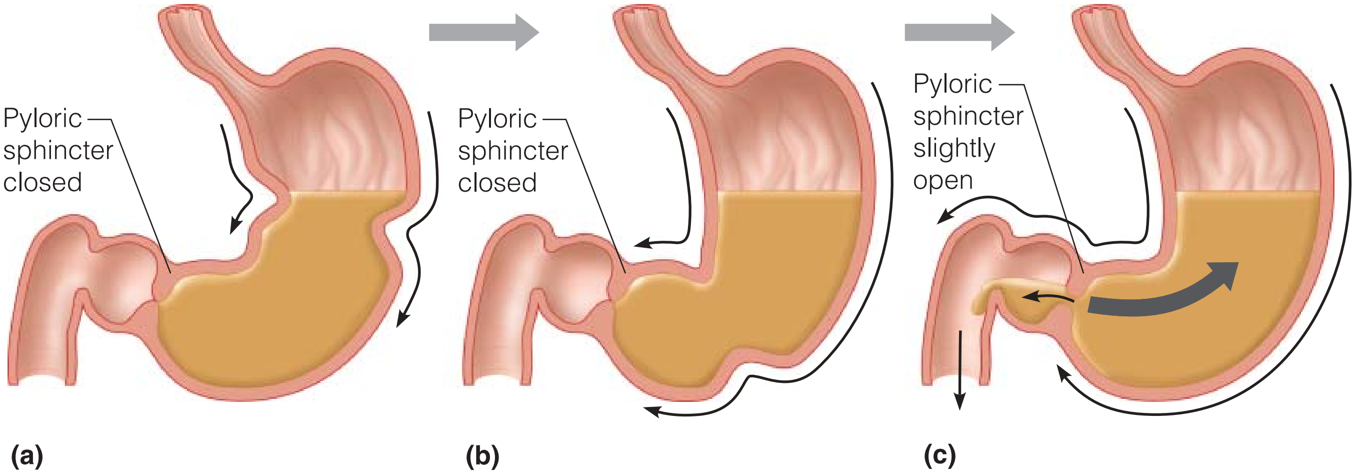

FIGURE 14.15 Peristaltic waves act primarily in the inferior portion of the stomach to mix and move chyme through the pyloric valve. **(a)** Peristaltic waves move toward the pylorus. **(b)** The most vigorous peristalsis and mixing action occurs close to the pylorus. **(c)** The pyloric end of the stomach acts as a pump that delivers small amounts of chyme into the duodenum while forcing most of the contained material backward into the stomach, where it undergoes further mixing.

like a meter that allows only liquids and very small particles to pass through the pyloric sphincter (Figure 14.15). Because the pyloric sphincter barely opens, each contraction of the stomach muscle squirts 3 ml or less of chyme into the small intestine. Since the contraction also *closes* the valve, the rest (about 27 ml) is propelled backward into the stomach for more mixing. When the duodenum is filled with chyme and its wall is stretched, a nervous reflex, the *enterogastric* (en″ter-o-gas′trik) *reflex,* occurs. This reflex "puts the brakes on" gastric activity and slows the emptying of the stomach by inhibiting the vagus nerves and tightening the pyloric sphincter, thus allowing time for intestinal processing to catch up. Generally, it takes about 4 hours for the stomach to empty completely after eating a well-balanced meal and 6 hours or more if the meal has a high fat content.

Homeostatic Imbalance

Local irritation of the stomach, such as occurs with bacterial food poisoning, may activate the *emetic* (ĕ-met′ik) *center* in the brain (medulla). The emetic center, in turn, causes **vomiting (emesis).** Vomiting is essentially a reverse peristalsis occurring in the stomach (and perhaps the small intestine), accompanied by contraction of the abdominal muscles and the diaphragm, which increases the pressure on the abdominal organs. The emetic center may also be activated through other pathways; disturbance of the equilibrium apparatus of the inner ear during a boat ride on rough water is one example.

Activities of the Small Intestine

Food Breakdown and Absorption

Food reaching the small intestine is only partially digested. Carbohydrate and protein digestion have been started, but virtually no fats have been digested up to this point. Here the process of chemical food digestion is accelerated as the food now takes a rather wild 3- to 6-hour journey through the looping coils and twists of the small intestine. By the time the food reaches the end of the small intestine, digestion is complete and nearly all food absorption has occurred.

The microvilli of small intestine cells bear a few important enzymes, the so-called **brush border enzymes** that break down double sugars into simple sugars and complete protein digestion (see Figure 14.13). *Intestinal juice* itself is relatively enzyme-poor, and protective mucus is probably the most important intestinal gland secretion. However, foods entering the small intestine are literally deluged with enzyme-rich **pancreatic**

TABLE 14.1 Hormones and Hormonelike Products That Act in Digestion

Hormone	Source	Stimulus for secretion	Action
Gastrin	Stomach	Food in stomach (chemical stimulus)	• Stimulates release of gastric juice • Stimulates mobility of small intestine • Relaxes ileocecal valve.
Histamine	Stomach	Food in stomach	• Activates parietal cells to secrete hydrochloric acid.
Somatostatin	Stomach	Food in stomach	• Inhibits secretion of gastric juice and pancreatic juice • Inhibits emptying of stomach and gallbladder.
Secretin	Duodenum	Acidic chyme and partially digested foods in duodenum	• Increases output of pancreatic juice rich in bicarbonate ions • Increases bile output by liver • Inhibits gastric mobility and gastric gland secretion.
Cholecystokinin (CCK)	Duodenum	Fatty chyme and partially digested proteins in duodenum	• Increases output of enzyme-rich pancreatic juice • Stimulates gallbladder to expel stored bile • Relaxes sphincter of duodenal papilla to allow bile and pancreatic juice to enter the duodenum.
Gastric inhibitory peptide (GIP)	Duodenum	Fatty chyme in duodenum	• Inhibits gastric mobility and secretion of gastric juice.

juice ducted in from the pancreas, as well as bile from the liver.

Pancreatic juice contains enzymes that (1) along with brush border enzymes, complete the digestion of starch *(pancreatic amylase);* (2) carry out about half of protein digestion (via the action of *trypsin, chymotrypsin, carboxypeptidase,* and others); (3) are totally responsible for fat digestion since the pancreas is essentially the only source of *lipases;* and (4) digest nucleic acids *(nucleases).*

In addition to enzymes, pancreatic juice contains a rich supply of bicarbonate, which makes it very basic (about pH 8). When pancreatic juice reaches the small intestine, it neutralizes the acidic chyme coming in from the stomach and provides the proper environment for activation and activity of intestinal and pancreatic digestive enzymes.

Homeostatic Imbalance

Pancreatitis (pan″kre-ah-ti′tis) is a rare but extremely serious inflammation of the pancreas that results from activation of pancreatic enzymes in the pancreatic duct. Since pancreatic enzymes break down all categories of biological molecules, the pancreatic tissue and duct are digested. This painful condition can lead to nutritional deficiencies, because pancreatic enzymes are essential to digestion in the small intestine.

The release of pancreatic juice into the duodenum is stimulated by both the vagus nerves and local hormones. When chyme enters the small intestine, it stimulates the mucosa cells to produce several hormones (Table 14.1). Two of these

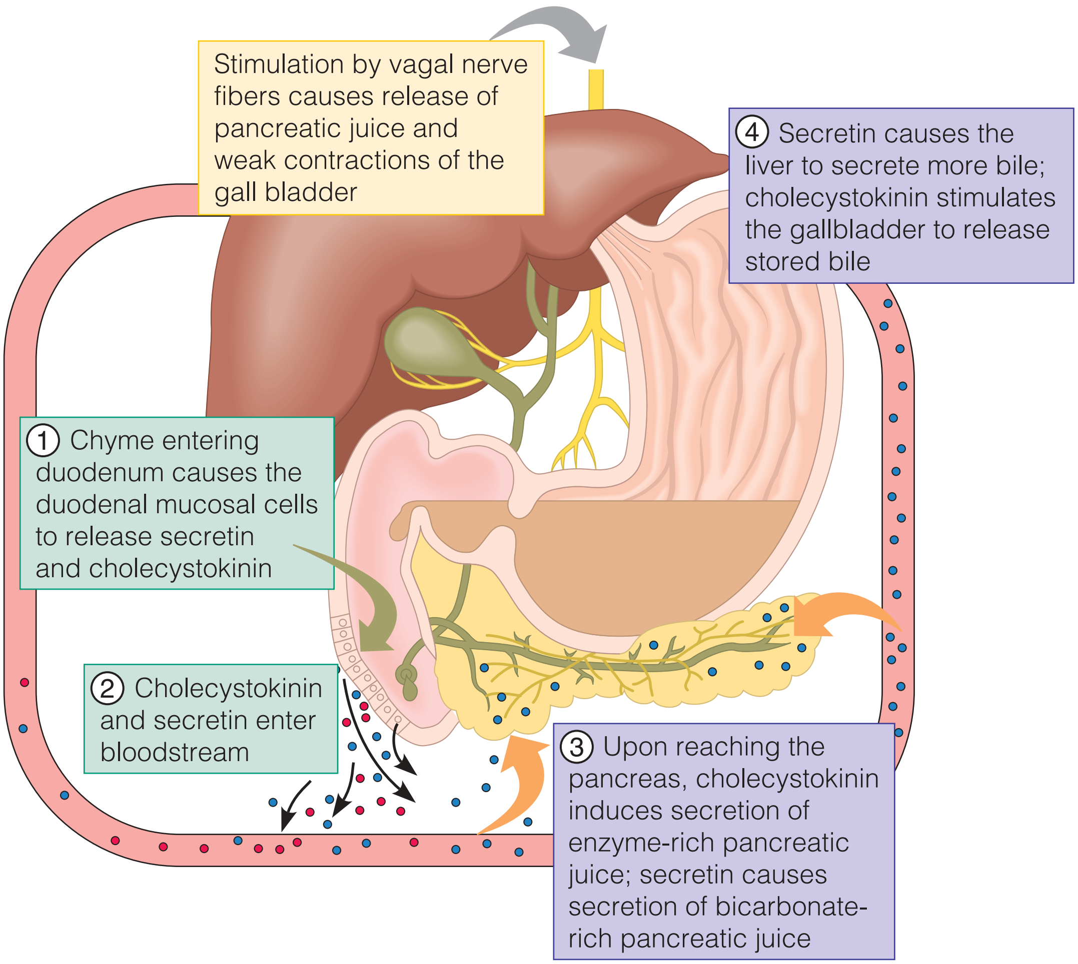

FIGURE 14.16 **Regulation of pancreatic juice secretion.** Hormonal controls, exerted by secretin and cholecystokinin (steps 1–3), are the main regulatory factors. Neural control is mediated by the vagus nerves.

hormones, **secretin** (se-kre′tin) and **cholecystokinin** (ko″le-sis″to-kin′in) **(CCK),** influence the release of pancreatic juice and bile.

The hormones enter the blood and circulate to their target organs, the pancreas, liver, and gallbladder. Both hormones work together to stimulate the pancreas to release its enzyme- and bicarbonate-rich product (Figure 14.16). In addition, secretin causes the liver to increase its output of bile, and cholecystokinin causes the gallbladder to contract and release stored bile into the bile duct so that bile and pancreatic juice enter the small intestine together. As mentioned before, bile is not an enzyme. Instead, it acts like a detergent to emulsify, or mechanically break down, large fat globules into thousands of tiny ones, providing a much greater surface area for the pancreatic lipases to work on. Bile is also necessary for absorption of fats (and other fat-soluble vitamins [K, D, and A] that are absorbed along with them) from the intestinal tract.

Homeostatic Imbalance

If *either* bile or pancreatic juice is absent, essentially no fat digestion or absorption goes on, and fatty, bulky stools are the result. In such cases, blood-clotting problems also occur because the liver needs vitamin K to make prothrombin, one of the clotting factors.

Absorption of water and of the end products of digestion occurs all along the length of the small intestine. Most substances are absorbed through the intestinal cell plasma membranes by the process of *active transport*. Then they enter the capillary beds in the villi to be transported in the blood to the liver via the hepatic portal vein. The exception seems to be lipids, or fats, which are absorbed passively by the process of *diffusion*. Lipid breakdown products enter both the capillary beds and the lacteals in the villi and are carried to the liver by both blood and lymphatic fluids.

At the end of the ileum, all that remains is some water, indigestible food materials (plant fibers such as cellulose), and large amounts of bacteria. This debris enters the large intestine through the ileocecal valve. The complete process of food digestion and absorption is summarized in Figure 14.13 (p. 469).

Food Propulsion

As mentioned previously, *peristalsis* is the major means of propelling food through the digestive tract. It involves waves of contraction that move along the length of the intestine, followed by waves of relaxation. The net effect is that the food is moved through the small intestine in much the same way that toothpaste is squeezed from a tube. Rhythmic segmental movements produce local constrictions of the intestine (see Figure 14.12b) that mix the chyme with the digestive juices, and help to propel food through the intestine.

Activities of the Large Intestine

Food Breakdown and Absorption

What is finally delivered to the large intestine contains few nutrients, but that residue still has 12 to 24 hours more to spend there. The colon itself produces no digestive enzymes. However, the "resident" bacteria that live within its lumen metabolize some of the remaining nutrients, releasing gases (methane and hydrogen sulfide) that contribute to the odor of feces. About 500 ml of gas (flatus) is produced each day, much more when certain carbohydrate-rich foods (such as beans) are eaten.

Bacteria residing in the large intestine also make some vitamins (vitamin K and some B vitamins). Absorption by the large intestine is limited to the absorption of these vitamins, some ions, and most of the remaining water. **Feces,** the more or less solid product delivered to the rectum, contain undigested food residues, mucus, millions of bacteria, and just enough water to allow their smooth passage.

Propulsion of the Residue and Defecation

Peristalsis and mass movements are the two major types of propulsive movements occurring in the large intestine. Colon peristalsis is sluggish and, compared to the mass movements, probably contributes very little to propulsion. **Mass movements** are long, slow-moving but powerful contractile waves that move over large areas of the colon three or four times daily and force the contents toward the rectum. Typically, they occur during or just after eating, when food begins to fill the stomach and small intestine. Bulk, or fiber, in the diet increases the strength of colon contractions and softens the stool, allowing the colon to act as a well-oiled machine.

Homeostatic Imbalance

When the diet lacks bulk, the colon narrows and its circular muscles contract more powerfully, which increases the pressure on its walls. This encourages formation of *diverticula* (di″ver-tik′u-lah), in which the mucosa protrudes through the colon walls, a condition called *diverticulosis. Diverticulitis,* a condition in which the diverticula become inflamed, can be life-threatening if ruptures occur.

The rectum is generally empty, but when feces are forced into it by mass movements and its wall is stretched, the **defecation reflex** is initiated. The defecation reflex is a spinal (sacral region) reflex that causes the walls of the sigmoid colon and the rectum to contract and the anal sphincters to relax. As the feces are forced through the anal canal, messages reach the brain giving us time to make a decision as to whether the external voluntary sphincter should remain open or be constricted to stop passage of feces. If it is not convenient, defecation (or "moving the bowels") can be delayed temporarily. Within a few seconds, the reflex contractions end and the rectal walls relax. With the next mass movement, the defecation reflex is initiated again.

Homeostatic Imbalance

Watery stools, or *diarrhea* (di″ah-re′ah), result from any condition that rushes food residue through the large intestine before that organ has had sufficient time to absorb the water (as in irritation of the colon by bacteria). Because fluids and ions are lost from the body, prolonged diarrhea may result in dehydration and electrolyte imbalance which, if severe, can be fatal.

If food residue remains in the large intestine for extended periods, too much water is absorbed, and the stool becomes hard and difficult to pass. This condition, called *constipation,* may result from lack of fiber in the diet, poor bowel habits ("failing to heed the call"), and laxative abuse. ▲

PART II: NUTRITION AND METABOLISM

Although it seems at times that people can be divided into two camps—those who live to eat and those who eat to live—we all recognize the vital importance of food for life. It has been said that "you are what you eat," and this is true in that part of the food we eat is converted to our living flesh. In other words, a certain fraction of nutrients is used to build cellular molecules and structures and to replace worn-out parts. However, most foods are used as metabolic fuels. That is, they are oxidized and transformed into **ATP,** the chemical energy form needed by body cells to drive their many activities. The energy value of foods is measured in units called **kilocalories (kcal),** or Calories (with a capital C), the units conscientiously counted by dieters.

We have just considered how foods are digested and absorbed. But what happens to these foods once they enter the blood? Why do we need bread, meat, and fresh vegetables? Why does everything we eat seem to turn to fat? We will try to answer these questions in this section.

Nutrition

A **nutrient** is a substance in food that is used by the body to promote normal growth, maintenance, and repair. The nutrients divide neatly into six categories. The *major nutrients*—carbohydrates, lipids, and proteins—make up the bulk of what we eat. Vitamins and minerals, while equally crucial for health, are required in minute amounts. Water, which accounts for about 60 percent of the volume of the food we eat, is also considered to be a major nutrient. However, because its importance as a solvent and in many other aspects of body functioning is described in Chapter 2, only the other five classes of nutrients will be considered here.

Most foods offer a combination of nutrients. For example, a bowl of cream of mushroom soup contains all of the major nutrients plus some vitamins and minerals. A diet consisting of foods selected from each of the five food groups (Table 14.2), that is, grains, fruits, vegetables, meats and fish, and milk products, normally guarantees adequate amounts of all of the needed nutrients.

Dietary Sources of the Major Nutrients

Carbohydrates

Except for milk sugar (lactose) and small amounts of glycogen in meats, all the **carbohydrates**—sugars and starches—we ingest are derived from plants. Sugars come mainly from fruits, sugar cane, and milk. The polysaccharide starch is found in grains, legumes, and root vegetables. The polysaccharide cellulose, which is plentiful in most vegetables, is not digested by humans, but it provides roughage, or fiber, which increases the bulk of the stool and aids defecation.

Lipids

Although we also ingest cholesterol and phospholipids, most dietary **lipids** are triglycerides. We eat saturated fats in animal products such as meat and dairy foods and in a few plant products, such as coconut. Unsaturated fats are present in seeds, nuts, and most vegetable oils. Major sources of cholesterol are egg yolk, meats, and milk products.

Proteins

Animal products contain the highest-quality **proteins,** molecules that are basically amino acid polymers. Eggs, milk, and most meat proteins are *complete proteins* that meet all of the body's amino acid requirements for tissue maintenance and growth. Legumes (beans and peas), nuts, and cereals are also protein-rich, but their proteins are nutritionally incomplete because they are low in one or more of the essential amino acids. As you can see, strict vegetarians must carefully plan their diets to obtain all the essential amino acids and prevent protein malnutrition. Cereal grains and legumes when ingested together provide all the essential amino acids, and some variety of this combination is found in the diets of all cultures