Have you seen Super Size Me—the movie by the man who ate nothing but McDonald’s for one excruciating month? Part of the delicious delight of watching Morgan Spurlock work his way through endless Big Macs stems from pure contrariness. Your mother, after all, told you not to eat junk food, and here is Spurlock, gobbling like mad. The other delight comes from mother’s vindication. Sure enough, Spurlock suffers mightily for his excess.

Long ago, when the Beatles sang, “You know that what you eat, you are,” the idea that food might affect health was revolutionary. But not anymore. Nowadays, the idea that the food that you consume can affect your health is commonplace, and indeed many are surprised by a study that finds, for example, that eating less fat may not reduce the incidence of breast cancer, or that calcium supplements may not ward off osteoporosis.

At the center of all this concern is the digestive system, an essential series of organs that are designed to extract every last gram of nutrition from whatever goes down the gullet. In an era of rising obesity, such efficiency is not necessarily a good thing: Some designer fats are being deliberately concocted to avoid digestion. But that’s the exception. In general, the goal of the digestive system is to convert food into simple compounds that the body can use for making adipose tissue, cellular energy, adenosine triphosphate (ATP), and the building blocks necessary for constructing cells and tissues.
Nutrients are Life-Sustaining

**LEARNING OBJECTIVES**
- Differentiate between macronutrients and micronutrients.
- Describe how nutrients enter our cells.

**Aerobic Cells**

Il aerobic cells, and therefore all humans, need oxygen to survive. This oxygen drives cellular respiration by serving as the ultimate electron "pull," creating the hydrogen ion concentration gradient required to form ATP. However, one cannot live by oxygen alone.

The cells of our body require nutrients in usable form to maintain homeostasis and create ATP. Because we are heterotrophs, we cannot manufacture our own organic compounds and must obtain them from the environment. Consequently, we spend an awful lot of our time locating, preparing, and ingesting food.

Eating is so important that virtually every culture has elaborate rituals surrounding food. Think of your last Thanksgiving celebration, or even your birthday. Both of these events traditionally include a specific celebratory food: turkey with all the trimmings, or a cake with candles. And in both cases, there were rituals surrounding the food. We take a moment to reflect on all the good things in our life before eating Thanksgiving dinner, and we sing "Happy Birthday" and blow out candles before cutting into the cake.

Although we may not understand why, we instantly know that we need nutrients in order to survive. But exactly what are nutrients? A nutrient is defined as any compound required by the body. The two main types of nutrients are macronutrients (carbohydrates, lipids, and proteins) and micronutrients (vitamins and minerals). These are organic and inorganic compounds, obtained from food rather than synthesized by us. We ingest carbohydrates, lipids, and proteins to provide the necessary energy and starting materials for us to create our own carbohydrates, lipids, and proteins. From these macronutrients, we synthesize cellular components such as the cell membrane, enzymes, organelles, and even entirely new cells during mitosis and meiosis. Micronutrients are required for the proper functioning of essential compounds, such as the enzymes of cellular respiration. Review Chapter 2, Everyday Chemistry, to refresh your understanding of carbohydrates, lipids, and proteins.

**There Are Three Classes of Macronutrients**

The average supermarket contains more than 20,000 food products, but these all come down to three macronutrient groups: carbohydrates, fats, and proteins. These groupings are distinct from the six major food groups, which are classified by food type rather than biochemistry. For example, fruits, a food group, provide us with carbohydrates in the form of fructose, and meats, another food group, are rich in protein.

The macronutrients we hear a lot about in diet discussions are carbohydrates, and for good reason. They are our most efficient source of energy. Carbohydrates are composed of carbon, hydrogen, and oxygen in a 1:2:1 ratio. The most common carbohydrate, glucose, has a chemical formula of $\text{C}_6\text{H}_{12}\text{O}_6$. The cells of our body are excellent at breaking down glucose to produce energy. Carbohydrate digestion is so efficient that we can ingest glucose and break it down completely into energy, carbon dioxide, and water. Although we are efficient carbohydrate burning machines, sometimes we eat too much and our bodies cannot use all of the energy. The Health Wellness and Disease box on the Atkins diet takes a closer look at this.

**Glycolysis, the Krebs cycle, and electron transport**

Glycolysis occurs in the cytoplasm, requiring two molecules of ATP to begin, but generating a total of four ATP molecules in the conversion of glucose to pyruvate. With oxygen present, the two pyruvate molecules are shuttled to the mitochondrion, where they are passed through a series of chemical reactions, each step of which releases energy that is harvested in ATP. NADH and $\text{FADH}_2$. These reactions are referred to as the Krebs, or TCA, cycle. The NADH and $\text{FADH}_2$, created in the Krebs cycle then drive the reactions of the electron transport chain, where hydrogen ions are moved to the center of the mitochondrion, creating a hydrogen ion gradient. This gradient drives chemiosmosis, the final step in this process. At this point, the energy harvested from the original glucose molecule is finally converted to ~32 ATP molecules.

1. **Glycolysis**: Oxidation of one molecule glucose to two pyruvic acid molecules yields 2 ATPs.
2. **Krebs cycle**: Oxidation of succinyl-CoA to succinic acid yields 2 ATPs.
3. **Production of 6 NADH and 6 $\text{FADH}_2$ yields 18 ATPs** in the electron transport chain. Production of 2 $\text{FADH}_2$ yields 4 ATPs in the electron transport chain.

**Carbohydrate Digestion**

Carbohydrate digestion, or cellular respiration, is actually a controlled burning of the glucose molecule through a series of enzymatic reactions. Burning releases energy all at once, whereas carbohydrate metabolism releases that same energy gradually. The first reaction is **glycolysis**, which converts one glucose molecule into two pyruvate molecules, releasing a bit of energy. Assuming oxygen is present, the pyruvates are then passed to a mitochondrion where oxidation continues.

The mitochondrion completes the enzymatic burning of glucose by passing the compounds through first the Krebs cycle, where energy-rich compounds are created, and then passing these energy-rich compounds through the electron transport chain. During these steps, the carbon dioxide we exhale is produced. Chemiosmosis within the inner membrane of the mitochondrion produces most of the ATP for the cells.
Lipids—fats—are a second class of macronutrient. Unlike carbohydrates, fats are long chains of carbon molecules, with many more carbon atoms and far fewer oxygen atoms than carbohydrates. We need a little fat in our diet, however, fats are added to many dishes in one form or another. They carry flavor and add texture to food. According to marketing tests, they coat our mouths and provide a much-needed oral gratification. Fats can be either saturated, meaning the carbon chain has every space occupied with hydrogens, or unsaturated, meaning there are some double bonds in the carbon chain (Figure 13.2). Because double bonds kink the long carbon chains, unsaturated fats cannot pack tightly together. Unsaturated fats, including vegetable oils, are liquid at room temperature. Saturated fats are solid at room temperature and are usually derived from animals, but coconut oil is also a saturated fat.

The American Cancer Society reports that diets high in fat can increase the incidence of cancer, and gives a number of recommendations for minimizing your risk (Table 13.1). They reason that these diets are high in calories, leading to obesity. Obesity is in turn associated with increased cancer risks. They note that saturated fats may increase cancer risk, whereas other fats, such as omega 3 fats from fish oils, may reduce the risk of cancer.

### Good and Bad Fats Table 13.1

<table>
<thead>
<tr>
<th>Fat Type</th>
<th>Good Fats</th>
<th>Bad Fats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated fatty acid</td>
<td>Palmitic acid</td>
<td>ít is solid at room temperature. It is the main component of animal fats.</td>
</tr>
<tr>
<td>Monounsaturated fatty acid</td>
<td>Oleic acid (omega-9)</td>
<td>ít is liquid at room temperature. It is the main component of plant fats.</td>
</tr>
<tr>
<td>Polyunsaturated fatty acid</td>
<td>Alpha-linolenic acid (omega-3)</td>
<td>ít is liquid at room temperature. It reduces inflammation.</td>
</tr>
</tbody>
</table>

### Table 13.2a

**Essential and nonessential amino acids**

<table>
<thead>
<tr>
<th>Essential Amino Acids</th>
<th>Nonessential Amino Acids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Histidine</td>
<td>Alanine</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>Arginine*</td>
</tr>
<tr>
<td>Leucine</td>
<td>Asparagine</td>
</tr>
<tr>
<td>Lysine</td>
<td>Aspartic acid (aspartate)</td>
</tr>
<tr>
<td>Methionine</td>
<td>Cysteine (cystine)</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>Glutamic acid (glutamine)</td>
</tr>
<tr>
<td>Threonine</td>
<td>Glutamine*</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>Glycine*</td>
</tr>
<tr>
<td>Valine</td>
<td>Proline*</td>
</tr>
</tbody>
</table>

### Table 13.2b

**Complementary proteins**

<table>
<thead>
<tr>
<th>Rice &amp; beans</th>
<th>Rice and lentils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bread with peanut butter</td>
<td></td>
</tr>
<tr>
<td>Tofu and cashew nuts</td>
<td>Peanut butter in tortilla</td>
</tr>
<tr>
<td>Blackened peas and corn bread</td>
<td></td>
</tr>
<tr>
<td>Tofu and cashew nuts</td>
<td>Peanut sauce</td>
</tr>
<tr>
<td>Tahini (sesame seed)</td>
<td>Tofu and cashew nuts</td>
</tr>
</tbody>
</table>

### Table 13.2c

**Essential and nonessential amino acids**

<table>
<thead>
<tr>
<th>Essential Amino Acids</th>
<th>Nonessential Amino Acids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Histidine</td>
<td>Alanine</td>
</tr>
<tr>
<td>Isoleucine</td>
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</tr>
<tr>
<td>Leucine</td>
<td>Asparagine</td>
</tr>
<tr>
<td>Lysine</td>
<td>Aspartic acid (aspartate)</td>
</tr>
<tr>
<td>Methionine</td>
<td>Cysteine (cystine)</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>Glutamic acid (glutamine)</td>
</tr>
<tr>
<td>Threonine</td>
<td>Glutamine*</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>Glycine*</td>
</tr>
<tr>
<td>Valine</td>
<td>Proline*</td>
</tr>
</tbody>
</table>

### Figure 13.2

Almost all animal fats are saturated, especially those found in beef and dairy products, heated fats produce unsaturated fats, the notable exceptions being coconut, cocoa butter, and palm kernel oils. For this reason, vegetable oil is liquid at room temperature, whereas butter or cocoa butter is solid.
In 1972, cardiologist Dr. Robert Atkins rocked the diet world with his book on a “diet revolution” that placed extreme emphasis on protein and fat, and discouraged eating vegetables or carbohydrates. When a revised version of the diet was published in 1992, the book became an instant best-seller. Dieters waxed rhapsodic about the quick and persistent weight loss they obtained by cutting carbs and preferring protein.

The physiology is pretty simple. Lacking carbohydrates, the normal source for glucose needed to produce ATP, the body mobilizes fat stores and converts fat into small molecules called ketones. As ketones are oxidized to produce ATP, the body enters a metabolic state called ketosis. The quick weight loss of the first week is caused by water loss, and that loss cannot be sustained. Starting the second week, weight loss slows drastically, because the only way to lose weight is to expend more energy than we take in, and Atkins is a calorie-rich diet.

As the Atkins diet sold millions of copies, it attracted a storm of criticism from researchers and organizations concerned with human biology who predicted that another best-seller, the Atkins diet, did not mark the death of the frenzy over being fat. The national obesity epidemic continues, and it’s safe to predict that another quick diet cannot last long. We can only hope that your knowledge of human biology will protect you from getting suckered by an unhealthy diet. In health, as in lovers, losers, and promises in general, the same rule applies: If it sounds too good to be true, it probably is.

The U.S. Department of Agriculture recently updated its food pyramid with MyPyramid, found online at http://www.mypyramid.gov (Figure 13.3). Although this pyramid is more in tune with current research, it is based on the same principles as the traditional pyramid. It still recommends that we get most of our calorie value from carbohydrates and that we limit our fat intake. Rather than arrange the food groups horizontally, however, they are arranged vertically. This gives a more accurate visual picture because we require all the food groups in order to be healthy. We should not base our caloric intake on carbohydrates, but we do get a majority of our calories from them. This site is also more personal, giving recommendations for serving size and number based on age, gender, and activity level. When you submit your personal statistics to the MyPyramid Web site, you receive food intake guidelines specific to your lifestyle.

VITAMINS AND MINERALS ARE MICRONUTRIENTS

A healthy diet must include vitamins and minerals. Unlike macronutrients, these micronutrients are not broken down, but instead are required for enzyme function or specific protein synthesis. Vitamins are organic substances, such as thiamine, riboflavin, and vitamin A (Table 13.2). Minerals are inorganic substances such as calcium, zinc, and iodine (Table 13.4).

A healthy diet with plenty of fruit and vegetables will give you most of the necessary vitamins and minerals.
### Vitamin Comment and Source Functions and Disorders

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Comment and Source</th>
<th>Functions</th>
<th>Deficiency Symptoms or Disorders</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Formed from prostanoids. (other prostanoids in GI tract. Stored in liver. Sources of vitamin A and other prostanoids include carrots, yellow and green leafy vegetables, orange, yellow, and green vegetables. Sources of vitamin A include liver and milk.</td>
<td>Maintains general health and vigor of epithelial cells. Beta-caroten acts as an antioxidant to inactivate free radicals. Essential for formation of light-sensitive pigments in photoreceptors of retina. Aids in growth of bones and teeth by helping to regulate activity of osteoclast and osteoblast.</td>
<td>Deficiency results in sterility and keratinization of epithelia, leading to dry skin and hair, increased incidence of ear, nose, respiratory, urinary, and gastrointestinal symptoms; inability to gain weight, difficulty in curing of cataracts, and skin and hair defects. Night blindness or decreased ability for dark adaptation. Weak and fragile development of bones and teeth.</td>
</tr>
<tr>
<td>D</td>
<td>Sunlight converts 7-dehydrocholesterol in the skin to cholecalciferol (vitamin D). A liver enzyme then converts cholecalciferol to 25-hydroxycholecalciferol. A second enzyme in the kidneys converts 25-hydroxycholecalciferol to calcitriol (1,25-dihydroxycalciferol), which is the active form of vitamin D. Most is excreted in bile. Dietary sources include milk, eggs, and fortified milk.</td>
<td>Essential for absorption of calcium and phosphorus from GI tract. Works with parathyroid hormone to maintain Ca2+ homeostasis.</td>
<td>Essential for absorption of calcium and phosphorus from GI tract. Works with PTH to maintain Ca2+ homeostasis.</td>
</tr>
<tr>
<td>E (thiamin)</td>
<td>Stored in liver, adipose tissue, and muscles. Sources include fresh nuts and seeds, green leafy vegetables, and green leafy vegetables.</td>
<td>Inhibits synthesis of certain fatty acids that help form cell structures, especially membranes. Involved in formation of DNA, RNA, and red blood cells. May prevent wound healing, contributing to the normal structure and function of the nervous system, and prevent scarring. May help protect liver from toxic chemicals such as carbon tetrachloride. Acts as an antioxidant to inactivate free radicals.</td>
<td>May cause oxidation of monounsaturated fats, resulting in abnormal structure and function of membranes, nervous system, and plasma membranes. A possible consequence is heart disease.</td>
</tr>
<tr>
<td>K</td>
<td>Produced by intestinal bacteria. Stored in liver and spleen. Dietary sources include spinach, cauliflower, broccoli, and citrus fruits.</td>
<td>Coenzyme essential for synthesis of several fatty acids by liver, including prothrombin.</td>
<td>Deficient, lasting time results in excess bleeding.</td>
</tr>
<tr>
<td>Water-soluble</td>
<td>Dosed in body fluids. Most are not stored in body. Excess intake is eliminated in urine.</td>
<td>Acts as coenzyme for many different enzymes that break carbohydrates and are involved in carboxylation of malonyl-CoA to acetyl-CoA.</td>
<td>Improper carboxylation leads to buildup of pyruvic acid, and fatty acids and insufficient production of ATP for muscle and nerve cells. Deficiency leads to: (1) beriberi, peripheral paralysis of both upper and lower extremities, causing digestive disturbances, drugged mood in patients, and atrophy of limbs; (2) polyneuritis, due to degeneration of myelin sheath, impaired reflexes, impaired sense of touch, slowed growth in children, and poor appetite.</td>
</tr>
<tr>
<td>B6 (pyridoxine)</td>
<td>Synthesized by bacteria of GI tract. Dietary sources include green leafy vegetables; sources of vitamin include orange, yellow, and green vegetables.</td>
<td>Essential for normal amino acid and neurotransmitter production. Essential for formation of choline in triglyceride metabolism.</td>
<td>Essential for normal amino acid and neurotransmitter production. Essential for formation of choline in triglyceride metabolism.</td>
</tr>
<tr>
<td>Folic acid</td>
<td>Synthesized by bacteria of GI tract. Dietary sources include liver, milk, and other organ meats. Other sources include kidney, liver, kidney, liver, and green vegetables.</td>
<td>Component of many enzymes and involved in the synthesis and manufacture of choline (used for cell formation, formation of the myelin sheath, and manufacture of choline).</td>
<td>Essential for cell formation, formation of the amino acid, and synthesis of fatty acids and cholesterol.</td>
</tr>
<tr>
<td>Vitamin C (ascorbic acid)</td>
<td>Rupted destruction. Sources include carrots, broccoli, apples, bananas, and citrus fruits.</td>
<td>Component of many enzymes and involved in the synthesis and manufacture of choline (used for cell formation, formation of the myelin sheath, and manufacture of choline).</td>
<td>Component of many enzymes and involved in the synthesis and manufacture of choline (used for cell formation, formation of the myelin sheath, and manufacture of choline).</td>
</tr>
</tbody>
</table>

### Deficiency Symptoms and Disorders

- **Deficiency symptoms** may lead to improper utilization of sugars resulting in blurred vision, cataracts, and corneal ulcers. Also dermatitis and cracking of skin, lesions of internal organs, and one type of anemia.
- **Deficiency symptoms** may appear in dermatitis of skin, nose, and mouth and in gastrointestinal infections. Other symptoms are reduced growth and anemia.

### Nutrients are Life-Sustaining

- **Fat-soluble**
  - All require bile salts and some dietary lipids for adequate absorption.

- **Water-soluble**
  - Rapidly destroyed by heat. Sources include whole-grain products, eggs, pork, nuts, liver, and yeast.
  - Acts as coenzyme for many different enzymes that break carbohydrates and are involved in carboxylation of malonyl-CoA to acetyl-CoA. Essential for synthesis of the non-metabolizable acetyl-CoA.
  - Improper carboxylation leads to buildup of pyruvic acid and fatty acids and insufficient production of ATP for muscle and nerve cells. Deficiency leads to: (1) beriberi, peripheral paralysis of both upper and lower extremities, causing digestive disturbances, drugged mood in patients, and atrophy of limbs; (2) polyneuritis, due to degeneration of myelin sheath, impaired reflexes, impaired sense of touch, slowed growth in children, and poor appetite.

- **Water-soluble**
  - Rupted destruction. Sources include carrots, broccoli, apples, bananas, and citrus fruits.
  - Component of many enzymes and involved in the synthesis and manufacture of choline (used for cell formation, formation of the myelin sheath, and manufacture of choline).

- **Deficiency symptoms** may lead to improper utilization of sugars resulting in blurred vision, cataracts, and corneal ulcers. Also dermatitis and cracking of skin, lesions of internal organs, and one type of anemia.

- **Deficiency symptoms** may appear in dermatitis of skin, nose, and mouth and in gastrointestinal infections. Other symptoms are reduced growth and anemia.
### Table 13.4

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Comments</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calcium</strong></td>
<td>Most abundant mineral in body. Appears in combination with phosphorus, about 95% is stored in bones and teeth. Bone (CaO) level is controlled by parathyroid hormone (PTH). Excess is excreted in urine and feces. Sources are milk, egg yolk, shellfish, and leafy green vegetables.</td>
<td>Formation of bones and teeth. Blood clotting, normal muscle and nerve activity, blood pressure, and nervous system function. Component of DNA and RNA.</td>
</tr>
<tr>
<td><strong>Phosphorus</strong></td>
<td>About 95% is found in bones and teeth as phosphate salts. Blood phosphate level is controlled by parathyroid hormone (PTH). Excess is excreted in urine. Small amount is eliminated in feces. Sources are dairy products, meat, fish, poultry, and nuts.</td>
<td>Formation of bones and teeth. Phosphates (HPO₄²⁻ and H₂PO₄⁻) constitute a major buffer system of blood. Phosphates play an important role in muscle contraction and nerve activity. Component of many enzymes involved in energy transfer (ATP). Component of DNA and RNA.</td>
</tr>
<tr>
<td><strong>Potassium</strong></td>
<td>Major cation (K⁺) in intracellular fluid. Excess excreted in urine. Present in most foods (meats, fish, poultry, and nuts).</td>
<td>Needed for generation and conduction of action potentials in neurons and muscle fibers.</td>
</tr>
<tr>
<td><strong>Sodium</strong></td>
<td>Most abundant cation (Na⁺) in extracellular fluid. Small amount is eliminated in feces. Sources include table salt (NaCl), soy sauce, and processed foods.</td>
<td>Strongly affects distribution of water through osmosis. Plays role in acid–base balance of blood, water balance, and muscle action potential conduction.</td>
</tr>
<tr>
<td><strong>Chloride</strong></td>
<td>Major anion (Cl⁻) in extracellular fluid. Small amount is eliminated in feces. Sources include table salt (NaCl), soy sauce, and processed foods.</td>
<td>Plays role in acid–base balance of blood, water balance, and formation of HCl in stomach.</td>
</tr>
<tr>
<td><strong>Iron</strong></td>
<td>About 65% found in hemoglobin of blood. Normal iron stores occur by shedding of hair, epithelial cells, and mucosal cells, and in the urine, feces, bile, and blood lost during menstruation. Sources are meat, fish, shellfish, egg yolk, beans, legumes, dried fruits, nuts, and cereals.</td>
<td>As component of hemoglobin, reversibly binds O₂. Component of cytochromes involved in electron transport chain.</td>
</tr>
<tr>
<td><strong>Iodide</strong></td>
<td>Component of thyroid hormones. Required by thyroid gland to synthesize thyroid hormones, which regulate metabolic rate.</td>
<td>Required by thyroid gland to synthesize thyroid hormones, which regulate metabolic rate.</td>
</tr>
<tr>
<td><strong>Manganese</strong></td>
<td>Some stored in liver and spleen. Most excreted in feces.</td>
<td>Acts on several enzymes. Needed for hormonal synthesis, bone formation, growth, reproduction, lactation, bone formation, and possibly production and hormone secretion of insulin, and inhibition of cell damage.</td>
</tr>
<tr>
<td><strong>Copper</strong></td>
<td>Some stored in liver and spleen. Most excreted in feces. Sources include eggs, whole-wheat flour, beans, nuts, fish, spinach, and asparagus.</td>
<td>Required with iron for synthesis of hemoglobin. Component of cytochromes in electron transport chain. Component of enzymes necessary for melanin formation.</td>
</tr>
<tr>
<td><strong>Chromium</strong></td>
<td>Important component of certain enzymes. Widespread in many foods, especially meats.</td>
<td>As component of carbohydrate–lipid metabolism. Important in synthesis of thyroid hormones. Promotes cholesterol breakdown and may play a role in preventing certain birth defects, microangiopathy, prostate cancer, and coronary artery disease.</td>
</tr>
<tr>
<td>** Zinc**</td>
<td>Important component of certain enzymes. Found in seafood, meat, chicken, tomatoes, egg yolk, milk, mushrooms, and garlic, and cereal grains grown in selenium-rich soil.</td>
<td>An important component of many enzymes. Essential for normal activity of insulin in carbohydrate–lipid metabolism.</td>
</tr>
<tr>
<td><strong>Selenium</strong></td>
<td>Important component of certain enzymes. Found in seafood, meat, chicken, tomatoes, egg yolk, milk, mushrooms, and garlic, and cereal grains grown in selenium-rich soil.</td>
<td>Needed for synthesis of thyroid hormones, sperm motility, and proper functioning of the immune system. Also functions as an antioxidant. Promotes chromosome breaks and may play a role in preventing certain birth defects, microangiopathy, prostate cancer, and coronary artery disease.</td>
</tr>
<tr>
<td><strong>Fluoride</strong></td>
<td>Component of bones, teeth, other tissues.</td>
<td>Appears to improve tooth structure and inhibit tooth decay.</td>
</tr>
<tr>
<td><strong>Folic acid</strong></td>
<td>Component of several coenzymes. Numerous vitamin-like compounds.</td>
<td>Important component of certain enzymes. Found in liver, fish, spinach, and asparagus.</td>
</tr>
<tr>
<td><strong>Folate</strong></td>
<td>Component of several coenzymes. Numerous vitamin-like compounds.</td>
<td>Important component of certain enzymes. Found in liver, fish, spinach, and asparagus.</td>
</tr>
</tbody>
</table>

**CONCEPT CHECK**

What are the major macronutrients? Describe the differences between the traditional food pyramid and MyPyramid.

What is a micronutrient? Differentiate between vitamins and minerals.

However, many Americans now supplement their diets with moderate levels of vitamins and minerals, just to ensure they receive what they need on a daily basis. The usual supplement taken is an over-the-counter (OTC) multivitamin supplement. These often include vitamins E, C, and A, which help remove free radicals, thereby boosting the immune system and perhaps prolonging cell life. As with anything, excess is not healthy. Taking too large a quantity of fat-soluble vitamins can cause them to build up in the liver, hampering its function.

Selected minerals are usually also found in OTC multivitamins, such as calcium, phosphorus, iron, magnesium, and zinc, among many other micronutrients. Some minerals are found in high concentrations in foods, especially prepared foods. Sodium, for example, is extremely high in most frozen and prepared foods. Because a large quantity of these nutrients is consumed as part of the general population, sodium supplements are seldom advisable, because too much sodium in the diet can lead to hypertension. By eating mostly whole grains, we obtain vitamins and minerals as well as fiber. Whole grains also provide fiber, which helps move food along the large intestine and decreases the risk of colon cancer.
The Digestive System Processes Food From Start to Finish

LEARNING OBJECTIVES

- Describe the general anatomy of the digestive tract.
- List the digestive organs in order from mouth to anus.

THE GI TRACT REMAINS THE SAME THROUGHOUT ITS LENGTH

The digestive system is sometimes called a “tube within a tube,” because it is a hollow structure with two openings that runs the length of your body. The digestive system, also called the “gastrointestinal system” or GI tract, begins at the oral cavity, winds through the abdominal cavity, and ends at the anus (Figure 13.4).

The structure of the GI tract is essentially the same along its entire length. The innermost layer is composed of a mucous membrane, or mucosa. This slippery, smooth layer allows ingested food to move along the tract without tearing it. Under the mucosa, the submucosa includes the glands, nerves, and blood supply for the tract itself. The muscularis gives the tract the ability to move substances lengthwise. For most of the tract, the muscularis is composed of one layer of longitudinal muscle above another layer of circular muscle (Figure 13.5). These layers work in unison to create the peristaltic wave (Figure 13.6) that propels food through the tube.

The outer layer of the GI tract, the serosa, is a slippery membrane that permits the tract to move inside the abdominal cavity without catching or causing discomfort. Your digestive system is always active, as muscular contractions shift, lengthen, and shorten the tube. Despite this constant movement, you normally neither see nor feel the movement.

Peristaltic wave

Rhythmic muscular contractions of a tube that force contents toward the open end.

Digestive system overview

The tubular structure of the GI tract is obvious when looking at it in its entirety. The tube begins at the esophagus, and with slight modifications, travels the length of the tract, ending at the anus. These modifications alter the function of the tract at various points, which we describe as different organs.

Peristaltic wave generation

The peristaltic wave is generated as you consciously swallow food. Movement of the tongue initiates the muscularis to begin a ring of contraction that is passed throughout the entire tract. Once you swallow food, the peristaltic wave travels the length of the tube; you no longer have conscious control over those smooth muscle contractions.

Layers of the GI tract

The serosa allows the GI tract to move as food passes within it. The muscularis is responsible for generating the movement of the tube, whereas the mucosa and submucosa come into contact with the food and provide the blood supply and innervation for the inner lining of the tract.
DIGESTION BEGINS IN THE ORAL CAVITY

The best way to understand the actions of the digestive system is to follow some food through the GI tract, starting at the oral cavity, or mouth. Think about a hot slice of pizza. How does it provide energy and nutrients? Let’s follow that slice along the digestive tract, and see how the body pulls nutrients from it, and how its energy is used to create adipose tissue for energy storage, or ATP for immediate use.

The pizza enters the digestive tract through the oral cavity. We tear off a bite of pizza with our teeth. Teeth erupt from the gums in a specific order as we mature. The pattern of eruption is predictable. They may appear more slowly in some individuals, but almost all of them appear before birth in a predictable pattern. Incisors appear first, then follow by canines (piercing and ripping teeth), and grinding instruments (molars). Although we are not born with teeth extending through the gums, they erupt soon after birth in a predictable pattern. Incisors appear first, allowing food to be bitten off, often by 8 months of age. The premolars and molars appear last, with “wisdom teeth,” our final set of grinding molars, appearing sometimes as late as our mid-twenties or early thirties.

We first obtain 20 primary, deciduous, or baby teeth (Figure 13.7). These are replaced by our 32 permanent teeth, usually by age 21 (Figure 13.8).

The small bits of pizza are macerated with saliva. Mechanical digestion increases the efficiency of enzymes in the stomach and small intestine, by creating small bits with a great deal of surface area where enzymes can carry out the process of chemical digestion.

Most people try to take good care of their teeth, with regular brushing, flossing, and visits to the dentist. Why do we bother with such dental cleanliness? Your mouth contains hundreds of species of bacteria, which live on the oral surfaces and multiply rapidly when sugar is available. These bacteria extract wastes as they grow and metabolize. The wastes are usually acidic, and if the acid remains on tooth surfaces, they can eat through the enamel to the softer dentin at the center of the tooth. Plaque is a combination of the bacterial colonies, their bacterial wastes, left over sugars from chewed up food, epithelial cells from the host, and saliva. Plaque begins as a sticky substance on the surfaces of the teeth but can calcify with time into the tough layer of tartar your hygienist must scrape off.

The largest increase in bacterial growth occurs 20 minutes after eating. The bacterial colonies are metabolizing the food from our last meal, growing and dividing at their highest rate. As the bacteria are multiplying rapidly, they are digesting the sugar in your mouth and creating large quantities of acidic waste. Once the food is removed, the bacterial division slows. If you do not thoroughly and routinely remove this buildup of bacteria and acid, the acid may decay the enamel on the teeth, causing cavities. A cavity does not cause pain at first, but as the acids reach farther into the tooth, they eventually hit softer tissue near the tooth’s nerve, called the pulp. By this time, the cavity is quite large and will require dental repair.

The recommended bimannual dental cleaning is a great way to monitor plaque buildup and cavity formation. While removing plaque, the hygienist may spot any small cavities, which the dentist can repair before they destroy the pulp of the tooth. The repair process involves drilling out all rotten enamel, and replacing it with an air-tight seal made of gold, silver alloy, or composite resin. Mercury amalgam is no longer used to fill cavities due to the health risks of mercury, which is a potent neurotoxin. Some dentists recommend replacing old amalgam fillings with composite resin, to avoid later complications.

The tongue balls things up. The tongue manipulates the unwashed pizza into a bolus and positions that bolus at the back of the oral cavity so it can be swallowed. The tongue is a muscle that can move in almost any direction in the oral cavity. On its surface, keratinized epithelium covers papillae, creating a rough texture to help move the slippery food into position where the teeth can masticate it. Taste buds reside along the sides of these papillae. The tongue also secretes watery mucus containing a digestive enzyme, lingual lipase, from sublingual salivary glands on its undersurface. This enzyme begins the chemical digestion of lipids by breaking down triglycerides, such as those in the pizza’s cheese.

<table>
<thead>
<tr>
<th>Oral cavity</th>
<th>Figure 13.8</th>
</tr>
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<tbody>
<tr>
<td>The teeth and tongue in the oral cavity are ideal for mechanical digestion. The food is rolled around with the tongue and broken into smaller pieces with the teeth.</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 13.8**

The teeth and tongue in the oral cavity are ideal for mechanical digestion. The food is rolled around with the tongue and broken into smaller pieces with the teeth.
MALT is a disease-prevention tissue. Food is rarely sterile, and yet we almost never suffer disease from ingesting it. Starting with the tonsils, the mucosa of the GI tract contain a disease-prevention tissue called MALT (mucosa-associated lymphatic tissue). MALT is also prevalent in the small intestine, large intestine, and appendix. These nodules of lymphatic tissue prevent disease from taking over the body, and are important for preserving homeostasis. MALT tissues represent a large percentage of the entire immune system, including about half of the body’s total lymphocytes and macrophages. Without MALT pathogens could grow within the digestive tract, penetrate the epithelial lining, and cause serious internal infections. Although MALT is effective, it can be overrun. Bacteria ingested with food suddenly enter a warm, moist, nutrient-rich environment, and they can bloom and overwhelm the body’s ability to combat them. Often the acid environment of the stomach will kill these blooming bacteria, but sometimes even that is not enough. If the bacterial colony survives the stomach, the body may flush the entire tract with diarrhea or vomiting to help the specific immune system rid the body of the invading bacterium.

The salivary glands aid in digestion. The salivary glands, located within the oral cavity, secrete water—the saliva. When food is in the mouth, excess saliva is needed to mix with the food and form the slippery bolus required for swallowing.

The major salivary glands are the parotid glands, located below and in front of the ears, and the submandibular glands under the tongue. The parotid glands produce watery saliva that includes some ions (sodium, potassium, chloride, bicarbonate, and phosphate) and organic substances. The submandibular glands produce thicker, more watery saliva with similar ion content but a larger concentration of mucous. When the sympathetic nervous system is active, watery secretion from the parotid glands is inhibited, whereas the sticky submandibular secretion is not. This leaves us with the familiar “cotton mouth” feeling that we associate with nervousness.

In addition to water and ions, saliva contains lysozyme, a bacteriolytic enzyme that helps destroy bacteria in the oral cavity. Another important component of saliva is salivary amylase, a digestive enzyme that breaks carbohydrate polysaccharides into monosaccharides. Amylase occurs in low levels in saliva and in larger amounts in pancreatic secretions. As we chew the pizza crust, salivary amylase begins breaking the large carbohydrate polymers into smaller monosaccharides that cells can absorb further down the GI tract.

Mumps, a common disease of the salivary glands, causes swelling of the glands, sore throat, tiredness, and fever (Figure 13.9). Mumps spreads from person to person in saliva, either by inhaling small bits of sneezed saliva or by sharing utensils or food contaminated with droplets of saliva. Cases of mumps have dropped steadily since 1967, when the mumps, measles, and rubella (MMR) vaccine was introduced. MMR is now part of routine infant vaccinations.

Mumps is a disease caused by a paramyxovirus (mumps) that causes swelling of the salivary glands, most often the parotid glands. In older children and adults, mumps is far more serious, leading to painful swelling but rarely sterility. Mumps may also cause swelling or inflammation of the pancreas, brain, meninges, or ovaries. Encephalitis (swelling of the brain tissue) can be life-threatening and may result in permanent damage. Fortunately, this is a rare complication of mumps. Hearing loss may also occur in mumps, but it is often temporary. As we vaccinate more infants, mumps could become a disease of the past, following the same pattern as German measles and polio.

Swallowing has three stages, two of which are shown in Figure 13.10. During the voluntary stage, you consciously swallow the pizza. During the pharyngeal stage, the bolus involuntarily passes through the pharynx. The esophageal stage, the trachea is closed to allow the bolus to pass the larynx and enter the esophagus. This is the final step of deglutition. The process of deglutition is seen in Figure 13.11. The bolus of food is swallowed, the larynx moves up, in turn shifting the position of the epiglottis during the esophageal stage. The bolus of food then slides past the larynx and on to the esophagus. The wave of contraction begins here continues through the entire system, pushing this mouthful into the stomach and eventually on to the remaining organs of the GI tract.

The digestive system processes food from start to finish.
The esophagus connects the oral cavity with the stomach

The esophagus is a collapsible 20- to 25-centimeter long conduit that connects the oral cavity with the stomach (Figure 13.11). Once the bolus of pizza arrives at the top of the esophagus, a peristaltic wave begins. This wave will push the bolus along the esophagus in a controlled manner (neither food nor drink free-fall into the stomach). The esophagus terminates at its lower end with a sphincter muscle. A sphincter muscle is a circular muscle that closes off a tube, functioning like a rubber band pulled tightly around a flexible straw. They appear many times along the GI tract, dividing one organ from the next. The lower esophageal sphincter (LES) at the base of the esophagus opens as the pizza bolus touches it, dropping the bolus into the upper portion of the stomach. You can listen to water traveling through the esophagus and hitting the LES if you have a stethoscope. Place the bell of the stethoscope near your xyphoid process and swallow a mouthful of water. You should be able to count to 10, then hear the water splash against the lower esophageal sphincter. If you are lucky, you might hear the water splash again as it enters the stomach when the LES opens.

THE STOMACH PUTS FOOD TO THE ACID TEST

The next organ the pizza will encounter in the digestive system is the stomach, a J-shaped organ that lies beneath the esophagus. The stomach is divided from the esophagus and the small intestine by two sphincter muscles. The lower esophageal sphincter indicates the upper boundary of the stomach, and the pyloric sphincter marks the end of the stomach. The pyloric sphincter is the strongest sphincter muscle of the digestive tract, opening to allow chyme to enter the small intestine only when chemically ready. This sphincter is so powerful that it can cause projectile vomiting in infants. The stomach contracts forcefully to push the food into the small intestine, but the pyloric sphincter remains closed until the chyme is fluid enough to be passed on. If the pyloric sphincter refuses to open, the contents of the stomach are instead ejected through the weaker lower esophageal sphincter, leaving the body at impressive speed.

Histologically speaking, the stomach is “the pits.” The typical structure of the gastrointestinal tract undergoes modification at the stomach (Figure 13.12). The muscularis is usually composed of two layers of muscle, one longitudinal and one circular. The stomach has a third layer of muscle, called the oblique layer. The function of the stomach is to churn and mix the accumulated pieces of pizza mixing the bolus with the acid environment of the stomach and begin digestion of proteins. The oblique layer helps this churning and mixing. Because the stomach is a holding area for food as it is ingested, it must be able to expand. The walls of the stomach contain folds, or rugae, that permit expansion somewhat like a deflated punching ball.

A final modification of the stomach is due to the chemical environment in the organ, where the pH is only 2. Such high acidity breaks down large macromolecules and destroys many microbes, but it can also harm the stomach lining. Furthermore, the stomach also secretes enzymes that digest protein, which is what the stomach walls are composed of. Therefore, the stomach must be protected from its own contents. The stomach does this by producing a protective layer of thick, viscous, alkaline mucus. Nowhere else does the stomach must be protected from its own contents. The stomach walls are composed of. Therefore, the stomach also secretes enzymes that digest protein, which is what the stomach walls are composed of. Therefore, the stomach must be protected from its own contents. The stomach does this by producing a protective layer of thick, viscous, alkaline mucus. Nowhere else does the stomach must be protected from its own contents. The stomach walls are composed of. Therefore, the stomach also secretes enzymes that digest protein, which is what

The stomach is an active organ. As the bolus of food reaches the stomach, small mixing waves are initiated. These waves occur every 15 seconds or so and help to break up the pizza. Even with these mixing waves, the pizza may stay in the fundus of the stomach for as long as an hour before being moved into the body of the stomach. There the pizza mixes with the gastric secretions and becomes soupy and thin. The mixing waves of the stomach become stronger, intensifying as they reach the pyloric sphincter. With each wave, a small portion of the chyme is forced through the pyloric sphincter and into the small intestine. The rest of the chyme washes back toward the body of the stomach to be churned further with the next mixing wave.

Gastric pits are composed of chief cells and parietal cells. The chief cells secrete pepsinogen and gastric lipase. Pepsinogen is an inactive precursor of the enzyme pepsin, which digests proteins, and therefore must be secreted in inactive form. (If pepsin itself were produced in stomach cells, it would digest the proteins of those cells.) Pepsinogen forms pepsin only under pH 2. The parietal cells produce hydrochloric acid and intrinsic factor. The hydrochloric acid is responsible for the acidic pH of the stomach, which both activates pepsin and kills microbes. Intrinsic factor is necessary for the absorption of vitamin B12, a micronutrient that helps produce blood cells. Although intrinsic factor is produced in the stomach, it is active in the small intestine.

As the pizza is churned in the stomach, gastric lipase will continue the chemical breakdown of fats that began in the mouth. This enzyme specializes in digesting short fatty acids such as those found in milk, but works at an optimum pH of 5.6 or 6. In adults, both gastric lipase and lingual lipase have limited roles. In the stomach, the pizza bolus is converted to a pasty, liquid chyme. Pepsinogen is converted to pepsin and digests the proteins of the tomato sauce and the cheese. The low pH assists in denaturing proteins and breaking down the remaining macromolecules, providing an easy substrate for digestion in the small intestine.

The activation of the stomach includes three phases. 1 Cephalic phase. In the first phase, thoughts of food and the feel of food in the oral cavity stimulates increased secretion from the gastric pits. The stomach also begins to churn more actively in preparation for the incoming food. 2 Gastric phase. When the bolus reaches the stomach, the second phase of gastric digestion begins. Here the stomach produces gastrin as well as continuing the production of pepsin and HCl. Gastrin acts in stimulation of the gastric pits, providing a feedback system that speeds digestion. Impulses from the stomach also go back to the brain, maintaining contact with the nervous system. 3 Intestinal phase. In the final phase of gastric digestion, the chyme begins to leave through the pyloric sphincter. As the chyme leaves the stomach, gastrin production decreases; the impulses to the brain indicate a lessening of chyme, and the brain begins to slow the stimulation of the gastric pits. At the same time, hormones from the beginning portion of the small intestine initiate activation of the small intestine.

Gastric digestion includes three phases. Digestion occurs in three phases in the stomach (Figure 13.14). During the cephalic phase, digestion consists of reflexes initiated by the senses, as the name implies. This phase started when you ordered the pizza, inhaled it as you got out the utensils to eat it, and peaked as you smelled the pizza after delivery. The scents and sounds associated with eating stimulate specific portions of the medulla oblongata, which in turn trigger secretion of the gastric pits. The parasympathetic nervous system is activated, increasing stomach movement. Interestingly, these reflexes can be dampened by stimulation of the sympathetic nervous system. Anger, fear, or anxiety opposes the parasympathetic nervous system, shutting down the cephalic phase and reducing your feelings of hunger.

Once food enters the stomach, stretch receptors and chemoreceptors are activated, initiating the gastric phase. Hormonal and neural pathways are set in motion, causing an increase in both gastric wave force and secretion from the gastric pits. As chyme is pushed past the pyloric sphincter, stomach volume decreases and stretch receptors begin to relax. This in turn diminishes the intensity of the gastric phase. The final phase of gastric digestion is the intestinal phase. As chyme passes through the pyloric sphincter, intestinal receptors are stimulated. These receptors inhibit the actions of the stomach, causing it to return to rest. At the same time, these receptors stimulate digestion in the small intestine.

Once in the small intestine, the chyme itself stimulates the release of hormones. Chyme containing glucose and fatty acids, such as the chyme from the pizza, causes the release of cholecystokinin (CCK) and secretin. CCK inhibits stomach emptying, whereas secretin decreases gastric secretions. Both of these also affect the liver, pancreas, and gall bladder, the accessory organs of the gastrointestinal tract. The combined
action of these hormones holds the pizza in the stomach for a prolonged period, ensuring the pizza is sufficiently broken down, despite its high level of hydrophobic fats.

After 2 to 4 hours, the stomach has emptied, and all the chyme has entered the small intestine. Because the pizza has a high fat concentration, it will move rather slowly through the stomach, taking closer to 4 hours. Had you eaten steamed vegetables with their much lower fat content instead, your stomach would have emptied much more quickly, leaving you feeling hungry again after just a few hours.

Sometimes food in the stomach does not “agree” with the stomach because it contains bacteria or toxins that irritate the stomach lining. This situation may cause vomiting. Although not an easy task from a physiological standpoint, reversing the peristaltic wave may cause vomiting. Although not an easy task from a physiological standpoint, reversing the peristaltic wave

The small intestine is characterized by its velvet-like mucosa. The entire purpose of this organ is to absorb nutrients, requiring a large surface area. The mucosa is thrown into folds, and cells are lined with microvilli and even covered in individual eyelash-like extensions to provide as much surface area as possible.

The small intestine completes the nutrient-extraction phase

Once in the small intestine, the pizza’s nutrients are finally ready for absorption. This organ is the only part of the GI tube where nutrients are taken into the body. Prior to reaching the small intestine, the food was cut up, broken down, and denatured. Some enzyme activity was initiated to break down large macromolecules. Here in the small intestine, the nutrients from the pizza are finally absorbed into the body.

The small intestine has three regions: the duodenum, the jejunum, and the ileum. The duodenum is the shortest of the regions, extending approximately 25 centimeters from the pyloric sphincter. The name duodenum means 12, reflecting the fact that the region is approximately 12 fingers long. The jejunum encompasses the next meter or so. Jejunum means empty, and this region is characteristically found to be empty during autopsies. The longest portion, the ileum, is about 2 meters long.

The entire length of the small intestine is 3 meters, making it the longest digestive organ. This structure is packed into the abdominal cavity by twisting and winding around the central mesenteries. How incredibly large is the surface of the small intestine? Within the small intestine, the mucosa is shaped into permanent circular folds, which add important surface area to the organ (Figure 13.15). Not only do these folds increase absorption, they also force the chyme to move in spiral fashion, which creates a longer pathway through the intestine, allowing more time to absorb nutrients.

The small intestine has an interesting histology: Because the whole point of the organ is to provide a surface area for absorption, the small intestine has many microscopic projections. The mucosa has finger-like extensions, or villi, each one approximately 0.5 to 1 mm long (Figure 13.16). These villi give the inner surface of the small intestine the look and feel of velvet. Areolar connective tissue is located at the center of each villus. This connective tissue supports an arteriole, a venule, a blood capillary network connecting the two, and a lacteal. Beyond the villi, the small intestine also has microvilli on each apical membrane of the small intestinal mucosa. These hairlike projections of the cell membrane increase the cell’s surface area. The microvilli are small and difficult to resolve under a light microscope, where they look like a fuzzy line, not individual structures. The entire surface of the cell is called a brush border.

Through an electron microscope, scientists have discovered even smaller projections on the surface of these brush borders, which again increase surface area.

The walls of the small intestine are also dotted with intestinal glands, which secrete intestinal juice to help digestion. The small intestine has an abundance of MALT, in the form of Peyers patches, nodules of lymphoid tissue akin to tonsils, embedded in the intestinal wall (Figure 13.17).
Digestion occurs in the small intestine. Both mechanical and chemical digestion occur in the small intestine. Mechanically, the peristaltic wave is modified into segmentations and migrating motility complexes. Segmentations are localized mixing contractions that swirl the chyme in one section of the intestine. They allow the chyme to interact with the walls of the small intestine but do not move it along the tract. Migrating motility complexes move the chyme along the length of the small intestine. These movements strengthen as the nutrient level in the chyme decreases.

When soupy chyme enters the duodenum, digestion of proteins, lipids, and carbohydrates has just begun. Pancreatic juice is added to the chyme as it enters the small intestine, adding a suite of digestive enzymes that are specific for different macromolecules. Sucrase, lactase, maltase, and pancreatic amylase all digest carbohydrates.

The pH buffers of the pancreatic juice immediately bring the pH of the chyme from 2 back to 7 in the small intestine to prevent damage to the lining of the duodenum. Bringing the pH up to 7 protects the walls of the small intestine, but renders pepsin inactive. Protruding into the small intestine is the pancreatic duct. Almost all of the enzymes that act in the small intestine are made in the pancreas. Pancreatic juice also buffers the acidity of the chyme as it leaves the stomach. The small intestine does not have the protective layer of mucus found in the stomach, so it has no protection from the corrosive pH 2 solution being released from the pyloric sphincter. The pancreas secretes pancreatic juice into chyme immediately as it enters the duodenum, largely neutralizing the chyme to safeguard the duodenum from acid burns.

In addition to secreting digestive enzymes into the digestive tract, the pancreas is also responsible for secreting hormones into the bloodstream. The pancreas makes insulin and glucagon, which are responsible for regulating glucose uptake by the cells. Insulin stimulates glucose uptake, whereas glucagon causes glucose to be released into the bloodstream by those muscles and liver cells sequestering it. These hormones will be covered in Chapter 15, The Endocrine System.

Ulcers are a hole in the GI tract. Ulcers are open wounds that remain aggravated and painful instead of healing. A gastric or duodenal ulcer is such a wound in the lining of the GI tract (Figures 13.18 and 13.19). Gastric ulcers occur in the stomach, whereas duodenal ulcers are located in the duodenum of the small intestine.

The mucous lining that normally protects the stomach from digestion must be compromised for an ulcer to develop. This can happen when alcohol or aspirin enters the stomach because these compounds can degrade the mucous lining. Aspirin labels direct you to take them with a full glass of water so that the pill is washed through the stomach, or dissolved rather than left sitting on the mucous layer. If the mucous layer is worn away, the pH of the lumens begins to burn the stomach lining, and pepsin will digest proteins of the stomach cells, creating an ulcer. Although in the past ulcers were commonly blamed on stress that caused the release of excess stomach acid, many gastric ulcers are actually caused by infection with Helicobacter pylori, a spiral bacterium that thrives in the highly acidic stomach. People who are susceptible to this bacterium often develop gastric ulcers due to bacterial colonies that live on the mucus. Rather than counsel these patients to reduce their stress level, the accepted ulcer treatment of old, they are given antibiotics to cure their ulcers.
The liver detoxifies what we add to the bloodstream

The liver is the largest organ aside from the skin and usually weighs about 1,450 grams. The liver has two lobes, and it’s mostly on the right side of the body. Within the lobes of the liver, the hepatocytes are arranged in lobules (Figure 13.20), designed to allow maximum contact between hepatocytes and venous blood. The lobules monitor blood collected from the small intestine, adding and subtracting materials to maintain fluid homeostasis.

The liver is served by a portal system. The veins of the small intestine drain into the liver, where they break into capillaries again before being collected into a larger vein and returned to the heart. Blood flow through the digestive organs travels from arteries to capillaries to veins to the liver, where it moves back to capillaries before going on to the veins that return to the heart. This portal system gives the hepatocytes access to the fluid composition of the blood coming from the small intestine. This blood includes all absorbed compounds, nutrients, as well as toxins, from the small intestine. The hepatocytes must cleanse the blood before it reaches the heart, removing toxins and storing excess nutrients, such as iron, and fat-soluble vitamins such as A, D, and E.

Cholesterol, plasma proteins, and blood lipids are manufactured in the hepatocytes. The liver also monitors the glucose level in the blood; when it exceeds 0.1%, hepatocytes remove and store the excess as glycogen. When the glucose level drops, stored glycogen is broken down and released from the hepatocytes, and glucose again rises in the blood.

Bile is formed by the liver as a byproduct of the breakdown of hemoglobin and cholesterol. It is stored in the gall bladder, under the right lobe of the liver. Bile salts from the gall bladder are released when fatty chyme is present in the duodenum, as that from the greasy pizza. The concentrated bile salts act as an emulsifier or biological detergent, breaking larger fat globules into smaller ones. Bile aids in fat digestion by increasing the surface area on which the digestive activities of pancreatic lipase can act.

Stones can form in bile: A small crystal of cholesterol that forms in the gall bladder may attract calcium ions from the concentrated bile, resulting in the formation of a stone. Stones can grow big enough to get stuck in the bile duct when the gall bladder releases its contents. This causes pain and blocks the flow of bile. The gall bladder is often removed if stones are a chronic problem. After removal, bile can be produced but not stored. The patient should not eat fatty meals, because there is no store of bile to aid in lipid digestion.

Liver diseases can be deadly

Because the liver serves as a detoxification center for blood coming from the intestinal tract, it is exposed to many toxic substances and toxins. The liver can be damaged by the very substances it is detoxifying. This occurs in the disease cirrhosis of the liver. Cirrhosis is a term for a series of events that cause scar tissue to build up in the liver. The scar tissue impedes the blood flow through the lobules, preventing hepatocytes from doing their job.

Other common liver diseases are viral, including hepatitis. Viruses infect the liver, and the damage progresses. It is most accurately diagnosed via tests for antibodies. Although there is no cure, treatment includes maintaining a healthy diet and exercise program. Hepatitis C is a major cause of liver transplants.

Chyme passes into the large intestine

Once the particle is formed, it is highly flammable. The large intestine absorbs many dissolved minerals and some vitamins. The valve that makes the transition from the ileum to the cecum prevents normal flow through the digestive organs.

Gangrene

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Figure 13.9

Colon

ascending colon runs up the right side of the abdominal cavity. The transverse colon cuts across the top of the abdominal cavity, posterior to the stomach. At the left side of the abdominal cavity the colon turns back down, in the descending colon. At the lower left of the abdominal cavity, the colon makes an S turn to wind up in the center of the body. This turn is called the sigmoid colon and is the portion of the colon where feces often sit for long periods of time before moving out the rectum. Often, polyps can develop in the colon as feces sit against the mucosa.

The walls of the large intestine have haustra, pouches created by strands of muscle in the walls. These pouches fill with undigested material, which moves from pouch to pouch via mass movements.

Diarrhea results from an irritation of the colon. The chyme moves through the colon far too quickly for water or minerals to be absorbed. Medicines that prevent mass movements are often helpful in slowing the movement of chyme through the large intestine, giving the walls of the organ ample time to return the excess water to the bloodstream. In severe diarrhea, remedies that contain minerals and fluid are ingested to replace what is lost in the diarrhea.

The last 20 centimeters of the colon are the rectum and anus. Chyme remains in the rectum for 3–18 hours, during which time it progressively becomes drier. Compacted chyme is referred to as feces. When feces enter the upper portion of the rectum, they trigger the opening of the internal anal sphincter, a smooth muscle. The feces move into the rectum and press against the external anal sphincter. This triggers defecation, a skeletal muscle action. As with all skeletal muscles, control over defecation is voluntary. On average, by age 2 1/2 years children are mature enough to control defecation.

Material moves through the large intestine in mass movements, created using a peristaltic wave. In the colon, water is reabsorbed from the soupy chyme, concentrating the waste material and conserving fluid. As the water is pulled back into the bloodstream across the lining of the colon, so too are minerals and vitamins. The removal of water leaves undigested remains of food and fiber in the colon, as well bacteria, such as E. coli and other obligate anaerobes that naturally live in the large intestine. These colonies are necessary in the colon because they break down indigestible material and often produce essential vitamins. Sometimes these colonies can be embarrassing because they generate gas when fermenting solids.

See Table 13.5 for a summary of the organs involved in digestion.

### Summary of the digestive organs

<table>
<thead>
<tr>
<th>Organ</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouth</td>
<td>See other listings in this table for the functions of the tongue, salivary glands, and teeth, all of which are in the mouth. Additionally, the lips and cheek keep food between the teeth during mastication, and buccal glands lining the mouth produce saliva.</td>
</tr>
<tr>
<td>Tongue</td>
<td>Muscles for mastication, shapes food into a bolus, maintains food for deglutition, detects taste and touch sensations, and initiates digestion of triglycerides.</td>
</tr>
<tr>
<td>Salivary glands</td>
<td>Produces saliva, which softens, moistens, and allows food to pass through the mouth and initiates the digestion of starch.</td>
</tr>
<tr>
<td>Teeth</td>
<td>Cut, tear, and pulverize food to reduce solids to smaller particles for swallowing.</td>
</tr>
<tr>
<td>Pharynx</td>
<td>Receives a bolus from the oral cavity and passes it into the esophagus.</td>
</tr>
<tr>
<td>Esophagus</td>
<td>Receives a bolus from the pharynx and moves it into the stomach. This requires relaxation of the upper esophageal sphincter and anterior esophagus.</td>
</tr>
<tr>
<td>Stomach</td>
<td>Mixture occurs cocoon food, mix it with secretions of gastric glands (gastric juice), and reduces food to chyme. Gastric juice activates pepsin and kills many microbes in food. intrinsic factor aids absorption of vitamin B12. The stomach serves as a reservoir for food before releasing it into the small intestine.</td>
</tr>
<tr>
<td>Pancreas</td>
<td>Pancreatic juice buffers acidic gastric juice in chyme (creating the proper pH for digestion in the small intestine), stops the action of pepsin from the stomach, and contains enzymes that digest carbohydrates, proteins, triglycerides, and nucleic acids.</td>
</tr>
<tr>
<td>Liver</td>
<td>Produces bile, which is needed for the emulsiﬁcation and absorption of lipids in the small intestine.</td>
</tr>
<tr>
<td>Gallbladder</td>
<td>Stores and concentrates bile and releases it into the small intestine.</td>
</tr>
<tr>
<td>Small intestine</td>
<td>Segments mix chyme with digestive juices, migrating motility complexes propel chyme toward the ileocecal valve. C. jejuni, E. coli, and other obligate anaerobes that naturally live in the small intestine aid in digestion. This is accomplished through two processes: mechanical digestion and chemical (or enzymatic) digestion. Mechanical digestion refers to the chopping, cutting, and tearing of large pieces of food into smaller ones. Bites of apple, for example, are crushed and torn into pieces in your mouth, but these pieces are still recognizable as apple pieces, and no chemical alteration has occurred. They have all the properties and chemical bonds of the original apple, but with a larger surface area needed for chemical digestion. Mechanical digestion occurs mainly in the mouth. Once the bolus of food is passed to the esophagus, a small amount of mechanical digestion occurs in the stomach, as it rolls and churns the food into chyme. The chyme then moves through the pyloric sphincter into the duodenum, where large droplets of fat are emulsified via bile. The action of bile is a form of mechanical digestion, breaking larger fat droplets into smaller ones without altering the chemical structure of the fats. At this point, the chyme is ready for enzymatic degradation, and mechanical digestion is finished. Unlike mechanical digestion, enzymatic digestion alters chemical bonds. Most of the food we ingest is composed of polymers, long chains of repeating subunits, which our digestive enzymes must break into short chains or monomers. It is these shorter units that are absorbed in the small intestine and used to produce the proteins and energy needed for survival.</td>
</tr>
</tbody>
</table>

### Table 13.5

<table>
<thead>
<tr>
<th>Learning objectives</th>
<th>Define mechanical and chemical digestion.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>List the major enzymes of chemical digestion, and note their substrate.</td>
</tr>
</tbody>
</table>

Digestion Is Both Mechanical and Chemical
In order to digest our myriad foodstuffs, we need several digestive enzymes (Figure 13.22). As you know, enzymes are functional proteins that work best under a set of optimal conditions of pH, temperature, substrate and product levels. (The substrate is the compound the enzyme acts upon, and the product is the result of that enzymatic action.) All enzymes are specific for a particular substrate and catalyze only one reaction.

Enzyme names are usually built from the name of the substrate, followed by the suffix “-ase”. For example, lipase digests lipids, and nucleases digest nucleic acids. The major digestive enzymes, along with their source, substrates, products, and sources, are listed in Table 13.6.

All digestive enzymes with the exception of two act in the small intestine. Salivary amylase begins to digest carbohydrates in the mouth and continues in the bolus of food entering the stomach. Pepsin, in the stomach, works best at pH 2. The rest of the digestive enzymes operate best at pH 7, and are found inside the small intestine.

2. Enzyme binds to food (substrate) molecule.

3. Enzyme uses H₂O to split the substrate molecule in half, leaving an OH⁻ on one product molecule and an H⁺ on the other.

Table 13.6 Digestive enzymes

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Source</th>
<th>Substrates</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>SALIVA</td>
<td>Salivary glands</td>
<td>Starches (polysaccharides).</td>
<td>Maltose (α-dextrin), maltotriose (β-maltotriose), and α-dextrins.</td>
</tr>
<tr>
<td>Lingual lipase</td>
<td>Lingual glands in the tongue.</td>
<td>Triglycerides (fat and oils) and other lipids.</td>
<td>Fatty acids and diglycerides.</td>
</tr>
<tr>
<td>GASTRIC JUICE</td>
<td>Stomach chief cells.</td>
<td>Triglycerides (fat and oils).</td>
<td>Fatty acids and monoglycerides.</td>
</tr>
<tr>
<td>PANCREATIC JUICE</td>
<td>Pancreatic acinar cells.</td>
<td>Starches (polysaccharides).</td>
<td>Maltose (α-dextrin), maltotriose (β-maltotriose), and α-dextrins.</td>
</tr>
<tr>
<td>Pancreatic lipase</td>
<td>Pancreatic acinar cells.</td>
<td>Triglycerides (fat and oils) that have been emulsified by bile salts.</td>
<td>Fatty acids and monoglycerides.</td>
</tr>
<tr>
<td>BRUSH BORDER</td>
<td>Small intestine.</td>
<td>α-Dextrin.</td>
<td>Glucose.</td>
</tr>
<tr>
<td>Lactase</td>
<td>Small intestine.</td>
<td>Lactose.</td>
<td>Glucose and glutamic acid.</td>
</tr>
</tbody>
</table>

For some organisms, locating and ingesting nutrients is relatively simple. The single-celled amoeba oozez through the environment, constantly searching for nutrients. When it literally runs across a bit of organic material, the amoeba engulfs the particle and brings it into its body via phagocytosis. Once inside the amoeba, the particle is broken into its building blocks by digestive enzymes in the lysosome (Figure 13.23). Monosaccha- rides are released from carbohydrates; amino acids are released from proteins; and small carbon compounds are released from fatty acids. These small organic compounds are then used by the amoeba to generate essential enzymes, cellular structures, and energy. Micronutrients are obtained by the amoeba in a similar fashion, via pinocytosis. Often microorganisms are released from larger compounds during bowel digestion.

The human body is far more complex than the amoeba, but each cell still needs nutrients in order to...
survive. Interestingly, human cells absorb nutrients in exactly the same manner as the amoeba: through diffusion, osmosis, facilitated diffusion, and active transport (including both phagocytosis and receptor-mediated endocytosis). However, the cells cannot leave their positions in the tissues to ooz through the environment in search of nutrients. Although that would make a wonderful B-movie plot, our cells must remain organized and in position! Therefore, the digestive system’s job is to prepare nutrients for circulation through the blood, which reaches every cell.

Regulation of our digestive activities is based on blood sugar levels. Normally, blood sugar is kept at approximately 70 to 110 mg glucose per 100 ml blood. This level is essential to keep neurons functioning. When blood glucose drops, we feel hungry. If we eat, blood sugar levels rise from the absorption of ingested glucose. If we choose not to eat, we begin to break down glycogen stores, where excess glucose has been stored in liver and skeletal muscles. Glycogen can break down to glucose relatively quickly. Fats and proteins can also be converted to glucose, but at a higher energy expense. During starvation, the protein of skeletal muscle, and even heart muscle, is broken down to provide glucose for the brain, as described in the material on the general adaptation syndrome in Chapter 9.

**Nutritional Health and Eating Disorders: You Truly are What You Eat**

**LEARNING OBJECTIVES**

Understand how to make healthy eating choices.

List the common eating disorders and their symptoms.

**D**iet and nutrition are important aspects of overall health because most of the compounds that enter the body enter through the digestive system. If we put nothing useful into the digestive system, our bodies will not have a good source of raw material for the proteins, enzymes, and energy required for life. Conversely, if we fill our digestive system with foods high in necessary nutrients, our bodies will function at peak levels. Of course, we can get too much of a good thing. If we ingest more calories than we “spend,” regardless of their quality, we will store the excess in adipose tissue as fat (triglycerides).

Much attention is given to our diets, and its effect on our body, both in the media and in society. As a society, we are obsessed with being thin. For some, this obsession takes an unhealthy turn, in the form of two common eating disorders, anorexia nervosa and bulimia nervosa. Both of them stem from the desire to be thin and therefore “beautiful,” and are described in the

**Ethics and Issues**

**Learning Objectives**

- List the enzymes that digest protein and specify where they are active.
- What are the products of the major pancreatic enzymes?

**CONCEPT CHECK**

Where does mechanical digestion occur?

**What is an ideal weight? How far should you go to look skinny?**

- Need to lose weight? In the United States, the rate of obesity is soaring. 30 percent of U.S. residents at least 20 years of age are considered obese. Since 1980, the rate of obesity has tripled among young people. But even people with normal weight seem to feel they would be smarter, sexier, and more lovable if they could dump a few pounds.
- Certainly, being overweight and especially obese is associated with high rates of hypertension, some cancers, type 2 diabetes, but an obsession with being overweight can take its own toll. Often those who suffer from this are stuck with a general feeling that they are not okay in their appearance or performance, and more specifically, they develop eating disorders.
- Eating disorders primarily affect young women; between 1 and 4 percent of women aged 14–25 suffer from one eating disorder or another, according to federal figures. The most common disorders are:
  - Anorexia nervosa, a form of self-starvation. Thin people think they are fat and use severe diets, intense exercise, or purging in an attempt to lose weight. The physical symptoms resemble starvation: osteoporosis, brittle hair, intolerance of cold, and muscle wasting, among many other possible problems.
  - Bulimia nervosa, secretive eating binges followed by vomiting or enemas to clear the food before it can be digested. Because bulimics may not be severely thin, the disorder can remain undiagnosed for a long while. Complications include electrolyte imbalance and acid damage to the upper GI tract.

**What is the ideal weight? How far should you go to look skinny?**

- BMI > 30, or ~ 30 lbs. overweight for 5’4” person

**What is the ideal weight?**

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The healthy human colon is a sea of bacteria, including vast numbers of Escherichia coli (E. coli). A large percentage of the mass of feces consists of billions of E. coli cells. Inside the GI tract, almost all E. coli are helpful or at worst harmless. However, E. coli can infect the urinary tract (causing UTI, a urinary tract infection). If it escapes the colon and enters the abdomen, it can cause peritonitis, a serious abdominal infection. We often hear about outbreaks of E. coli infections in the media; outbreaks that cause serious illness or even death. The number of bacteria needed to start an E. coli infection is unknown but seems to be much lower than for typical food-borne pathogens.

The routes of infection suggest the tactics for self-defense against E. coli O157:H7. While preparing meat, segregate it from other food, clean up carefully, and wash hands often. Cook hamburger to at least 72°C (160°F). If you cannot check the temperature with a digital thermometer, cook until the pink inside turns brown. If children develop this infection, they must be especially careful to observe sanitary procedures, especially frequent hand-washing, so they do not pass it along.

E. coli O157:H7 normally lives in the intestines of healthy cattle, and some other ruminants. Most human infections come from meat contaminated by the contents of cattle intestines at the slaughterhouse. Ground beef is the most common carrier because the bacteria can reside deep inside the meat, where it cannot be washed off or easily heat-sterilized by cooking. More rarely, E. coli O157:H7 can be spread by an infected person, or in unpasteurized juice or water. The number of bacteria needed to start an E. coli O157:H7 infection is unknown but seems to be much lower than for typical food-borne pathogens.

Are E. coli Bacteria Hazardous to My Health?

Food is Life-Sustaining, But Sometimes It Can Be Life-Threatening as Well

Eating disorders are not the only pathologies of the digestive system. There are almost as many food-borne diseases as there are foods to carry them. More than 250 food-borne diseases are known, ranging from bacteria and viruses to parasites and toxins from the foods themselves. The many types of food poisoning share a common thread. They are usually found growing in or on the foods we eat. All of these diseases enter the body through the digestive tract. Symptoms can vary, but the immediate symptoms usually include nausea, vomiting, abdominal cramps, and/or diarrhea. These symptoms represent the body’s attempt to rid itself of the pathogen or toxin. If these flushing techniques fail, we will experience the specific symptoms of the invading organism.

Three common bacterial food poisonings are Campylobacter, Salmonella, and Escherichia coli (E. coli). Campylobacter is a normal resident of the intestinal tract of chickens and other food. Commonly ingested in undercooked poultry, Campylobacter is the number one cause of bacterial diarrhea in the world. Salmonella, found in the intestines of birds, reptiles, and mammals, causes the usual food poisoning symptoms, but can become much more serious if untreated. Salmonella can escape the intestinal tract and enter the bloodstream, leading to septicemia, a life-threatening condition in which the blood carries a poison throughout the body. E. coli is normally present in the colon of cattle, pigs, and humans. A toxic form of E. coli is described in the I Wonder box.

The most common viral food contaminant is Calicivirus or Norwalk-like virus, which causes vomiting that lasts for approximately two days, with little diarrhea or fever. Norwalk-like virus has even spread from infected fisherman through their oyster catch. Stomach flu has similar symptoms; it is actually not influenza but rather a viral infection that attacks and irritates the stomach and small intestine. Stomach flu is transmitted through kissing, touching, or sharing food, drinks, or utensils. Food preparation workers who carry the virus can spread it through the food.

Adding nutrients to the blood changes the blood chemistry, and digesting that pizza has pulled water from body fluids. These changes must be rectified to keep the blood and other body fluids within their narrow ranges. Maintaining fluid homeostasis is a matter of survival. Monitoring and maintaining the composition of the blood and the entire internal environment is the job of yet another system, the urinary system, which is covered in Chapter 14.
CHAPTER SUMMARY

1 Nutrients Are Life-sustaining

Food contains macronutrients: carbohydrates, fats, and proteins; and micronutrients: vitamins and minerals. Vitamins are organic substances and minerals are inorganic. Both are necessary for maintaining homeostasis, and both can be obtained safely from over-the-counter supplements, but the daily diet should be rich in fruits and vegetables. How much and what type of food we ingest plays a large role in our health. The U.S. Food and Drug Administration has recently upgraded the basic food pyramid to factor in age, activity levels, and gender.

2 The Digestive System Processes Food from Start to Finish

The digestive system ingests food, mixes and propels food through the digestive organs, mechanically and chemically breaks down the food, absorbs the nutrients from the food, and releases the undigested wastes. The digestive system, or GI tract, is composed of one continuous tube, divided by sphincter muscles. Each organ has anatomical alterations that allow it to perform a specific function. The organs, in order, are the oral cavity, esophagus, stomach, small intestine, large intestine, and rectum. Accessory organs, including the salivary glands, liver, gall bladder, and pancreas, aid in digestion. The salivary glands release salivary amylase and lubricate the bolus of food. The liver cleanses the blood as it drains from the small intestine. The gall bladder stores and releases bile. The pancreas produces digestive enzymes and buffers that control the pH of the digestive chyme in the small intestine.

3 Digestion Is Both Mechanical and Chemical

Mechanical digestion starts in the mouth, where the teeth grind and crush the food. Saliva moistens the food, forming a bolus that can be swallowed. Muscular contractions push the bolus through the esophagus into the stomach, where high acidity starts to break it down. This acidity kills most pathogens but can attack the stomach wall if the mucus lining is damaged. In the small intestine, enzymes continue to break-down the material called chyme. Macronutrients are absorbed through the highly convoluted lining of the small intestine and into the blood supply. As the now-nutrient absorbed chyme moves through the large intestines, water is removed. The waste material, including a large proportion of harmless bacteria, is moved into the rectum and excreted.

4 Nutritional Health and Eating Disorders: You Truly Are What You Eat

The primary nutritional disease in the United States is probably obesity. The major eating disorders are anorexia nervosa, bulimia nervosa, and binge eating disorder. All can be treated with a combination of proper diet and professional mental health care. A number of food-borne pathogens, both bacterial and viral, can cause disease, but good sanitation can prevent many of them from being spread.

KEY TERMS

○ aerobes p. 000
○ anorexia p. 000
○ bacterial p. 000
○ biotics p. 000
○ chyme p. 000
○ chylomicrons p. 000
○ chemosmosis p. 000
○ chyme p. 000
○ chylomicrons p. 000
○ chyme p. 000
○ chemical digestion p. 000
○ disease p. 000
○ disease p. 000
○ disease p. 000
○ disease p. 000
○ disease p. 000
○ disease p. 000
○ disease p. 000

CRITICAL THINKING QUESTIONS

1. Go to the MyPyramid Web site (http://www.mypyramid.gov) and obtain your personal food guide. After you check your personal characteristics, and compare the results. Describe what happens to the recommended guidelines as you age. What happens as the exercise level increases? Are these changes the same for males and females, or does gender radically alter the caloric recommendation?

2. Starting at the esophagus, trace the pathway of food through the system. At each organ, indicate what anatomical adaptations have been made to the general GI tract tube structure that allow for the specific functions of that organ.

3. One of the more drastic solutions for overeating is to “staple” the stomach—a procedure called gastric bypass surgery. This surgery reduces stomach size, preventing it from holding so much. How would this affect the functioning of the stomach? What essential hormone will decrease in the blood as the surface area of the stomach decreases?

4. Give a brief review of the structure of a liver lobule. Explain why cirrhosis of the liver can lead to jaundice and eventual liver failure. What exactly prevents the liver lobule from functioning?

5. Some emotions curb the appetite. How does this happen?
SELF TEST

1. Macronutrients include all of the following EXCEPT:
   a. carbohydrates.
   b. lipids.
   c. vitamins.
   d. proteins.

2. The reactions in this diagram are collectively referred to as:
   a. chemiosmosis.
   b. the Krebs cycle.
   c. mitochondrial reactions.
   d. cellular respiration.

3. The first step in the reaction shown above:
   a. is called glycolysis.
   b. converts one glucose molecule to two pyruvate molecules.
   c. releases a net of 2 ATP molecules.
   d. all of the above describe the first reaction shown.

4. In the figure below, the molecule of unsaturated fat is indicated as:
   a. A
   b. B
   c. Neither of these molecules are unsaturated fats.
   d. Both of these molecules are unsaturated fats.

5. The myPyramid website is designed to give you:
   a. tips on healthy eating in general.
   b. easy access to the caloric content of most common foods.
   c. tips on healthy eating based on your gender, age and activity level.
   d. assistance in reducing obesity.

6. True or false: Calcium, zinc and iodine are all examples of vitamins.

7. The correct order of layers in the GI tract from external surface to lumen is:
   a. serosa → submucosa → muscularis → mucosa
   b. mucosa → submucosa → muscularis → serosa
   c. muscularis → submucosa → mucosa → serosa
   d. submucosa → mucosa → muscularis → serosa

8. The muscularis of the GI tract is responsible for:
   a. protecting the lumen.
   b. creating the peristaltic wave.
   c. absorbing water and nutrients.
   d. allowing the tract to slide around inside the abdominal cavity.

9. The tooth responsible for grinding and crushing are the:
   a. incisors.
   b. canines.
   c. premolars.
   d. All types of teeth grind food.

10. Immune defenses in the digestive system include all of the following EXCEPT:
    a. MALT.
    b. Peyers patches.
    c. liver.
    d. All three phases are triggered by the smell of food.

11. The stage of swallowing that involves the rising of the larynx is shown in this figure as:
    a. A
    b. B

12. One function of the organ containing these structures is:
    a. chemical digestion of carbohydrates.
    b. mechanical digestive action of bile.
    c. chemical digestion of proteins.
    d. nutrient absorption.

13. The organ that is responsible for producing digestive enzymes is the:
    a. liver.
    b. gall bladder.
    c. pancreas.
    d. sublingual salivary gland.

14. Most stomach ulcers are caused by:
    a. stress.
    b. aspirin eroding the mucus lining of the stomach.
    c. a spiral bacterium.
    d. alcoholism.

15. The phase of gastric digestion that is initiated simply by the smell of food is the:
    a. cephalic phase.
    b. gastric phase.
    c. intestinal phase.
    d. All three phases are triggered by the smell of food.

16. The function of the organ containing the structures shown below is:
    a. chemically digested food.
    b. mechanically digest food.
    c. absorbs nutrients.
    d. All of the above are true of this organ.

17. The structure shown below is found in the _______ and serves to ________.
    a. large intestine, decreases surface area
    b. small intestine, increases surface area
    c. stomach, produce HCl
    d. liver, produce and store bile

18. The most common viral liver disease in the United States is:
    a. hepatitis A.
    b. hepatitis B.
    c. hepatitis C.
    d. All three are equally uncommon.

19. The common eating disorder, anorexia nervosa, can be described as:
    a. the binge-purge disease.
    b. food poisoning.
    c. overeating.
    d. severe under-eating.

20. The bacterium E. coli is normally found:
    a. in the colon.
    b. in the small intestine.
    c. in the stomach.
    d. throughout the digestive system.