitamins. Some of them are listed in **Table** (17.1) . The table also shows how much of each vitamin you need each day. Vitamins have many roles in the body. For example, Vitamin A helps maintain good vision. Vitamin B_9 helps form red blood cells. Vitamin K is needed for blood to clot when you have a cut or other wound.

Table 17.1: **Vitamins Needed For Good Health**

Vitamin	One Reason You Need It	Some Foods that Have It	How Much of It You Need Each Day (at ages 9–13 years)
Vitamin A	Needed for good vision	Carrots, spinach, milk, eggs	600 g (1 g = 1 x 10^{-6} g)
Vitamin B_1	Needed for healthy nerves	Whole wheat, peas, meat, beans, fish, peanuts	0.9 mg (1 mg = 1 x 10^{-3} g)
Vitamin B_3	Needed for healthy skin and nerves	Beets, liver, pork, turkey, fish, peanuts	12 mg
Vitamin B_9	Needed to make red blood cells	Liver, peas, dried beans, green leafy vegetables	300 g
Vitamin B_{12}	Needed for healthy nerves	Meat, liver, milk, shellfish, eggs	1.8 g
Vitamin C	Needed for growth and repair of tissues	Oranges, grapefruits, red peppers, broccoli	45 mg
Vitamin D	Needed for healthy bones and teeth	Milk, salmon, tuna, eggs	5 g
Vitamin K	Needed for blood to clot	Spinach, Brussels sprouts, milk, eggs	60 g

Some vitamins are produced in the body. For example, vitamin D is made in the skin when it is exposed to sunlight. Vitamins B_{12} and K are produced by bacteria that normally live inside the body. Most other vitamins must come from foods. Foods that are good sources of vitamins are listed in **Table 1**. They include whole grains, vegetables, fruits, and milk.

Not getting enough vitamins can cause health problems. For example, too little vitamin C causes a disease called scurvy. People with scurvy have bleeding gums, nosebleeds, and other symptoms. Getting too much of some vitamins can also cause health problems. The vitamins to watch out for are vitamins A, D, E, and K. These vitamins are stored by the body, so they can build up to high levels. Very high levels of these vitamins can even cause death, although this is very rare.

Minerals

Minerals are chemical elements that are needed for body processes. Minerals that you need in relatively large amounts are listed in **Table** (17.2). Minerals that you need in smaller amounts include iodine, iron, and zinc. Minerals have many important roles in the body. For example, calcium and phosphorus are needed for strong bones and teeth. Potassium and sodium are needed for muscles and nerves to work normally.

Table 17.2: **Minerals Needed For Good Health.**

Mineral	One Reason You Need It	Some Foods that Have It	How Much of It You Need Each Day (at ages 9–13 years)
Calcium	Needed for strong bones and teeth	Milk, soy milk, green leafy vegetables	1,300 mg
Chloride	Needed for proper balance of water and salts in body	Table salt, most packaged foods	2.3 g
Magnesium	Needed for strong bones	Whole grains, green leafy vegetables, nuts	240 mg
Phosphorus	Needed for strong bones and teeth	Meat, poultry, whole grains\	1,250 mg
Potassium	Needed for muscles and nerves to work normally	Meats, grains, bananas, orange juice	4.5 g
Sodium	Needed for muscles and nerves to work normally	Table salt, most packaged foods	1.5 g

Your body cannot produce any of the minerals that it needs. Instead, you must get minerals from the foods you eat. Good sources of minerals are listed in **Table** (17.2). They include milk, green leafy vegetables, and whole grains.

Not getting enough minerals can cause health problems. For example, too little calcium may cause osteoporosis. This is a disease in which bones become soft and break easily. Getting too much of some minerals can also cause health problems. Many people get too much sodium. Sodium is added to most packaged foods. People often add more sodium to their food by using table salt (sodium chloride). Too much sodium causes high blood pressure in some people.

Water

Did you know that water is also a nutrient? By weight, your cells are about two-thirds water, so you cannot live without it. In fact, you can survive for only a few days without water. You lose water in each breath you exhale. You also lose water in sweat and urine. If you do not take in enough water to replace the water that you lose, you may develop dehydration. Symptoms of dehydration include dry mouth, headaches, and feeling dizzy. Dehydration can be very serious. Severe dehydration can even cause death.

When you exercise, especially on a hot day, you lose more water in sweat than you usually do. You need to drink extra water before, during, and after exercise. The children in **Figure** 17.5 are drinking water while playing outside on a warm day. They need to drink water to avoid dehydration.

Figure 17.5: When you are active outside on a warm day, it's important to drink plenty of water. You need to replace the water you lose in sweat. (8)

Getting too much water can also be dangerous. Excessive water may cause a condition called hyponatremia. In this condition, water collects in the brain and causes it to swell.

Hyponatremia can cause death. It requires emergency medical care.

Lesson Summary

- The body needs food for energy, building materials, and substances that help control body processes.
- Carbohydrates, proteins, and lipids provide energy and have other important roles in the body.
- Vitamins and minerals do not provide energy but are needed in small amounts for the body to function properly.
- The body must have water to survive.

Review Questions

1. What are three reasons that your body needs food?
2. Which nutrients can be used for energy?
3. Name two types of fiber and state the role of each type of fiber in the body.
4. What are some foods that are good sources of vitamin C?
5. What are two minerals that are needed for strong bones and teeth?
6. List some of the functions of proteins in the body. Based on your list, predict health problems people might have if they do not get enough proteins in foods.
7. Your body needs 20 different amino acids. Why do you need to get only ten of these amino acids from food? Name foods you can eat to get these ten amino acids.
8. Compare and contrast saturated and unsaturated lipids.
9. Identify three vitamins that are produced in the body. How are they produced?
10. Why do you need to drink extra water when you exercise on a hot day? What might happen if you did not drink extra water?

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- http://www.textbookofbacteriology.net/normalflora.html
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Vocabulary

calories Units used to measure the energy in food.

carbohydrates Nutrients that include sugars, starches, and fiber; give your body energy; organic compound.

essential amino acids Amino acids that must come from the proteins in foods; you cannot make these amino acids.

insoluble fiber Large, complex carbohydrate; does not dissolve in water; moves through the large intestine and helps keep food waste moist so it can pass easily out of the body.

lipids Nutrients such as fats that are rich in energy; organic compound.

minerals Chemical elements that are needed for body processes.

nutrients Chemicals in food that your body needs.

proteins Nutrients made up of smaller molecules called amino acids; give your body energy; help control body processes; organic compound.

saturated fats Found mainly in animal foods, such as meats, whole milk, and eggs; increase cholesterol levels in the blood.

soluble fiber Large, complex carbohydrate; dissolves in water; helps keep sugar and fat at normal levels in the blood.

starch Large, complex carbohydrate; found in foods such as vegetables and grains; broken down by the body into sugars that provide energy.

trans fat Manufactured and added to certain foods to keep them fresher for longer. Foods that contain trans fats include cakes, cookies, fried foods, and margarine.

unsaturated lipids Found mainly in plant foods, such as vegetable oil, olive oil, and nuts; also found in fish such as salmon.

vitamins Substances that the body needs in small amounts to function properly.

Points to Consider

- Think about how you can be sure you are getting enough nutrients?
- Do you think knowing the nutrients in the foods you eat are important?
- Do you have to keep track of all the nutrients you eat, or is there an easier way to choose foods that provide the nutrients you need?

17.2 Lesson 17.2: Choosing Healthy Foods

Lesson Objectives

- State how to use MyPyramid to get the proper balance of nutrients.
- Describe how to read food labels to choose foods wisely.
- Explain how to balance food with exercise.

Check Your Understanding

- What is a nutrient?
- Why do you need extra energy when you exercise?

Introduction

Foods such as whole grain breads, fresh fruits, and fish provide nutrients you need for good health. However, various foods provide different nutrients. You also need different amounts of each nutrient. How can you choose the right mix of foods to get the proper balance of nutrients? Two tools can help you choose foods wisely: MyPyramid and food labels.

MyPyramid

MyPyramid is a diagram that shows how much you should eat each day of foods from six different food groups. It recommends the amount of nutrients you need based on your age, your sex, and your levels of activity. MyPyramid is shown in **Figure** 17.6. The six food groups in MyPyramid are:

- Grains—such as bread, rice, pasta, and cereal.
- Vegetables—such as spinach, broccoli, carrots, and sweet potatoes.
- Fruits—such as oranges, apples, bananas, and strawberries.
- Oils—such as vegetable oil, canola oil, olive oil, and peanut oil.
- Milk—such as milk, yogurt, cottage cheese, and other cheeses.

- Meat and beans—such as chicken, fish, soybeans, and kidney beans.

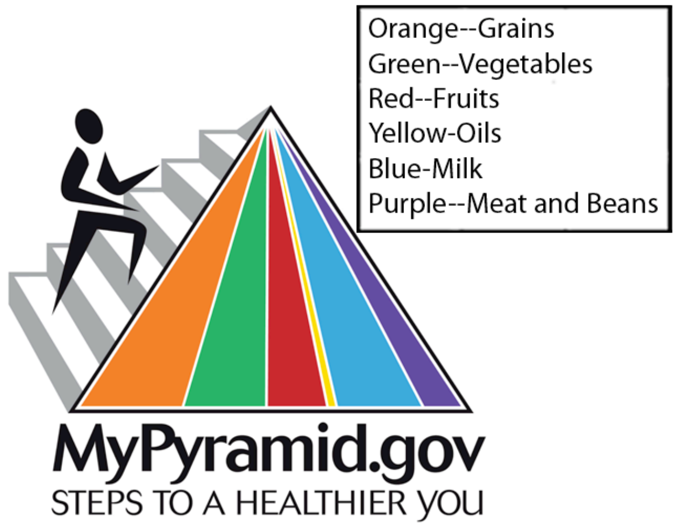


Figure 17.6: MyPyramid can help you choose foods wisely for good health. Each colored band represents a different food group. The key shows which food group each color represents. Which colored band of MyPyramid is widest? Which food group does it represent? (3)

Using MyPyramid

In MyPyramid, each food group is represented by a band of a different color. For example, grains are represented by an orange band, and vegetables are represented by a green band. The wider the band, the more foods you should choose from that food group each day. The orange band in MyPyramid is the widest band. This means that you should choose more foods from the grain group than from any other single food group. The green, blue, and red bands are also relatively wide. Therefore, you should choose plenty of foods from the vegetable, milk, and fruit groups, as well. You should choose the fewest foods from the food group with the narrowest band. Which band is narrowest? Which food group does it represent?

Healthy Eating Guidelines

Did you ever hear the saying, “variety is the spice of life”? Variety is also the basis of a healthy eating plan. When you choose foods based on MyPyramid, you should choose a variety of different foods. Follow these guidelines to make the wisest food choices for good health. Keep in mind that nutritional guidelines may change throughout life. As food provides energy and nutrients for growth and development, nutritional requirements may vary with body weight, age, sex, activity, and body functioning.

- Make at least half your daily grain choices whole grains. Examples of whole grains are whole wheat bread, whole wheat pasta, and brown rice.
- Choose a variety of different vegetables each day. Be sure to include both dark green vegetables, such as spinach and broccoli, and orange vegetables, such as carrots and sweet potatoes.
- Choose a variety of different fruits each day. Select mainly fresh fruits rather than canned fruits and whole fruits instead of fruit juices.
- When choosing oils, go for unsaturated oils, such as olive oil, canola oil, or vegetable oil.
- Choose low-fat or fat-free milk and other dairy products. For example, select fat-free yogurt and low-fat cheese.
- For meats, choose fish, chicken, and lean cuts of beef. Also, be sure to include beans, nuts, and seeds.

What about Ice Cream, Cookies, and Potato Chips?

Are you wondering where foods like ice cream, cookies, and potato chips fit into MyPyramid? The white tip of MyPyramid represents foods such as these. These are foods that should be eaten only in very small amounts and not very often. Such foods contain very few nutrients, and are called nutrient-poor. Instead, they are high in fats, sugars, and sodium, but low in other nutrients. Fats, sugars, and sodium are nutrients that you should limit in a healthy eating plan. Ice cream, cookies, and potato chips are also high in Calories. Eating too much of them may lead to unhealthy weight gain.

Food Labels

In the United States, packaged foods are required by law to have nutrition facts labels. A **nutrition facts label** shows the nutrients in a food. Packaged foods are also required to list their ingredients. An **ingredient** is a specific item that a food contains.

Using Nutrition Facts Labels

An example of a nutrition facts label is shown in **Figure** 17.7. The information listed at the right of the label tells you what to look for. At the top of the label, look for the serving size. The serving size tells you how much of the food you should eat to get the nutrients listed on the label. A cup of food from the label in **Figure** 17.7 is a serving. The Calories in one serving are listed next. In this food, there are 250 Calories per serving.

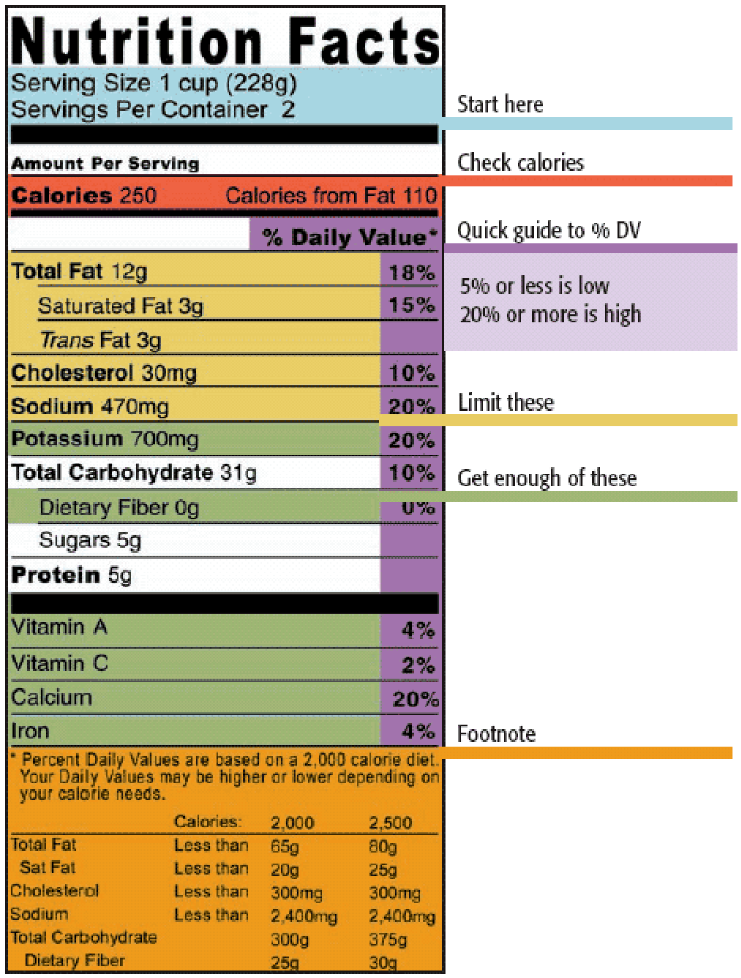
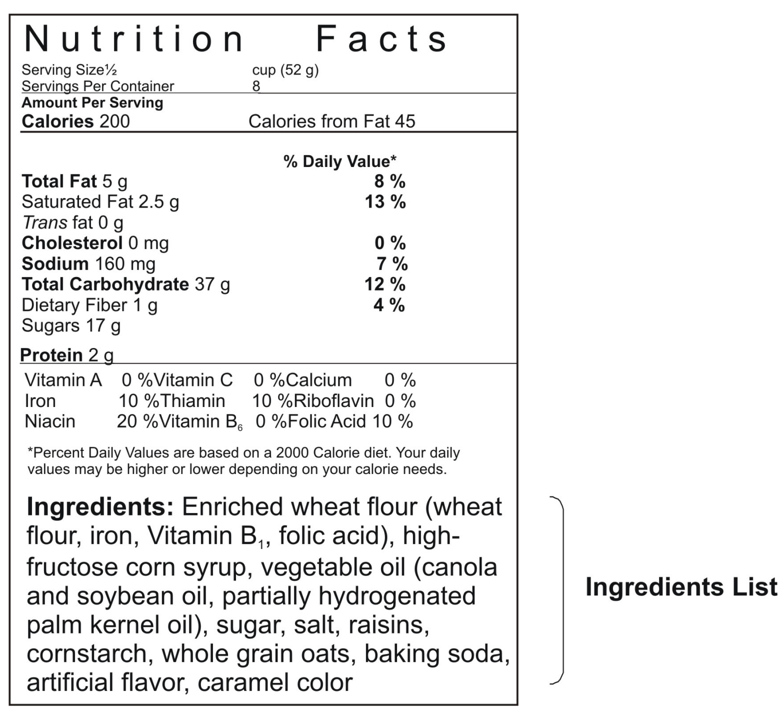


Figure 17.7: Reading nutrition facts labels can help you choose healthy foods. Look at the nutrition facts label shown here. Do you think this food is a good choice for a healthy eating plan? Why or why not? (1)

Next on the nutrition facts label, look for the percent daily values (% DV) of nutrients. A food is low in a nutrient if the percent daily value of the nutrient is 5% or less. The healthiest foods are low in nutrients such as fats and sodium. A food is high in a nutrient if the percent daily value of the nutrient is 20% or more. The healthiest foods are high in nutrients such as fiber and proteins. Look at the percent daily values on the food label in **Figure** 17.7. Which nutrients have values of 5% or less? These are the nutrients that are low in this food. They include fiber, vitamin A, vitamin C, and iron. Which nutrients have values of 20% or more? These are the nutrients that are high in this food. They include sodium, potassium, and calcium.

Using Ingredients Lists

The food label in **Figure** 17.8 includes the list of ingredients in a different food. The ingredients on food labels are always listed in descending order. This means that the main ingredient is listed first. The main ingredient is the ingredient that is present in the food in the greatest amount. As you go down the list, the ingredients are present in smaller and smaller amounts.



Nutrition Facts

Serving Size ½ cup (52 g)
Servings Per Container 8

Amount Per Serving

Calories 200 | Calories from Fat 45

	% Daily Value*
Total Fat 5 g	**8 %**
Saturated Fat 2.5 g	**13 %**
Trans fat 0 g	
Cholesterol 0 mg	**0 %**
Sodium 160 mg	**7 %**
Total Carbohydrate 37 g	**12 %**
Dietary Fiber 1 g	**4 %**
Sugars 17 g	
Protein 2 g	

Vitamin A	0 %	Vitamin C	0 %	Calcium	0 %
Iron	10 %	Thiamin	10 %	Riboflavin	0 %
Niacin	20 %	Vitamin B_6	0 %	Folic Acid	10 %

*Percent Daily Values are based on a 2000 Calorie diet. Your daily values may be higher or lower depending on your calorie needs.

Ingredients: Enriched wheat flour (wheat flour, iron, Vitamin B_1, folic acid), high-fructose corn syrup, vegetable oil (canola and soybean oil, partially hydrogenated palm kernel oil), sugar, salt, raisins, cornstarch, whole grain oats, baking soda, artificial flavor, caramel color

Ingredients List

Figure 17.8: This food label includes the list of ingredients in the food. The main ingredient is enriched wheat flour, followed by high-fructose corn syrup. Why should you avoid foods with ingredients such as these at the top of the ingredients list? (15)

Reading the ingredients lists on food labels can help you choose the healthiest foods. At the top of the list, look for ingredients such as whole grains, vegetables, milk, and fruits. These are the ingredients you need in the greatest amounts for balanced eating. Avoid foods that list fats, oils, sugar, or salt at the top of the list. For good health, you should avoid getting too much of these ingredients. Be aware that ingredients such as corn syrup are sugars.

You should also use moderation when eating foods that contain ingredients such as white flour or white rice. These ingredients have been processed, and processing removes nutrients. The word "enriched" is a clue that an ingredient has been processed. Ingredients are enriched with added nutrients to replace those lost during processing. However, enriched ingredients are still likely to have fewer nutrients than unprocessed ingredients.

Balancing Food with Exercise

Look at MyPyramid in **Figure** 17.6. Note the person walking up the side of the pyramid. This shows that exercise is important for balanced eating. Exercise helps you use any extra energy in the foods you eat. The more active you are, the more energy you use. You should try to get at least an hour of physical activity just about every day. **Figure** 17.9 shows some activities that can help you use extra energy.

Any unused energy in food is stored in the body as fat. This is true whether the extra energy comes from carbohydrates, proteins, or lipids. What happens if you take in more energy than you use, day after day? You will store more and more fat and become overweight. Eventually, you may become obese. Obesity is having a very high percentage of body fat. Obese people are at least 20 percent heavier than their healthy weight range. The excess body fat of obesity is linked to many diseases. Obese people often have serious health problems, such as diabetes, high blood pressure, and high cholesterol. They are also more likely to develop arthritis and some types of cancer. People that remain obese throughout adulthood usually do not live as long as people that stay within a healthy weight range.

The current generation of children and teens is the first generation in our history that may have a shorter life than their parents. The reason is their high rate of obesity and the health problems associated with obesity.

You can avoid gaining weight and becoming obese. The choice is yours. Choose healthy foods by using MyPyramid and reading food labels. Then get plenty of exercise to balance the energy in the foods you eat.

Lesson Summary

- MyPyramid shows how much you should eat each day of foods from six different food groups.
- Reading food labels can help you choose the healthiest foods.
- Regular exercise helps you use extra energy and avoid unhealthy weight gain.

Figure 17.9: All of these activities are good ways to exercise and use extra energy. The Calories given for each activity are the number of Calories used in an hour by a person that weighs 100 pounds. Which of these activities uses the most Calories? Which of the activities do you enjoy? (2)

Review Questions

1. List the six food groups represented by MyPyramid.
2. Which food group contains soybeans, kidney beans, and fish?
3. What guideline should you follow in choosing foods from the grains food group?
4. Which ingredient is always listed first on a food label?
5. What happens if you take in more energy than you use, day after day?
6. Explain how you can use MyPyramid to choose foods that provide the proper balance of nutrients.
7. Why should you limit foods like ice cream and potato chips in a healthy eating plan?
8. Explain how you can use food labels to choose foods that are high in fiber.
9. Why should you try to avoid foods with processed ingredients? What are some examples of processed ingredients?
10. How does physical activity help prevent obesity?

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- http://en.wikipedia.org/wiki

Vocabulary

enriched Term used for an ingredient that has been processed; ingredients are enriched with added nutrients to replace those lost during processing; likely to have fewer nutrients than unprocessed ingredients.

ingredient A specific item that a food contains.

main ingredient The ingredient that is present in the food in the greatest amount.

MyPyramid Diagram that shows how much you should eat each day of foods from six different food groups.

nutrition facts label The label on packaged food that shows the nutrients in the food.

obesity Having a very high percentage of body fat; obese people are at least 20 percent heavier than their healthy weight range.

serving size Tells you how much of the food you should eat to get the nutrients listed on the label.

Points to Consider

- Discuss how foods may be broken down into nutrients that your body can use? For example, how do you think an apple becomes simple sugars that your body can use for energy? Or how might a piece of cheese become proteins that your body can use for building materials?

17.3 Lesson 17.3: The Digestive System

Lesson Objectives

- State the functions of the digestive system.
- Explain the role of enzymes in digestion.
- Describe the digestive organs and their functions.
- Explain the roles of helpful bacteria in the digestive system.
- List ways to help keep your digestive system healthy.

Check Your Understanding

- What is a chemical reaction?
- What is an enzyme?
- What are bacteria?

Introduction

Nutrients in the foods you eat are needed by the cells of your body. How do the nutrients in foods get to your body cells? What organs and processes break down the foods and make the nutrients available to cells? The organs are those of the digestive system. The processes are digestion and absorption.

What Does the Digestive System Do?

The **digestive system** is the body system that breaks down food and absorbs nutrients. It also gets rid of solid food waste. The main organs of the digestive system are shown in **Figure** 17.10.

Digestion is the process of breaking down food into nutrients. There are two types of digestion: mechanical digestion and chemical digestion. In mechanical digestion, large chunks of food are broken down into small pieces. This is a physical process. In chemical digestion, large food molecules are broken down into small nutrient molecules. This is a chemical process.

Absorption is the process in which substances are taken up by the blood. After food is broken down into small nutrient molecules, the molecules are absorbed by the blood. Then the nutrient molecules travel in the bloodstream to cells throughout the body.

Some substances in food cannot be broken down into nutrients. They remain behind in the digestive system after the nutrients are absorbed. Any substances in food that cannot be digested and absorbed pass out of the body as solid waste. The process of passing solid food waste out of the body is called **elimination.**

The Role of Enzymes in Digestion

Chemical digestion could not take place without the help of digestive enzymes. An **enzyme** is a protein that speeds up chemical reactions in the body. Digestive enzymes speed up chemical reactions that break down large food molecules into small nutrient molecules.

Did you ever use a wrench, like the one in **Figure** 17.11, to tighten a bolt? You could tighten a bolt with your fingers, but it would be difficult and slow. If you use a wrench, you can tighten a bolt much more easily and quickly. Enzymes are like wrenches. They make it

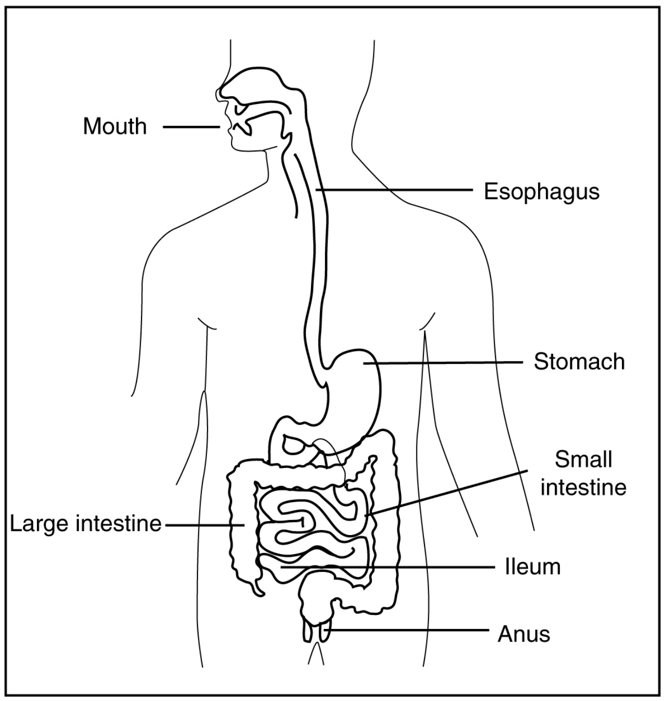

Figure 17.10: This drawing shows the major organs of the digestive system. Trace the path of food through the organs of the digestive system as you read about them in this lesson. (11)

much easier and quicker for chemical reactions to take place. Like a wrench, enzymes can also be used over and over again. But you need the appropriate size and shape of the wrench to efficiently tighten the bolt, just like each enzyme is specific for the reaction it helps.

Figure 17.11: Turning a bolt with a wrench is easier and quicker than trying to turn a bolt with your fingers. How is a wrench like an enzyme? (13)

Digestive enzymes are secreted by the organs of the digestive system. Examples of digestive enzymes are:

- Amylase is produced by the mouth. It helps break down large starches molecules into smaller sugar molecules.
- Pepsin is produced by the stomach. Pepsin is a protease; it helps break down proteins into amino acids.
- Trypsin is produced in the pancreas. Trypsin is a protease; it cleaves peptide chains.
- Pancreatic lipase is secreted by the pancreas. It is a lipase, used to break apart fats.
- Deoxyribonuclease and ribonuclease are nucleases secreted by the pancreas. They are enzymes that break bonds in nucleic acid backbones.

Bile salts are bile acids whose main function is to facilitate the processing of dietary fat. Bile acids are made in the liver. Upon eating a meal, the contents of the gallbladder are secreted into the intestine, where bile acids break down dietary fats. Bile acids serve other functions, including eliminating cholesterol from the body.

Digestive Organs and Their Roles

The mouth and stomach are just two of the organs of the digestive system. Other digestive system organs are the esophagus, small intestine, and large intestine. From **Figure** 17.10, you can see that the digestive organs form a long tube. In adults, this tube is about 9 meters (30 feet) long! At one end of the tube is the mouth. At the other end is the anus. Food enters the mouth and then passes through the rest of the digestive system. Food waste leaves the body through the anus.

The organs of the digestive system are lined with muscles. The muscles contract, or tighten, to push food through the system. This is shown in **Figure** 17.12. The muscles contract in waves. The waves pass through the digestive system like waves through a Slinky®. This movement of muscle contractions is called **peristalsis**. Without peristalsis, food would not be able to move through the digestive system. Peristalsis is an involuntary process, which means that it occurs without your conscious control.

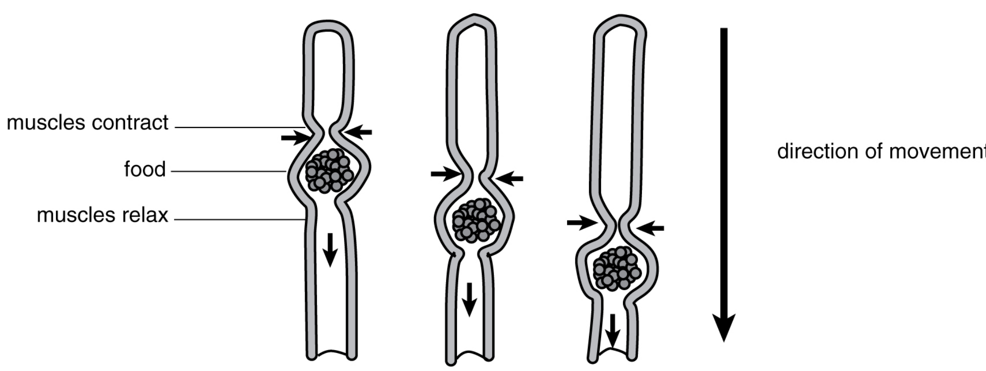

Figure 17.12: This diagram shows how muscles push food through the digestive system. Muscle contractions travel through the system in waves, pushing the food ahead of them. This is called peristalsis. (9)

The liver, gall bladder, and pancreas are also organs of the digestive system. They are shown in **Figure** 17.13. Food does not pass through these three organs. However, these organs are important for digestion. They secrete or store enzymes or other chemicals that are needed to help digest food chemically.

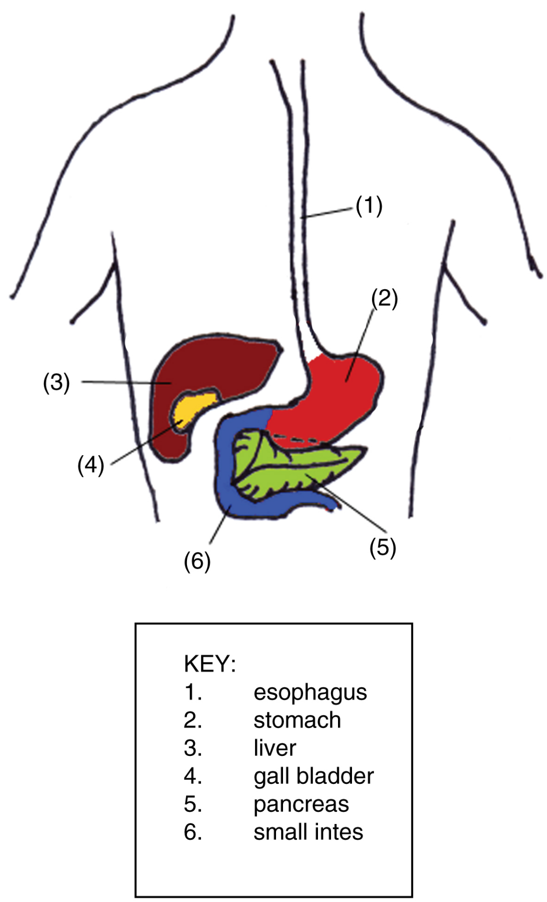

Figure 17.13: This drawing shows the liver, gall bladder, and pancreas. These organs are part of the digestive system. Food does not pass through them, but they secrete substances needed for chemical digestion. (12)

Mouth, Esophagus, and Stomach

The mouth is the first organ that food enters. However, digestion may start even before you put the first bite of food into your mouth. Just seeing or smelling food can cause the release of saliva and digestive enzymes in your mouth. Once you start eating, saliva wets the food, which makes it easier to break up and swallow. Digestive enzymes, including amylase, start breaking down starches into sugars. Your tongue helps mix the food with the saliva and enzymes.

Your teeth also help digest food. Your front teeth are sharp. They cut and tear food when you bite into it. Your back teeth are broad and flat. They grind food into smaller pieces when you chew. Chewing is part of mechanical digestion. Your tongue pushes the food to the back of your mouth so you can swallow it. When you swallow, the lump of chewed food passes down your throat to your esophagus.

The **esophagus** is a narrow tube that carries food from the throat to the stomach. Food moves through the esophagus because of peristalsis. At the lower end of the esophagus, a circular muscle controls the opening to the stomach. The muscle relaxes to let food pass into the stomach. Then the muscle contracts again to prevent food from passing back into the esophagus. Some people think that gravity moves food through the esophagus. If that were true, food would move through the esophagus only when you are sitting or standing upright. In fact, because of peristalsis, food can move through the esophagus no matter what position you are in—even upside down. Just don't try to swallow food when you upside down! You could choke if you try to swallow when you are not upright.

The **stomach** is a sac-like organ at the end of the esophagus. It has thick muscular walls. The muscles alternately contract and relax. This churns the food and helps break it into smaller pieces. The churning also mixes the food with the enzyme pepsin and other chemicals that are secreted by the stomach. The pepsin and other chemicals help digest proteins chemically.

Water, salt, and simple sugars can be absorbed into the blood from the stomach. Most other substances are broken down further in the small intestine before they are absorbed. The stomach stores food until the small intestine is ready to receive it. A circular muscle controls the opening between the stomach and small intestine. When the small intestine is empty, the muscle relaxes. This lets food pass from the stomach into the small intestine.

Small Intestine

The **small intestine** is narrow tube that starts at the stomach and ends at the large intestine (see **Figure** 17.10). In adults, the small intestine is about 7 meters (23 feet) long. It is made up of three parts: the duodenum, jejunum, and ileum. Each part has different functions.

The duodenum is the first part of the small intestine. This is where most chemical digestion takes place. Many enzymes and other chemicals are secreted here. Some are secreted by the duodenum itself. Others are secreted by the pancreas or liver.

The jejunum is the second part of the small intestine. This is where most nutrients are absorbed into the blood. The jejunum is lined with tiny "fingers" called villi. A magnified picture of villi is shown in **Figure** 17.14. Villi contain microscopic blood vessels. Nutrients are absorbed into the blood through these tiny vessels. There are millions of villi, so altogether there is a very large area for absorption to take place. In fact, villi make the inner surface area of the small intestine 1,000 times larger than it would be without them. The entire inner surface area of the small intestine is about as big as a basketball court!

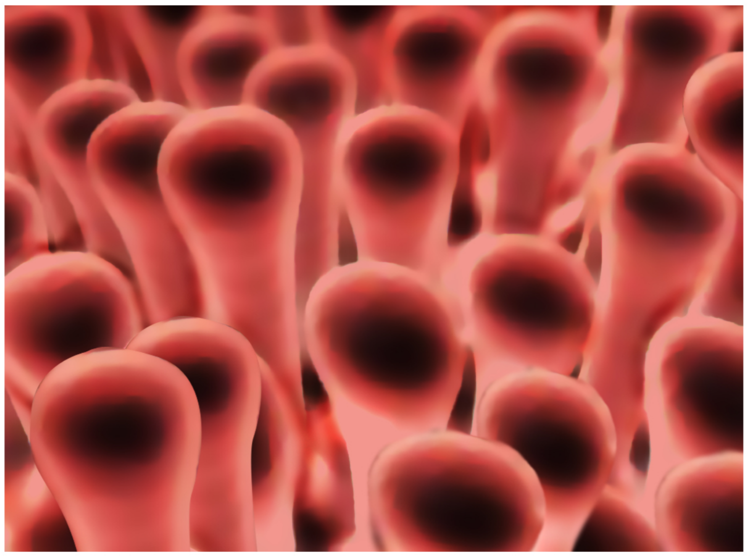

Figure 17.14: This is what the villi lining the small intestine look like when magnified. Each one is actually only about 1 millimeter long. Villi are just barely visible with the unaided eye. (7)

The ileum is the third part of the small intestine. Like the jejunum, the ileum is covered with villi. A few remaining nutrients are absorbed in the ileum. From the ileum, any remaining food waste passes into the large intestine.

The small intestine is much longer than the large intestine. So why is it called "small"? If you compare the small and large intestines in **Figure** 17.10, you will see why. The small intestine is smaller in width that the large intestine.

Large Intestine

The **large intestine** is a relatively wide tube that connects the small intestine with the anus. In adults, it is about 1.5 meters (5 feet) long. Waste enters the large intestine from the small intestine in a liquid state. As the waste moves through the large intestine, excess water is absorbed from it. After the excess water is absorbed, the remaining solid waste is called feces. Circular muscles control the anus. They relax to let the feces pass out of the body through the anus. After feces pass out of the body, they are called stool. The excretion of stool is referred to as a bowel movement.

Liver

The **liver** has a wide range of functions, a few of which are blood detoxification, maintaining glucose balance, protein synthesis, and production of biochemicals necessary for digestion. The liver is necessary for survival; there is currently no way to compensate for the absence of liver function.

The liver is one of the most important organs in the body when it comes to detoxifying or getting rid of foreign substances or toxins, especially from the gut. The liver filters blood from the intestine. This filtering process can remove a wide range of microorganisms such as bacteria, fungi, viruses and parasites from the blood. Almost 2 quarts of blood pass through the liver every minute.

The liver also has several roles in maintaining glucose levels, including gluconeogenesis (the synthesis of glucose from certain amino acids, lactate or glycerol), glycogenolysis (the breakdown of glycogen into glucose), and glycogenesis (the formation of glycogen from glucose).

Bacteria in the Digestive System

The large intestine provides a home for trillions of bacteria. Most of these bacteria are helpful. They have several roles in the body. For example, intestinal bacteria:

- Produce vitamins B_{12} and K.
- Control the growth of harmful bacteria.
- Break down poisons in the large intestine.
- Break down some substances in food that cannot be digested, such as fiber and some starches and sugars.

Keeping Your Digestive System Healthy

Most of the time, you probably aren't aware of your digestive system. It works well without causing any problems. However, most people have problems with their digestive system at least once in awhile. Did you ever eat something that didn't "agree" with you? Maybe you had a stomachache or felt sick to your stomach. Maybe you had diarrhea. These could be symptoms of foodborne illness.

Foodborne Illness

Harmful bacteria can enter your digestive system in food and make you sick. This is called **foodborne illness.** The bacteria, or the toxins they produce, may cause vomiting or cramping, in addition to the symptoms mentioned above. You can help prevent foodborne illness by following a few simple rules:

- Keep hot foods hot and cold foods cold. This helps prevent any bacteria in the foods from multiplying.
- Wash your hands before you prepare or eat food. This helps prevent bacteria on your hands from getting on the food.
- Wash your hands after you touch raw foods such as meats, poultry, fish, or eggs. These foods often contain bacteria that your hands could transfer to your mouth.
- Cook meats, poultry, fish, and eggs thoroughly before eating them. The heat of cooking kills any bacteria the foods may contain so they cannot make you sick.

Food Allergies

Food allergies are like other allergies. They occur when the immune system reacts to harmless substances as though they were harmful. Almost 10 percent of children have food allergies. Some of the foods most likely to cause allergies are shown in **Figure** 17.15. Eating foods you are allergic to may cause vomiting, diarrhea, or skin rashes. Some people are very allergic to certain foods. Eating even tiny amounts of the foods causes them to have serious symptoms, such as difficulty breathing. If they eat the foods by accident, they may need emergency medical treatment.

If you think you may have food allergies, a doctor can test you to find out for sure. The tests will identify which foods you are allergic to. Then you can avoid eating these foods. This is the best way to prevent the symptoms of food allergies. To avoid the foods you are allergic to, you may have to read food labels carefully. This is especially likely if you are allergic to common food ingredients, such as soybeans, wheat, or peanuts.

A food intolerance, or food sensitivity, is different to a food allergy. A food intolerance happens when the digestive system is unable to break down a certain type of food. This can result in stomach cramping, diarrhea, tiredness, and weight loss. Food intolerances are often mistakenly called allergies. Lactose intolerance is a food intolerance. A person who is lactose intolerant does not make enough lactase, the enzyme that breaks down the milk sugar lactose. About 75 percent of the world's population is lactose intolerant.

Constipation

Constipation means that a person has three bowel movement or less each week. The stools may also be hard and dry. Sometimes the stools are difficult or painful to pass. The person

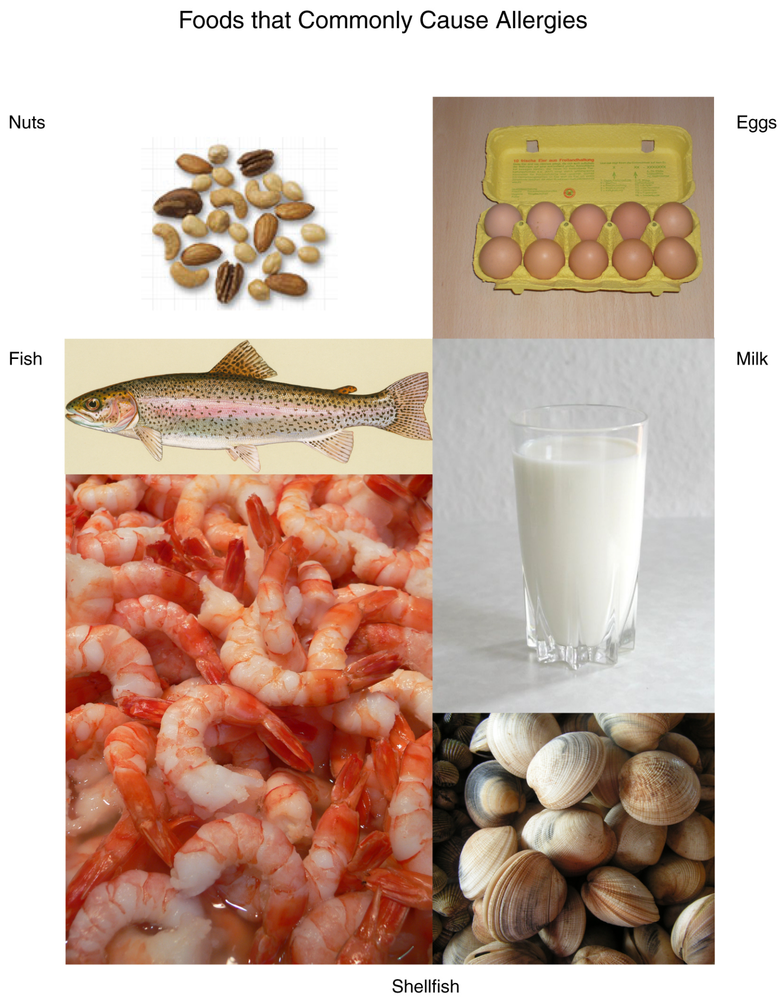

Figure 17.15: Some of the foods that commonly cause allergies are shown here. They include nuts, eggs, fish, milk, and shellfish. Are you allergic to any of these foods? (4)

may feel “draggy” and full.

Some people think they should have a bowel movement every day. This is not necessarily true. There is no “right” number of bowel movements. What is normal for one person may not be normal for another. It depends on the foods they eat, how much they exercise, and other factors.

At one time or another, almost everyone has constipation. In most cases, it lasts for a short time and isn’t serious. However, constipation can be very uncomfortable. You can follow these tips to help prevent it:

- Eat enough high-fiber foods, including vegetables, fruits, beans, and whole grains.
- Drink plenty of water and other liquids.
- Exercise regularly.
- Don’t ignore the urge to have a bowel movement.

Following these tips will help keep your digestive system working properly. It will help you feel good and stay healthy.

Lesson Summary

- The digestive system breaks down food, absorbs nutrients, and gets rid of food wastes.
- Digestive enzymes speed up the reactions of chemical digestion.
- The main organs of the digestive system are the mouth, esophagus, stomach, small intestine, and large intestine.
- Bacteria in the large intestine produce vitamins and have other roles in the body.
- You can follow simple tips to help keep your digestive system healthy.

Review Questions

1. What are three functions of the digestive system?
2. Describe the roles of the mouth in digestion.
3. In which organs of the digestive system does absorption of nutrients take place?
4. Identify two roles of helpful bacteria in the large intestine.
5. List two rules that can help prevent foodborne illness.
6. Explain the role of enzymes in digestion. Give examples to illustrate your answer.
7. Describe peristalsis, and explain why it is necessary for digestion.
8. How can the inner surface area of the small intestine be as big as a basketball court? How does this help the small intestine absorb nutrients?
9. Assume a person has an illness that prevents the large intestine from doing its normal job. Why might the person have diarrhea?
10. Explain why eating high-fiber foods can help prevent constipation.

Further Reading / Supplemental Links

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Vocabulary

absorption Process in which substances are taken up by the blood; after food is broken down into small nutrient molecules, the molecules are absorbed by the blood.

chemical digestion Digestion in which large food molecules are broken down into small nutrient molecules.

constipation Having three or less bowel movements each week.

digestion Process of breaking down food into nutrients.

digestive system Body system that breaks down food, absorbs nutrients, and gets rid of solid food waste.

duodenum The first part of the small intestine; where most chemical digestion takes place.

elimination The process in which solid food waste passes out of the body.

enzyme A substance, usually a protein, that speeds up chemical reactions in the body.

esophagus The narrow tube that carries food from the throat to the stomach.

food allergies A condition in which the immune system reacts to harmless substances in food as though they were harmful.

foodborne illness An illness caused by harmful bacteria that enter the digestive system in food.

food intolerance Occurs when the digestive system is unable to break down a certain type of food.

ileum The third part of the small intestine; covered with villi; the few remaining nutrients are absorbed in the ileum.

jejunum The second part of the small intestine; where most nutrients are absorbed into the blood; lined with tiny "fingers" called villi.

large intestine The relatively wide tube between the small intestine and anus where excess water is absorbed from food waste.

mechanical digestion Digestion in which large chunks of food are broken down into small pieces.

peristalsis Involuntary muscle contractions which push food through the digestive system.

small intestine The narrow tube between the stomach and large intestine where most chemical digestion and absorption of nutrients take place.

stomach The sac-like organ at the end of the esophagus where proteins are digested.

villi Contain microscopic blood vessels; nutrients are absorbed into the blood through these tiny vessels; located on the jejunum and the ileum.

Points to Consider

- After nutrients are absorbed into the blood, think about how the blood could carry them to all the cells of the body. How does the blood travel? What keeps the blood moving?

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Chapter 18

Cardiovascular System

18.1 Lesson 18.1: Introduction to the Cardiovascular System

Lesson Objectives

- Identify the main structures of the cardiovascular system.
- Identify three types of blood vessels.
- Describe the differences between the pulmonary and the systemic circulations.
- Identify the main structures of the lymphatic system.
- Outline how the cardiovascular and the lymphatic systems work together.

Check Your Understanding

- What is an organ system?
- What are the three types of muscles found in the human body?

Introduction

Your cardiovascular system has many jobs. It acts as a message delivery service, a pump, a heating system, and a protector of the body against infection. Every cell in your body depends on your cardiovascular system. In this chapter, you will learn how your cardiovascular system works and how it helps to maintain homeostasis.

Functions of the Cardiovascular System

The **cardiovascular system** shown in **Figure** 18.1 is the organ system that is made up of the heart, the blood vessels, and the blood. Your cardiovascular system has many important roles in maintaining homeostasis. It moves nutrients, hormones, gases (such as oxygen) and wastes (such as carbon dioxide) to and from your body cells. It also helps to keep you warm by moving warm blood around your body. To do these tasks, your cardiovascular system works with other body systems such as the respiratory, endocrine, and nervous systems.

The Movement of Gases

It could be said that the movement of gases, especially oxygen and the waste product of cellular respiration, carbon dioxide, is one of the most important aspects of the cardiovascular system. But the cardiovascular system cannot do this alone. It must work with other organ systems, especially the respiratory system (discussed in a later chapter), to move these gases throughout your body.

Oxygen is needed by every cell in your body as it is the final electron acceptor during aerobic cellular respiration. You breath oxygen in and carbon dioxide out through your respiratory system. Once oxygen enters your lungs, it must diffuse into your blood stream for transport around your body.

Oxygen is transported in your blood by attaching to the hemoglobin protein. The oxygen diffuses from the blood into the tissues, while carbon dioxide diffuses in the opposite direction. Carbon dioxide is transported back to the lungs, where it diffuses out of the blood and into your lungs for release from your body.

Parts of the Cardiovascular System

Your heart pushes the blood around your body through the blood vessels. The heart, shown in **Figure** 18.2, is made of cardiac muscle (refer to the *Skin, Bones, and Muscles* chapter). The heart is connected to many blood vessels that bring blood all around the body. The cardiac muscle contracts and pumps blood through the heart and blood vessels.

Blood Vessels

The job of these blood vessels is to channel the blood around the body. There are three main types of blood vessels in the body; arteries, veins, and capillaries.

Arteries are blood vessels that carry blood away from the heart. Arteries have thick walls that have a layer of smooth muscle, as shown in **Figure** 18.3. Arteries usually carry oxygen-rich blood around the body. The blood that is in arteries is under pressure. The contractions

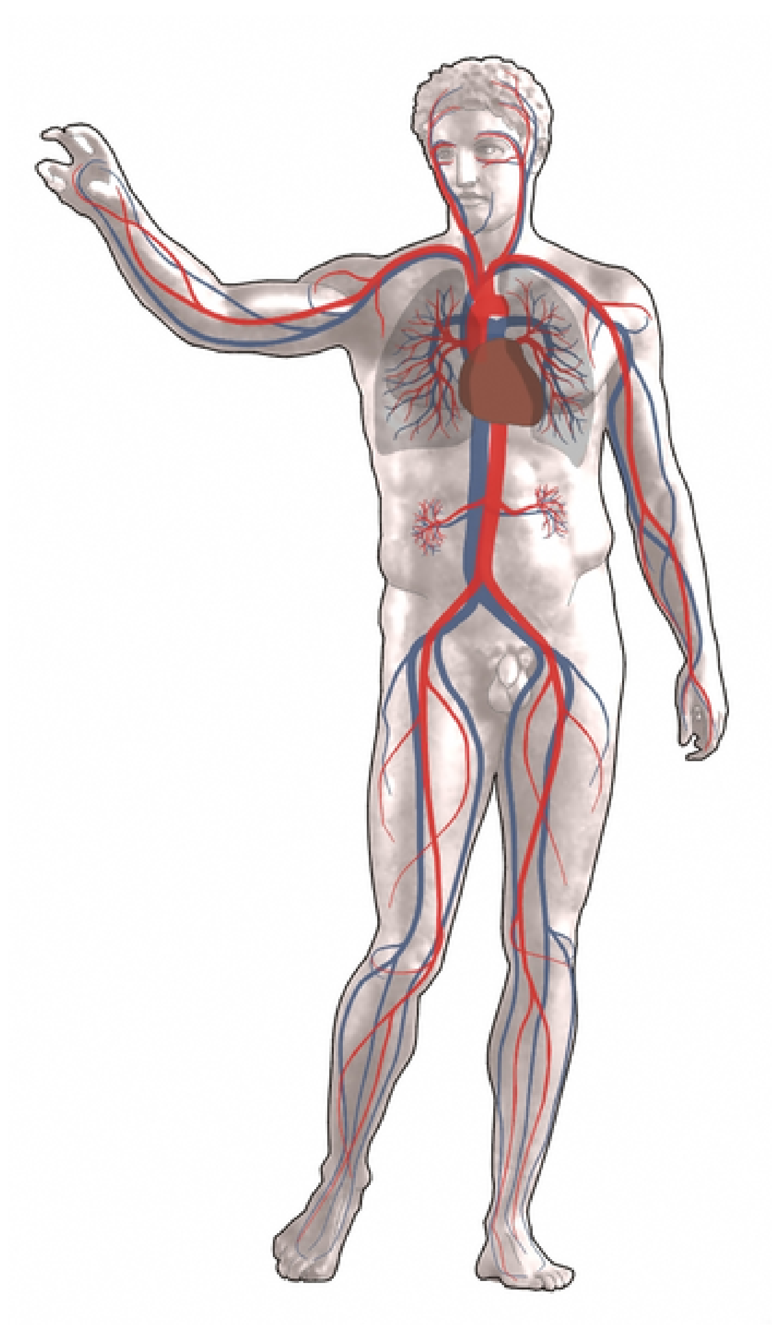

Figure 18.1: The cardiovascular system moves nutrients and other substances through cells. (25)

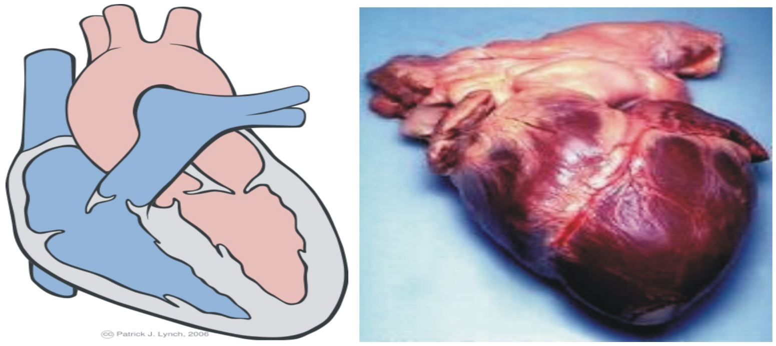

Figure 18.2: Blood is collected in the heart and pumped out to the lungs, where it releases carbon dioxide and picks up oxygen before it is pumped to the rest of the body. (6)

of the heart muscle causes blood to exert force on the walls of the arteries. This force is referred to as *blood pressure.* Blood pressure is highest in the arteries and decreases as the blood moves into smaller blood vessels. Thick walls help prevent arteries from bursting from the pressure of blood.

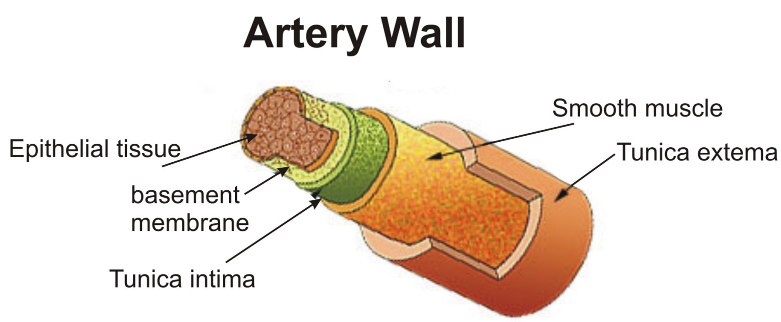

Figure 18.3: Arteries are thick-walled vessels with many layers, including a layer of smooth muscle. (11)

Every cell in the body needs oxygen, but arteries are too large to bring oxygen and nutrients to single cells. Further from the heart, arteries form smaller arteries. These smaller arteries branch into smaller vessels. The smaller blood vessels help to bring nutrients and oxygen and take away waste from body tissues.

The tiniest blood vessels in the body are called **capillaries.** The walls of capillaries are only a single layer of cells thick. Capillaries connect arteries and veins together, as shown in **Figure** 18.4. Capillaries also allow the delivery of water, oxygen and other substances to body cells. They also collect carbon dioxide and other wastes from cells and tissues. Capillaries are so narrow that blood cells must move in single file through them.

A *capillary bed* is the network of capillaries that supply an organ with blood. The more metabolically active a tissue or organ is, the more capillaries it needs to get nutrients and oxygen.

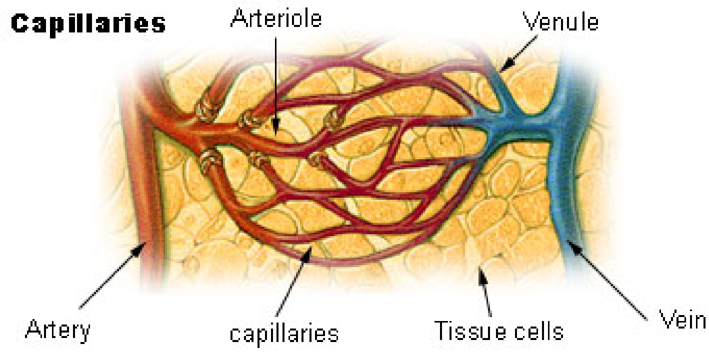

Figure 18.4: Capillaries connect arteries and veins. (1)

Blood is carried back to the heart in blood vessels called **veins.** Veins have thinner walls than arteries do, as you can see in **Figure** 18.5. The blood in veins is not under pressure. Veins have valves that stop blood from moving backward. Blood is moved forward in veins when the surrounding skeletal muscles squeeze the veins. Blood that is carried by veins is usually low in oxygen. The exception is the pulmonary veins that return oxygen-rich blood to the heart from the lungs.

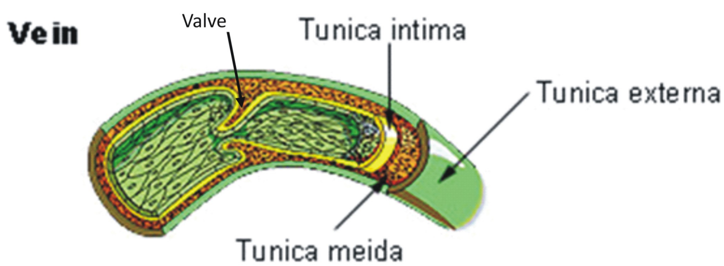

Figure 18.5: The walls of veins are not as thick as artery walls; veins have valves that stop blood from flowing backward. (17)

Blood is a body fluid that is a type of connective tissue. Blood is made of blood cells, and a fluid called **plasma.** The main types of cells found in blood are red blood cells and white blood cells. Red blood cells are the cells that carry oxygen. Oxygen-rich blood is bright red and oxygen-poor blood is dark red. You will learn more about blood in a later lesson in this chapter.

The cardiovascular system of humans is *closed.* That means the blood never leaves the large loop of blood vessels in which it travels. Other animals such as invertebrates have open circulatory systems, in which their blood can leave the blood vessels.

Two Blood Circulation Systems

The blood is pumped around in two large "loops" within the body. One loop moves blood around the body—to the head, limbs, and internal organs. The other loop moves blood to and from the lungs where carbon dioxide is released and oxygen is picked up by the blood. A simple version of these two "loops" is shown in **Figure** 18.6. **Systemic circulation** is the portion of the cardiovascular system which carries oxygen-rich blood away from the heart, to the body, and returns oxygen-poor blood back to the heart. The **pulmonary circulation** is the part of the cardiovascular system which carries oxygen-poor blood away from the heart to the lungs, and returns oxygen-rich blood back to the heart. This oxygen-rich blood then gets pumped around the body in the systemic circulation. These two circulations will be further discussed in Lesson 2.

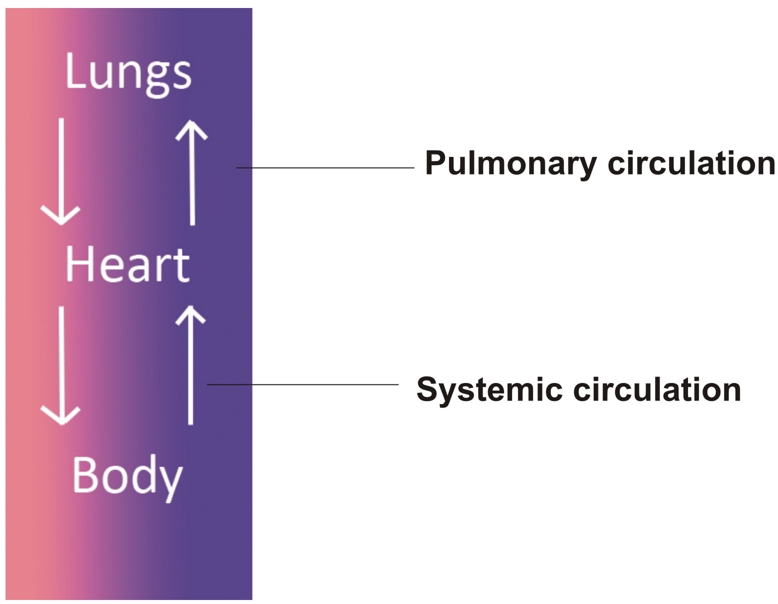

Figure 18.6: The double circulatory system; blood in one circuit has to go through the heart to enter the other circuit. (19)

The Lymphatic System

The **lymphatic system** is a network of vessels and tissues that carry a clear fluid called *lymph.* The lymphatic system, shown in **Figure** 18.7, extends all around the body. Lymph tissues include lymph nodes, lymph ducts, and lymph vessels. Lymph vessels are tube-shaped just like blood vessels. The lymphatic system works with the cardiovascular system to return body fluids to the blood. The lymphatic system and the cardiovascular system are often called the body's two *circulatory systems.*

The lymphatic system has two main jobs:

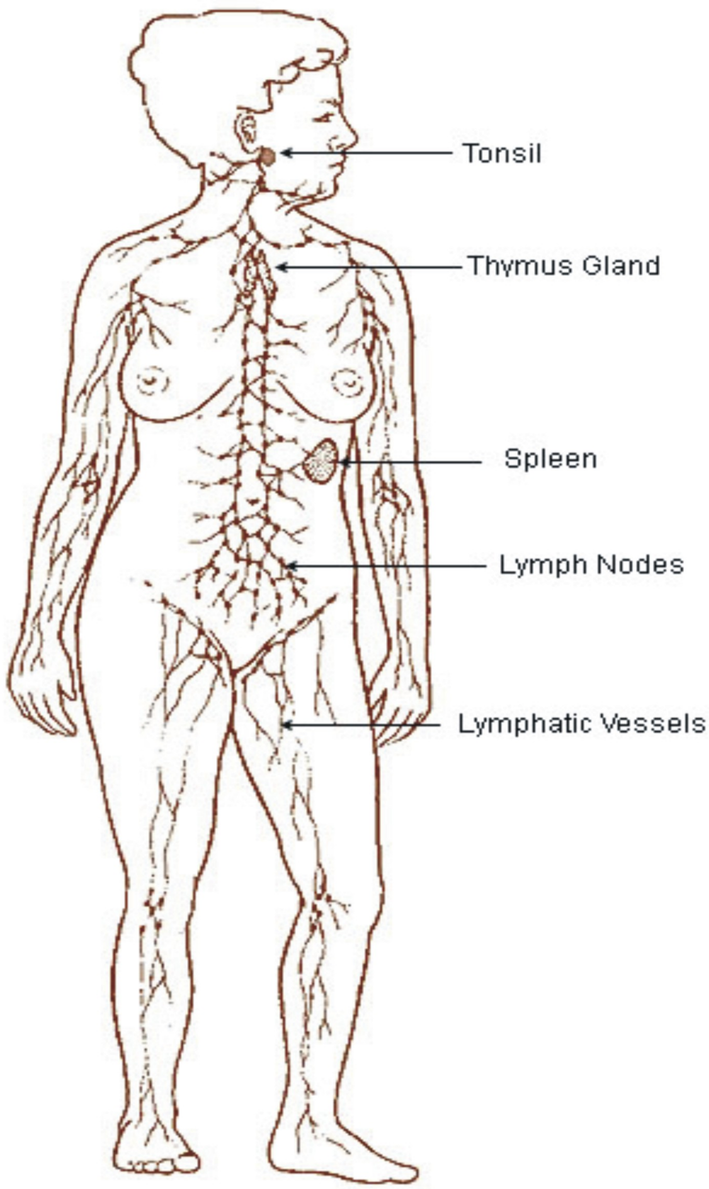

Figure 18.7: The lymphatic system helps return fluid that leaks from the blood vessels back to the cardiovascular system. (5)

- Removing excess fluids from body tissues.
- Making certain types of white blood cells.

Role of the Lymphatic System in Circulation

The lymphatic system collects and returns fluid to the cardiovascular system. A small amount of fluid leaks from the blood vessels when blood is pumped around your body. This fluid collects in the spaces between cells and tissues. Some of the fluid returns to the cardiovascular system, and the rest is collected by the lymph vessels of the lymphatic system, which are shown in **Figure** 18.8.

The fluid that collects in the lymph vessels is called lymph. The lymphatic system then returns the lymph to the cardiovascular system. Unlike the blood system, the lymphatic system is not closed and has no central pump. Lymph moves slowly in lymph vessels. It is moved along in the lymph vessels by the squeezing action of smooth muscles and skeletal muscles.

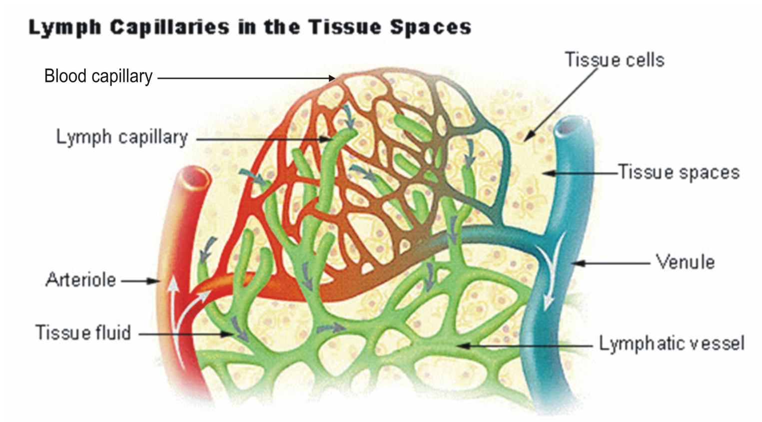

Figure 18.8: Lymph capillaries collect fluid that leaks out from blood capillaries. (3)

Role of the Lymphatic System in the Body's Defenses

The lymphatic system also plays an important role in the immune system. The lymphatic system makes certain blood cells, and also filters, or traps foreign particles. The lymphatic system and contain white blood cells to protect the body from infection.

Organs of the Lymphatic System

Along with the lymph vessels, lymph ducts, and lymph nodes, the lymphatic system also includes many organs. The tonsils, thymus, and spleen, which are shown **Figure** 18.7, each have a role in the defense of the body against infection. Many of these organs are also part of the immune system.

Tonsils

The tonsils are areas of lymphoid tissue on either side of the throat. The term *tonsils* refers most often to the tonsils in the back of the throat as shown in **Figure** 18.9. But, there are tonsils in the nasal cavity and behind the tongue too. Like other organs of the lymphatic system, the tonsils are also part of the immune system. The immune system help protect the body against infection. The tonsils are believed to help fight off nose and throat and other upper respiratory tract infections such as colds. Tonsils tend to reach their largest size near puberty, after which they get smaller. *Tonsillitis* is an infection of the tonsils that can cause a sore throat and fever.

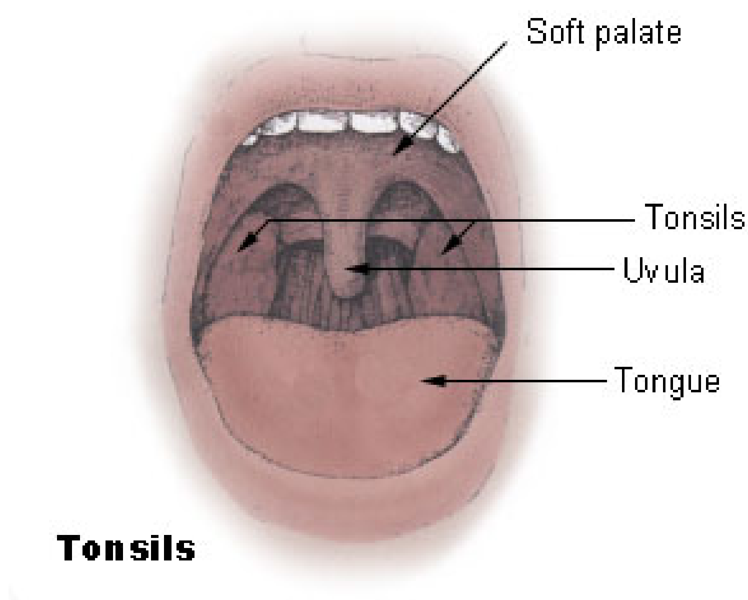

Figure 18.9: The term *tonsils* refers most often to the tonsils in the back of the throat, but there are tonsils in the nasal cavity and behind the tongue too. (9)

Bone Marrow

Bone marrow is the tissue found in the middle of bones. The marrow in the large bones of adults makes new blood cells. Certain white blood cells, called *T-cells,* are made in the bone marrow and move to the thymus to mature. Other white blood cells called *B-cells,* move from the bone marrow to the spleen after they have matured.

Thymus

The thymus is found in the upper chest. Chemicals made by the thymus help the production of certain infection-fighting cells. The thymus is where certain white blood cells called *lymphocytes* mature. These cells move from the bone marrow to the thymus to finish growing. The thymus grows to its largest size near puberty, and gets smaller as a person ages. If a person's thymus is surgically removed or damaged by disease while they are young, the person will be very prone to infections.

Spleen

The spleen is in the abdomen, as shown in **Figure** 18.10. In an area of the spleen called *red pulp*, materials are filtered from the blood, including old and dead red blood cells. The spleen also makes red blood cells. Areas called *white pulp* help fight infections by making white blood cells. If a person's spleen is surgically removed, or does not work properly, the person is prone to certain infections.

You can learn more about the roles of the lymphatic system and white blood cells in the *Diseases and the Body's Defenses* chapter.

Table 18.1: **Structures and Functions of the Cardiovascular and Lymphatic Systems**

System	**Structure (organs and tissues)**	**Function**
Lymphatic	Lymph vessels	Transports fluid (lymph) from between body cells back to blood
	Lymph nodes	Traps invading microbes, foreign particles, cancerous cells
	Spleen, tonsils, and adenoids	Traps invading microbes and foreign particles
	Thymus	Site of white blood cell (lymphocyte)maturation
Cardiovascular	Blood vessels	Transports blood around the body
	Blood	Transport of oxygen and nutrients; transports white blood cells to sites of infection and inflammation
	Heart	Pumps blood around the body

Table 18.1: (continued)

System	Structure (organs and tissues)	Function

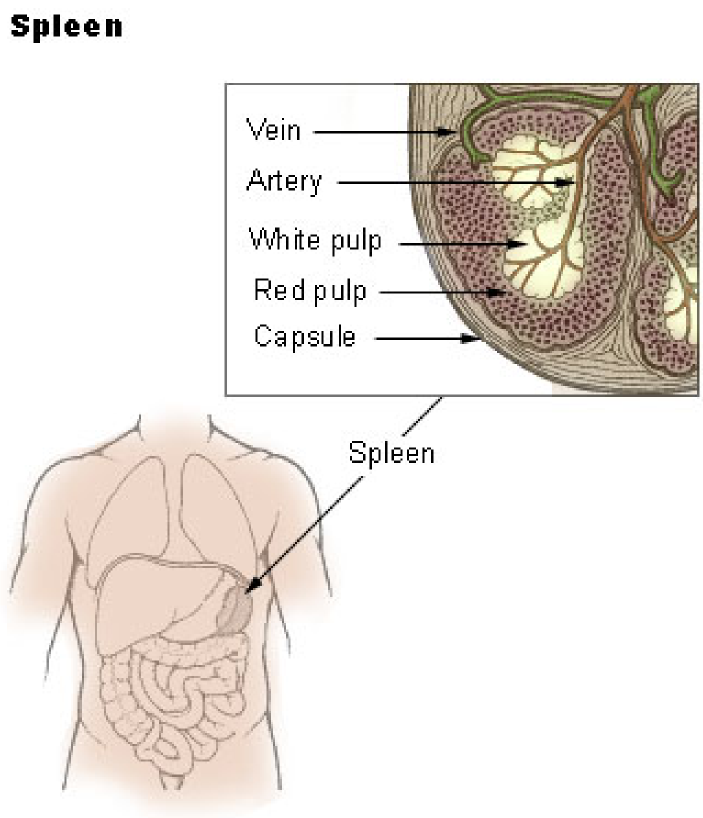

Figure 18.10: In the spleen, the white pulp makes white blood cells, and the red pulp acts like a filter that removes dead and dying cells from the blood. (16)

Lesson Summary

- The cardiovascular system consists of the heart, the blood vessels, and the blood. There are three main types of blood vessels in the body; arteries, veins, and capillaries.
- The systemic circulation is the portion of the cardiovascular system, which carries oxygen-rich blood away from the heart, to the body, and returns oxygen-poor blood back to the heart. The pulmonary circulation is the part of the cardiovascular system, which carries oxygen-poor blood away from the heart to the lungs, and returns oxygen-rich blood back to the heart.

- Lymph tissues include lymph nodes, lymph ducts, and lymph vessels. Organs of the lymphatic system include the tonsils, thymus, and spleen. The lymphatic system works with the cardiovascular system to return body fluids to the blood. The two systems together are often called the body's two *circulatory systems.*

Review Questions

1. Identify the main structures of the cardiovascular system.
2. Identify three types of blood vessels found in the body.
3. Which blood vessels bring blood away from the heart?
4. What are the smallest blood vessels in the body called?
5. What blood vessels bring blood back to the heart?
6. Where does blood in the pulmonary system go once it leaves the heart?
7. Where does blood in the systemic circulation go once it leaves the heart?
8. What does blood that leaves the heart in the systemic circulation have that body cells need?
9. Identify the main tissues and organs of the lymphatic system.
10. Outline how the cardiovascular and the lymphatic systems work together.
11. What is lymph, and where does it come from?
12. Identify one function of tonsils.
13. What might happen if a person did not have a spleen?
14. Name the two circulatory systems of the body.

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki/Heart

Vocabulary

arteries Blood vessels that carry blood away from the heart.

blood A body fluid that is a type of connective tissue; moves oxygen and other compounds throughout the body.

capillaries The smallest and narrowest blood vessels in the body.

cardiovascular system The organ system that is made up of the heart, the blood vessels, and the blood.

lymphatic system A network of vessels and tissues that carry a clear fluid called *lymph;* includes lymph nodes, lymph ducts, and lymph vessels.

plasma The straw-colored fluid in blood.

pulmonary circulation The part of the cardiovascular system which carries oxygen-poor blood away from the heart to the lungs, and returns oxygen-rich blood back to the heart.

systemic circulation The portion of the cardiovascular system which carries oxygen-rich blood away from the heart to the body, and returns oxygen-poor blood back to the heart.

veins Blood vessels that carry blood back to the heart.

Points to Consider

- Consider how the structure of the heart helps to maintain the systemic and pulmonary circulations.
- Consider how problems with the coronary circulation can affect the entire body.
- How would a hole in the heart muscle that allowed blood in the two ventricles to mix affect the rest of the body?

18.2 Lesson 18.2: Heart and Blood Vessels

Lesson Objectives

- Describe the structure of the heart.
- Outline how blood moves through the heart.
- Describe the importance of valves in the heart.
- Describe the coronary circulation.

Check Your Understanding

- What is the role of the cardiovascular system?
- What is the main function of the heart?

Introduction

The heart is divided into four chambers, the left and right *atria* and the left and right *ventricles.* An **atrium** is one of the two small, thin-walled chambers on the top of the heart that blood first enters. A **ventricle** is one of the two muscular V-shaped chambers that pump blood out of the heart. The four chambers of the heart are shown in **Figure** 18.11. The atria receive the blood, and the ventricles pump the blood out of the heart. Each of the four chambers of the heart have a specific job, these are:

- The right atrium receives oxygen-poor blood from the body.
- The right ventricle pumps oxygen-poor blood toward the lungs.
- The left atrium receives oxygen-rich blood from the lungs.
- The left ventricle pumps oxygen-rich blood out of the heart to the rest of the body.

The heart is usually found in the left to middle of the chest with the largest part of the heart slightly to the left. The heart is usually felt to be on the left side because the left ventricle is bigger and stronger than the right ventricle. The heart is surrounded by the lungs.

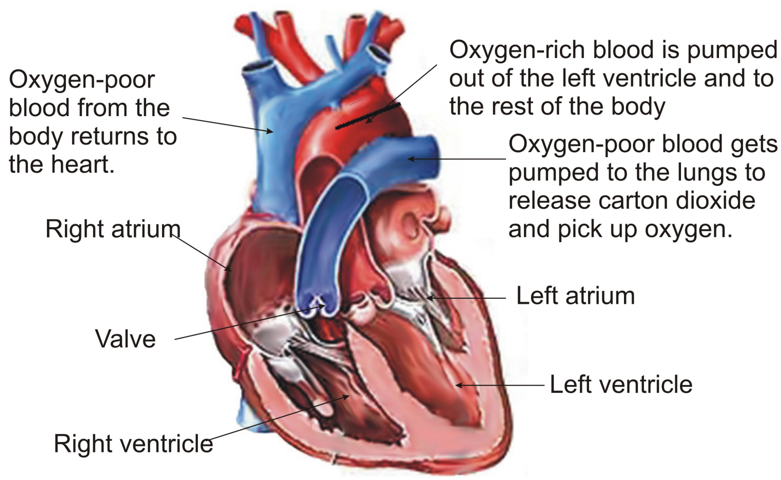

Figure 18.11: The atria receive blood and the ventricles pump blood out of the heart. (18)

Blood Flow Through the Heart

Blood flows through the heart in two separate loops; you could think of them as a "left side loop" and a "right side loop". The *right side* and *left side* of the heart refer to your heart as it sits inside your chest. Its left side is your left side and, its right side is your right side.

The right side of the heart collects deoxygenated blood from the body and pumps it into the lungs where it releases carbon dioxide and picks up oxygen. The left-side carries the oxygenated blood back from the lungs, into the left side of the heart which then pumps the oxygenated blood throughout the rest of the body.

The Heartbeat

To move blood through the heart, the cardiac muscle needs to contract in an organized way. Blood first enters the atria, as shown in **Figure** 18.12. When the atria contract blood is pushed into the ventricles. After the ventricles fill with blood, they contract and blood is pushed out of the heart. Valves in the heart keep the blood flowing in one direction. You can see some of the valves in **Figure** 18.12. The valves do this by opening and closing in one direction only. Blood moves only forward through the heart. The valves stop the blood from flowing backward. There are four valves of the heart:

- The two *atrioventricular (AV) valves* stop blood from moving from the ventricles to the atria.
- The two *semilunar (SL) valves* are found in the arteries leaving the heart, and they prevent blood flowing back from the arteries into the ventricles.

The "lub-dub" sound of the heartbeat is caused by the closing of the AV valves (lub), and SL valves (dub), after blood has passed through them.

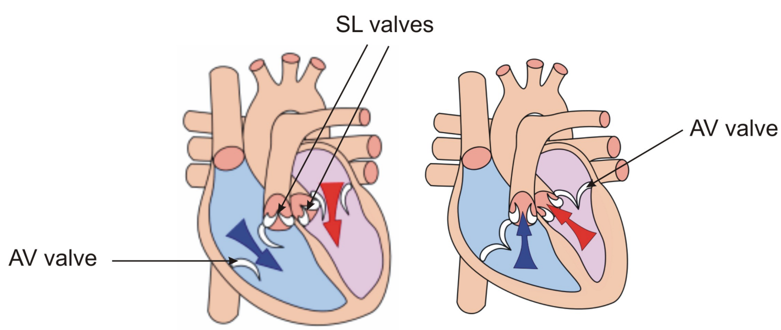

Figure 18.12: Blood flows in only one direction in the heart; blood enters the atria, contracting and pushing blood into the ventricles, the atria relax, the ventricles fill with blood, contract, and push blood around the body. (21)

Control of the Heartbeat

The heart is a made up of cardiac muscle cells. Cardiac cells are able to contract by themselves. They do not need help from the nervous system. This is different than skeletal muscle, which needs messages from nerve to contract. But the contractions of cardiac muscle still need to be coordinated to make sure the cells contract as a group.

The contraction rate of cardiac muscle is controlled by two small groups of cardiac muscle cells called the *sinoatrial (SA)* and *atrioventricular (AV) nodes.* The SA node is found in the wall of the right atrium. It starts the contraction of muscle cells in the atria. The contracting cells send electrical messages called *impulses* to other muscle cells. The impulses then reach the AV node. The AV node is found in the lower part of the right atrium. The AV node conducts the impulses that come from the SA node through the atria to the ventricles. The impulses then spread around the ventricles and they contract.

The frequency of the heart's contractions, called the *heart rate,* can be changed by nervous or hormonal signals. Activities such as exercise or getting frightened can make the heart rate increase. After the exercise is over, or the fright has passed, the heart rate returns to normal.

Blood Circulation and Blood Vessels

There are actually two separate circulation systems within the heart. Both of these together make up the complete circulatory system of humans and other animals. Neither system can work alone. These are the **pulmonary circulation** and the **systemic circulation.** The human heart is made up of two separate pumps, the right side which pumps deoxygenated blood into the pulmonary circulation, and the left side which pumps oxygenated blood into the systemic circulation. Blood in one circuit has to go through the heart to enter the other circuit.

The blood vessels are an important part of the cardiovascular system. They connect the heart (the pump), to every cell in the body. Arteries carry blood away from the heart, while veins return blood to the heart. The main arteries and veins of the heart are shown in **Figure** 18.13.

The veins that return oxygen- poor blood to the heart are the *superior vena cava* and the *inferior vena cava.* The *pulmonary veins* return oxygen-rich blood to the heart. The *pulmonary veins* are the only veins that carry oxygen-rich blood all other veins carry oxygen-poor blood.

The *pulmonary arteries* carry oxygen-poor blood away from the heart to the lungs. These are the only arteries that carry oxygen-poor blood. The aorta is the largest artery in the body. It carries oxygen-rich blood away from the heart. Further away from the heart, the aorta branches into smaller arteries.

Pulmonary Circulation

The **pulmonary circulation** is the part of the cardiovascular system which carries oxygen-poor blood away from the heart and brings it to the lungs. Oxygen-poor blood returns to the heart from the body and leaves the right ventricle through the pulmonary arteries, which carry the blood to each lung. Once at the lungs, the red blood cells release carbon dioxide and pick up oxygen during *respiration.* The oxygen-rich blood then leaves the lungs through the pulmonary veins which return it to the left side of the heart. This completes

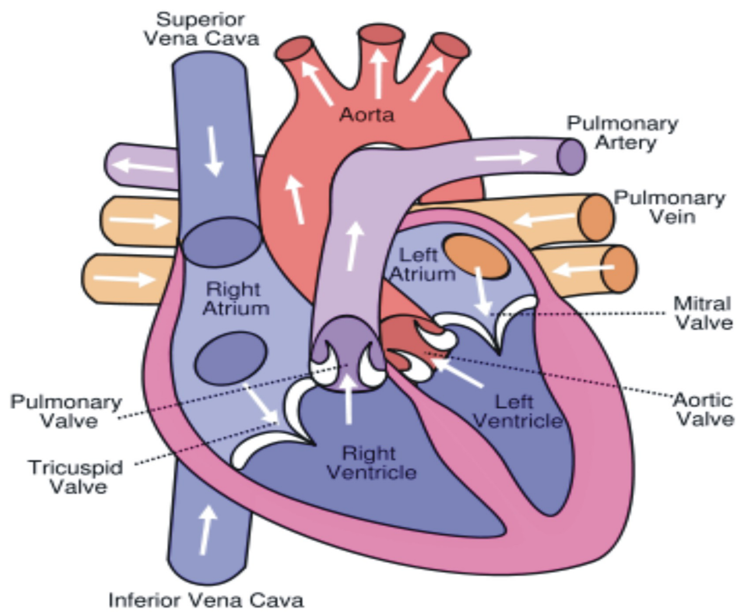

Figure 18.13: The right side of the heart pumps deoxygenated blood into the pulmonary circulation; the left side pumps oxygenated blood into the systemic circulation. (7)

the *pulmonary cycle.*

The oxygenated blood is then pumped to the body through the systemic circulation before returning again to the pulmonary circulation.

Systemic Circulation

The **systemic circulation** is the part of the cardiovascular system which carries oxygen-rich blood away from the heart, to the body, and returns oxygen-poor blood back to the heart. Oxygen-rich blood leaves the left ventricle through the aorta, from where it goes to the body's organs and tissues. The blood vessels that supply oxygen and nutrients to organs and tissues are much smaller than the vessels that leave the heart. Recall that capillaries are the smallest blood vessels. The tissues and organs absorb the oxygen, through the capillaries. Oxygen-poor blood is collected from the tissues and organs by tiny veins, which then flow into bigger veins. The inferior and superior venae cavae, are the large veins that return oxygen-poor blood to the right side of the heart. This completes the systemic cycle. The blood released carbon dioxide and gets more oxygen in the pulmonary circulation before returning to the systemic circulation.

Coronary Circulation

Just like every other organ in the body, the heart needs its own blood supply. It gets this blood in the **coronary circulation.** Although blood fills the chambers of the heart, the heart muscle tissue is so thick that it needs its own blood vessels to deliver oxygen and nutrients into the muscle. The coronary circulation is part of the systemic circulation. The vessels that deliver oxygen-rich blood to the heart muscle are called *coronary arteries.* The coronary arteries branch directly from the aorta, just above the heart, as shown in **Figure** 18.14. The vessels that remove the deoxygenated blood from the heart muscle are known as *cardiac veins.* Problems with the coronary circulation are often referred to as *heart disease.*

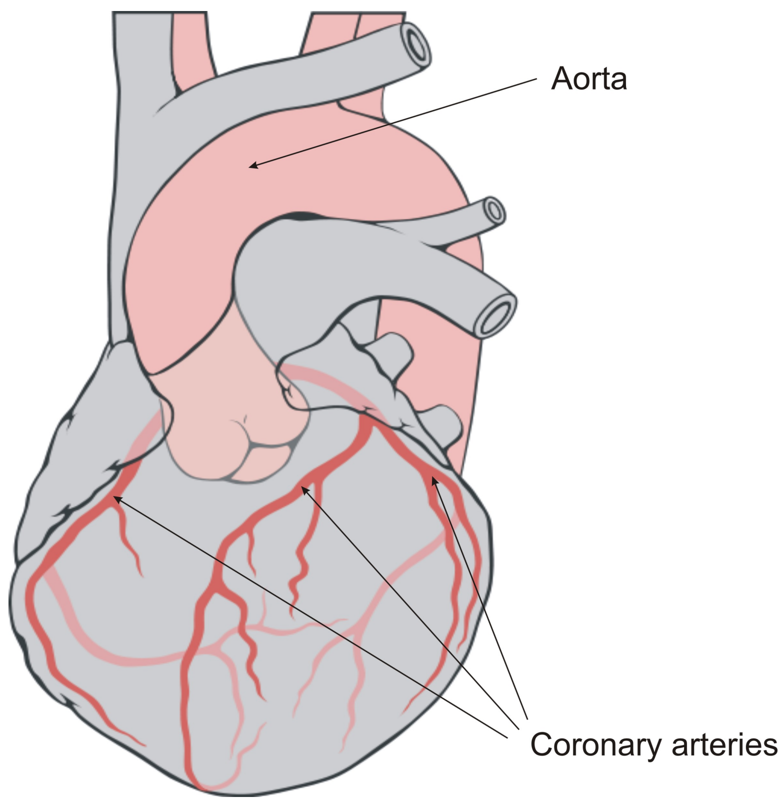

Figure 18.14: In coronary circulation, the arteries that bring oxygen to the cardiac cells branch off the aorta; heart attacks are caused by blockages of the coronary arteries and blockages in the coronary arteries stop oxygen from getting to the heart muscle. (8)

The circulation of blood around the body has been studied by people for a long time. The roles of the organs of the circulatory system were a mystery for many hundreds of years. For example, it was once believed that the left ventricle and arteries were filled with air, and the liver made blood. The pulmonary circulation was first discovered by a Syrian physician, Ibn al-Nafis, in 1242. Ibn al-Nafis was the first person to describe the coronary circulation. However, credit for the first description of blood circulation is given to an English physician

William Harvey. In 1616, Harvey first described the pulmonary and systemic circulation systems in detail.

Lesson Summary

- The heart is divided into four chambers, the left and right *atria* and the left and right *ventricles.* The right side of the heart collects deoxygenated blood from the body and pumps it into the lungs where it releases carbon dioxide and picks up oxygen. The left-side carries the oxygenated blood back from the lungs, into the left side of the heart which then pumps the oxygenated blood throughout the rest of the body.
- The valves in the heart prevent blood from flowing backward into the heart. The contraction rate of cardiac muscle is controlled by two small groups of cardiac muscle cells called the *sinoatrial* (SA) and *atrioventricular* (AV) nodes.
- The heart has its own blood supply, which is called the coronary circulation. The heart is fed oxygen-rich blood by coronary arteries. Oxygen-poor blood is collected by coronary veins.

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki/William_Harvey
- http://thevirtualheart.org/anatomyindex.html
- http://en.wikipedia.org/wiki/Cardiac_cycle

Review Questions

1. Name the four chambers of the heart.
2. Where does oxygen-poor blood first enter the heart?
3. Do ventricles pump blood out of the heart or do they pump blood into the atria?
4. What is the purpose of the valves in the heart?
5. What do the AV valves do?
6. Does the vena cava carry oxygen-poor or oxygen-rich blood?
7. Why can the heart be considered to be two separate pumps?
8. How might a hole in the heart wall between the two ventricles affect the circulation of blood?
9. To what organ or organs does the coronary circulation bring blood?
10. To what organ or organs does the pulmonary circulation bring blood?

Vocabulary

atrioventricular (AV) valves Valves that stop blood from moving from the ventricles back into the atria.

atrium One of the two small, thin-walled chambers on the top of the heart that blood first enters.

coronary circulation The blood supply that feeds the heart.

semilunar (SL) valves Found in the arteries leaving the heart; prevents blood flowing back from the arteries into the ventricles.

ventricle One of the two muscular V-shaped chambers that pump blood out of the heart.

Points to Consider

- Identify how the different components of the blood have very different roles in the cardiovascular system.
- Consider how diet can affect the oxygen-carrying ability of blood.

18.3 Lesson 18.3: Blood

Lesson Objectives

- List the components of blood.
- Identify three functions of blood.
- Name the oxygen-carrying protein found in red blood cells.
- Identify the main function of white blood cells.
- Describe the importance of the ABO blood system.
- Identify three blood disorders or diseases.

Check Your Understanding

- What is the main function of the blood?
- What is the role of oxygen in aerobic (cellular) respiration?

Introduction

Did you know that blood is a tissue? Blood is a fluid connective tissue that is made up of red blood cells, white blood cells, platelets, and plasma. It moves around the body through the blood vessels by the pumping action of the heart. Oxygen rich blood carried in arteries brings oxygen and nutrient to all the body's cells. Oxygen-poor blood carries carbon dioxide and other metabolic wastes away from the cells. As well as the transport of gases, nutrients, and wastes, blood has many other functions that are important to homeostasis. You will learn more about these functions in this lesson.

Components of Blood

Blood is a colloidal solution. A colloidal solution it is made up of particles that are suspended in a fluid. The cells in blood are suspended in plasma, the liquid part of blood. The cells that make up the blood are shown in **Figure** 18.15. The different components of blood have different roles. Some of the roles of blood include:

- The defense of the body against infection by microorganisms or parasites.
- The transport of chemical messages, such as hormones and hormone-like substances.
- The control of body temperature.
- The repair of damage to body tissues.

Plasma

If you were to filter out all the cells in blood, plasma is what would be left over. **Plasma** is the golden-yellow liquid part of the blood. Plasma is about 90 percent water and about 10 percent dissolved proteins, glucose, ions, hormones, and gases. Blood is made up of mostly plasma. The blood cells make up the rest of the volume.

Red Blood Cells

Red blood cells (RBCs) are flattened disk-shaped cells that carry oxygen. They are the most common blood cell in the blood. There are about 4 to 6 million RBCs per cubic millimeter of blood. Each RBC has 200 million molecules of hemoglobin. Hemoglobin is the protein that carries oxygen. Hemoglobin also gives the RBCs their red color. Red blood cells are made in the red marrow of long bones, ribs, skull, and vertebrae. Each red blood cell lives for only 120 days (about three months). After this time, they are destroyed in liver and spleen. Red blood cells are shown in **Figure** 18.16. Mature RBCs do not have a nucleus or other organelles.

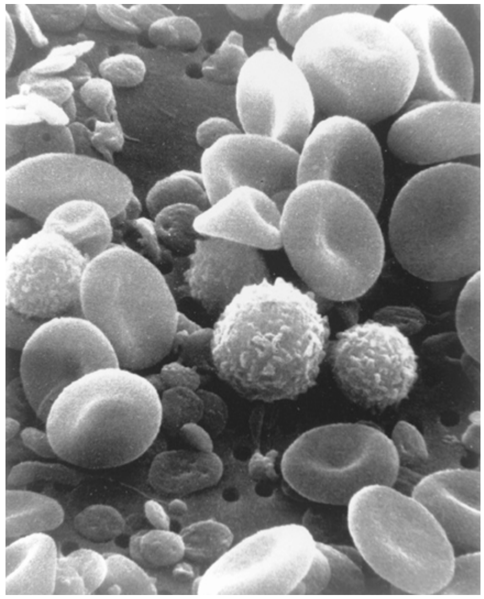

Figure 18.15: A scanning electron microscope (SEM) image of human blood cells; red blood cells are the flat, bowl-shaped cells, the tiny disc-shaped pieces are platelets and white blood cells are the round cells visible in the center. (10)

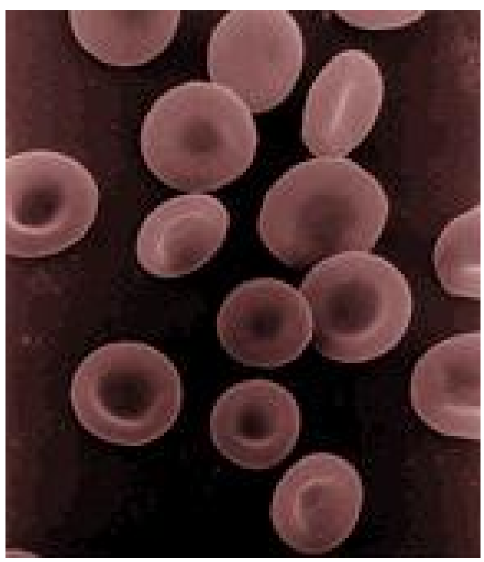

Figure 18.16: The flattened shape of RBCs helps them to carry more oxygen than if they were rounded. (13)

White Blood Cells

White blood cells (WBCs) are usually larger than red blood cells. They have a nucleus but do not have hemoglobin. White blood cells make up less than one percent of the blood's volume. Most WBCs are made in the bone marrow, some mature in the lymphatic system. WBCs defend the body against infection by bacteria, viruses and other pathogens. Each WBC type has a specific defense job. Three of the most common white blood cells in the body are listed here.

- *Neutrophils* can squeeze through capillary walls and swallow particles such as bacteria and parasites.
- *Macrophages* can also swallow and destroy old and dying cells, bacteria, or viruses. In **Figure** 18.17 a macrophage is attacking and swallowing two particles, possibly pathogens. Macrophages also release chemical messages that cause the number of WBC to increase.
- *Lymphocytes* fight infections by viruses and bacteria. Some lymphocytes attack and kill cancer cells. Other lymphocytes attack cells that are infected by viruses. Lymphocytes called B-cells make antibodies. **Antibodies** are chemicals that identify pathogens or other substances as being harmful, or they can destroy the pathogen. To learn more about the role of WBCs in protecting the body from infection, go to the *Diseases and the Body's Defenses* chapter.

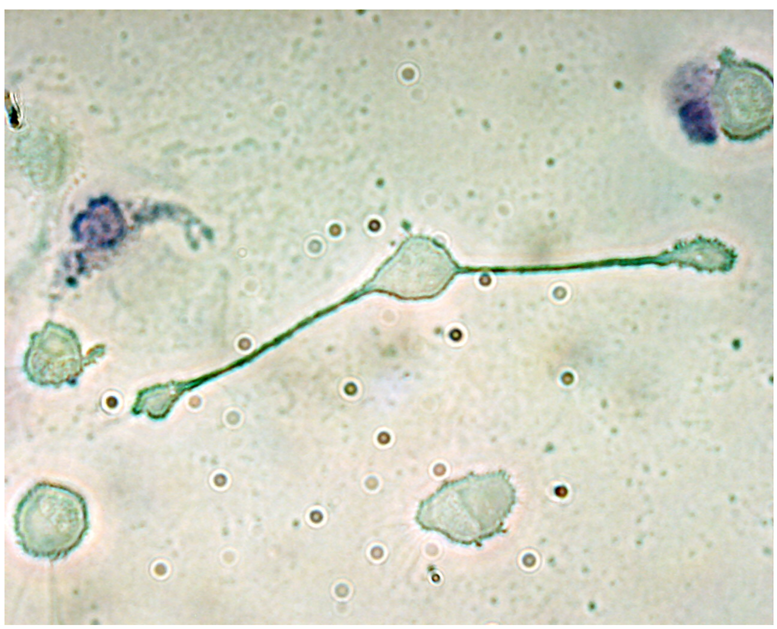

Figure 18.17: A type of WBC, called a macrophage, is attacking and about to swallow two particles. (23)

Platelets

Platelets are very small, but they are very important in blood clotting. Platelets are not cells they are sticky little pieces of larger cells. They bud off large cells that stay in the bone marrow. A platelet sits between a RBC and a WBC in **Figure** 18.18. Platelets carry chemicals that are important for proper blood clotting. When a blood vessel gets cut, platelets stick to the injured areas. They release chemicals called *clotting factors* which cause a web of protein fibers to form. This web catches RBCs and forms a clot. This clot stops more blood from leaving the body through the cut blood vessel. The clot also stops bacteria from entering the body.Platelets survive in the blood for 10 days before they are removed by the liver and spleen.

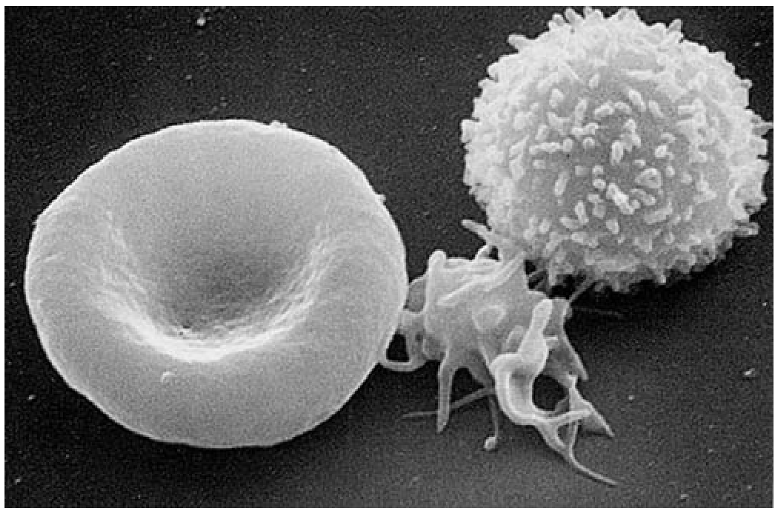

Figure 18.18: A platelet lies between a RBC, at left, and a WBC at right; platelets are little pieces of larger cells, called *megakaryocytes,* which are found in the bone marrow. (20)

Transport of Chemical Messages

The blood also acts as a messenger delivery service. Chemical messages called *hormones* are carried and delivered by the blood to cells around the body. Hormones are released into the blood by the cells that make them and are delivered by the blood to the cells the hormones are made for. An example of a hormone transported in the blood is insulin, which regulates the concentration of glucose in the blood.

Control of Body Temperature

Your blood system does more than deliver oxygen and nutrients to your body cells. Your blood also moves heat (thermal energy) around your body. When your brain senses that your body temperature is increasing, it sends messages to the blood vessels in the skin to increase in diameter. Increasing the diameter of the blood vessels increases the amount of blood and heat that moves near the skin surface. The heat is then released from the skin.

Blood Clotting

Blood clotting is a complex process by which blood forms solid clots. As discussed above, clotting is important to stop bleeding and begin repair of damaged blood vessels. Blood clotting disorders can lead to an increased risk of bleeding or clotting inside a blood vessel. Platelets are important for the proper clotting of blood.

Clotting is started almost immediately when an injury damages the inside lining of a blood vessel. Platelets clump together, forming a plug at the site of injury. Then, proteins in the plasma cause a series of chemical reactions that form a tough protein called **fibrin.** The fibrin strands form a web across the platelet plug, trapping red blood cells before they can leave through the wound site. This mass of platelets, fibrin, and red blood cells forms a clot that hardens into a scab.

Certain nutrients are needed for the clotting system to work properly. Two of these are calcium and vitamin K. Bacteria that live in your intestines make enough vitamin K so you do not need to eat extra vitamin K in your food.

Blood Types

Blood type is determined by the presence or absence of certain molecules, called *antigens,* on the surface of red blood cells (RBCs). There are four blood types; A, B, AB, and O.

Type A blood has type A antigens on the RBCs in the blood.

Type AB blood has A and B antigens on the RBCs.

Type B has B antigens on the RBCs.

Type O does not have any antigens (neither A nor B).

The blood types may also have antibodies for other blood types in their plasma. For example, a person with type A blood may have anti-B antibodies (against B antigens), and a person with type O blood can have anti-A and anti-B antibodies in their blood. The blood type of a person can be worked out by testing a drop of a person's blood using anti-A or anti-B antibodies.

The ABO blood group system is most important if a person needs a blood transfusion. A **blood transfusion** is the process of putting blood or blood products from one person into the circulatory system of another person.

If a person with type O blood received type A blood, the anti-A antibodies in the person's blood would attack the A antigens on the RBCs in the donor blood, as shown in **Figure** 18.19. The antibodies would cause the RBCs to clump together, and the clumps could block a blood vessel. Such a reaction could be fatal.

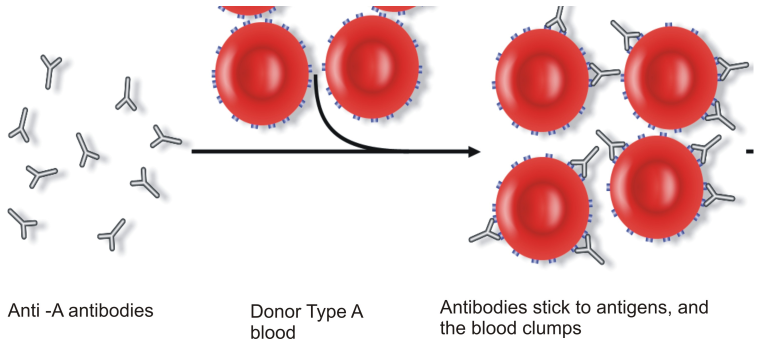

Figure 18.19: A person with type O blood has A and B antibodies in their plasma; if the person was to get type A blood instead of type O, Their A antibodies would attach to the antigens on the RBCs and cause them to clump together. (14)

The Rhesus System

The second most important blood group system in human blood is the Rhesus (Rh) system. The Rh blood group system currently consists of 50 blood group antigens, including the 5 antigens D, C, c, E, and e. The commonly used terms Rh factor, Rh positive and Rh negative refer to the D antigen only. A person either has, or does not have the Rh(D) antigen on the surface of their RBCs; written as *Rh(D) positive* (does have the RhD antigen) or *Rh(D) negative* (does not have the antigen).

Blood Donors

Recall that people with type O blood do not have any antigens on their RBCs. As a result, type O blood can be given to people with blood types A, B, or AB. If there are no antigens on the RBCs, there cannot be an antibody reaction to the blood. People with type O blood are often called **universal donors.**

The blood plasma of AB blood does not contain any anti-A or anti-B antibodies. People with type AB blood can receive any ABO blood type. People with type AB positive blood are called **universal recipients.** The antigens and antibodies that define blood type are listed in **Table** (18.2).

In April 2007 researchers discovered a way to convert blood types A, B, and AB to O. The researchers used enzymes to remove the antigens on the surface of the RBCs. This discovery could lead to producing or modifying blood cells that can be used as donors to people with all blood types.

Table 18.2: **Blood Types, Antigens, and Antibodies**

Blood type	Antigen type	Plasma antibodies	Can receive blood from types	Can donate blood to types
A	A	anti-B	A,O	A, AB
B	B	anti-A	B,O	B, AB
AB	A and B	none	AB, A, B, O	AB
O	none	anti-A, anti-B	O	AB, A, B, O

(*Source:* Niamh Gray-Wilson)

Blood Diseases

Problems can occur with red blood cells, white blood cells, platelets, and other parts of the blood. Many blood disorders are genetic, they are inherited from a parent. Some blood diseases are a caused by not getting enough of a certain nutrient, while others are cancers of the blood.

Sickle-Cell Disease

Sickle cell disease is a blood disease that is caused by abnormally-shaped blood protein hemoglobin. Many of the RBCs of a person with sickle cell disease are long and curved (sickle-shaped), as shown in **Figure** 18.20. The long, sickle-shaped RBCs can have damaged cell membranes, which can cause them to burst. The long shape of the cells can cause them to get stuck in narrow blood vessels. This clotting causes oxygen starvation in tissues, which causes pain and may cause damage such as stroke or heart attack. People with sickle-cell disease are most often well, but can on occasion have painful attacks. The disease is not curable, but can be treated with medicines. Heterozygous individuals have an advantage; they are resistant to severe malaria. See the *Genetics* chapter for further discussion.

Anemia

Hemoglobin is the oxygen-carrying molecule found inside RBCs. **Anemia** results when there is not enough hemoglobin in the blood to carry oxygen to body cells. Hemoglobin normally carries oxygen from the lungs to the tissues. Anemia leads to a lack of oxygen in organs. Anemia is usually caused by one of three things:

- A loss of blood volume through a bleeding wound or a slow leak of blood.
- The destruction of RBCs.

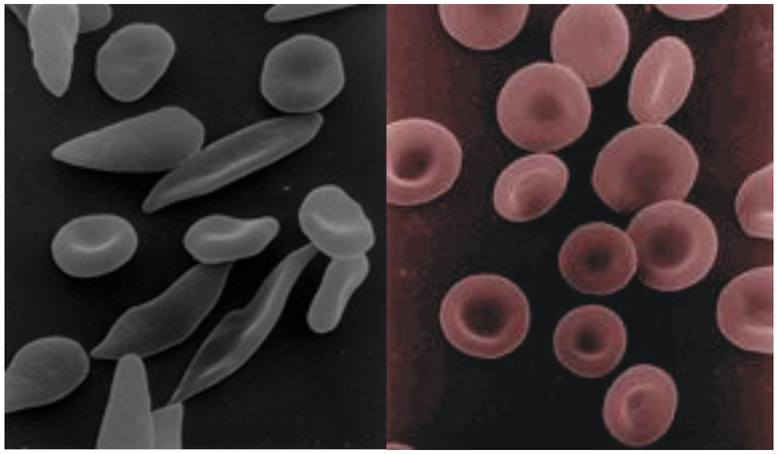

Figure 18.20: The RBCs of a person with sickle cell disease (left) are long and pointed rather than straight like normal cells (right); the abnormal cells cannot carry oxygen properly and can get stuck in capillaries. (15)

- Lack of RBC production.

Anemia may not have any symptoms. Some people with anemia feel weak or tired in general or during exercise. They also may have poor concentration. People with more severe anemia often get short of breath during activity. **Iron-deficiency anemia** is the most common type of anemia. It occurs when the dietary intake or absorption of iron is less than what is needed by the body. As a result, hemoglobin, which contains iron, cannot be made. In the United States, 20 percent of all women of childbearing age have iron deficiency anemia, compared with only 2 percent of adult men. The most common cause of iron deficiency anemia in young women is blood lost during menstruation. Iron deficiency anemia can be avoided by getting the recommended amount of iron in the diet. Anemia is often treated or prevented by taking iron supplements.

Boys and girls aged between the ages of 9 and 13 should get 9 mg of iron every day. Girls between the ages of 14 and 18 should get 15 mg of iron every day. Boys aged between the ages of 14 and 18 should get 11 mg of iron every day. Pregnant women need the most iron—27 mg daily.

Good sources of iron include shellfish such as clams and oysters. Red meat such as beef is also a good source of iron. Non-animal sources of iron include seeds, nuts, and legumes. Breakfast cereals often have iron added to them in a process called *fortification.* Some good sources of iron are listed in **Table** (18.3). Eating vitamin C along with the iron-containing food increases the amount of iron that the body can absorb.

Table 18.3:

Food	Milligrams (mg) of Iron
Canned clams, drained, 3 oz	23.8
Fortified dry cereals, about 1 oz	1.8 to 21.1
Roasted pumpkin and squash seeds, 1 oz	4.2
Cooked lentils, ½ cup	3.3
Cooked fresh spinach, ½ cup	3.2
Cooked ground beef, 3 oz	2.2
Cooked sirloin beef, 3 oz	2.0

(*Created by:* Niamh Gray-Wilson. *Information Source:* Centers of Disease Control and Prevention http://www.cdc.gov/nccdphp/dnpa/nutrition/nutrition_for_everyone/iron_deficiency/#Iron%20Sources)

Leukemia

Leukemia is a cancer of the blood or bone marrow. It is characterized by an abnormal production of blood cells, usually white blood cells. **Lymphoma** is a type of cancer in white blood cells called *lymphocytes.* There are many types of lymphoma.

Hemophilia

Hemophilia is the name of a group of sex-linked (X-linked) hereditary diseases that affect the body's ability to control blood clotting (see the *Genetics* chapter). Hemophilia is caused by a lack of clotting factors in the blood. Clotting factors are needed for the normal clotting of blood. A person who has hemophilia is initially able to make a clot to stop the bleeding, but because fibrin is not produced, the body is unable to keep a clot at an injury site. The risk of internal bleeding is also increased in hemophilia, especially into muscles, joints, or bleeding into closed spaces.

Lesson Summary

- Blood is a colloidal solution that contains red blood cells, white blood cells, and platelets. The cells are suspended in plasma. The red blood cells give blood its red color. Blood carries oxygen and nutrients to body calls and carries wastes away. It also helps to maintain body temperature and to carry chemical messages called *hormones* around the body.
- Hemoglobin is the oxygen-carrying protein that is found in red blood cells. White blood cells defend the body against infection by bacteria, viruses and other pathogens.

Some WBCs swallow pathogens, and others produce antibodies that attack and destroy pathogens.
- Blood type is determined by the presence or absence of certain molecules, called *antigens,* on the surface of red blood cells (RBCs). There are four blood types; A, B, AB, and O.
- If a person receives the wrong blood type, antibodies in the person's blood would attack the antigens on the RBCs in the donor blood. The antibodies would cause the RBCs to clump together, and the clumps could block a blood vessel.
- Sickle cell disease is a blood disease that is caused by abnormally-shaped blood protein hemoglobin.
- Anemia is a disorder in which there is not enough hemoglobin in the blood to carry oxygen to body cells.

Review Questions

1. What types of cells are found in blood?
2. What is the liquid part of blood called?
3. What is the function of platelets?
4. Identify two functions of blood other than bringing oxygen to body cells.
5. What is the oxygen-carrying protein found in red blood cells?
6. Identify two ways that white blood cells defend the body from infection.
7. How are the red blood cells of the different blood groups different?
8. They have different antigens on the surface of the cells.
9. Why are people with type O blood called *universal donors?*
10. Why are people with type AB blood called *universal recipients?*
11. Problem | question=Identify three blood disorders or diseases. |difficulty=Beginning | solution= Problem | question=How can the shape of the hemoglobin protein in a person with sickle-cell disease affect other body systems? |difficulty=Challenging | solution=
12. What is a common cause of anemia in young people?
13. Identify two good sources of iron in the diet.

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki

Vocabulary

ABO blood type system Blood group system that is determined by the presence or absence of certain molecules, called antigens, on the surface of red blood cells (RBCs); there are four blood types in the ABO system: A, B, AB, and O.

anemia The condition of not having enough hemoglobin in the blood to carry oxygen to body cells.

antibodies Proteins that identify pathogens or other substances as being harmful; flow in blood; can destroy pathogens by attaching to the cell membrane of the pathogen.

blood clotting The complex process by which blood forms solid clots.

blood transfusion The process of putting blood or blood products from one person into the circulatory system of another person.

fibrin A tough protein that forms strands during the blood clotting process.

hemophilia A group of hereditary diseases that affect the body's ability to control blood clotting.

iron-deficiency anemia Occurs when the dietary intake or absorption of iron is less than what is needed by the body. As a result, hemoglobin, which contains iron, cannot be made.

leukemia Cancer of the blood or bone marrow; characterized by an abnormal production of blood cells, usually white blood cells.

lymphoma Cancer of white blood cells called *lymphocytes.*

plasma The golden-yellow liquid part of the blood.

platelets Fragments of larger cells that are important in blood clotting.

red blood cells (RBCs) Flattened disk-shaped cells that carry oxygen, the most common blood cell in the blood. Mature red blood cells do not have a nucleus.

rhesus (Rh) system The second most important blood group system in human blood transfusion. A person either has, or does not have the Rh(D) antigen on the surface of their RBCs; written as *Rh(D) positive* (does have the RhD antigen) or *Rh(D) negative* (does not have the antigen).

sickle cell disease A blood disease that is caused by abnormally-shaped blood protein hemoglobin.

universal donor A person with type O positive blood; type O RBC do not have any antigens on their membranes and so would not cause an immune reaction in the body of a recipient.

universal recipient A person with type AB positive blood; the blood plasma of AB blood does not contain any anti-A or anti-B antibodies. People with type AB blood can receive any ABO blood type.

white blood cells Nucleated blood cells that are usually larger than red blood cells; defend the body against infection by bacteria, viruses, and other pathogens.

Points to Consider

- Why is the blood in veins not under pressure?
- How can your diet affect the cardiovascular system?

18.4 Lesson 18.4: Health of the Cardiovascular System

Lesson Objectives

- Outline the cause of blood pressure in arteries.
- Identify the healthy range for blood pressure.
- Describe three types of cardiovascular disease.
- Identify things you can do to avoid cardiovascular disease.

Check Your Understanding

- What is the role of the cardiovascular system?

Introduction

The health of your whole body depends on the good health of your cardiovascular system. The health of the cardiovascular system (CV system) can be overlooked because damage to the CV system often does not have any symptoms. In this lesson you will learn about common health problems with the CV system, and how you can work toward having a healthy CV system.

Blood Vessels and Blood Pressure

Blood pressure is the force exerted by circulating blood on the walls of blood vessels. The contracting ventricles push blood out of the heart under force. The force of the contractions put the blood under pressure. The pressure causes the walls of the arteries to move in a rhythmic fashion. Blood in arteries is under the greatest amount of pressure. A person's pulse is the throbbing of their arteries that results from the heart beat.

The pressure of the circulating blood gradually decreases as blood moves from the arteries, and into the smaller blood vessels. Blood that is in veins is not under pressure. The term *blood pressure* generally refers to the pressure in the larger arteries that take blood away from the heart. Arterial pressure results from the force that is applied to blood by the contracting heart, where the blood "presses" against the walls of the arteries.

The *systolic* arterial pressure is the highest pressure in the arteries. The *diastolic* arterial pressure is the lowest pressure. Arterial pressure is most commonly measured by an instrument called a *sphygmomanometer,* shown in **Figure** 18.21. The height of a column of mercury indicates the pressure of the circulating blood. Many modern blood pressure devices no longer use mercury, but values are still reported in millimeters of mercury (mm Hg).

Figure 18.21: A digital sphygmomanometer is made of an inflatable cuff and a pressure meter to measure blood pressure. (22)

Healthy Blood Pressure Ranges

In the United States, the healthy ranges for arterial pressure are:

- Systolic: less than 120 mm Hg
- Diastolic: less than 80 mm Hg

Blood pressure is usually written as systolic/diastolic mm Hg. For example, a reading of 120/80 mm Hg, is said as "one twenty over eighty." These measures of arterial pressure are not static, they change with each heartbeat and during the day. Factors such as age, gender and race also influence blood pressure values. Pressure also varies with exercise, emotions, sleep, stress, nutrition, drugs, or disease.

Studies have shown that people whose systolic pressure is around 115 mm Hg rather than 120 mm Hg have fewer health problems. Clinical trials have shown that people who have arterial pressures at the low end of these ranges have much better long term cardiovascular health.

Hypertension which is also called *high blood pressure,* is a condition in which a person's blood pressure is always high. Hypertension is said to be present when a person's systolic blood pressure is always 140 mm Hg or higher, and/or their diastolic blood pressure is always 90 mm Hg or higher. Having hypertension increases a person's chance for developing heart disease, having a stroke, and other serious cardiovascular diseases.

Hypertension often does not have any symptoms, so a person may not know they have high blood pressure. For this reason hypertension is often called the silent killer. However, hypertension can be easily diagnosed and is usually treatable. Treatments for hypertension include diet changes, exercise, and medication.

Atherosclerosis and Other Cardiovascular Diseases

A **cardiovascular disease (CVD)** is any disease that affects the cardiovascular system. But, the term is usually used to describe diseases that are linked to atherosclerosis. **Atherosclerosis** is a chronic inflammation of the walls of arteries that causes swelling and a buildup of material called **plaque.** Plaque is made of cell pieces, fatty substances, calcium, and connective tissue that build up around the area of inflammation. As a plaque grows it stiffens and narrows the artery, which reduces the flow of blood through the artery, shown in **Figure** 18.22.

Atherosclerosis

Atherosclerosis normally begins in later childhood, and is usually found in most major arteries. It does not usually have any early symptoms. Causes of atherosclerosis include a high-fat diet, high cholesterol, smoking, obesity, and diabetes. Atherosclerosis becomes a threat to health when the plaque buildup interferes with the blood circulation in the heart or the brain. A blockage in the blood vessels of the heart can cause a *heart attack.* Blockage of the

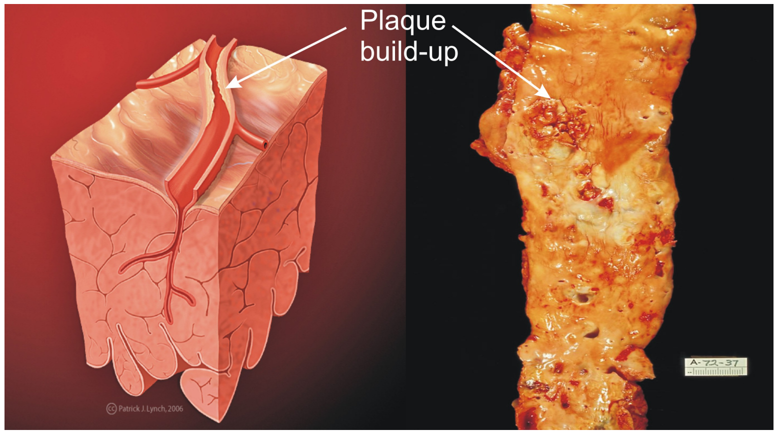

Figure 18.22: Atherosclerosis is sometimes referred to as *hardening* of the arteries; plaque build-up reduces the blood flow through the artery. (24)

circulation in the brain can cause a *stroke.* According to the American Heart Association, atherosclerosis is a leading cause of CVD.

Coronary Heart Disease

Cardiac muscle cells are fed by the coronary arteries. Blocked flow in a coronary artery can result in a lack of oxygen and the death of heart muscle. **Coronary heart disease** is the end result of the buildup of plaques within the walls of the coronary arteries. Coronary heart disease often does not have any symptoms. A symptom of coronary heart disease is chest pain. Occasional chest pain, called *angina* can happen during times of stress or physical activity. The pain of angina means the heart muscle fibers need more oxygen than they are getting.

Most people with coronary heart disease often have no symptoms for many years until they have a heart attack. **A heart attack** happens when the blood supply to a part of the heart is blocked. The cardiac muscle that depends on the blood supply from the blocked artery does not get any oxygen. Cardiac muscle fibers that is starved of oxygen for more than about five minutes will die. Cardiac muscle does not divide, so dead cardiac muscle cells are not replaced. Coronary heart disease is the leading causes of death of adults in the United States. How a blocked coronary artery can cause a heart attack, and cause part of the heart muscle to die is shown in **Figure** 18.23. Injured cardiac muscle does not contract as well as healthy tissue, so the heart will not work as well as it used to.

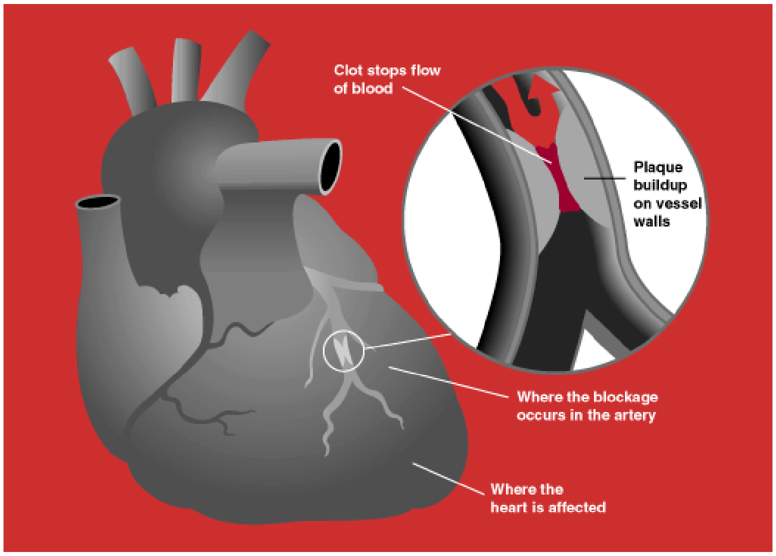

Figure 18.23: A blockage in a coronary artery stops oxygen getting to part of the heart muscle; areas of the heart that depend on the blood flow from the blocked artery are starved of oxygen. (4)

Stroke

Atherosclerosis in the arteries of the brain can lead to a stroke. A **stroke** is a loss of brain function due to a blockage of the blood supply to the brain. It can be caused by a blood clot, a free-floating object that gets caught in a blood vessel, or by a bleeding blood vessel.

Risk factors for stroke include advanced age, high blood pressure, having a previous stroke, diabetes, high cholesterol, and cigarette smoking. Reducing blood pressure is the most important controllable risk factor of stroke. However, many other risk factors, such as avoiding tobacco or quitting tobacco smoking are also important.

Keeping Your Cardiovascular System Healthy

There are many risk factors that can cause a person to develop CVD. A **risk factor** is anything that is linked to an increased chance of developing a disease or an infection. Some of the risk factors for CVD you cannot control, but there are many risk factors you can control.

Risk factors you cannot control include:

- **Age** The older a person is, the greater their chance of developing a cardiovascular disease.
- **Gender** Men under age 64 are much more likely to die of coronary heart disease than women, although the gender difference declines with age.

- **Genetics** Family history of cardiovascular disease increases a person's chance of developing heart disease.

Risk factors you can control include:

- **Tobacco Smoking** Giving up smoking or never starting to smoke is the single most effective way of reducing the risk of heart disease.
- **Diabetes** Having diabetes can cause changes (such as high cholesterol levels) which in themselves are risk factors.
- **High Cholesterol Levels** High amounts of low density lipids in the blood, also called *bad cholesterol,* are a significant risk factor
- **Obesity** Being obese, especially if the fat is deposited mostly in the torso, rather than the hips and thighs, increases risk significantly
- **High Blood Pressure** Hypertension can cause atherosclerosis
- **Lack of Physical Activity** Aerobic activities, such as the one shown in **Figure** 18.24, help keep your heart healthy To reduce the risk of disease, you should be active for at least 60 minutes a day, five days a week (or most days of the week).
- **Poor Eating Habits** Eating mostly foods that are nutrient poor (do not have many nutrients other than fat or carbohydrate) leads to high cholesterol levels and overweight, among other things.

Figure 18.24: Thirty minutes a day of vigorous aerobic activity, such as basketball, is enough to help keep your cardiovascular system healthy. (12)

Although there are uncontrollable risk factors, a person whose family has a history of CVD does not have to develop heart disease. There are many things a person can do to help prevent CVD, even if CVD is in their family. A person who is physically active every day, eats healthfully, and avoids tobacco can lower their chances of developing a CVD.

Men have a higher rate of cardiovascular disease than women do, but it is the number one health problem for women in industrialized countries. The risk for older women (in late adulthood) is almost equal that of older men.

Cardiovascular Disease Awareness: What You Can Do

Being active every day and eating healthfully are two of the most important things you can do to maintain a healthy cardiovascular system. Avoiding tobacco is also very important. You do not to be on a sports team or join a gym to be physically active. For example, shooting hoops at your school or local basketball courts can help keep your heart healthy. *Aerobic activities* are activities that cause your heart to beat faster and allow your muscles to use oxygen to get energy to contract. When done regularly, aerobic activities increase the size of the heart so it pumps blood around the body more efficiently. Aerobic activities also help to keep blood vessels healthy. To stay healthy, teens and children should be active for at least 60 minutes most days of the week.

Limiting the amount of saturated fat in your diet can also keep your heart healthy. Saturated fats are found in dairy foods, meats, cookies, pies, some chocolates, and ice cream. Saturated fats are usually solid at room temperature. Fat gives food flavor and texture. Saturated fats occur naturally in foods that come from animals, such as meat and milk, but they are often added to baked products such as cookies, shown in **Figure** 18.25, to give the foods flavor and texture. Not all fats are harmful to the cardiovascular system. Fats called *monounsaturated* and *polyunsaturated fats* are needed by the body, and should make up most of the fats that you eat in your diet. Monounsaturated and polyunsaturated fats are found in plants and fish, and are usually liquid at room temperature. To learn more about the importance of fats in your diet, read the *Choosing Healthful Foods* lesson of the *Food and the Digestive System* chapter.

Cardiovascular diseases are called *lifestyle diseases* because they are caused mostly by everyday choices that people make, such as what to eat for dinner, or what to do during their free time. For example, watching TV with your dog does not involve much moving around so it does not exercise the body, whereas bringing the dog for a walk outside exercises both of you. Decisions that you make today and everyday - those of developing healthy lifelong habits - will affect your cardiovascular health many years from now.

Many studies have shown that plaque build-up starts in the teen years. However, teens are more concerned about risks such as HIV, accidents, and cancer than cardiovascular disease. One in three people will die from complications due to atherosclerosis. For this reason there is an emphasis on the prevention of CVD through risk reduction. For example, healthy eating, regular physical activity, and avoidance of smoking can greatly decrease a person's chance of developing a CVD.

Figure 18.25: The USDA's MyPyramid recommends that you limit the amount of such foods in your diet to occasional treats; some foods containing saturated fats may contain other nutrients. (2)

Lesson Summary

- Blood pressure is the force exerted by circulating blood on the walls of blood vessels. The force of the contractions put the blood under pressure. Blood pressure is measured by an instrument called a *sphygmomanometer.*
- In the United States the healthy ranges for systolic pressure is less than 120 mm Hg and a diastolic pressure of less than 80 mm Hg. Hypertension is a condition in which a person's blood pressure is always high.
- A cardiovascular disease (CVD) is any disease that affects the cardiovascular system. Atherosclerosis, coronary heart disease, and stroke are examples of CVDs.
- Cardiovascular diseases are lifestyle diseases, they are mostly caused by lifestyle choices that people make. Having a poor diet and not getting enough exercise are two major causes of CVD.

Further Reading / Supplemental Links

- http://mypyramid.gov http://www.presidentschallenge.org/; http://mypyramid.gov
- http://www.cdc.gov/youthcampaign/marketing/tweens/yellowball/index.htm
- http://www.cdc.gov/nccdphp/dnpa/physical/everyone/recommendations/index.htm
- http://www.cdc.gov/bloodpressure http://en.wikipedia.org/wiki/Aerobic_exercise; http://www.cdc.gov/bloodpressure

Review Questions

1. What is the cause of blood pressure?
2. How is the pulse related to blood pressure?
3. Is the blood in veins under pressure? Explain your answer.
4. What is the healthy range for blood pressure?
5. When is a person considered to have hypertension?
6. Why is hypertension called a silent killer?
7. A stroke is often called a *brain attack,* in a similar way to a *heart attack.* How are these two things similar?
8. What is atherosclerosis?
9. What is a risk factor?
10. What is the difference between a controllable risk factor and an uncontrollable risk factor?
11. Why are cardiovascular diseases called lifestyle diseases?
12. Identify three things a person could do to reduce their chances of developing a CVD.

Vocabulary

angina Chest pain caused by the lack of oxygen to the heart muscle; can happen during times of stress or physical activity.

atherosclerosis A chronic inflammation of the walls of arteries that causes swelling and a buildup of material called plaque.

blood pressure The force exerted by circulating blood on the walls of blood vessels.

cardiovascular disease (CVD) Any disease that affects the cardiovascular system, although the term is usually used to describe diseases that are linked to atherosclerosis.

coronary heart disease The end result of the buildup of plaques within the walls of the coronary arteries.

heart attack Event that occurs when the blood supply to a part of the heart is blocked.

hypertension Also called high blood pressure; a condition in which a person's blood pressure is always high; the systolic blood pressure is always 140 mm Hg or higher, and/or their diastolic blood pressure is always 90 mm Hg or higher.

plaque Cell pieces made up of fatty substances, calcium, and connective tissue that build up around the area of inflammation; builds up on the lining of blood vessels.

risk factor Anything that is linked to an increased chance of developing a disease or an infection.

stroke A loss of brain function due to a blockage of the blood supply to the brain.

Points to Consider

- Do you think there is a relationship between the cardiovascular system and the respiratory system? What could it be?
- Do you think hypertension affects the ability of the blood to release carbon dioxide and pick up oxygen in the lungs? Why?

Image Sources

(1) *Capillaries connect arteries and veins.*. Public Domain-gov.

(2) Keksbaggern. http://commons.wikimedia.org/wiki/File:Christmas_Cookies.jpg. CC-BY.

(3) http://commons.wikimedia.org/wiki/File:Illu_lymph_capillary.png. Public Domain.

(4) http://commons.wikimedia.org/wiki/File:Heart_attack_diagram.png. Public Domain.

(5) http://commons.wikimedia.org/wiki/File:Illu_lymphatic_system.jpg. Public Domain.

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(10) Bruce Wetzel, Harry Schaefer. http://visualsonline.cancer.gov/details.cfm?imageid=2129. Public Domain.

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(23) Obli. http://commons.wikimedia.org/wiki/File:Macrophage.jpg. CC-BY-SA 2.0.

(24) *http://commons.wikimedia.org/wiki/File:Atherosclerosis,_aorta,_gross_pathology_PHIL_846_lores.jpg*. (a)CC-BY (b)Public Domain.

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Chapter 19

Respiratory and Excretory Systems

19.1 Lesson 19.1: Respiratory System

Lesson Objectives

- Identify the parts of the respiratory system.
- Identify the main function of the respiratory system.
- Describe how breathing works.
- Outline how the respiratory system and the cardiovascular system work together.
- Identify how breathing and cellular respiration are connected.

Check Your Understanding

- What is an organ system?
- What is the role of the circulatory system?
- How does your blood get oxygen?

Introduction

You breathe mostly without thinking about it. But, do you remember how uncomfortable you felt the last time you had a cold or a cough? You usually do not think about your respiratory system or how it works until there is a problem with it. Every cell in your body depends on your respiratory system. In this lesson, you will learn how your respiratory system works with your cardiovascular system to bring oxygen to every cell in your body.

Roles of the Respiratory System

Your respiratory system is made up of the tissues and organs that allow oxygen to enter and carbon dioxide to leave your body. These structures include your nose, mouth, larynx, pharynx, lungs, and diaphragm. These structures are shown in **Figure** 19.1. The main function of the respiratory system is to bring oxygen into the body and releases carbon dioxide into the atmosphere.

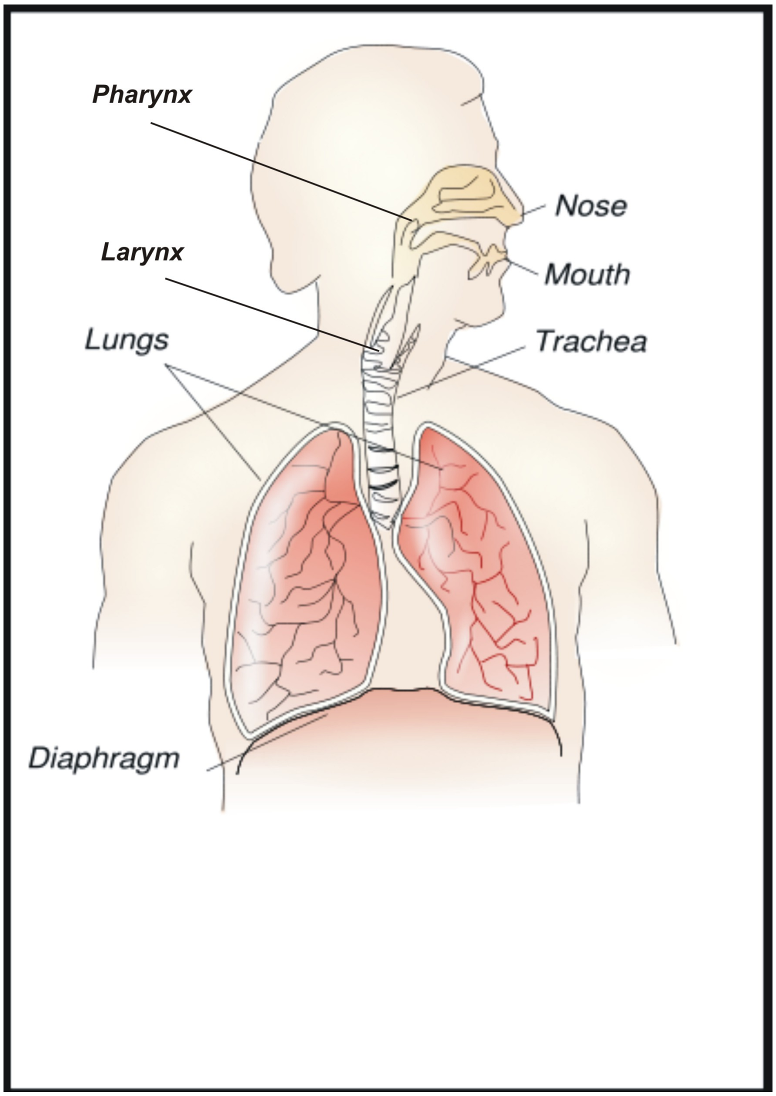

Figure 19.1: The respiratory system; air moves in through the nose and mouth, and down the trachea which is a long straight tube in the chest. (14)

Parts of the Respiratory System

Figure 1 shows many of the structures of the respiratory system. Each of the parts has a specific job. The parts of the respiratory system include:

The **diaphragm** is a sheet of muscle that extends across the bottom of the rib cage. It performs an important function in respiration. When the diaphragm contracts the chest volume gets larger and the lungs take in air. When the diaphragm relaxes, the chest volume gets smaller and air is pushed out of the lungs.

The **nose and nasal cavity** filters, warms, and moistens the inhaled air. The nose hairs and mucus produced by the cells that line the nose catch airborne particles and prevent them from reaching the lungs.

Behind the nasal cavity, air next passes through the **pharynx,** a long tube that is shared with the digestive system. Both food and air pass through the pharynx. A flap of connective tissue called the *epiglottis* closes over the trachea when food is swallowed to prevent choking or inhaling food.

The **larynx,** also called the *voicebox,* is found just below the point at which the pharynx splits into the trachea and the esophagus. Your voice comes from your larynx. Air from the lungs passes across thin membranes in the larynx and produces sound.

The **trachea,** or wind pipe, is a long tube that leads down to the chest where it divides into the right and left **bronchi** in the lungs. The bronchi branch out into smaller bronchioles in each lung.

The bronchioles lead to the alveoli. **Alveoli** are the little sacs at the end of the bronchioles. They look like little bunches of grapes at the end of the bronchioles, as shown in **Figure** 19.2. Most of the gas exchange occurs in the alveoli. **Gas exchange** is the movement of oxygen across a membrane and into the blood and the movement of carbon dioxide out of the blood.

How We Breathe

Most of the time, you breathe without thinking of it. Breathing is mostly an involuntary action that is controlled by a part of your brain that also controls your heart beat. If you swim, do yoga, or sing, you know you can also control your breathing.

Taking air into the body through the nose and mouth is called **inhalation.** Pushing air out of the body through the nose or mouth is called **exhalation.** The man in **Figure** 19.3 is exhaling before he surfaces in the pool water. The lungs cannot move by themselves. As mentioned above, air moves into and out of the lungs by the movement of muscles. The diaphragm and rib muscles contract and relax to move air in to and out of the lungs.

During inhalation, the diaphragm contracts and moves downward. The rib muscles contract

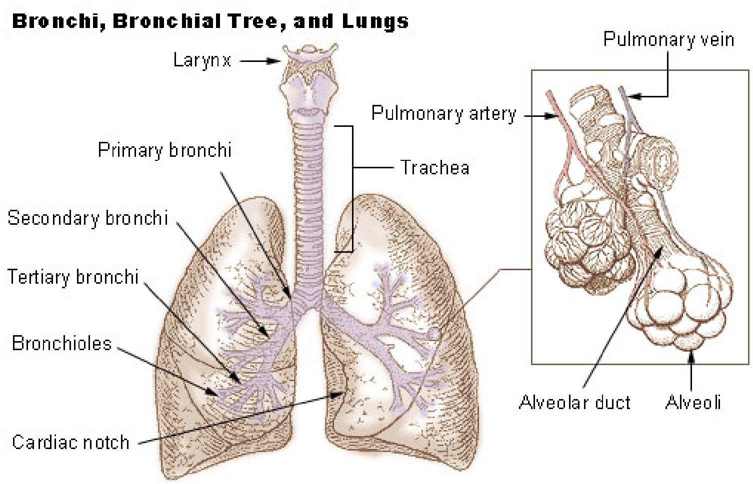

Figure 19.2: The alveoli are the tiny grape-like structures in the lungs and the sites of gas exchange. (11)

Figure 19.3: Being able to control breathing is important for many activities, such as swimming. The man in the photograph is exhaling before he surfaces the water. (10)

and cause the ribs to move outward. This causes the chest volume to increase. Because the chest volume is larger, the air pressure inside the lungs is less than the air pressure outside. This difference in air pressures causes air to be sucked into the lungs. When the diaphragm and rib muscles relax, air is pushed out of the lungs. Exhalation is normally a passive process, similar to letting the air out of a balloon.

The walls of the alveoli are very thin and are permeable to gases. The alveoli are lined with capillaries, the walls of which are also thin enough to allow gas exchange. These capillaries are shown in **Figure** 19.4. Oxygen diffuses from the alveoli to the blood in the capillaries that surround the alveoli. At the same time, carbon dioxide diffuses in the opposite direction, from capillary blood to the alveoli. At this point, the pulmonary blood is oxygen-rich, and the lungs are holding carbon dioxide. Exhalation follows, thereby ridding the body of the carbon dioxide and completing the cycle of respiration.

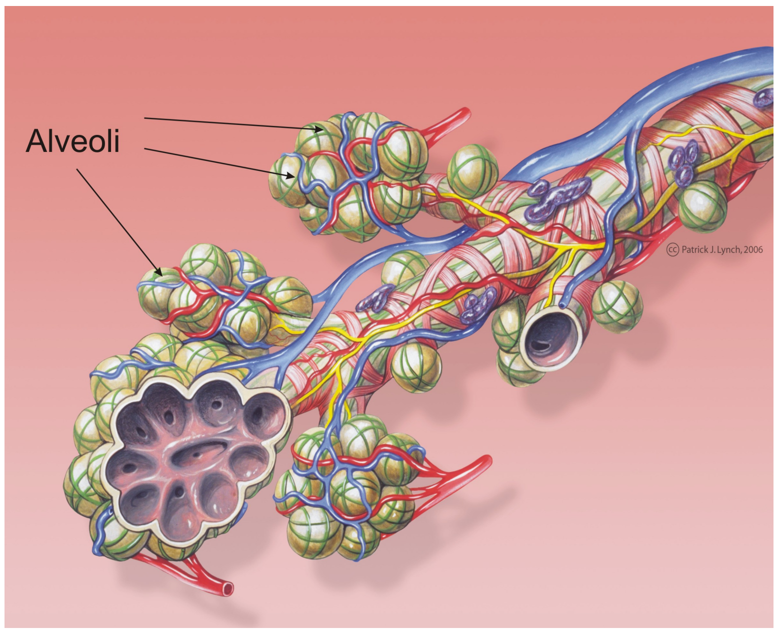

Figure 19.4: The bronchi and alveoli; during respiration, oxygen gets pulled into the lungs and enters the blood by passing across the thin alveoli membranes and into the capillaries. (12)

Breathing and Respiration

When you breath in, oxygen is drawn in through the mouth and down into the lungs. The oxygen then passes across the thin lining of the capillaries and into the blood. The oxygen molecules are carried to the body cells by the blood. Carbon dioxide from the body cells is carried by the blood to the lungs where it is released into the air. The process of getting oxygen into the body and releasing carbon dioxide is called **respiration.**

Sometimes breathing is called *respiration.* But, there is much more to respiration than just breathing. There are actually two parts to respiration. The movement of oxygen into the body and carbon dioxide out of the body is called *external respiration.* The exchange of gases between the blood and the cells of the body is celled *internal respiration.*

The Journey of a Breath of Air

Breathing is only part of the process of delivering oxygen to where it is needed in the body. **Gas exchange** occurs in the alveoli by passive diffusion of gases between the alveoli and the blood in the capillaries of the lungs. The passive diffusion of oxygen and carbon dioxide is shown in **Figure** 19.5.

Recall that diffusion is the movement of substances from an area of higher concentration to an area of lower concentration. The difference between the high concentration of oxygen (O_2) in the alveoli and the low O_2 concentration of the blood in the capillaries is enough to cause O_2 molecules to diffuse across the thin walls of the alveoli and capillaries and into the blood. Carbon dioxide (CO_2) moves out of the blood and into the alveoli in a similar way.

After leaving the lungs, the oxygenated blood returns to the heart to be pumped through the aorta and around the body. The oxygenated blood travels through the aorta, to the smaller arteries and finally to the capillaries where gas exchange occurs. The oxygen molecules move out of the capillaries and into the body cells. While oxygen diffuses from the capillaries and into body cells, carbon dioxide diffuses from the cells into the capillaries.

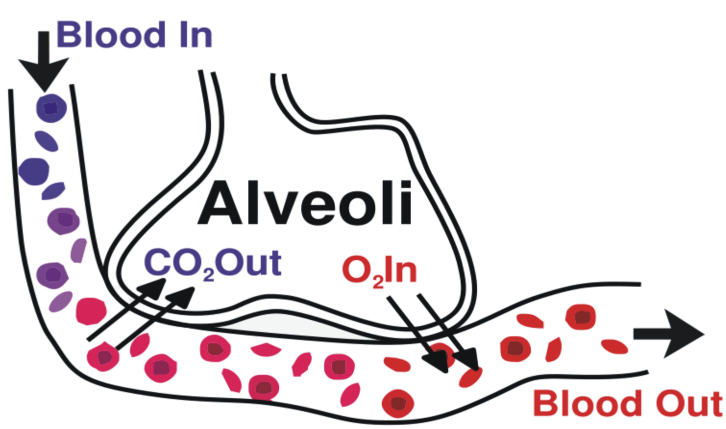

Figure 19.5: Gas exchange is the movement of oxygen into the blood and carbon dioxide out of the blood. (17)

Breathing and Cellular Respiration

The oxygen that arrives at the cells from the lungs is used by the cells to release the energy stored in molecules of sugar. **Cellular respiration** is the process of breaking down glucose to release energy (see the *Cell Functions* chapter). The waste products of cellular respiration include carbon dioxide and water. The carbon dioxide molecules move out of the cells and into the capillaries that surround the cells. The carbon dioxide is removed from the body by the lungs.

Lesson Summary

- Your respiratory system is made up of the tissues and organs that allow oxygen to enter and carbon dioxide to leave your body. These structures include your nose, mouth, larynx, pharynx, lungs, and diaphragm. The main function of the respiratory system is to bring oxygen into the body and releases carbon dioxide into the atmosphere. During inhalation, the diaphragm contracts and moved downward. The rib muscles contract and cause the ribs to move outward, causing the chest volume to increase. Air pressure inside the lungs is less than the air pressure outside so air is sucked into the lungs. When the diaphragm and rib muscles relax, air is pushed out of the lungs. Exhalation is normally a passive process.
- Oxygen enters the lungs, passes through the alveoli and into the blood. The oxygen is carried around the body in blood vessels. In a similar way, carbon dioxide, a waste product, moves into the blood capillaries by passive diffusion and is brought to the lungs in the pulmonary circulation. The carbon dioxide is released into the air during exhalation. The oxygen that arrives from the lungs is used by the cells during cellular respiration to release the energy stored in molecules of sugar. A waste product of cellular respiration, carbon dioxide, is removed from the body by exhalation.

Review Questions

1. Name the parts of the respiratory system.
2. What is the main function of the respiratory system?
3. A classmate says that the lung muscles cause the lungs to move during breathing. Do you agree with your classmate?
4. How do the respiratory system and the cardiovascular system work together?
5. Breathing is an involuntary action. Does this mean that you cannot control your breathing?
6. In what part of the lung does gas exchange occur?
7. What is the difference between breathing and respiration?
8. Identify how breathing and cellular respiration are connected.
9. What is the important gas that is carried into the lungs during inhalation?

10. What is the name of the waste gas that is released during exhalation?
11. If a disease caused the alveoli to collapse, how might this affect a person's health?

Further Reading / Supplemental Links

- http://en.wikipedia.org/wiki

Vocabulary

alveoli Little "sacs" at the end of the bronchioles where most of the gas exchange occurs.

diaphragm A sheet of muscle that extends across the bottom of the rib cage. When the diaphragm contracts the chest volume gets larger and the lungs take in air; when the diaphragm relaxes, the chest volume gets smaller and air is pushed out of the lungs.

epiglottis A flap of connective tissue that closes over the trachea when food is swallowed to prevent choking or inhaling food.

exhalation Pushing air out of the body through the nose or mouth.

external respiration The movement of oxygen into the body and carbon dioxide out of the body.

gas exchange The movement of oxygen across a membrane and into the blood and the movement of carbon dioxide out of the blood.

inhalation Taking air into the body through the nose and mouth.

internal respiration The exchange of gases between the blood and the cells of the body.

larynx Found just below the point at which the pharynx splits into the trachea and the esophagus. Your voice comes from your larynx; air from the lungs passes across thin membranes in the larynx and produces sound; also called the voicebox.

pharynx A long tube that is shared with the digestive system; both food and air pass through the pharynx.

respiration The process of getting oxygen into the body and releasing carbon dioxide.

trachea A long tube that leads down to the chest where it divides into the right and left bronchi in the lungs; also called the windpipe.

Points to Consider

- How do you think the health of your respiratory system might affect the health of other body systems?

19.2 Lesson 19.2: Health of the Respiratory System

Lesson Objectives

- Identify the organs affected by a respiratory disease.
- Identify how a respiratory disease can affect the rest of the body.
- Describe how asthma affects breathing.
- Outline how smoking affects the respiratory system.
- Identify what you can do to keep your respiratory system healthy.

Check Your Understanding

- What is the role of the respiratory system?
- What are some of the organs of the respiratory system?

Introduction

Most of the time your respiratory system works well, and you don't notice it doing its job. But your respiratory system can sometimes be knocked out of homeostasis. Recall that homeostasis is the balancing act your body performs that keeps conditions in your body stable. Anything that disrupts the respiratory system from doing its job disrupts homeostasis. When homeostasis no longer exists, there is disease. There are many causes of respiratory diseases, and many ways to treat such diseases. In this lesson you will learn about some of the most common respiratory diseases, and what you can do to help avoid them. You will also learn how the use of tobacco disrupts homeostasis, which leads to some of the most serious respiratory diseases.

Respiratory System Disease

In general, diseases that last a short time are called *acute diseases.* Other diseases can last for a long time, perhaps years. Diseases that last for a long time are called *chronic diseases.* Both acute and chronic diseases affect the respiratory system. **Respiratory diseases** are diseases of the lungs, bronchial tubes, trachea, nose, and throat (**Figure** 19.6). These diseases can range from a mild cold to a severe case of bacterial pneumonia. Respiratory diseases are common and may cause illness or death. Some respiratory diseases are caused by bacteria while others are caused by viruses, environmental pollutants such as tobacco smoke, or are hereditary.

Figure 19.6: This boy is suffering from whooping cough (also known as *pertussis*) which gets its name from the loud whooping sound that is made when the person inhales during a coughing fit. (4)

Bronchitis

Bronchitis is an inflammation of the bronchi. *Acute bronchitis* is usually caused by viruses or bacteria and may last several days or weeks. It is characterized by a cough that produces phlegm (mucus). Symptoms include shortness of breath and wheezing, which are related to the inflammation of the airways. Acute bronchitis is usually treated with antibiotics.

Chronic bronchitis may not be caused by a bacterium or a virus. Chronic bronchitis is defined as having a cough that produces phlegm, for at least three months in a two-year period. Tobacco smoking is the most common cause of chronic bronchitis, but it can be caused by environmental pollution such as smog and dust. It is generally part of a syndrome called *chronic obstructive pulmonary disease* (COPD), which we will learn about later. Treatments for bronchitis include antibiotics and steroid drugs to reduce inflammation.

Asthma

Asthma is a chronic illness in which the bronchioles are inflamed and become narrow, as shown in **Figure** 19.7. The muscles around the bronchioles contract which narrows the airways further. Large amounts of mucus are also made by the cells that line the lungs. A person with asthma has difficulty breathing. Their chest feels tight and they wheeze.

Asthma can be caused by different things such as exposure to an allergen. An **allergen** is any antigen that is not an infectious organism. Allergens can cause allergic reactions. Common allergens that cause asthma are mold, dust, or pet hair. Asthma can also be caused by cold air, warm air, moist air, exercise, or stress. The most common asthma triggers are viral illnesses such as the common cold. The symptoms of asthma can usually be controlled with medicine. *Bronchodilators* are drugs that reduce inflammation of the bronchioles allowing air through.

Asthma is not contagious and cannot be passed onto other people. Sometimes people with asthma are afraid that being active could cause them to have an asthma attack. Having asthma does not mean that you have to miss out on being active. Many teens that have asthma are active every day. Asthma cannot be cured, but is treatable with medicines. Children and adolescents who have asthma can still lead active lives if they control their asthma. Asthma can be controlled by taking medication and by avoiding contact with environmental triggers for asthma.

Pneumonia

Pneumonia is an illness in which the alveoli become inflamed and flooded with fluid. Pneumonia is a restrictive respiratory disease. Gas exchange cannot happen properly across the alveoli membranes. Pneumonia can be caused by many things. Infection by bacteria, viruses, fungi, or parasites can cause pneumonia. An injury caused by chemicals or a physical injury

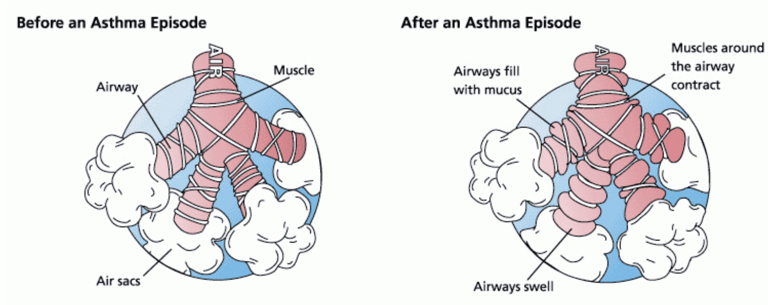

Figure 19.7: The two reactions that lead to asthma are when the bronchioles swell and the muscles around the bronchioles contract. (6)

to the lungs can also cause pneumonia. Symptoms of pneumonia include cough, chest pain, fever, and difficulty in breathing. Treatment depends on the cause of pneumonia. Bacterial pneumonia is treated with antibiotics.

Pneumonia is a common illness which occurs in all age groups, and is a leading cause of death among the elderly and people who are chronically and terminally ill. Vaccines to prevent certain types of pneumonia are available.

Tuberculosis

Tuberculosis (TB) is a common and often deadly infectious disease caused by a type of bacterium called *mycobacterium.* Tuberculosis most commonly attacks the lungs but can also affect other parts of the body. Mycobacteria in the alveoli cause an immune reaction in the body that damages the alveoli. TB is a chronic disease, but most people who become infected do not develop the full disease. The TB mycobacteria are spread in the air when people who have the disease cough, sneeze or spit. To help prevent the spread of the disease, public health notices, such as the one in **Figure** 19.8, reminded people how to stop the spread of the disease. Currently, drug resistant forms of TB are creating a new challenge for health professionals.

Cancer

Lung cancer is a disease where the cells that line the lungs grow out of control. The growing mass of cells pushes into nearby tissues and can affect how these tissues work. Lung cancer, which is the most common cause of cancer-related death in men and the second most common in women, is responsible for 1.3 million deaths worldwide every year The most common symptoms are shortness of breath, coughing (including coughing up blood), and weight loss. The most common cause of lung cancer is exposure to tobacco smoke.

Figure 19.8: A public health notice from the early 20th century reminded people that TB could be spread very easily. (9)

Emphysema

Emphysema is a chronic lung disease caused by loss of elasticity of the lung tissue. The surfaces of healthy alveoli are springy and elastic. They stretch out a little when full of air and relax when air leaves them. But the breakdown of the tissues that support the alveoli and the capillaries that feed the alveoli cause the alveoli to become hard and stiff. Eventually the walls of the alveoli break down and the alveoli become larger. When alveoli become larger, the amount of oxygen that can enter the blood with each breath is reduced. Much of the oxygen that gets into the large alveoli cannot be absorbed across the alveoli walls into the blood. Symptoms of emphysema include shortness of breath on exertion (usually when climbing stairs or a hill). Damage to the alveoli, which can be seen in **Figure** 19.9, is not curable. Smoking is a leading cause of emphysema.

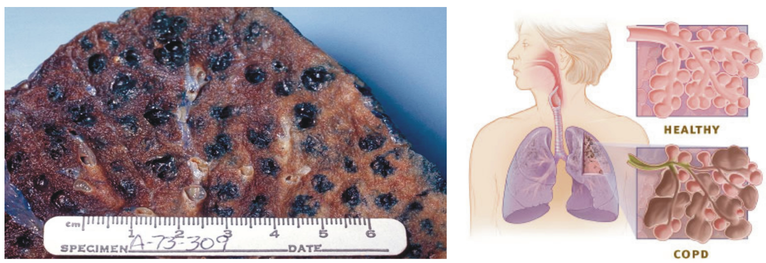

Figure 19.9: The lung of a smoker who had emphysema (left); the black areas are enlarged alveoli and tar, a sticky, black substance found in tobacco smoke is evident, and (right) COPD (Chronic obstructive pulmonary disease), a tobacco-related disease that is characterized by emphysema. (18)

Causes of Respiratory Diseases

Pathogens

Many respiratory diseases are caused by pathogens. A **pathogen** is an organism that causes disease in another organism. Certain bacteria, viruses, and fungi are pathogens of the respiratory system. The common cold and flu are caused by viruses. The influenza virus that causes the flu is shown in **Figure** 19.10. Tuberculosis, whooping cough, and acute bronchitis are caused by bacteria. The pathogens that cause colds, flu, and TB can be passed from person to person by coughing, sneezing, and by spitting.

Pollution

Air quality is related to several respiratory diseases. Asthma, heart and lung diseases, allergies, and several types of cancers are all linked to air quality. Air pollution can be caused by outdoor pollution or indoor pollution. Outdoor air pollution can be caused by car exhaust fumes, smoke from factories and forest fires, volcanoes, and animal feces. Some of

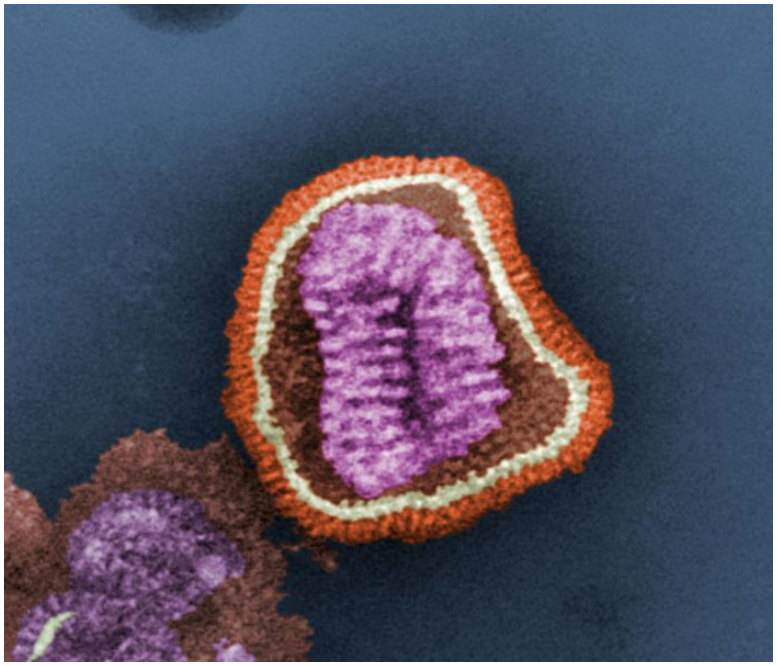

Figure 19.10: This is the influenza virus that causes the flu; the CDC (The Center for Disease Control and Prevention) recommends that children between the ages of 6 months and 19 years get a flu vaccination each year. (16)

the pollutants of concern include particulates, carbon dioxide, sulfur oxides, and lead. These pollutants contain tiny particles that can get "stuck" in the lining of the respiratory system and irritate the lungs. Indoor air pollution can be caused by tobacco smoke, dust, mold, insects, rodents, and cleaning chemicals.

Lifestyle Choices

Smoking is the major cause of chronic respiratory disease as well as cardiovascular disease and cancer. Exposure to tobacco smoke, by smoking or by breathing air that contains tobacco smoke is the leading cause of preventable death in the U.S. Regular smokers die about 10 years earlier than nonsmokers do. The Centers for Disease Control and Prevention (CDC) describes tobacco use as "the single most important preventable risk to human health in developed countries and an important cause of premature death worldwide.

Dangers of Smoking

Tobacco use, particularly cigarette smoking, is the single most preventable cause of death in the United States. Cigarette smoking alone is directly responsible for approximately 30 percent of all cancer deaths annually in the United States. The main health risks of using tobacco are linked to diseases of the cardiovascular system and respiratory system.

Cardiovascular diseases caused by smoking include heart disease and stroke. Diseases of the respiratory system that are caused by exposure to tobacco smoke include emphysema, lung cancer, and cancers of the larynx and mouth. Cigarette smoking causes 87 percent of lung cancer deaths. Smoking and using tobacco is also linked to the risk of developing other types of cancer such as pancreatic and stomach cancer.

Cigarettes, like the ones shown in **Figure** 19.11, are a major source of indoor air pollution. Cigarette smoke contains about 4,000 substances, including over 60 cancer-causing chemicals. Many of these substances, such as carbon monoxide, tar, arsenic, and lead, are toxic to the body. Non-smokers can also be affected by tobacco smoke. Exposure to secondhand smoke, also known as **environmental tobacco smoke (ETS)**, greatly increases the risk of lung cancer and heart disease in nonsmokers.

Chronic obstructive pulmonary disease (COPD) is a disease of the lungs in which the airways become narrowed. This leads to a limitation of the flow of air to and from the lungs causing shortness of breath. The limitation of airflow usually gets worse over time. COPD is most commonly caused by smoking. Gases and particles in tobacco smoke trigger an abnormal inflammatory response in the lung. The inflammatory response in the larger airways is known as chronic bronchitis. In the alveoli, the inflammatory response causes the breakdown of the tissues in the lungs, leading to emphysema.

Figure 19.11: Tobacco use, particularly cigarette smoking, is the single most preventable cause of death in the United States. (7)

Keeping Your Respiratory System Healthy

Many of the diseases related to smoking are called **lifestyle diseases,** diseases that are caused by choices that people make in their daily lives. For example, the choice to smoke can lead to cancer in later life. But, there are many things you can do to help keep your respiratory system healthy. Some of these are listed here:

Avoid Smoking

Never smoking or quitting now are the most effective ways to reduce your risk of developing chronic respiratory diseases such as cancer.

Eat Well, Exercise Regularly, and Get Rest

Eating a healthful diet, getting enough sleep, and being active every day can help keep your immune system strong.

Wash Your Hands

Washing your hands often, and after sneezing, coughing or blowing your nose help to protect you and others from diseases. Washing your hands for 20 seconds with soap and warm water can help prevent colds and flu. Some viruses and bacteria can live from 20 minutes up to 2 hours or more on surfaces like cafeteria tables, doorknobs, and desks. A public health notice that shows people how to prevent the spread of respiratory diseases is shown in **Figure** 19.12.

Avoid Contact with Others When Sick

Do not go to school or to other public places when you are sick. You risk spreading your illness to other people and getting sicker if you catch something else.

Visit Your Doctor

Getting the recommended vaccinations can help prevent diseases such as whooping cough and flu. Seeking medical help for diseases such as asthma can help control the severity of the disease.

Figure 19.12: *Cover your Cough; Clean your Hands* is a public health campaign that reminds people of the quickest and easiest ways to avoid spreading respiratory diseases such as colds and the flu. (5)

Lesson Summary

- Respiratory diseases are diseases that affect the lungs, bronchial tubes, trachea, nose, and throat. Respiratory diseases can reduce the amount of oxygen that gets into the blood. Asthma is an illness in which the bronchioles are inflamed and become narrow. The muscles around the bronchioles contract which narrows the airways further.
- Difficulty in breathing happens because of the inflammation, contraction of the muscles, and the production of mucus by the cells that line the bronchioles. Diseases of the respiratory system that are caused by exposure to tobacco smoke include emphysema, lung cancer and cancers of the larynx and mouth.
- Cigarette smoking causes 87 percent of lung cancer deaths. Smoking and using tobacco is also linked to the risk of developing other types of cancer. Avoiding smoking, getting enough exercise, and washing your hands often are three things you can do to help protect your respiratory system from illness.

Further Reading / Supplemental Links

- http://www.cdc.gov/vaccines/vpd-vac/pertussis/default.htm
- http://www.cdc.gov/tobacco/data_statistics/fact_sheets/youth_data/youth_tobacco.htm
- http://www.cdc.gov/asthma/children.htm http://www.cdc.gov/nceh/globalhealth/projects/airpollution.htm; http://www.cdc.gov/asthma/children.htm
- http://www.bmj.com/cgi/content/abstract/328/7455/1519 http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5644a2.htm; http://www.bmj.com/cgi/content/abstract/328/7455/1519
- http://www.cdc.gov/flu/protect/keyfacts.htm http://www.cdc.gov/germstopper/home_work_school.htm; http://www.cdc.gov/flu/protect/keyfacts.htm
- http://www.cancer.gov/cancertopics/factsheet/Tobacco/cancer http://en.wikipedia.org/wiki/Cigarette_smoking; http://www.cancer.gov/cancertopics/factsheet/Tobacco/cancer
- http://www.cancer.gov/cancertopics/factsheet/Tobacco/cancer
- http://www.cdc.gov/tobacco/data_statistics/sgr/sgr_2004/sgranimation/html/welcome.html
- http://www.cdc.gov/flu/protect/covercough.htm

Review Questions

1. Identify the organs that are affected by a respiratory disease.
2. How might a respiratory disease affect the rest of the body?
3. How does asthma affects the bronchioles?
4. Medicines called bronchodilators are used to treat the symptoms of asthma. What

action do you think these drugs have on the lungs?

5. What lifestyle activity has the largest health impact on the respiratory system?
6. Identify three diseases are linked to tobacco smoking.
7. Identify three things that can cause a respiratory disease.
8. What are two things you can do to keep your respiratory system healthy?
9. Pneumonia is a disease in which the alveoli fill up with fluid. How might this affect the lungs' ability to absorb oxygen?
10. How can washing your hands help prevent you from catching a cold?

Vocabulary

acute disease A disease that lasts a short time.

allergen Any antigen that is not an infectious organism, such as mold, dust, or pet hair.

asthma A chronic illness in which the bronchioles are inflamed and become narrow.

bronchodilators Drugs that reduce inflammation of the bronchioles allowing air through.

bronchitis An inflammation of the bronchi.

chronic bronchitis Having a cough that produces phlegm, for at least three months in a two-year period.

chronic disease A disease that lasts for a long time, perhaps a few years or longer.

chronic obstructive pulmonary disease (COPD) A disease of the lungs in which the airways become narrowed; leads to a limitation of the flow of air to and from the lungs causing shortness of breath.

emphysema A chronic lung disease caused by loss of elasticity of the lung tissue.

environmental tobacco smoke (ETS) Secondhand smoke, which greatly increases the risk of lung cancer and heart disease in nonsmokers.

lifestyle disease A disease that is caused by choices that people make in their daily lives.

lung cancer A disease where the cells that line the lungs grow out of control; the growing mass of cells pushes into nearby tissues and can affect how these tissues work.

pathogen An organism that causes disease in another organism; certain bacteria, viruses, and fungi are pathogens of the respiratory system.

pertussis Whooping cough; gets its name from the loud whooping sound that is made when the person inhales during a coughing fit.

pneumonia An illness in which the alveoli become inflamed and flooded with fluid.

respiratory disease A disease of the lungs, bronchial tubes, trachea, nose, and/or throat.

tuberculosis (TB) A common and often deadly infectious disease caused by a type of bacterium called *mycobacterium.*

Points to Consider

- The respiratory system gets rids of a certain type of wastes. What type of wastes do you think are removed by your respiratory system?

19.3 Lesson 19.3: Excretory System

Lesson Objectives

- Identify the functions of the excretory system.
- List the organs of the excretory system.
- Describe the parts of urinary system.
- Outline how the kidneys filter blood.
- Identify three disorders of the urinary system.

Check Your Understanding

- What are some "wastes" that must be removed from your body?
- Do your circulatory and respiratory systems remove "waste?"

Introduction

One of the most important homeostatic jobs your body does it to keep the right amount of water and salts inside your body. Too much water and your cells would swell and burst. Too little water and your cells would shrivel up like an old apple. Either extreme would cause illness and death of cells, tissues, and organs. The organs of your excretory system help to keep the correct balance of water and salts within your body.

Your body also needs to remove the wastes that build up from the metabolic activity of cells and digestion. These wastes include carbon dioxide, urea, and certain plant materials. If these wastes were not removed, your cells would stop working and you would get very sick. In this lesson you will learn how waste is removed from the body, and how the kidneys filter waste from the blood.

The Excretory System

The **excretory system** is the organ system that maintains homeostasis by keeping the correct balance of water and salts in your body. It also helps to release wastes from the body. **Excretion** is the process of removing wastes from the body. The organs of the excretory system are also parts of other organ systems. For example, your lungs are part of the respiratory system. Your lungs remove carbon dioxide from your body so they are also part of the excretory system. More organs of the excretory system, and the other organs systems of which they are part are listed in **Table** (19.1).

Table 1: Organs of the Excretory System

Table 19.1: **Organs of the Excretory System**

Organ(s)	Function	Other Organ System of which it is Part
Lungs	Remove carbon dioxide	Respiratory system
Skin	Sweat glands remove water, salts, and other wastes	Integumentary system
Large intestine	Removes solid waste and some water in the form of feces	Digestive system
Kidneys	Remove urea, salts, and excess water from the blood	Urinary system

Functions of the Excretory System

The excretory system controls the chemical make-up of body fluids. The organs of the excretory system remove metabolic wastes. They also maintain the proper concentrations of water, salts, and nutrients in the body. In this way the excretory system has an important homeostatic job.

Your body takes nutrients from food and uses them for energy, growth, and repair. After your body has taken what it needs from the food, waste products are left behind in the blood and in the large intestine. These waste products need to be removed from the body. The kidneys work with the lungs, skin, and intestines to keep the correct balance of nutrients, salts and water in your body.

The Urinary System

Sometimes and confusingly, the urinary system is called the excretory system. But, the urinary system is only a part of the excretory system. Recall that the excretory system is made up of the skin, lungs, and large intestine as well as the kidneys. The **urinary system** is the organ system that makes, stores, and gets rid of urine. It includes two kidneys, two ureters, the bladder, and the urethra. The urinary system is shown in **Figure** 19.13.

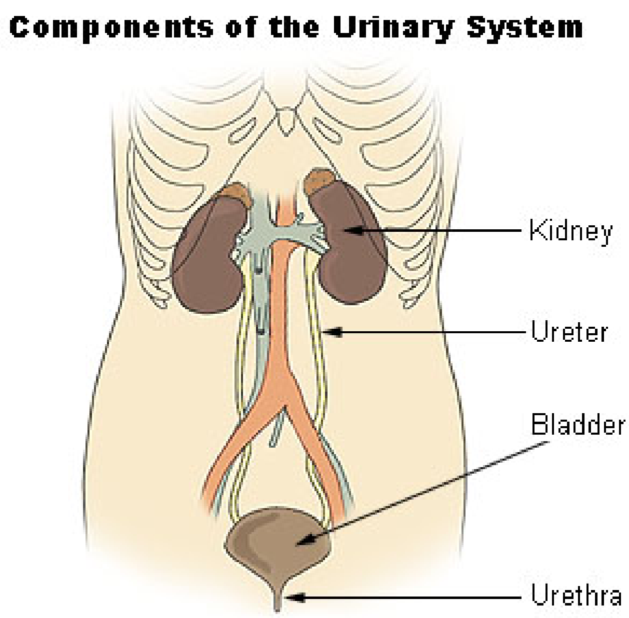

Figure 19.13: The kidneys filter the blood that passes through them and the urinary bladder stores the urine until it is released from the body. (8)

Organs of the Urinary System

As you can see from Figure 1, the kidneys are two bean-shaped organs. The **kidneys** filter and clean the blood and form urine. They are about the size of your fists and are found near the middle of the back, just below your rib cage. The **ureters** are tube-shaped structures that bring urine from the kidneys to the urinary bladder. The **urinary bladder** is a hollow, muscular, and elastic-walled organ. It is shaped a little like a balloon. It is the organ that collects urine which comes from the kidneys. Urine leaves the body through the **urethra.**

What is Urine?

Urine is a liquid that is formed by the kidneys when they filter wastes from the blood. Urine contains mostly water and also dissolved salts and nitrogen-containing molecules. The amount of urine excreted from the body depends on many things. Some of these include the amounts of fluid and food a person consumes and how much fluid they have lost in sweat and breathing.

Urine is can range from colorless to dark yellow, but is usually a pale yellow color. Dilute urine is light yellow in color. Concentrated urine is dark yellow or may be brown. The darker the urine, the less water it contains.

The urinary system removes a type of waste called *urea* from your blood. **Urea** is a nitrogen-containing molecule that is made when foods containing protein, such as meat, poultry, and certain vegetables, are broken down in the body. Urea and other wastes are carried in the bloodstream to the kidneys were they are removed and form urine.

How the Kidneys Filter Wastes

The kidneys are important organs in maintaining homeostasis. Kidneys perform a number of homeostatic functions:

- Maintain the volume of body fluids
- Maintain the balance of salt ions in body fluids
- Excrete harmful nitrogenous wastes (metabolic by-products) such as urea, ammonia, and uric acid

There are many blood vessels in the kidneys, as you can see in **Figure** 19.14. The kidneys remove urea from the blood through tiny filtering units called *nephrons.* **Nephrons** are tiny, tube-shaped structures found inside each kidney. A nephron is shown in **Figure** 19.15. Each kidney has up to a million nephrons. Each nephron collects a small amount of fluid and waste products from a small group of capillaries. If the body is in need of more water, water is removed from the fluid inside the nephron and is returned to the blood. The fluid within nephrons is carried out into a larger tube in the kidney called a *ureter* which you can see in **Figure** 19.14. Urea, together with water and other wastes, forms the urine as it passes through the nephrons and the kidney.

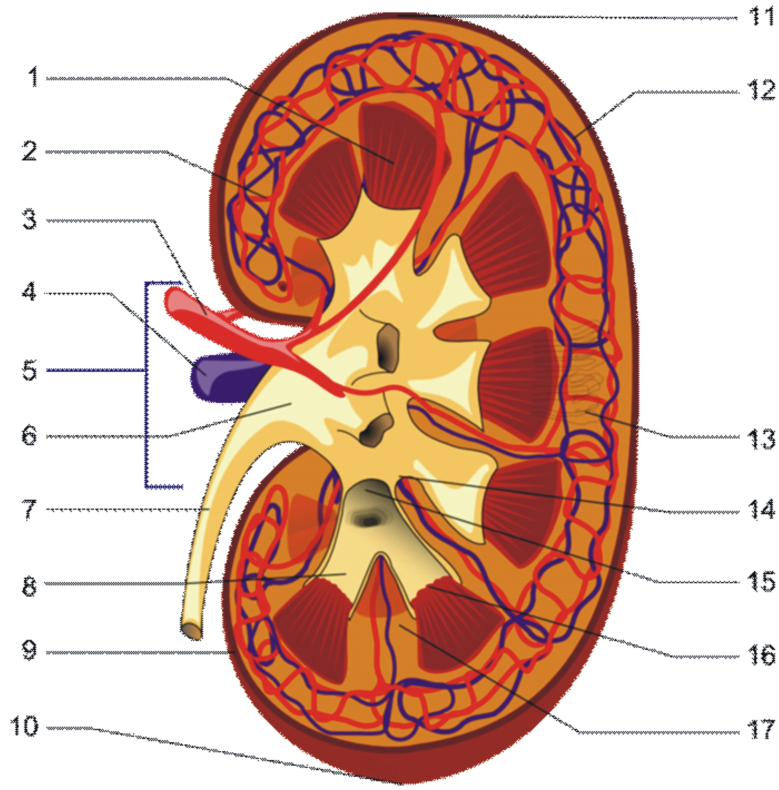

Figure 19.14: Structures of the kidney; fluid leaks from the capillaries and into the nephrons where the fluid forms urine then moves to the ureter and on to the bladder. (1)

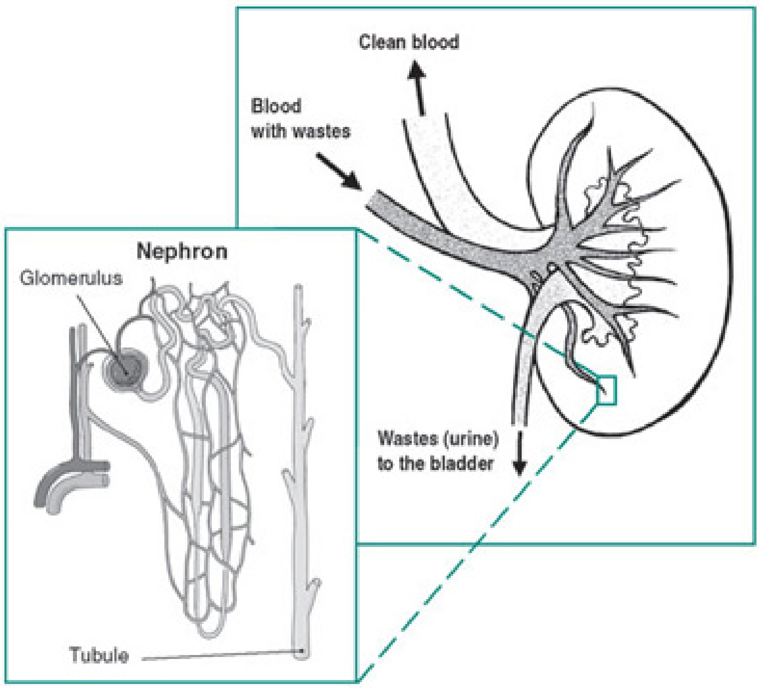

Figure 19.15: The location of nephrons in the kidney; the glomerulus is the network of blood vessels that filter liquid into the nephron, collects in the nephron tubules, and moves to the bladder through the ureter. (13)

Formation of Urine

The process of urine formation is as follows:

1. Blood flows into the kidney through the renal artery, shown in Figure 2. The renal artery branches into capillaries inside the kidney. Capillaries and the nephrons lie very close to each other in the kidney.
2. The blood pressure within the capillaries causes water and solutes such as salts, sugars, and urea to leave the capillaries and move into the nephron.
3. The water and solutes move along through the tube-shaped nephron to a lower part of the nephron. At this point most of the water and solutes are returned to the capillaries that surround the nephron.
4. The fluid that remains in the nephron at this point is called urine.
5. The blood that leaves the kidney in the renal vein has much less waste than the blood that entered the kidney.
6. The urine is collected in the ureters and is moved to the urinary bladder where it is stored.

Nephrons filter 125 ml (about ¼ cup) of body fluid per minute. In a 24-hour period nephrons produce about 180 liters of filtrate, of which 178.5 liters are reabsorbed. The remaining 1.5 liters of fluid forms urine.

Urine enters the bladder through the ureters. Similar to a balloon, the walls of the bladder are stretchy. The stretchy walls allow the bladder to hold a large amount of urine. The bladder can hold about 400 to 620 mL (about 1½ to 2½ cups) of urine, but may also hold more if the urine cannot be released immediately. **Urination** is the process of releasing urine from the body. Urine leaves the body through the urethra.

Nerves in the bladder tell you when it is time to urinate. As the bladder first fills with urine, you may notice a feeling that you need to urinate. The urge to urinate becomes stronger as the bladder continues to fill up.

Brain Control

The kidneys never stop filtering waste products from the blood, so they are always producing urine. The amount of urine your kidneys produce is dependent on the amount of fluid in your body. Your body loses water through sweating, breathing, and urination. The water and other fluids you drink every day help to replace the lost water. This water ends up circulating in the blood because blood plasma is mostly water.

The kidneys will normally adjust to the level of water a person drinks. For example, if a person suddenly increases their water intake, the kidneys will produce more diluted (watery) urine. If a person drinks much less fluid than they usually do, their urine will be more concentrated (contain much less water).

The filtering action of the kidneys is controlled by the pituitary gland. The pituitary gland is about the size of a pea and is found below the brain, as shown in **Figure** 19.16. The pituitary gland is also part of the endocrine system. The pituitary gland releases hormones which affect the ability of the kidneys to filter water from the blood.

The absorption of water back into blood is controlled by a hormone called *antidiuretic hormone (ADH)*. ADH is released from the pituitary gland in the brain. One of the most important roles of ADH is to control the body's ability to hold onto water. If a person does not drink enough water, ADH is released and it causes the kidneys to remove more water from the urine. The urine is more concentrated and is less in volume.

When too much fluid is present in the blood, the amount of ADH in the blood is reduced. This increases the amount of water that filters into the nephrons. The kidneys then produce a large volume of more dilute urine.

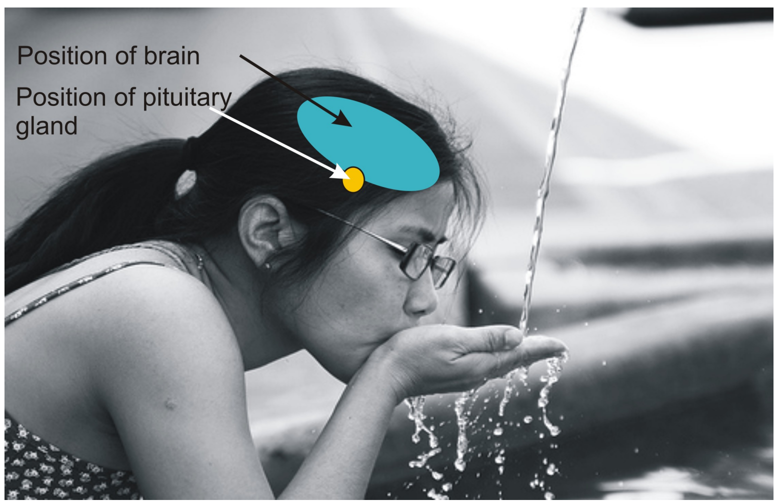

Figure 19.16: The pituitary gland is found directly below the brain and releases hormones that control the production of urine. (2)

Excretory System Problems

The urinary system controls the amount of water in the body, and removes wastes, so any problem with the urinary system can badly affect many other body systems. Some common urinary system problems are described here.

Kidney Stones

In some cases, certain mineral wastes in urine crystallize and form kidney stones like the one shown in**Figure** 19.17. Stones form in the kidneys and may be found anywhere in the urinary system. They vary in size. Some stones cause great pain while others cause very little pain. Some stones may need to be removed by surgery or ultrasound treatments.

Figure 19.17: A kidney stone; the stones can form anywhere in the urinary system. (15)

Kidney failure

Kidney failure results when the kidneys are not able to regulate water and chemicals in the body or remove waste products from the blood. If the kidneys are unable to filter wastes from the blood, the wastes build up in the body. Homeostasis is disrupted because the ions and fluids in the body are out of balance.

Kidney failure can be caused by an accident that injures the kidneys, the loss of a lot of blood, or it can be caused by some drugs or poisons. Kidney failure may lead to permanent loss of kidney function. But if the kidneys are not seriously damaged, they may recover. Chronic kidney disease is the gradual reduction of kidney function that may lead to permanent kidney failure.

A person who has lost kidney function may need to undergo kidney dialysis. Kidney dialysis is the process of artificially filtering the blood of wastes. A dialysis machine (also called a *hemodialyzer*) filters the blood of waste by pumping it through a semipermeable membrane. The cleansed blood is then returned to the patient's body. A dialysis machine is shown in **Figure** 19.18.

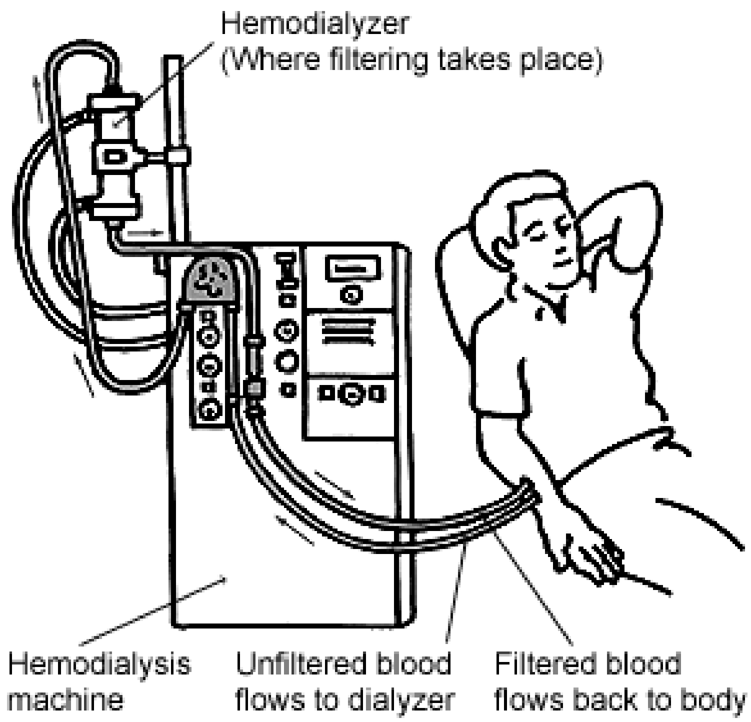

Figure 19.18: During hemodialysis, a patient's blood is sent through a filter that removes waste products and the clean blood is returned to the body. (3)

Urinary tract infections (UTIs)

Urinary tract infections are bacterial infections of any part of the urinary tract. When bacteria get into the bladder or kidney and multiply in the urine, they cause a UTI. The most common type of UTI is a bladder infection. Women get UTIs more often than men. UTIs are often treated with antibiotics.

Lesson Summary

- The excretory system controls the chemical make-up of body fluids. The organs of the excretory system remove metabolic wastes. They also maintain the proper concentrations of water, salts, and nutrients in the body.

- The lungs, skin, kidneys, and large intestine are all part of the excretory system. The urinary system is made up of the kidneys, the ureters, the bladder, and the urethra. The filtering structures of the kidneys are the nephrons.
- Water and waste molecules move out of the blood capillaries and into the nephrons. Most of the water returns to the blood. Urine collects in the nephron and moves to the urinary bladder through the ureters.
- The filtering action of the kidneys is controlled by the pituitary gland. ADH is the hormone that controls the uptake of water from the kidneys. Disorders of the urinary system include kidney stones, kidney disease and urinary tract infections.

Review Questions

1. What are the functions of the excretory system?
2. List the organs that make up the excretory system.
3. What is the difference between the urinary system and the excretory system?
4. What is urine made up of?
5. Outline how the kidneys filter blood.
6. What is the purpose of the urinary bladder?
7. The walls of the urinary bladder are stretchy, what do you think is the advantage to having these stretchy walls?
8. What connects the kidneys to the urinary bladder?
9. What does antidiuretic hormone do?
10. What is a urinary tract infection?
11. Why is kidney failure such a serious health problem?

Further Reading / Supplemental Links

- http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookEXCRETE
- http://kidney.niddk.nih.gov/kudiseases/pubs/yourkidneys
- http://en.wikipedia.org/wiki

Vocabulary

antidiuretic hormone (ADH) Hormone that controls the absorption of water back into blood.

excretion The process of removing wastes from the body.

excretory system The organ system that maintains homeostasis by keeping the correct balance of water and salts in your body; also helps to release wastes from the body.

homeostasis The ability to maintain a stable internal environment despite external changes.

kidney Organ that filters and cleans the blood and forms urine; also maintains the volume of body fluids, maintains the balance of salt ions in body fluids, and excretes harmful metabolic by-products such as urea, ammonia, and uric acid.

kidney dialysis The process of artificially filtering the blood of wastes; a patient's blood is sent through a filter that removes waste products and the clean blood is returned to the body.

kidney failure When the kidneys are not able to regulate water and chemicals in the body or remove waste products from the blood.

kidney stone "Stones" formed when certain mineral wastes in urine crystallize; may be found anywhere in the urinary system.

nephron Tiny, tube-shaped filtering unit found inside each kidney.

urea A nitrogen-containing molecule that is made when foods containing protein, such as meat, poultry, and certain vegetables, are broken down in the body.

ureter Tube-shaped structure that brings urine from the kidneys to the urinary bladder.

urethra Structure through urine leaves the body.

urinary bladder Organ that collects the urine which comes from the kidneys.

urinary system The organ system that makes, stores, and gets rid of urine.

urinary tract infection (UTI) Bacterial infections of any part of the urinary tract.

urination The process of releasing urine from the body.

urine A liquid that is formed by the kidneys when they filter wastes from the blood; contains mostly water and also dissolved salts and nitrogen-containing molecules.

Points to Consider

- Next we turn our attention to the nervous system. What do you think the nervous system is? What do you think it does?

Image Sources

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(2) J.C. Rojas. http://www.flickr.com/photos/jcrojas/523383835/. CC-BY-SA 2.5.

(3) http://kidney.niddk.nih.gov/kudiseases/pubs/yourkidneys/. National Kidney and Urologic Diseases Information Clearinghouse encourages users of this publication to duplicate and distribute as many copies as desired..

(4) http://en.wikipedia.org/wiki/Image:Pertussis.jpg. Public Domain.

(5) http://www.cdc.gov/flu/images/CoverCgh-Sch-view.gif. (b)Public Domain.

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(11) http://training.seer.cancer.gov/anatomy/respiratory/passages/bronchi.html.

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