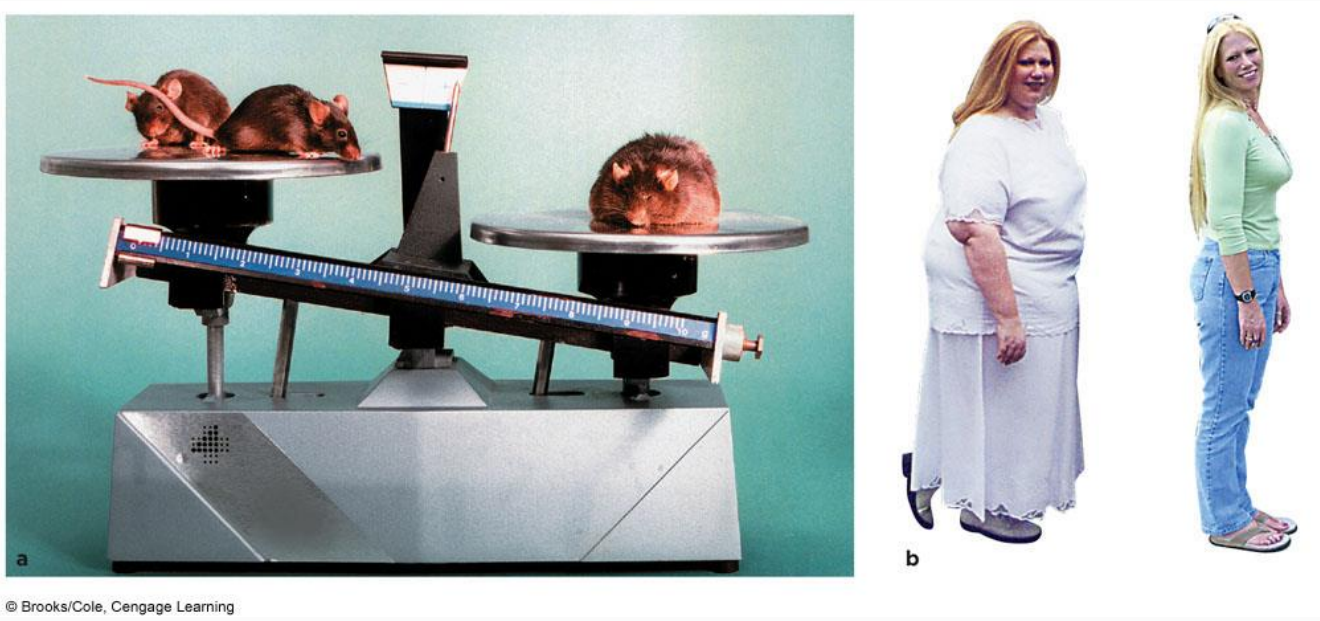
Digestion and Nutrition

Chapter 40

Impacts, Issues
Hormones and Hunger

- Fat cells secrete leptin, which reduces appetite; an empty stomach secretes ghrelin, which makes you hungry – the goal is healthy nutrition



40.1 The Nature of Digestive Systems

- **Digestive system**
  - A body cavity or tube that mechanically and chemically breaks food down to small particles, then to molecules that can be absorbed into the internal environment
  - Interacts with other organ systems to maintain homeostasis

Digestive System Interactions

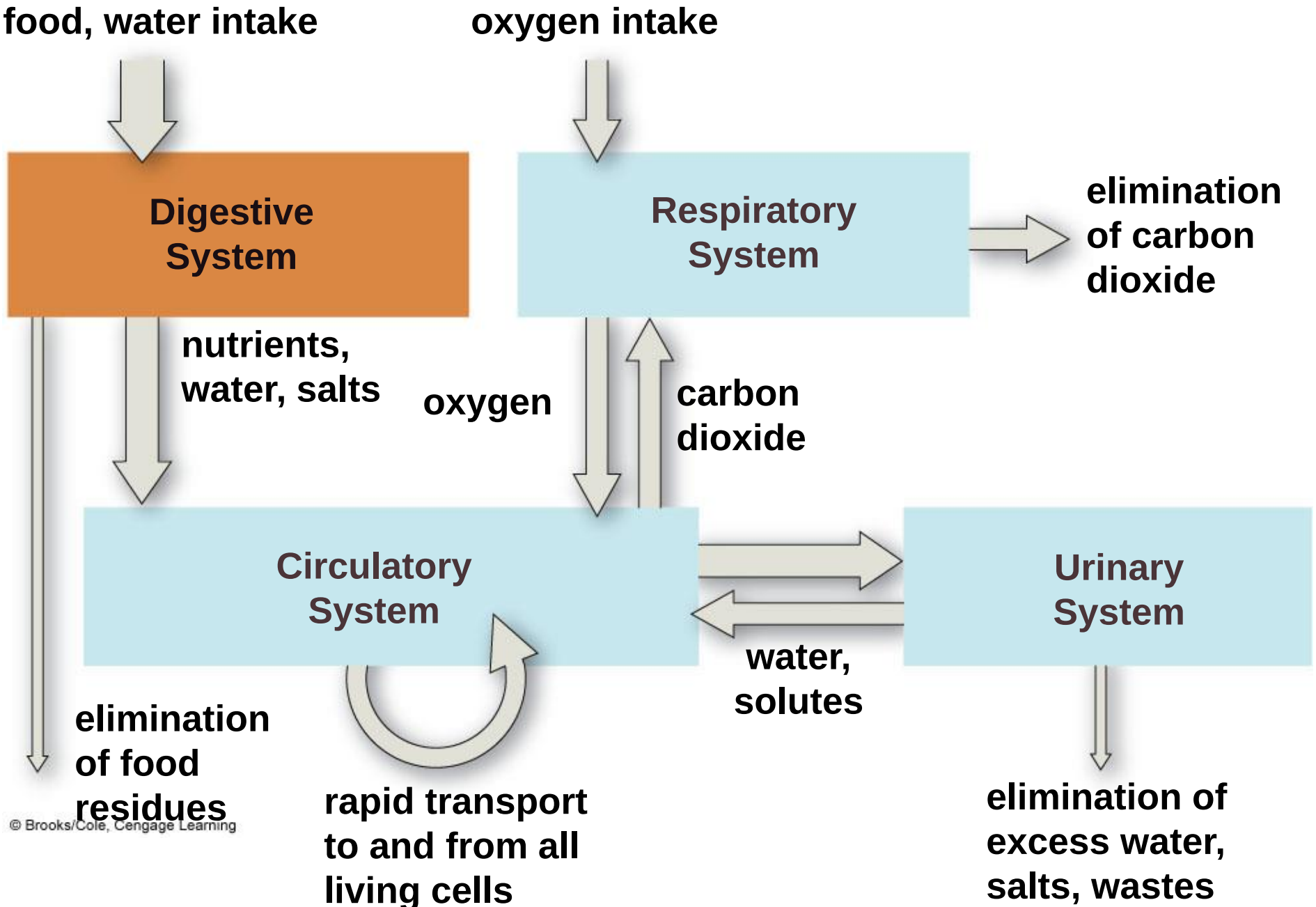
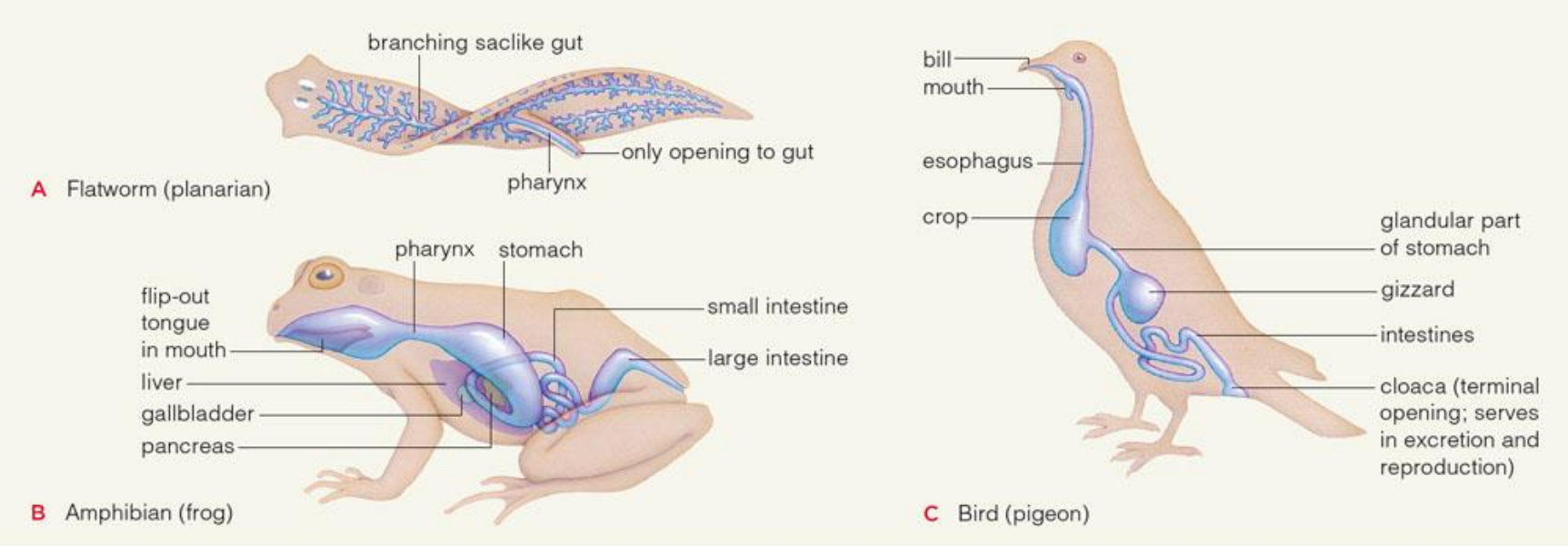


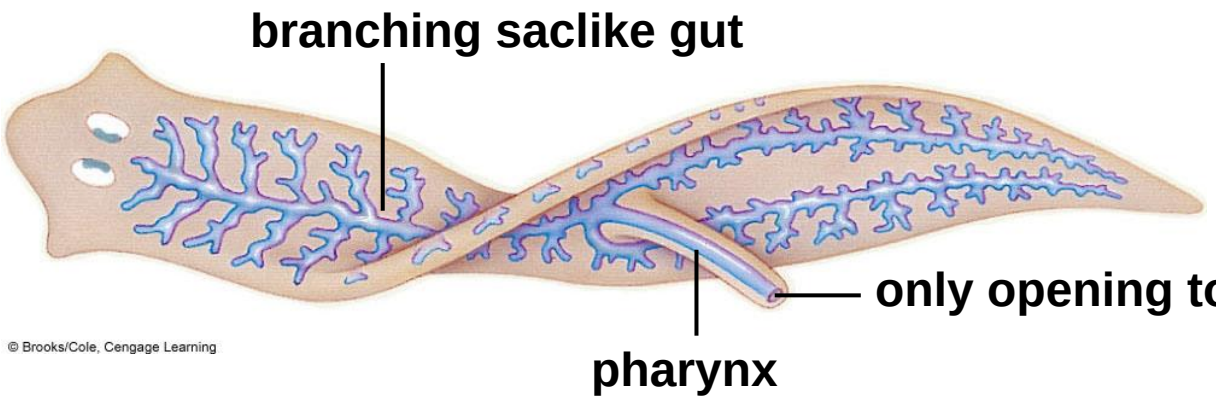
Fig. 40-2, p. 702

Incomplete and Complete Digestive Systems

- **Incomplete digestive system**
  - A saclike gut with one opening in the body surface for food to enter and waste to leave
- **Complete digestive system**
  - A tubular gut with an opening at both ends
  - Includes mouth, pharynx, esophagus, stomach, small and large intestines, and anus

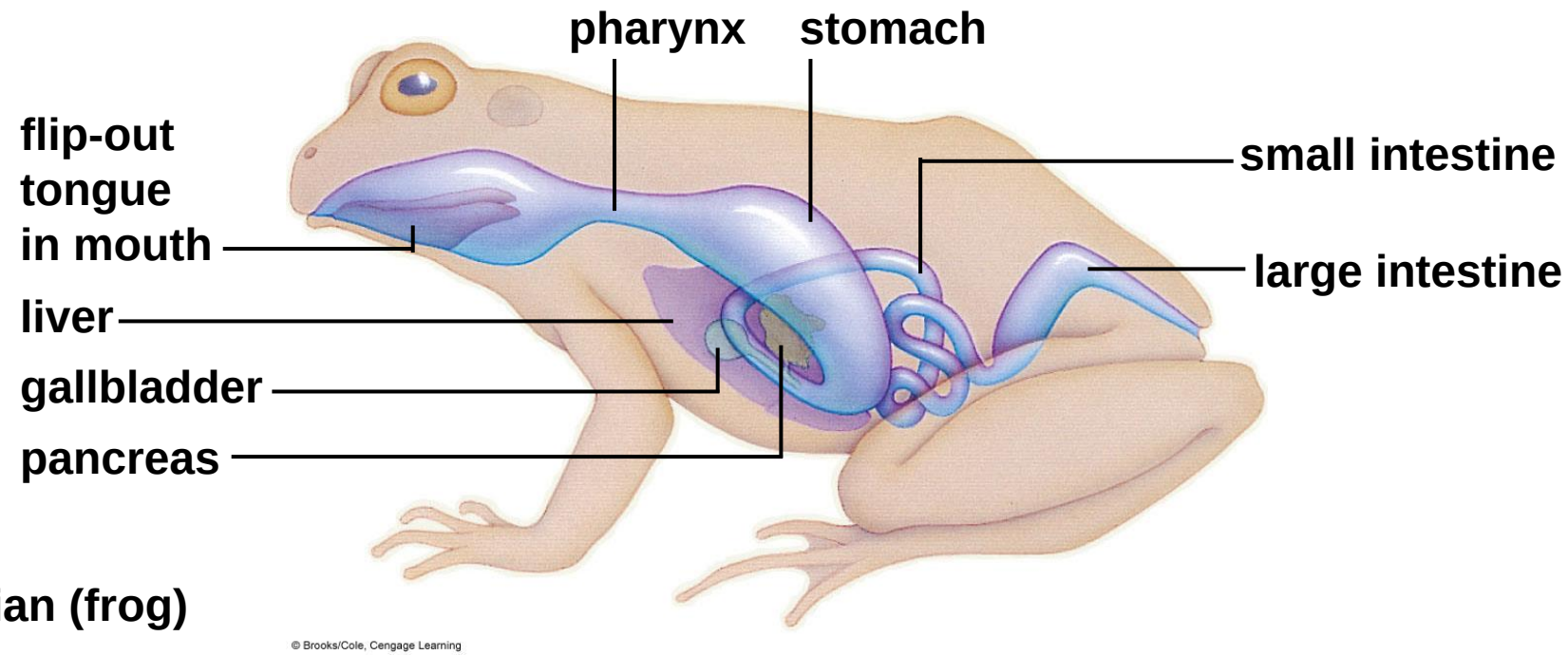
Incomplete and Complete Digestive Systems





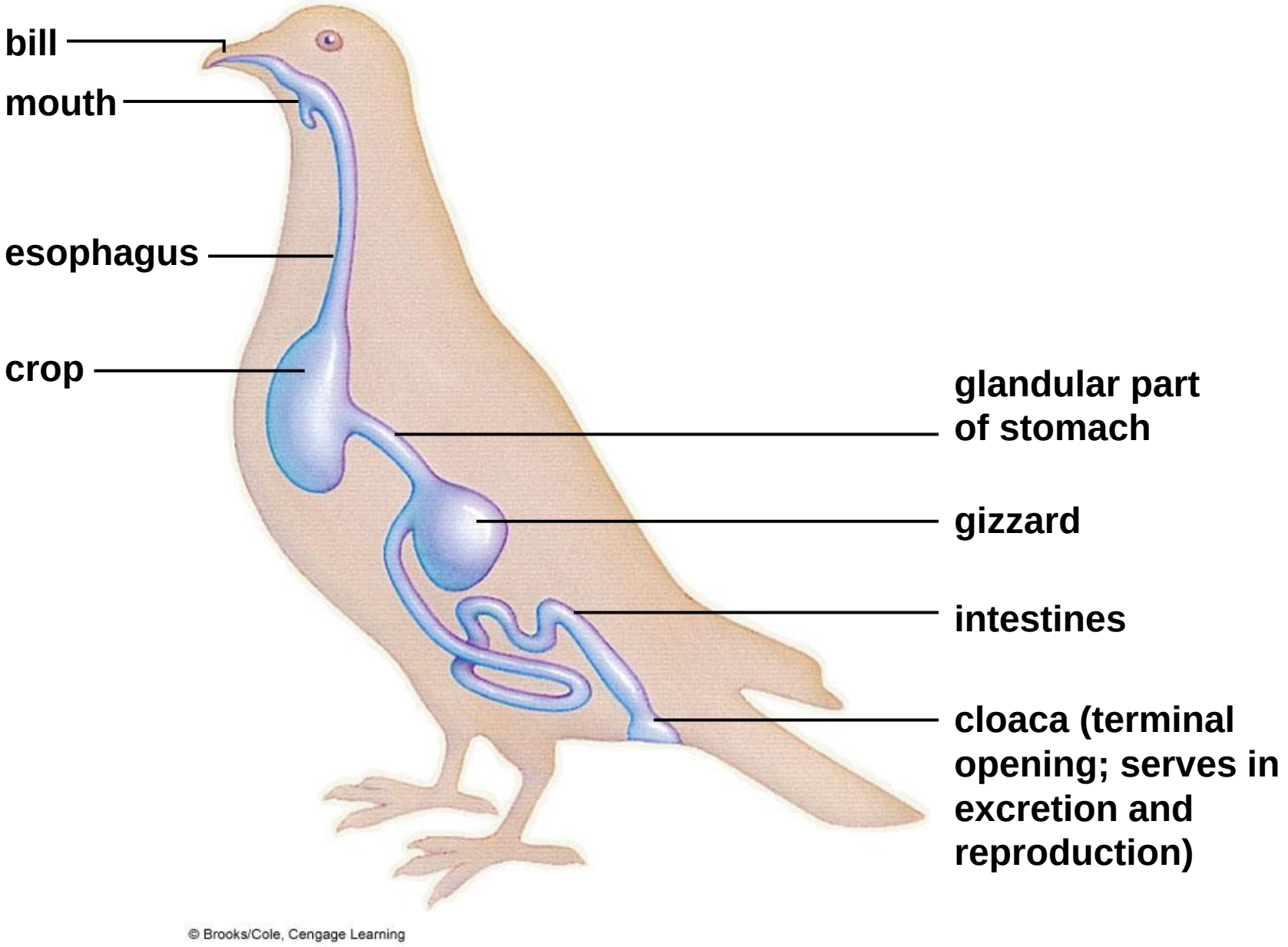
A **Flatworm (planarian)**

Fig. 40-3a, p. 702



B Amphibian (frog)

Fig. 40-3b, p. 702



C **Bird (pigeon)**

Fig. 40-3c, p. 702

Five Functions of a Complete Digestive System

1. *Mechanical processing and motility*
2. *Secretion* of digestive enzymes into the lumen
3. *Digestion* of food into absorbable molecules
4. *Absorption* of nutrients into extracellular fluid
5. *Elimination* of solid residues

Dietary Adaptations

- Bird adaptations
  - Size and shape of bills adapted to different diets
  - Crops and gizzards
- Mammal adaptations
  - Teeth adapted to different diets
  - Multiple stomach chambers in **ruminants**

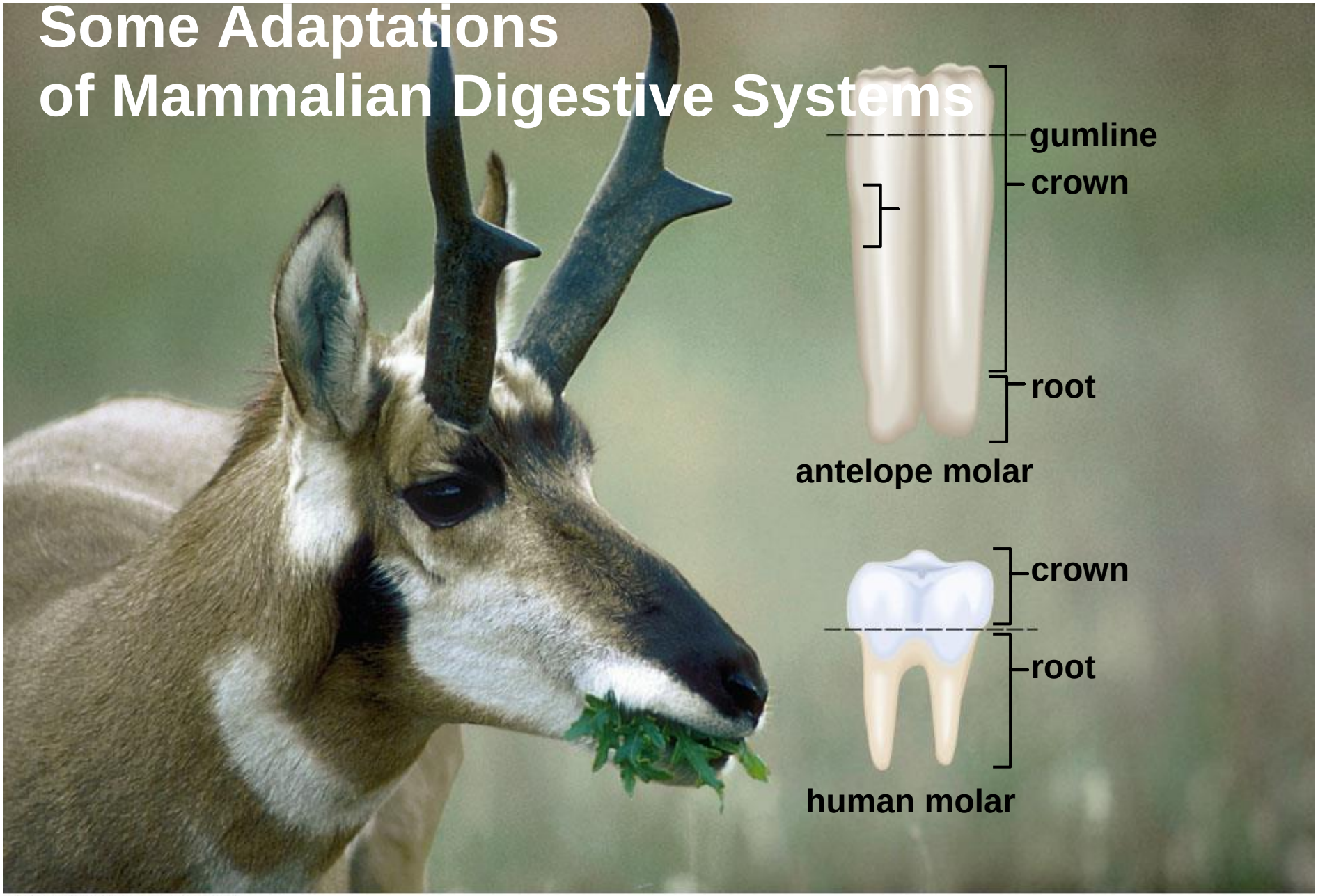


Fig. 40-4a, p. 703

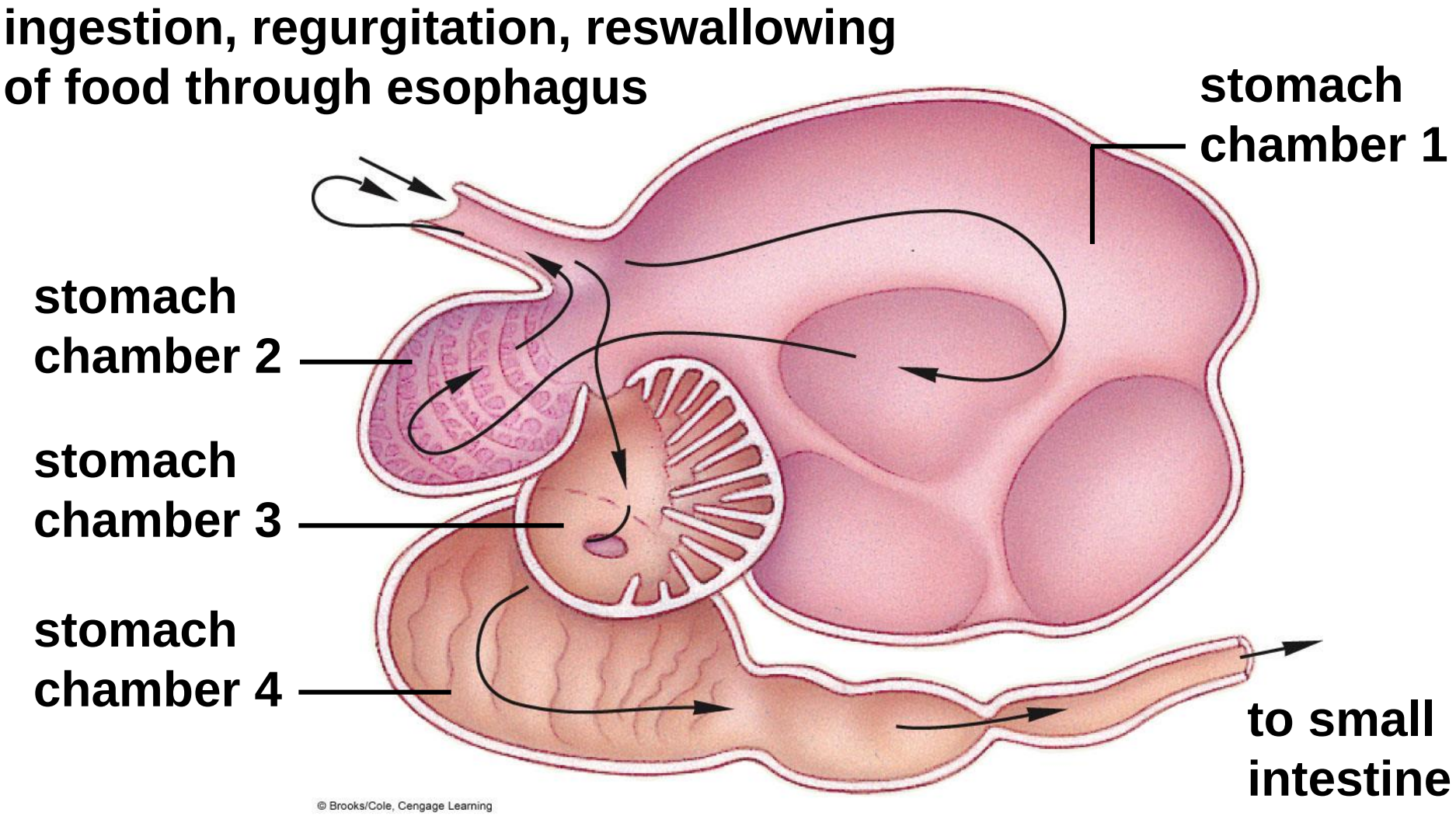


Fig. 40-4b, p. 703

40.1 Key Concepts
Overview of Digestive Systems

- *Some animal digestive systems are saclike, but most are a tube with two openings*

- *In complex animals, a digestive system interacts with other organ systems in the distribution of nutrients and water, disposal of residues and wastes, and homeostasis*

40.2 Overview of the Human Digestive System

- Humans have a complete digestive system lined with mucus-covered epithelium
- If the tubular gut of an adult human were fully stretched out, it would extend up to 9 meters (30 feet)

Accessory Organs

- Accessory organs along the length of the gut secrete enzymes and other substances that break down food into its component molecules
  - Salivary glands
  - Pancreas
  - Liver
  - Gallbladder

From Mouth to Stomach

- Food is partially digested in the **mouth** and forced into the **pharynx** by swallowing

- Food is moved through the **esophagus** by **peristalsis** through a **sphincter** to the **stomach**, which adds acids and enzymes to food and mixes them together to form **chyme**

Gastrointestinal Tract

- In the **small intestine**, carbohydrates, lipids and proteins are digested by secretions from liver and pancreas; nutrients and water are absorbed

- The **large intestine** absorbs water and ions, and compacts wastes, which collect in the **rectum**, and are expelled from the **anus**

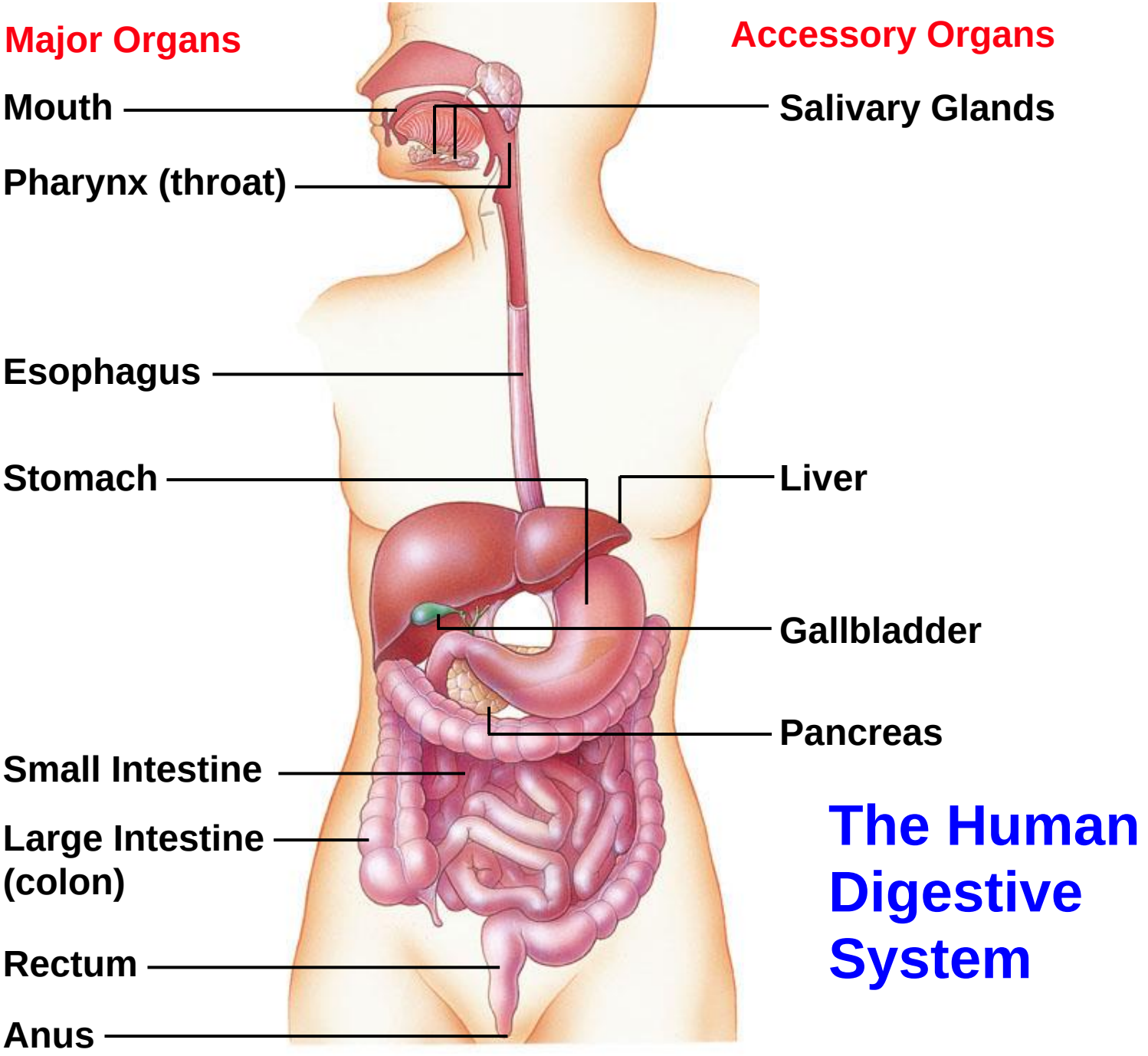
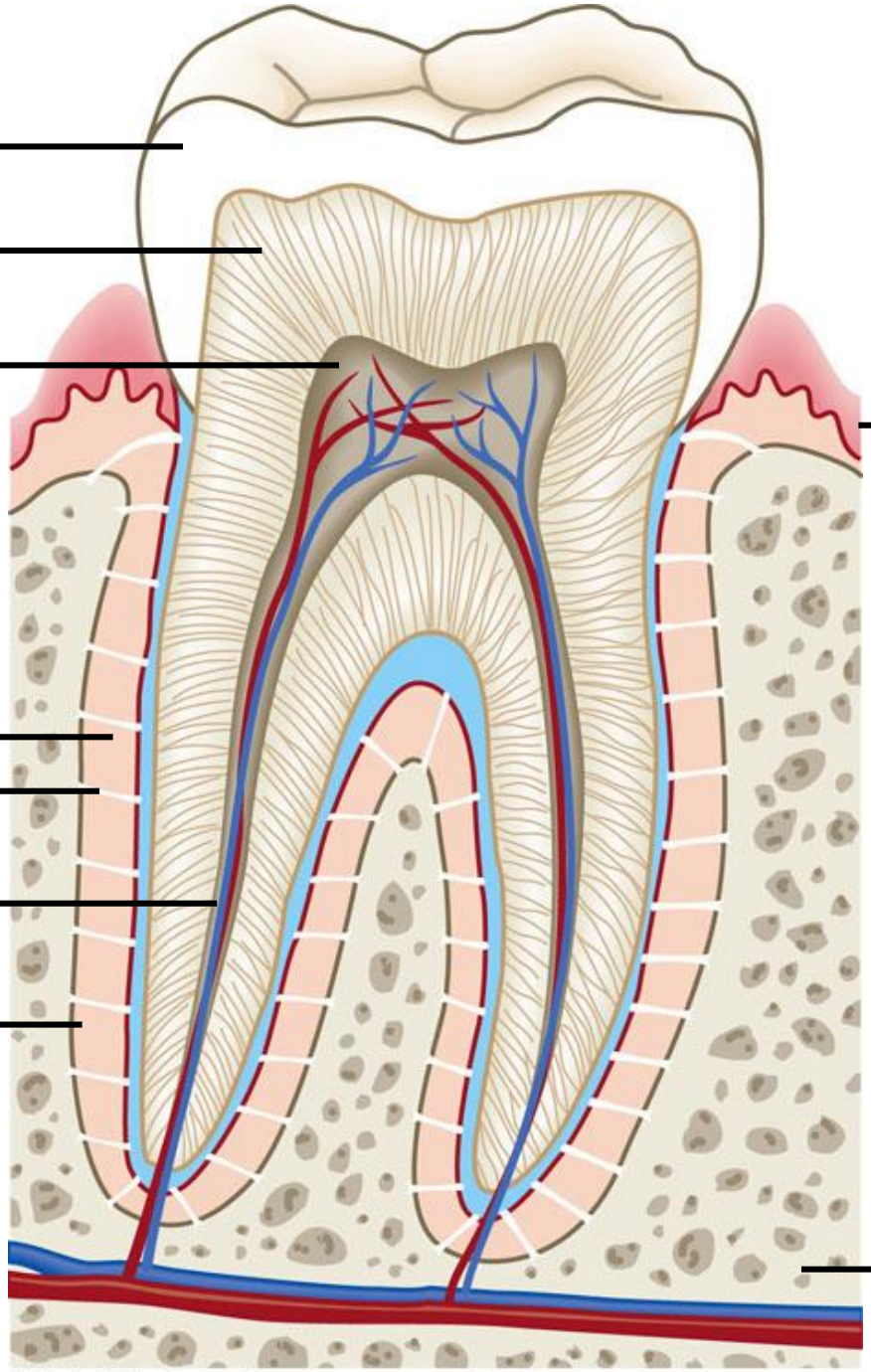


Fig. 40-5, p. 704

40.3 Food in the Mouth

- Digestion begins when teeth mechanically break down food into smaller bits
- Teeth consist mostly of bonelike **dentin**; the crown is covered by a hard layer of **enamel**
- **Salivary amylase** secreted by **salivary glands** hydrolyses starch into disaccharides

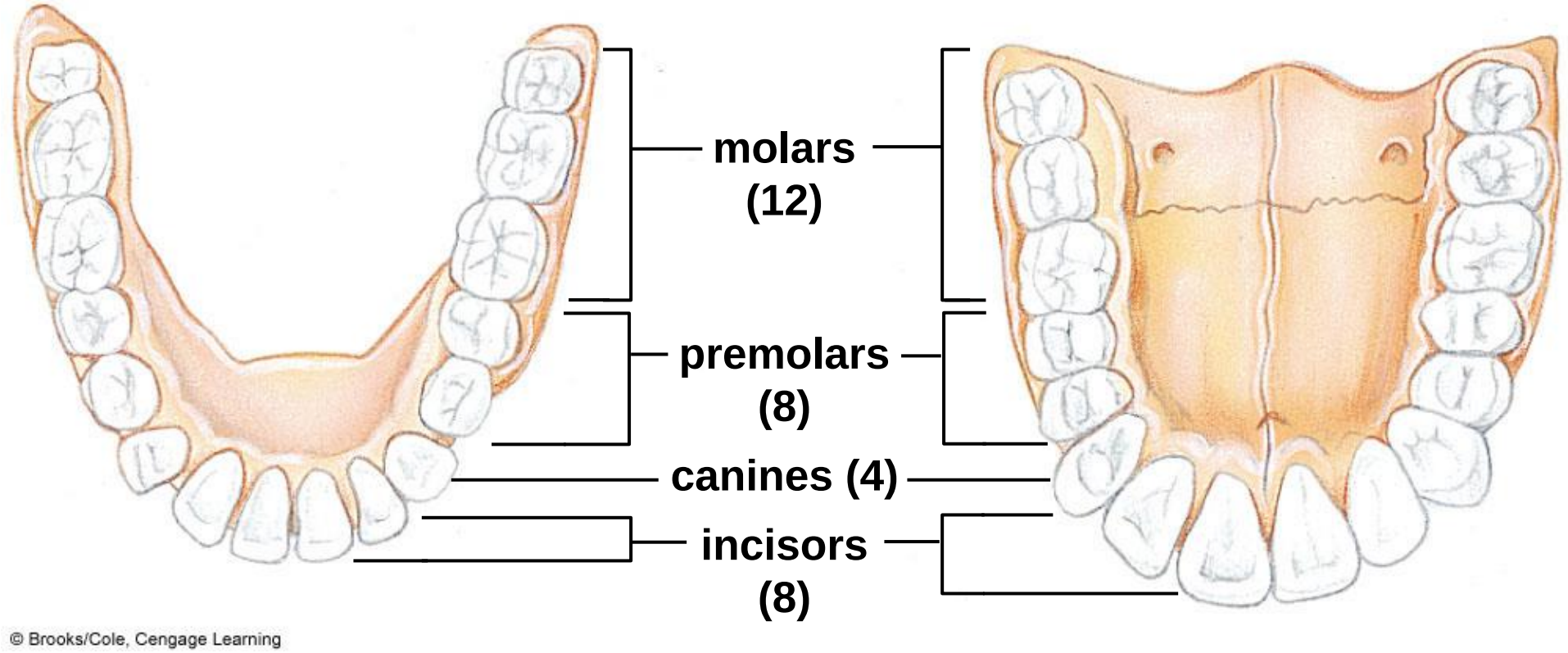


Four Types of Teeth in Humans

Cross-section of a human tooth. The crown is the portion extending above the gum; the root is embedded in the jaw. Tiny ligaments attach the tooth to the jawbone.

Fig. 40-6a, p. 705

Four Types of Teeth in Humans



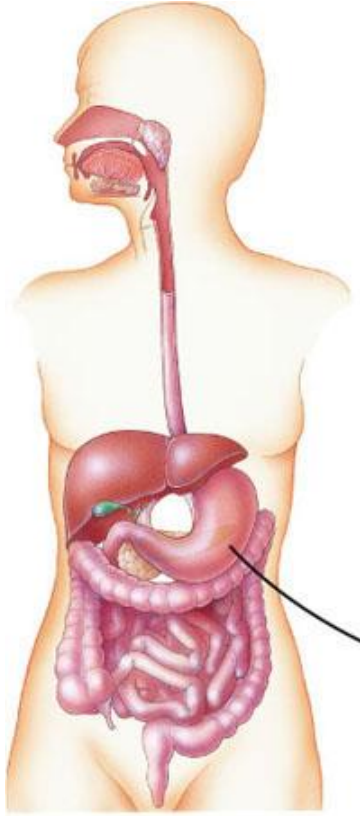
The four types of teeth in adults. Molars and premolars grind up food. Incisors and canines rip and tear offbits.

Fig. 40-6b, p. 705

40.4 Food Breakdown in the Stomach and Small Intestine

- Carbohydrate breakdown begins in the mouth and is completed in the small intestine
- Protein breakdown begins in the stomach and is completed in the small intestine
- Lipids are digested in the small intestine

Stomach Structure



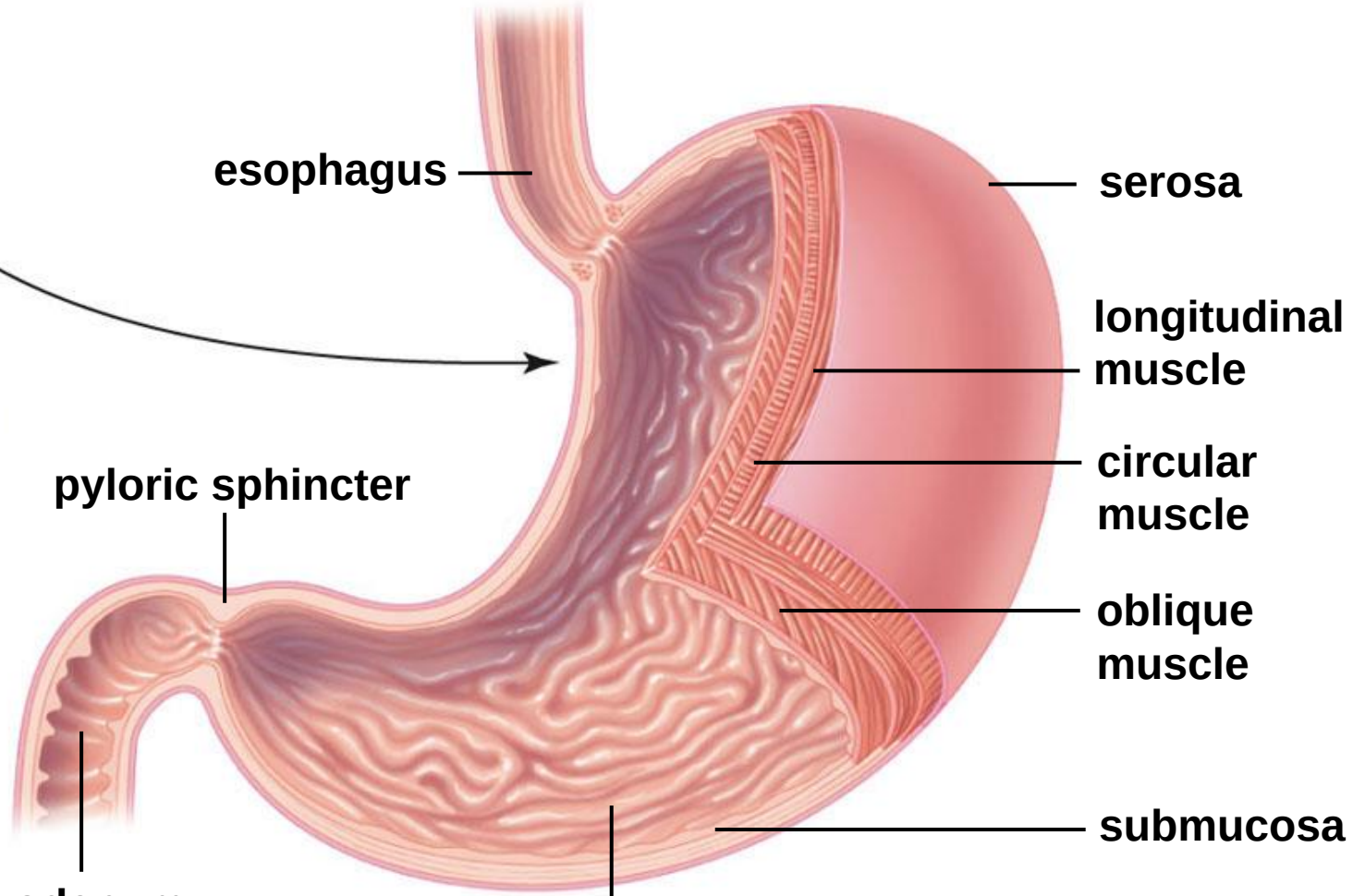


Fig. 40-7, p. 706

Digestion in the Stomach

- The stomach has three digestive functions
  - Stores food and controls the rate of passage to the small intestine
  - Mechanically mixes and breaks down food
  - Secretes substances used in chemical digestion

Digestion in the Stomach

- Stomach **mucosa** secretes **gastric fluid** containing hydrochloric acid and enzymes that begin protein digestion
  - Gastrin signals secretion of acid and pepsinogens
  - Acid unfolds proteins
  - Pepsin breaks proteins into peptides

- **Chyme** passes into the small intestine

Digestion in the Small Intestine

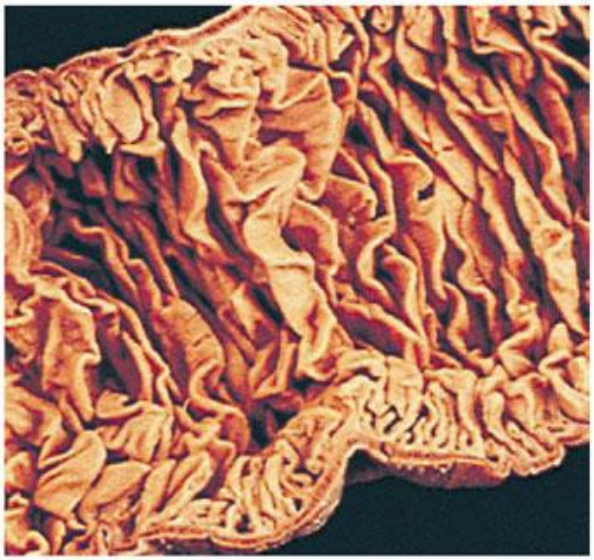
- In the small intestine, chyme mixes with secretions from the pancreas and liver

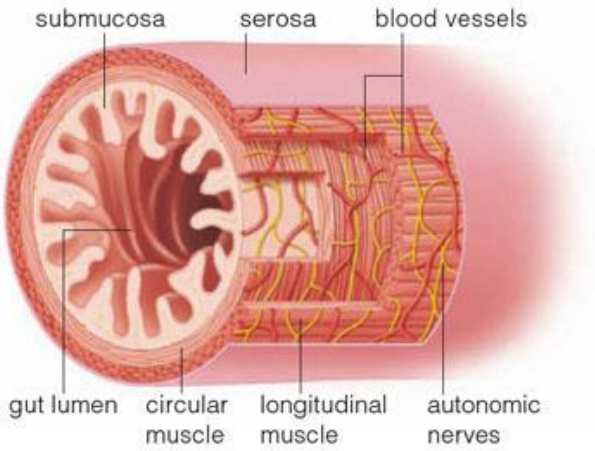
- Pancreatic enzymes break down larger molecules into units that can be absorbed
  - Monosaccharides, monoglycerides, fatty acids, amino acids, nucleotides, nucleotide bases
  - Bicarbonate from the pancreas buffers acids so enzymes can work

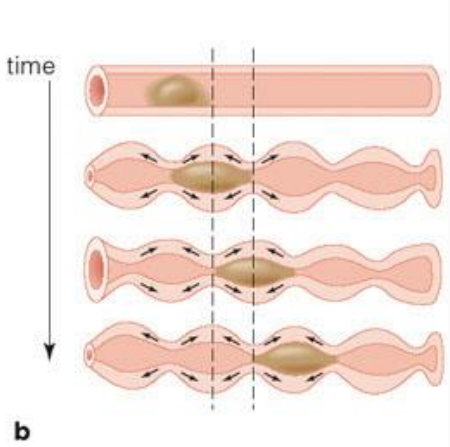
Digestion in the Small Intestine

- Lipid (fat) digestion in the small intestine requires enzymes and bile, which is produced by the liver and stored in the **gallbladder**

- **Bile**
  - A mixture of salts, pigments, cholesterol and lipids that **emulsifies** fats into small drops that enzymes can break down into fatty acids and monoglycerides







a A section of highly folded mucosa

Structure of the Small Intestine

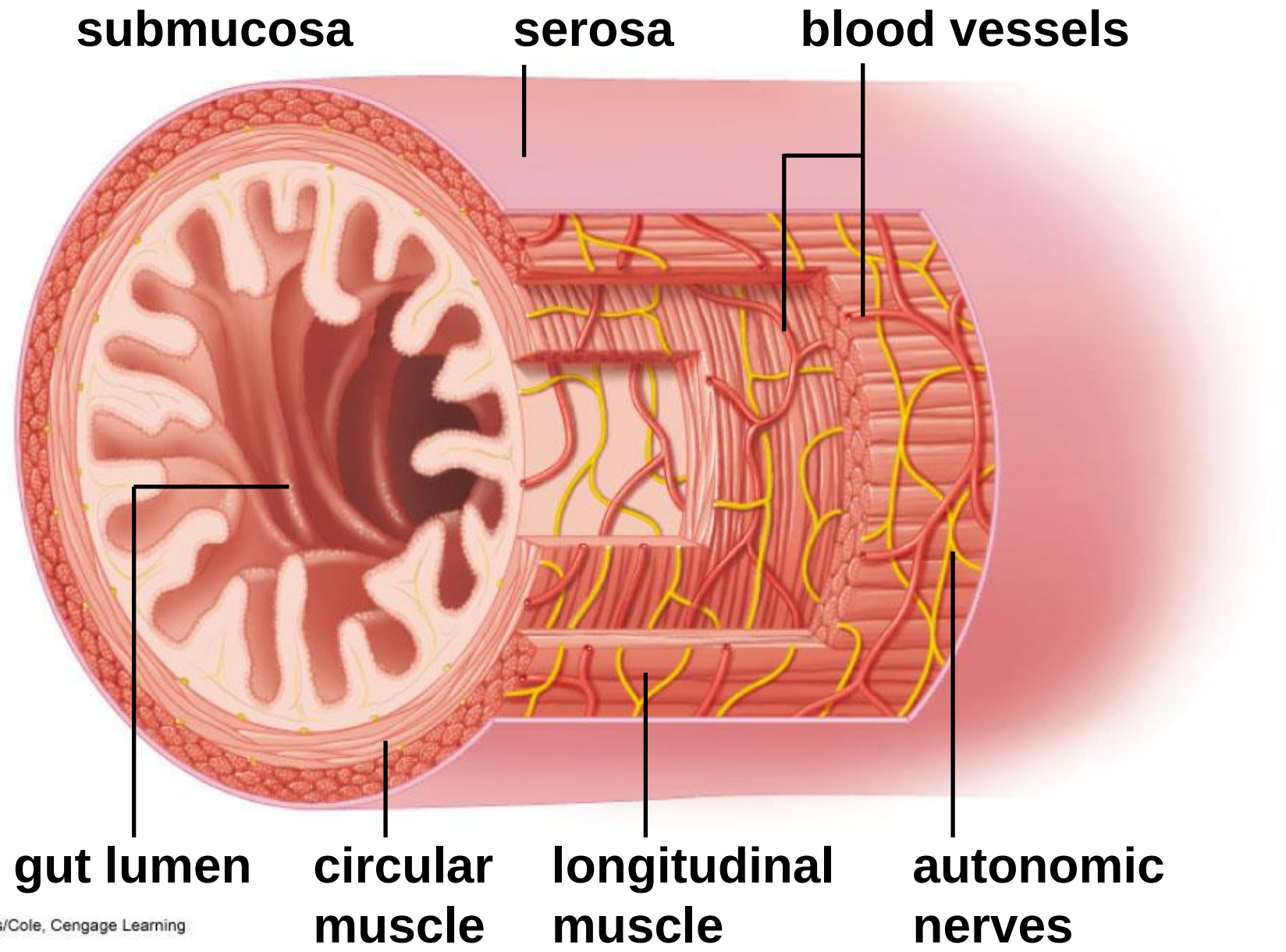
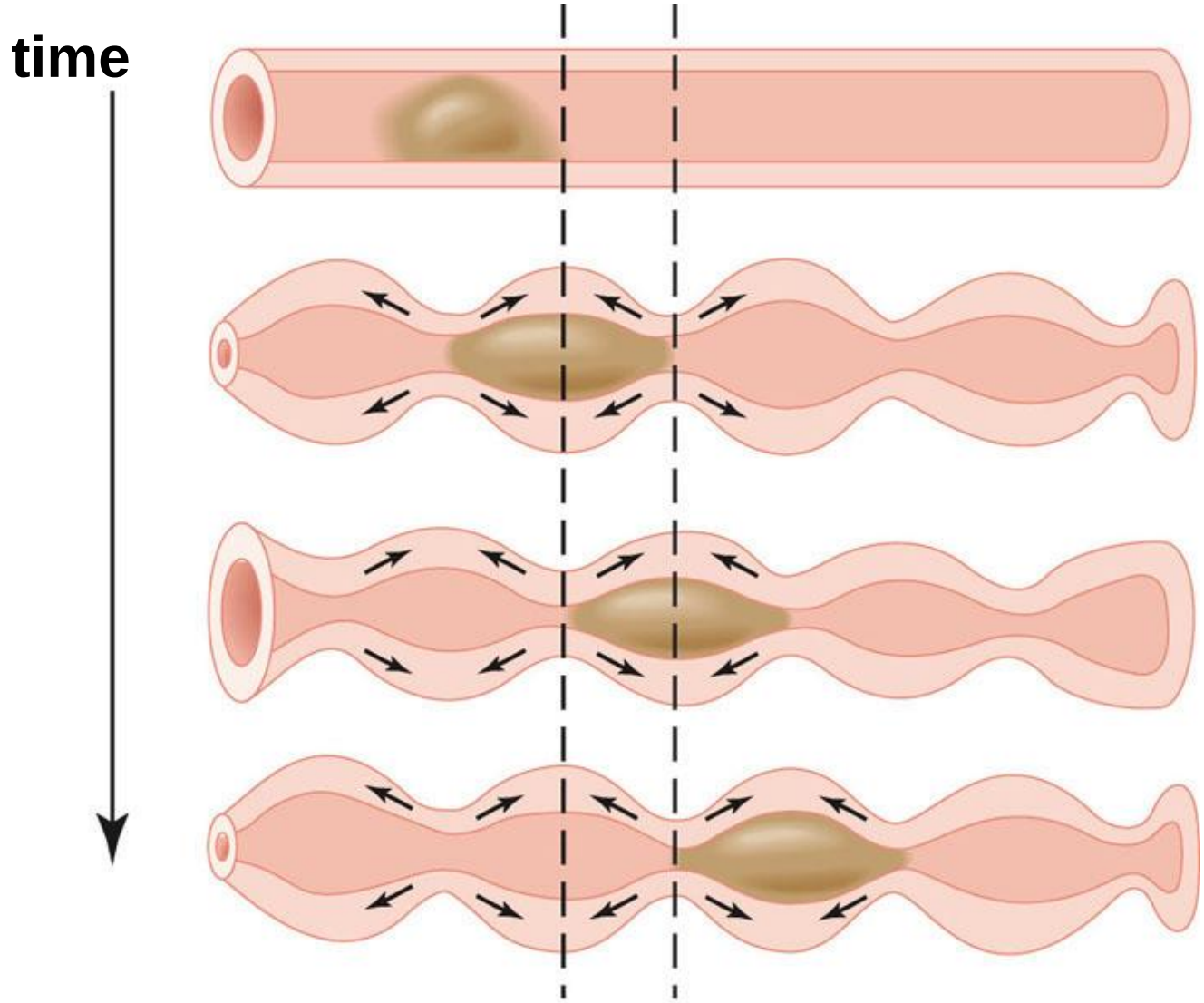


Fig. 40-8a, p. 707



Structure of the Small Intestine

Rings of circular muscle inside the wall contract and relax in a pattern. Back-and-forth movement propels, mixes, and forces chyme up against the wall, enhancing digestion and absorption.

Fig. 40-8b, p. 707

Summary: Chemical Digestion

Table 40.1 Summary of Chemical Digestion

Location	Enzymes Present	Enzyme Source	Enzyme Substrate	Main Breakdown Products
Carbohydrate Digestion				
Mouth, stomach	Salivary amylase	Salivary glands	Polysaccharides	Disaccharides
Small intestine	Pancreatic amylase	Pancreas	Polysaccharides	Disaccharides
	Disaccharidases	Intestinal lining	Disaccharides	Monosaccharides* (such as glucose)
Protein Digestion				
Stomach	Pepsins	Stomach lining	Proteins	Protein fragments
Small intestine	Trypsin, chymotrypsin	Pancreas	Proteins	Protein fragments
	Carboxypeptidase	Pancreas	Protein fragments	Amino acids*
	Aminopeptidase	Intestinal lining	Amino acids*	
Lipid Digestion				
Small intestine	Lipase	Pancreas	Triglycerides	Free fatty acids, monoglycerides*
Nucleic Acid Digestion				
Small intestine	Pancreatic nucleases	Pancreas	DNA, RNA	Nucleotides
	Intestinal nucleases	Intestinal lining	Nucleotides	Nucleotide bases, monosaccharides*

* Breakdown products small enough to be absorbed into the internal environment.

Controls Over Digestion

- The nervous system, endocrine system, and nerves of the gut wall control digestion
- Arrival of food in the stomach sends signals to gut muscles, glands, and brain
- Sympathetic neurons slow digestion during stress or exercise

Hormonal Controls of Digestion

Table 40.2 Main Hormonal Controls of Digestion

Hormone	Source	Effects on Digestive System
Gastrin	Stomach	Stimulates stomach acid secretion
Cholecystokinin (CCK)	Small intestine	Stimulates pancreatic enzyme secretion and gallbladder contraction
Secretin	Small intestine	Stimulates pancreas to secrete bicarbonate and slows contractions of small intestine

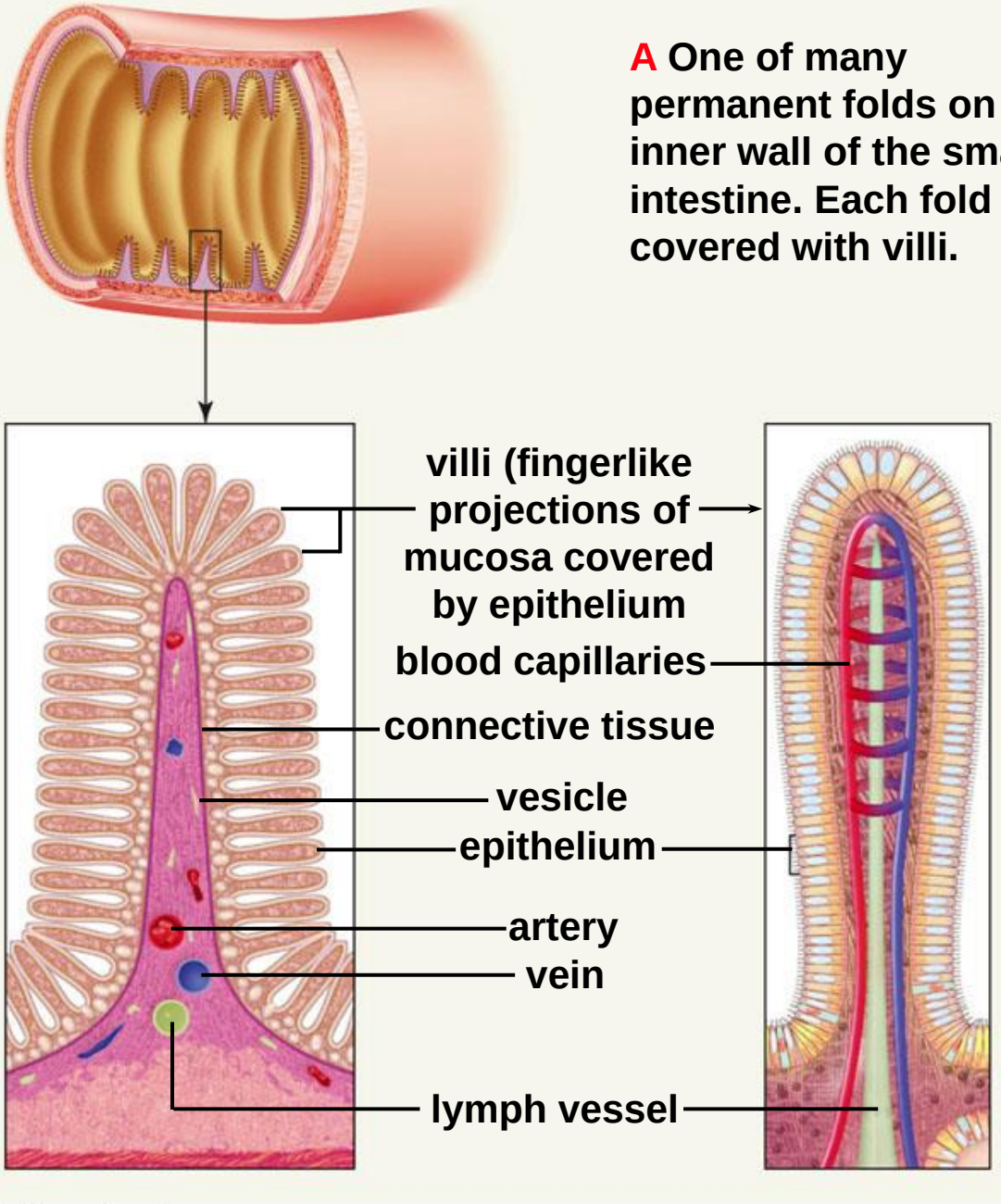
40.5 Absorption From the Small Intestine

- The small intestine is the main site of absorption for the products of digestion
- **Brush border cells** that project into the lumen function in both digestion and absorption
- Cells in the intestinal lining secrete digestive enzymes, hormones, mucus, and lysozyme

Surface Area of Intestinal Mucosa Enhances Absorption

- Three features increase surface area:
  - The lining is folded
  - Multicelled, fingerlike absorptive structures (**villi**) with lymph and blood vessels extend from folds
  - Brush border cells on the villus surface have membrane extensions (**microvilli**) that project into the lumen

The Lining of the Small Intestine



A One of many permanent folds on the inner wall of the small intestine. Each fold is covered with villi.

B At the free surface of each mucosal fold are many fingerlike absorptive structures called villi.

C A villus is covered with specialized epithelial cells. It also contains blood capillaries and lymph vessels.

Fig. 40-9 (a-c), p. 708

The Lining of the Small Intestine

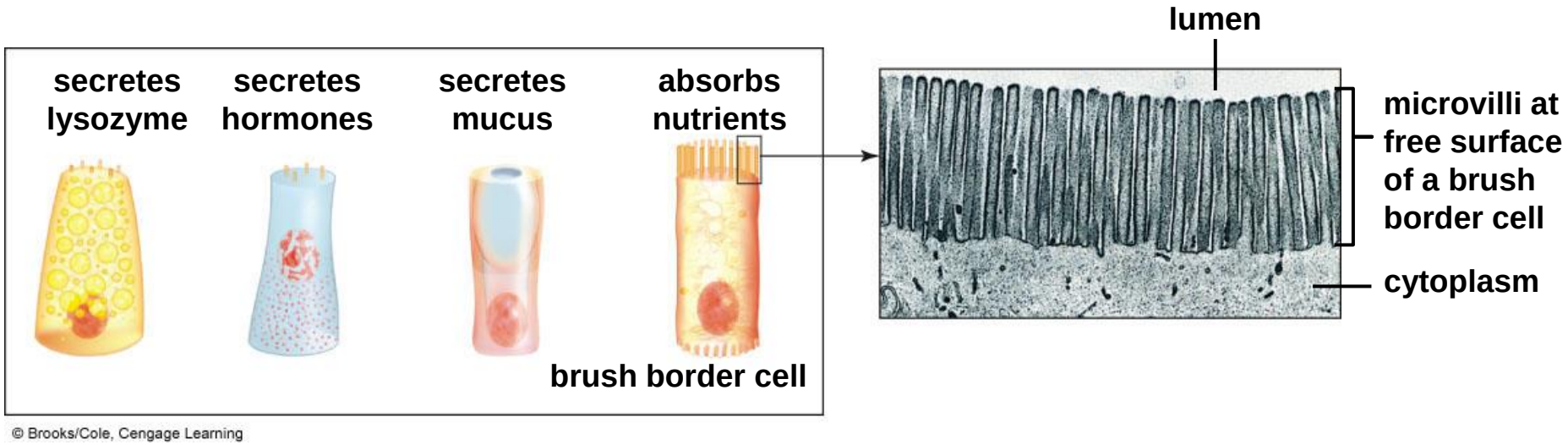


Fig. 40-9d, p. 708

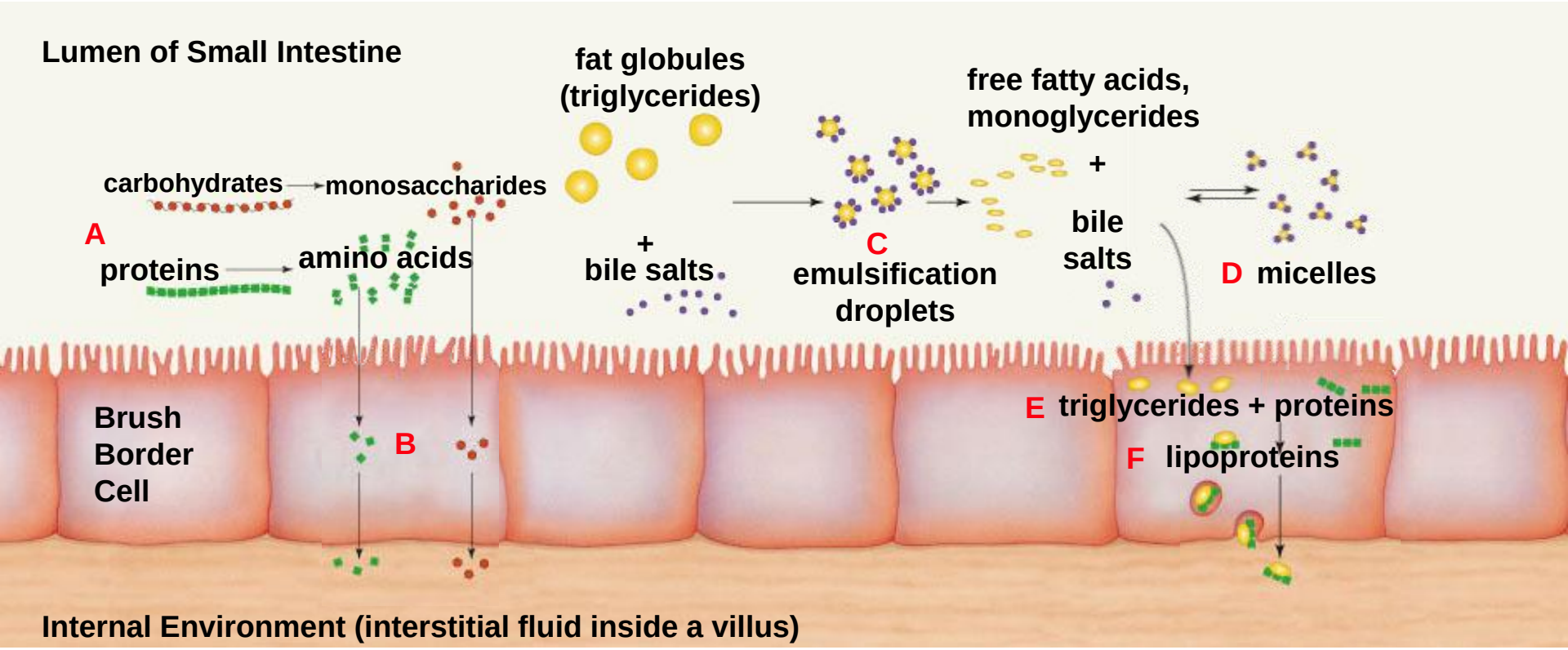
Water and Solute Absorption

- Transport proteins move salts, sugars, and amino acids from the intestinal lumen, into brush border cells, then into interstitial fluid in a villus
- Water follows the solutes by osmotic gradient
- Capillaries in the villus distribute water and solutes through the body

Fat Absorption

- Fatty acids and monoglycerides combine with bile salts to form micelles, which aid diffusion into brush border cells (bile salts stay in lumen)
- In brush border cells, fatty acids and monoglycerides combine with proteins to form lipoproteins, which enter the villus by exocytosis
- From interstitial fluid, triglycerides enter lymph vessels, which empty into the bloodstream

Digestion and Absorption in the Small Intestine



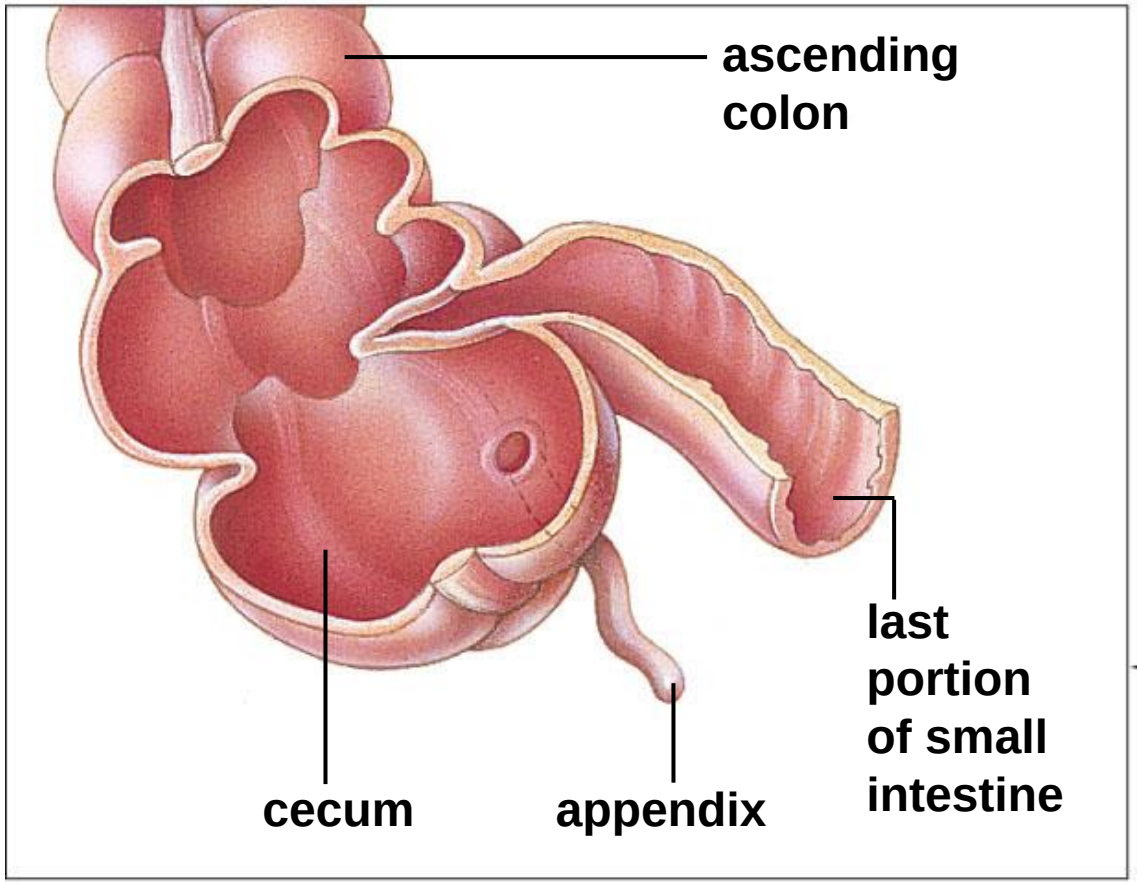
Stepped Art

Fig. 40-10, p. 709

40.6 The Large Intestine

- The large intestine is wider than the small intestine, but also much shorter—only about 1.5 meters (5 feet) long
- The ascending colon begins at the cecum, where the **appendix** is attached
- The descending colon attaches to the rectum

Structure of the Large Intestine



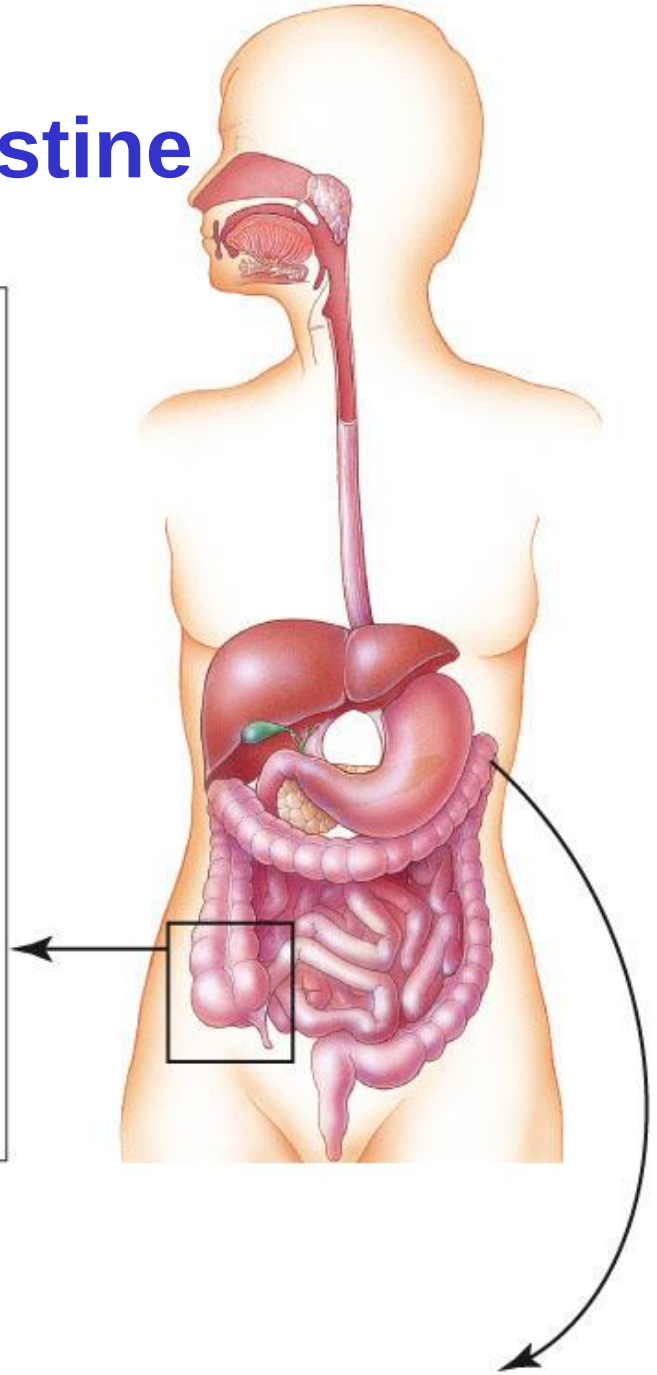


Fig. 40-11a, p. 710

Structure of the Large Intestine

transverse colon

colon polyp

descending colon

Fig. 40-11b, p. 710

Function of the Large Intestine

- The large intestine completes the process of absorption, then concentrates, stores, and eliminates wastes
- Bacteria in the colon make vitamins K and B12, which are absorbed through the colon lining
- Stretch receptors in the rectum trigger the defecation reflex

Disorders of the Large Intestine

- Diarrhea may result from a bacterial infection, and cause dehydration
- Appendicitis must be treated to prevent rupture and infection of the abdominal cavity
- Colon polyps leading to cancer can be detected and removed by colonoscopy

40.2-40.6 Key Concepts
Human Digestive System

- *Human digestion starts in the mouth, continues in the stomach, and is completed in the small intestine*
- *Secretions of the salivary glands, liver, and pancreas aid digestion*
- *Most nutrients are absorbed in the small intestine*
- *The large intestine concentrates wastes*

40.7 Metabolism of Absorbed Organic Compounds

- Absorbed compounds are carried by the blood to the **liver**, which plays a central role in metabolism
- Most absorbed compounds are broken down for energy, stored, or used to build larger compounds
- Excess carbohydrates and proteins are converted to fat and stored in adipose tissue

Liver Function

- The liver detoxifies dangerous substances (alcohol, NH_3), and stores fat-soluble vitamins (A, D) and glucose (as glycogen)

- Between meals, the liver provides the brain with glucose by breaking down stored glycogen

Liver Function

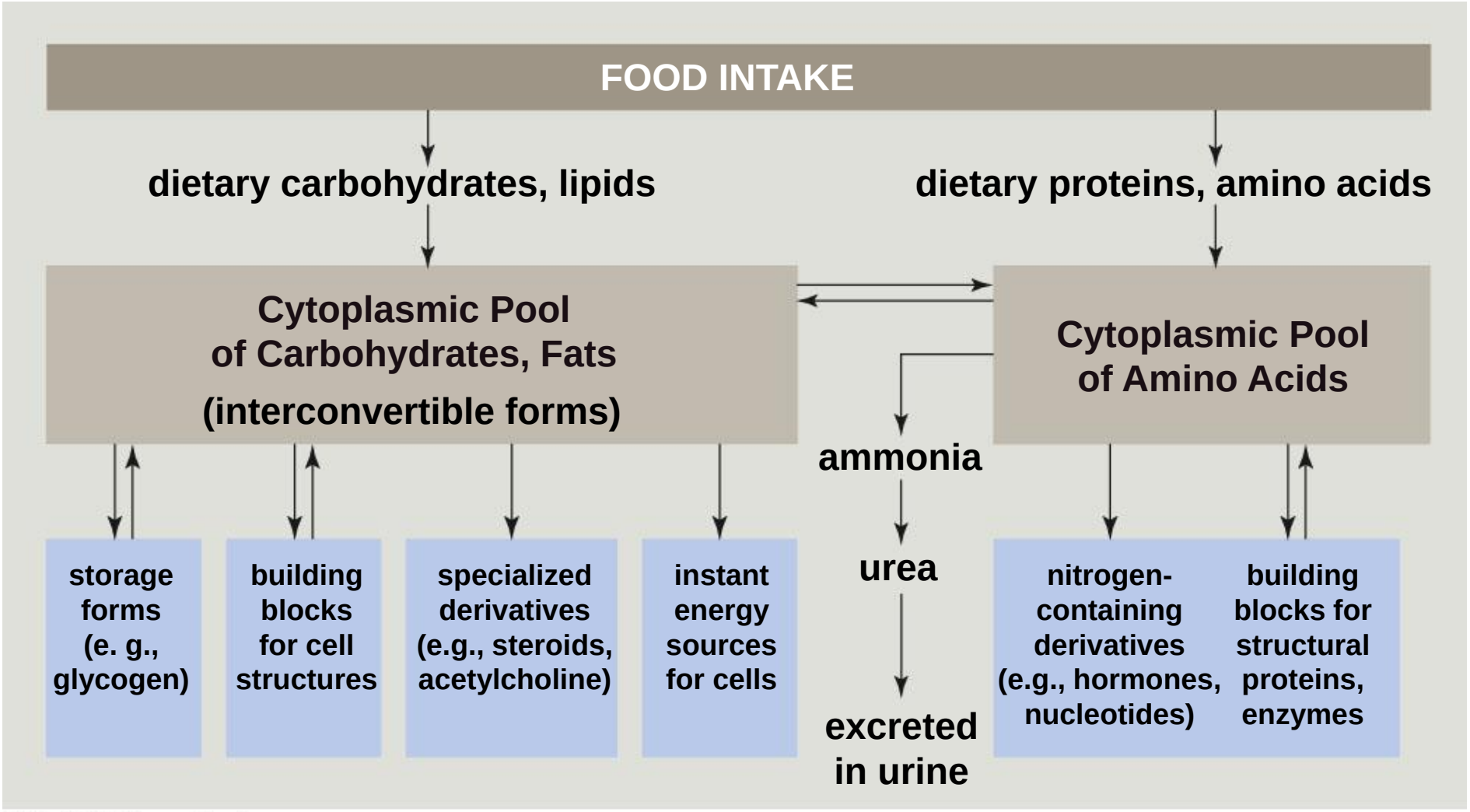


Fig. 40-12a, p. 711

Liver Function

Liver Functions

Forms bile (assists fat digestion), rids body of excess cholesterol and blood's respiratory pigments

Controls amino acid levels in the blood; converts potentially toxic ammonia to urea

Controls glucose level in blood; major reservoir for glycogen

Removes hormones that served their functions from blood

Removes ingested toxins, such as alcohol, from blood

Breaks down worn-out and dead red blood cells, and stores iron

Stores some vitamins

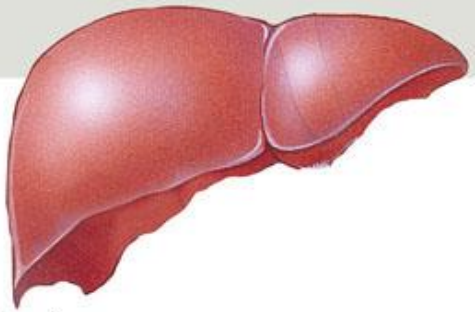


Fig. 40-12b, p. 711

40.8 Human Nutritional Requirements

- Eating provides your cells with a source of energy and a supply of essential building materials

- Nutritional guidelines based on age, sex, height, weight, and activity level can be generated online at mypyramid.gov

Some USDA Nutritional Guidelines

USDA Nutrition Guidelines

Food Group	Amount Recommended
Vegetables	2.5 cups/day
Dark green vegetables	3 cups/week
Orange vegetables	2 cups/week
Legumes	3 cups/week
Starchy vegetables	3 cups/week
Other vegetables	6.5 cups/week
Fruits	2 cups/day
Milk Products	3 cups/day
Grains	6 ounces/day
Whole grains	3 ounces/day
Other grains	3 ounces/day
Fish, poultry, lean meat	5.5 ounces/day
Oils	24 grams/day

Energy-Rich Carbohydrates

- Good (complex) carbohydrates provide energy, vitamins, and fiber (soluble and insoluble)
  - Fresh fruits, whole grains, and vegetables
- Not so good (processed) carbohydrates have “empty calories”
  - White flour, refined sugar, corn syrup

Lipids

- Lipids are used in cell membranes (phospholipids and cholesterol), as energy reserves, insulation and cushioning, and to store fat-soluble vitamins

- **Essential fatty acids** (linoleic and alpha-linoleic acids) must be obtained from the diet

Good Fat, Bad Fat

- Unsaturated fats are liquid at room temperature
  - Polyunsaturated fats (such as omega-3 fatty acids) and monounsaturated fats (such as oleic acid) have specific health benefits
- Saturated fats (in meat and dairy products) can increase risk of heart disease, stroke, or cancer
- *Trans* fats are worse than saturated fats

Main Types of Dietary Lipids

Table 40.3 Main Types of Dietary Lipids

Polyunsaturated Fatty Acids: Liquid at room temperature; essential for health.

- Omega-3 fatty acids
  - Alpha-linoleinc acid and its derivatives
  - Sources: Nut oils, vegetable oils, oily fish
- Omega-6 fatty acids
  - Linoleic acid and its derivatives
  - Sources: Nut oils, vegetable oils, meat

Monounsaturated Fatty Acids: Liquid at room temperature. Main dietary source is olive oil. Beneficial in moderation.

Saturated Fatty Acids: Solid at room temperature. Main sources are meat and dairy products, palm and coconut oils. Excessive intake may raise risk of heart disease.

***Trans* Fatty Acids (Hydrogenated Fats):** Solid at room temperature. Manufactured from vegetable oils and used in many processed foods. Excessive intake may raise risk of heart disease.

Body-Building Proteins

- Proteins are the source of amino acids used to build all body proteins
- Meat provides all eight **essential amino acids**
- Most plant foods lack one or more amino acids, but can meet all human amino-acid needs when combined correctly

40.9 Vitamins, Minerals, and Phytochemicals

- **Vitamins**
  - Organic substances that are essential in very small amounts in the diet (coenzymes)

- **Minerals**
  - Inorganic substances with essential metabolic functions (such as iron in hemoglobin)

- **Phytochemicals**
  - Beneficial organic molecules found in plant foods

Major Vitamins

Table 40.4 Major Vitamins: Sources, Functions, and Effects of Deficiencies or Excesses*

Vitamin	Common Sources	Main Functions	Effects of Chronic Deficiency	Effects of Extreme Excess
Fat-Soluble Vitamins				
A	Its precursor comes from beta-carotene in yellow fruits, yellow or green leafy vegetables; also in fortified milk, egg yolk, fish, liver	Used in synthesis of visual pigments, bone, teeth; maintains epithelia	Dry, scaly skin; lowered resistance to infections; night blindness; permanent blindness	Malformed fetuses; hair loss; changes in skin; liver and bone damage; bone pain
D	Inactive form made in skin, activated in liver, kidneys; in fatty fish, egg yolk, fortified milk products	Promotes bone growth and mineralization; enhances calcium absorption	Bone deformities (rickets) in children; bone softening in adults	Retarded growth; kidney damage; calcium deposits in soft tissues
E	Whole grains, dark green vegetables, vegetable oils	Counters effects of free radicals; helps maintain cell membranes; blocks breakdown of vitamins A and C in gut	Lysis of red blood cells; nerve damage	Muscle weakness; fatigue; headaches; nausea
K	Enterobacteria form most of it; also in green leafy vegetables, cabbage	Blood clotting; ATP formation via electron transport	Abnormal blood clotting; severe bleeding (hemorrhaging)	Anemia; liver damage and jaundice

Major Minerals

Table 40.5 Major Minerals: Sources, Functions, and Effects of Deficiencies or Excesses*

Mineral	Common Sources	Main Functions	Effects of Chronic Deficiency	Effects of Extreme Excess
Calcium	Dairy products, dark green vegetables, dried legumes	Bone, tooth formation; blood clotting; neural and muscle action	Stunted growth; fragile bones; nerve impairment; muscle spasms	Impaired absorption of other minerals; kidney stones in susceptible people
Chloride	Table salt (usually too much in diet)	HCl formation in stomach; contributes to body's acid–base balance; neural action	Muscle cramps; impaired growth; poor appetite	Contributes to high blood pressure in certain people
Copper	Nuts, legumes, seafood, drinking water	Used in synthesis of melanin, hemoglobin, and some transport chain components	Anemia; changes in bone and blood vessels	Nausea; liver damage
Fluorine	Fluoridated water, tea, seafood	Bone, tooth maintenance	Tooth decay	Digestive upsets; mottled teeth and deformed skeleton in chronic cases
Iodine	Marine fish, shellfish, iodized salt, dairy products	Thyroid hormone formation	Enlarged thyroid (goiter) with metabolic disorders	Toxic goiter
Iron	Whole grains, green leafy vegetables, legumes, nuts, eggs, lean meat, molasses, dried fruit, shellfish	Formation of hemoglobin and cytochrome (transport chain component)	Iron-deficiency anemia; impaired immune function	Liver damage; shock; heart failure
Magnesium	Whole grains, legumes, nuts, dairy products	Coenzyme role in ATP–ADP cycle; roles in muscle, nerve function	Weak, sore muscles; impaired neural function	Impaired neural function
Phosphorus	Whole grains, poultry, red meat	Component of bone, teeth, nucleic acids, ATP, phospholipids	Muscular weakness; loss of minerals from bone	Impaired absorption of minerals into bone
Potassium	Diet alone provides ample amounts	Muscle and neural function; roles in protein synthesis and body's acid–base balance	Muscular weakness	Muscular weakness; paralysis; heart failure
Sodium	Table salt; diet provides ample to excessive amounts	Key role in body's salt–water balance; roles in muscle and neural function	Muscle cramps	High blood pressure in susceptible people
Sulfur	Proteins in diet	Component of body proteins	None reported	None likely
Zinc	Whole grains, legumes, nuts, meats, seafood	Component of digestive enzymes; roles in normal growth, wound healing, sperm formation, and taste and smell	Impaired growth; scaly skin; impaired immune function	Nausea, vomiting, diarrhea; impaired immune function and anemia

* Guidelines for appropriate daily intakes are being worked out by the Food and Drug Administration.

40.7-40.9 Key Concepts
Organic Metabolism and Nutrition

- *Nutrients absorbed from the gut are raw materials used in synthesis of the body's complex carbohydrates, lipids, proteins, and nucleic acids*

- *A healthy diet normally provides all nutrients, vitamins, and minerals necessary to support metabolism*

40.10 Weighty Questions, Tantalizing Answers

- Being overweight increases health risks
  - Type 2 diabetes, high blood pressure, heart disease, breast and colon cancer, arthritis, gallstones
- An unhealthy overabundance of fat (**obesity**) stresses fat cells, triggers inflammatory response
  - Fat cells do not increase in number after birth
  - Excess weight overfills existing fat cells

The “Right” Body Weight

- Body mass index (BMI) estimates health risks
  - Overweight: 25 to 29.9
  - Obese: 30 or more

BMI = [weight (lbs) x 703] ÷ height (in)^2

Weight Guidelines

Weight Guidelines for Women

Starting with an ideal weight of 100 pounds for a woman who is 5 feet tall, add five additional pounds for each additional inch of height. Examples:

Height (feet)	Weight (pounds)
5′ 2″	110
5′ 3″	115
5′ 4″	120
5′ 5″	125
5′ 6″	130
5′ 7″	135
5′ 8″	140
5′ 9″	145
5′ 10″	150
5′ 11″	155
6′	160

Weight Guidelines for Men

Starting with an ideal weight of 106 pounds for a man who is 5 feet tall, add six additional pounds for each additional inch of height. Examples:

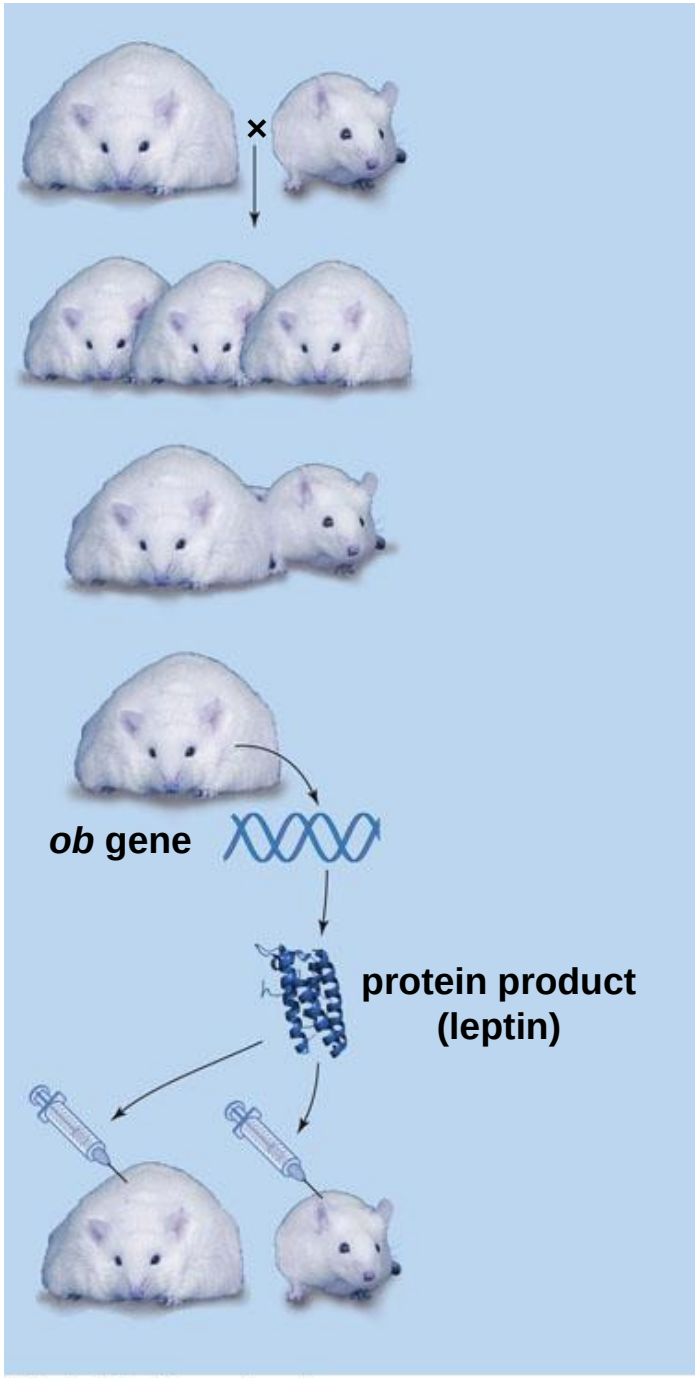
Height (feet)	Weight (pounds)
5′ 2″	118
5′ 3″	124
5′ 4″	130
5′ 5″	136
5′ 6″	142
5′ 7″	148
5′ 8″	154
5′ 9″	160
5′ 10″	166
5′ 11″	172
6′	178

Genes, Hormones, and Obesity

- To maintain body weight, energy (caloric) intake must balance with energy output
- Genetic factors influence how difficult it is for a person to reach and maintain a healthy weight
- Hormones such as leptin can influence both appetite and metabolic rate

Genes, Hormones, and Obesity

a *1950.* Researchers at the Jackson Laboratories in Maine notice that one of their laboratory mice is extremely obese, with an uncontrollable appetite. Through cross-breeding of this apparent mutant individual with a normal mouse, they produce a strain of obese mice.



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b *Late 1960s.* Douglas Coleman of the Jackson Laboratories surgically joins the bloodstreams of an obese mouse and a normal one. The obese mouse now loses weight. Coleman hypothesizes that a factor circulating in blood may be influencing its appetite, but he is not able to isolate it.

c *1994.* Late in the year, Jeffrey Friedman of Rockefeller University discovers a mutated form of what is now called the *ob* gene in obese mice. Through DNA cloning and gene sequencing, he defines the protein that the mutated gene encodes. The protein, now called leptin, is a hormone that influences the brain's commands to suppress appetite and increase metabolic rates.

d *1995.* Three different research teams develop and use genetically engineered bacteria to produce leptin, which, when injected in obese and normal mice, triggers significant weight loss, apparently without harmful side effects.

Fig. 40-15, p. 717

40.10 Key Concepts

Balancing Caloric Inputs and Outputs

- *Maintaining body weight requires balancing calories taken in with calories burned in metabolism and physical activity*