Chapter 41

Animal Nutrition

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: The Need to Feed

- Food is taken in, taken apart, and taken up in the process of animal **nutrition**
- In general, animals fall into three categories:
  - **Herbivores** eat mainly autotrophs (plants and algae)
  - **Carnivores** eat other animals
  - **Omnivores** regularly consume animals as well as plants or algal matter

Fig. 41-1

Concept 41.1: An animal's diet must supply chemical energy, organic molecules, and essential nutrients

- An animal's diet provides chemical energy, which is converted into ATP and powers processes in the body
- Animals need a source of organic carbon and organic nitrogen in order to construct organic molecules
- **Essential nutrients** are required by cells and must be obtained from dietary sources

Essential Nutrients

- There are four classes of essential nutrients:
  - Essential amino acids
  - Essential fatty acids
  - Vitamins
  - Minerals

Essential Amino Acids

- Animals require 20 amino acids and can synthesize about half from molecules in their diet
- The remaining amino acids, the **essential amino acids**, must be obtained from food in preassembled form
- Essential amino acids for many animals & adult humans: Ile, Leu, Lys, Met, Phe, Thr, Trp, Val (+ His for human infants)
- A diet that provides insufficient essential amino acids causes malnutrition called protein deficiency

- Meat, eggs, and cheese provide all the essential amino acids and are thus “complete” proteins
- Most plant proteins are incomplete in amino acid makeup
- Individuals who eat only plant proteins need to eat specific plant combinations to get all essential amino acids

Fig. 41-2

Essential amino acids for adults

Corn (maize) and other grains

Methionine

Valine

Threonine

Phenylalanine

Leucine

Isoleucine

Tryptophan

Lysine

Beans and other legumes

- Some animals have adaptations that help them through periods when their bodies demand extraordinary amounts of protein

Fig. 41-3

Essential Fatty Acids

- Animals can synthesize most of the fatty acids they need
- The **essential fatty acids** are certain unsaturated fatty acids that must be obtained from the diet
- Deficiencies in fatty acids are rare

Vitamins

- **Vitamins** are organic molecules required in the diet in small amounts
- 13 vitamins essential to humans have been identified
- Vitamins are grouped into two categories: fat-soluble and water-soluble

Table 41-1

Table 41.1 Vitamin Requirements of Humans

Vitamin	Major Dietary Sources	Major Functions in the Body	Symptoms of Deficiency or Extreme Excess
Water-Soluble Vitamins			
Vitamin B_1 (thiamine)	Pork, legumes, peanuts, whole grains	Coenzyme used in removing CO_2 from organic compounds	Beriberi (nerve disorders, emaciation, anemia)
Vitamin B_2 (riboflavin)	Dairy products, meats, enriched grains, vegetables	Component of coenzymes FAD and FMN	Skin lesions such as cracks at corners of mouth
Niacin (B_3)	Nuts, meats, grains	Component of coenzymes NAD^+ and $NADP^+$	Skin and gastrointestinal lesions, nervous disorders **Liver damage**
Vitamin B_6 (pyridoxine)	Meats, vegetables, whole grains	Coenzyme used in amino acid metabolism	Irritability, convulsions, muscular twitching, anemia **Unstable gait, numb feet, poor coordination**
Pantothenic acid (B_5)	Most foods: meats, dairy products, whole grains, etc.	Component of coenzyme A	Fatigue, numbness, tingling of hands and feet
Folic acid (folacin) (B_9)	Green vegetables, oranges, nuts, legumes, whole grains	Coenzyme in nucleic acid and amino acid metabolism	Anemia, birth defects **May mask deficiency of vitamin B_{12}**
Vitamin B_{12}	Meats, eggs, dairy products	Coenzyme in nucleic acid metabolism; maturation of red blood cells	Anemia, nervous system disorders
Biotin	Legumes, other vegetables, meats	Coenzyme in synthesis of fat, glycogen, and amino acids	Scaly skin inflammation, neuromuscular disorders
Vitamin C (ascorbic acid)	Fruits and vegetables, especially citrus fruits, broccoli, cabbage, tomatoes, green peppers	Used in collagen synthesis (such as for bone, cartilage, gums); antioxidant; aids in detoxification; improves iron absorption	Scurvy (degeneration of skin, teeth, blood vessels), weakness, delayed wound healing, impaired immunity **Gastrointestinal upset**
Fat-Soluble Vitamins			
Vitamin A (retinol)	Provitamin A (beta-carotene) in deep green and orange vegetables and fruits; retinal in dairy products	Component of visual pigments; maintenance of epithelial tissues; antioxidant; helps prevent damage to cell membranes	Blindness and increased death rate **Headache, irritability, vomiting, hair loss, blurred vision, liver and bone damage**
Vitamin D	Dairy products, egg yolk; also made in human skin in presence of sunlight	Aids in absorption and use of calcium and phosphorus; promotes bone growth	Rickets (bone deformities) in children, bone softening in adults **Brain, cardiovascular, and kidney damage**
Vitamin E (tocopherol)	Vegetable oils, nuts, seeds	Antioxidant; helps prevent damage to cell membranes	Degeneration of the nervous system
Vitamin K (phylloquinone)	Green vegetables, tea; also made by colon bacteria	Important in blood clotting	Defective blood clotting **Liver damage and anemia**

Table 41-1a

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Table 41-1b

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Minerals

- **Minerals** are simple inorganic nutrients, usually required in small amounts

Table 41-2

Table 41.2 Mineral Requirements of Humans

	Mineral	Major Dietary Sources	Major Functions in the Body	Symptoms of Deficiency*
Greater than 200 mg per day required	Calcium (Ca)	Dairy products, dark green vegetables, legumes	Bone and tooth formation, blood clotting, nerve and muscle function	Retarded growth, possibly loss of bone mass
	Phosphorus (P)	Dairy products, meats, grains	Bone and tooth formation, acid-base balance, nucleotide synthesis	Weakness, loss of minerals from bone, calcium loss
	Sulfur (S)	Proteins from many sources	Component of certain amino acids	Symptoms of protein deficiency
	Potassium (K)	Meats, dairy products, many fruits and vegetables, grains	Acid-base balance, water balance, nerve function	Muscular weakness, paralysis, nausea, heart failure
	Chlorine (Cl)	Table salt	Acid-base balance, formation of gastric juice, nerve function, osmotic balance	Muscle cramps, reduced appetite
	Sodium (Na)	Table salt	Acid-base balance, water balance, nerve function	Muscle cramps, reduced appetite
	Magnesium (Mg)	Whole grains, green leafy vegetables	Cofactor; ATP bioenergetics	Nervous system disturbances
	Iron (Fe)	Meats, eggs, legumes, whole grains, green leafy vegetables	Component of hemoglobin and of electron carriers in energy metabolism; enzyme cofactor	Iron-deficiency anemia, weakness, impaired immunity
	Fluorine (F)	Drinking water, tea, seafood	Maintenance of tooth (and probably bone) structure	Higher frequency of tooth decay
	Zinc (Zn)	Meats, seafood, grains	Component of certain digestive enzymes and other proteins	Growth failure, skin abnormalities, reproductive failure, impaired immunity
	Copper (Cu)	Seafood, nuts, legumes, organ meats	Enzyme cofactor in iron metabolism, melanin synthesis, electron transport	Anemia, cardiovascular abnormalities
	Manganese (Mn)	Nuts, grains, vegetables, fruits, tea	Enzyme cofactor	Abnormal bone and cartilage
	Iodine (I)	Seafood, dairy products, iodized salt	Component of thyroid hormones	Goiter (enlarged thyroid)
	Cobalt (Co)	Meats and dairy products	Component of vitamin B_{12}	None, except as B_{12} deficiency
	Selenium (Se)	Seafood, meats, whole grains	Enzyme cofactor; antioxidant functioning in close association with vitamin E	Muscle pain, possibly heart muscle deterioration
	Chromium (Cr)	Brewer's yeast, liver, seafood, meats, some vegetables	Involved in glucose and energy metabolism	Impaired glucose metabolism
	Molybdenum (Mo)	Legumes, grains, some vegetables	Enzyme cofactor	Disorder in excretion of nitrogen-containing compounds

*All of these minerals are also harmful when consumed in excess.

Table 41-2a

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Dietary Deficiencies

- **Undernourishment** is the result of a diet that consistently supplies less chemical energy than the body requires
- **Malnourishment** is the long-term absence from the diet of one or more essential nutrients

Undernourishment

- An undernourished individual will
  - Use up stored fat and carbohydrates
  - Break down its own proteins
  - Lose muscle mass
  - Suffer protein deficiency of the brain
  - Die or suffer irreversible damage

Malnourishment

- Malnourishment can cause deformities, disease, and death
- Malnourishment can be corrected by changes to a diet

Fig. 41-4

Assessing Nutritional Needs

- Insights into human nutrition have come from *epidemiology*, the study of human health and disease in populations
- Neural tube defects were found to be the result of a deficiency in folic acid in pregnant mothers

Fig. 41-5

RESULTS

Group	Number of infants/fetuses studied	Infants/fetuses with a neural tube defect
Vitamin supplements (experimental group)	141	1 (0.7%)
No vitamin supplements (control group)	204	12 (5.9%)

Concept 41.2: The main stages of food processing are ingestion, digestion, absorption, and elimination

- **Ingestion** is the act of eating

Suspension Feeders

- Many aquatic animals are **suspension feeders**, which sift small food particles from the water

Fig. 41-6a

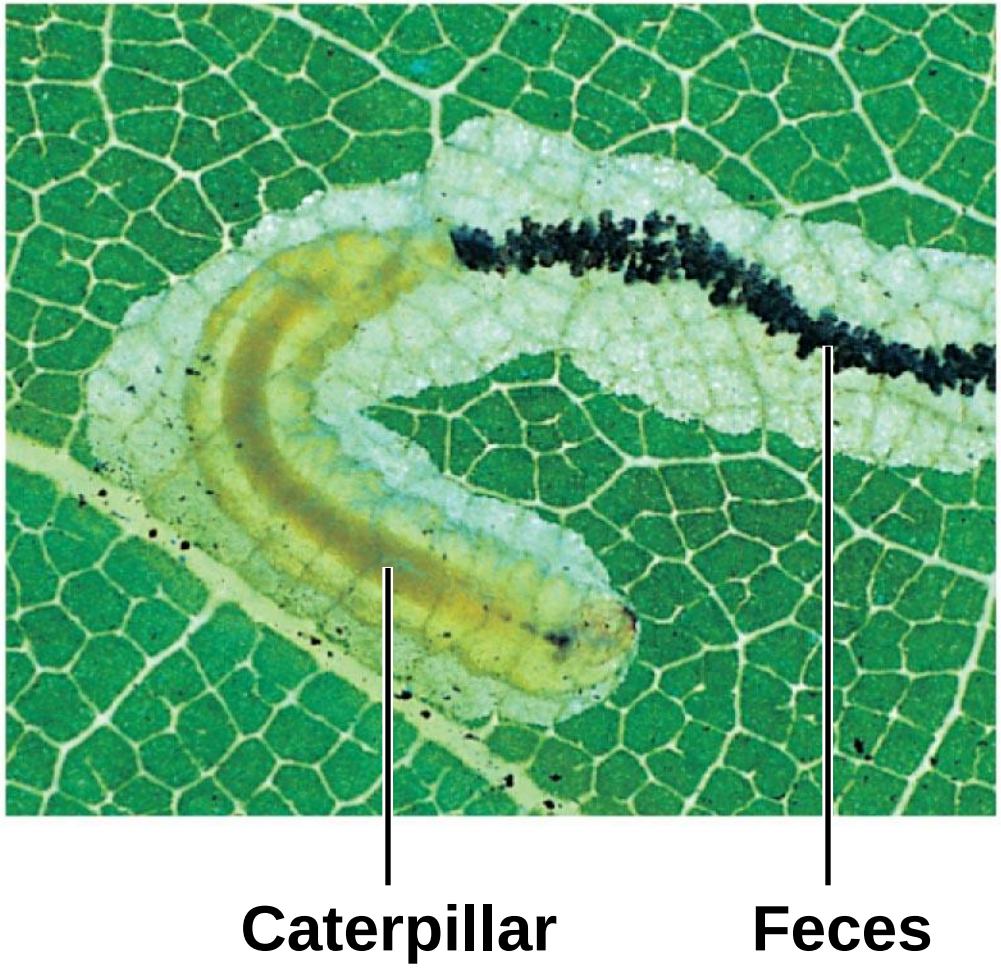
Humpback whale, a suspension feeder

Substrate Feeders

- **Substrate feeders** are animals that live in or on their food source

Fig. 41-6b

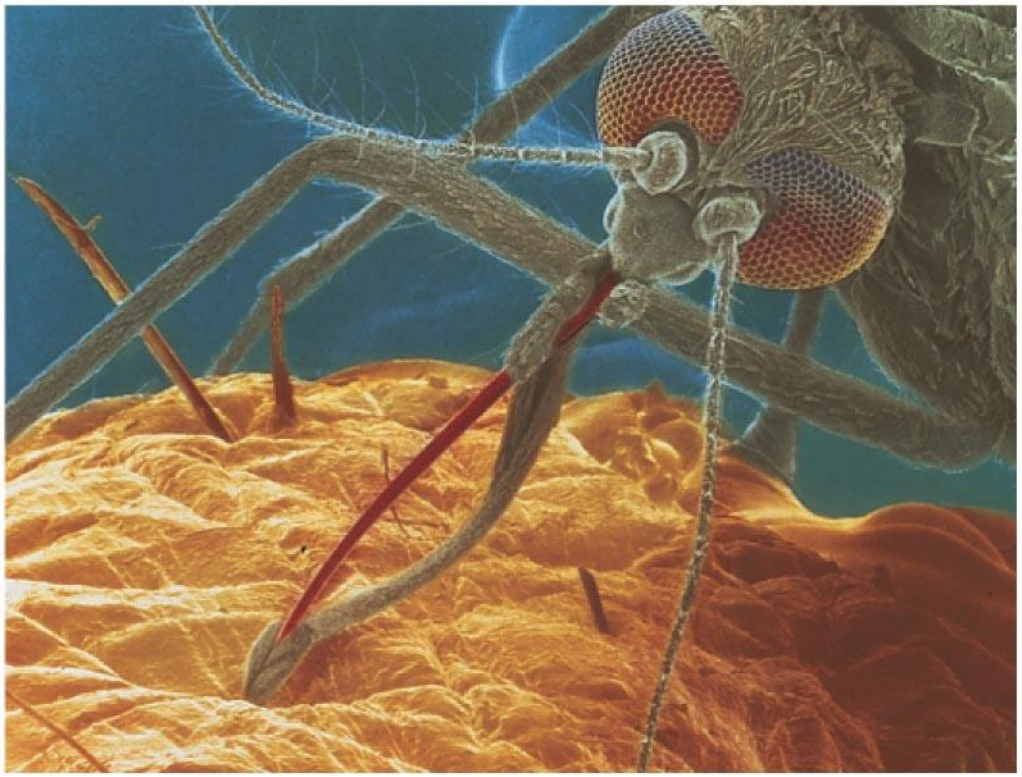
Leaf miner caterpillar, a substrate feeder



Fluid Feeders

- **Fluid feeders** suck nutrient-rich fluid from a living host

Fig. 41-6c



Mosquito, a fluid feeder

Bulk Feeders

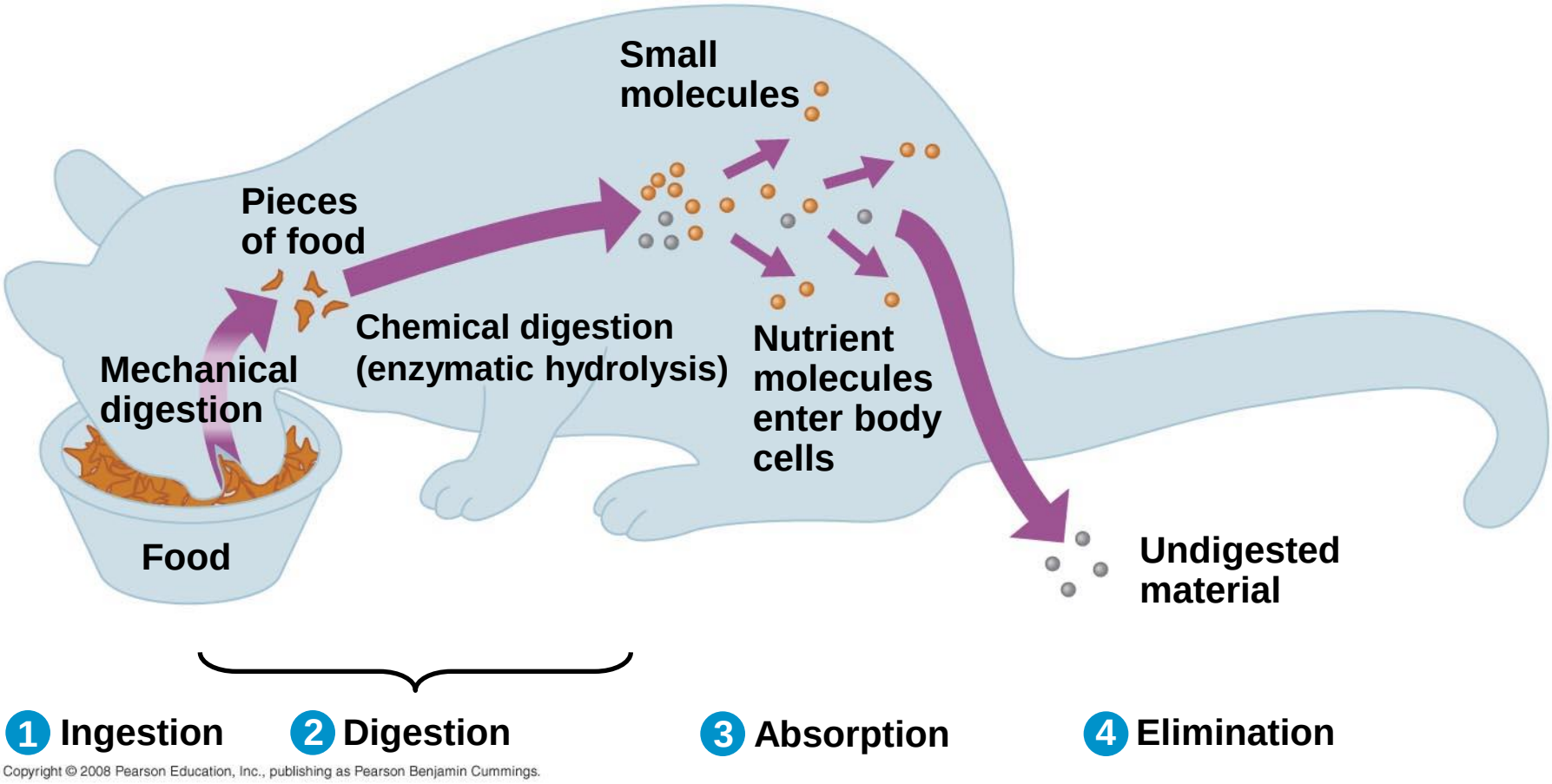
- **Bulk feeders** eat relatively large pieces of food

Fig. 41-6d

Rock python, a bulk feeder

- **Digestion** is the process of breaking food down into molecules small enough to absorb
  - In chemical digestion, the process of **enzymatic hydrolysis** splits bonds in molecules with the addition of water
- **Absorption** is uptake of nutrients by body cells
- **Elimination** is the passage of undigested material out of the digestive compartment

Fig. 41-7



Digestive Compartments

- Most animals process food in specialized compartments
- These compartments reduce the risk of an animal digesting its own cells and tissues

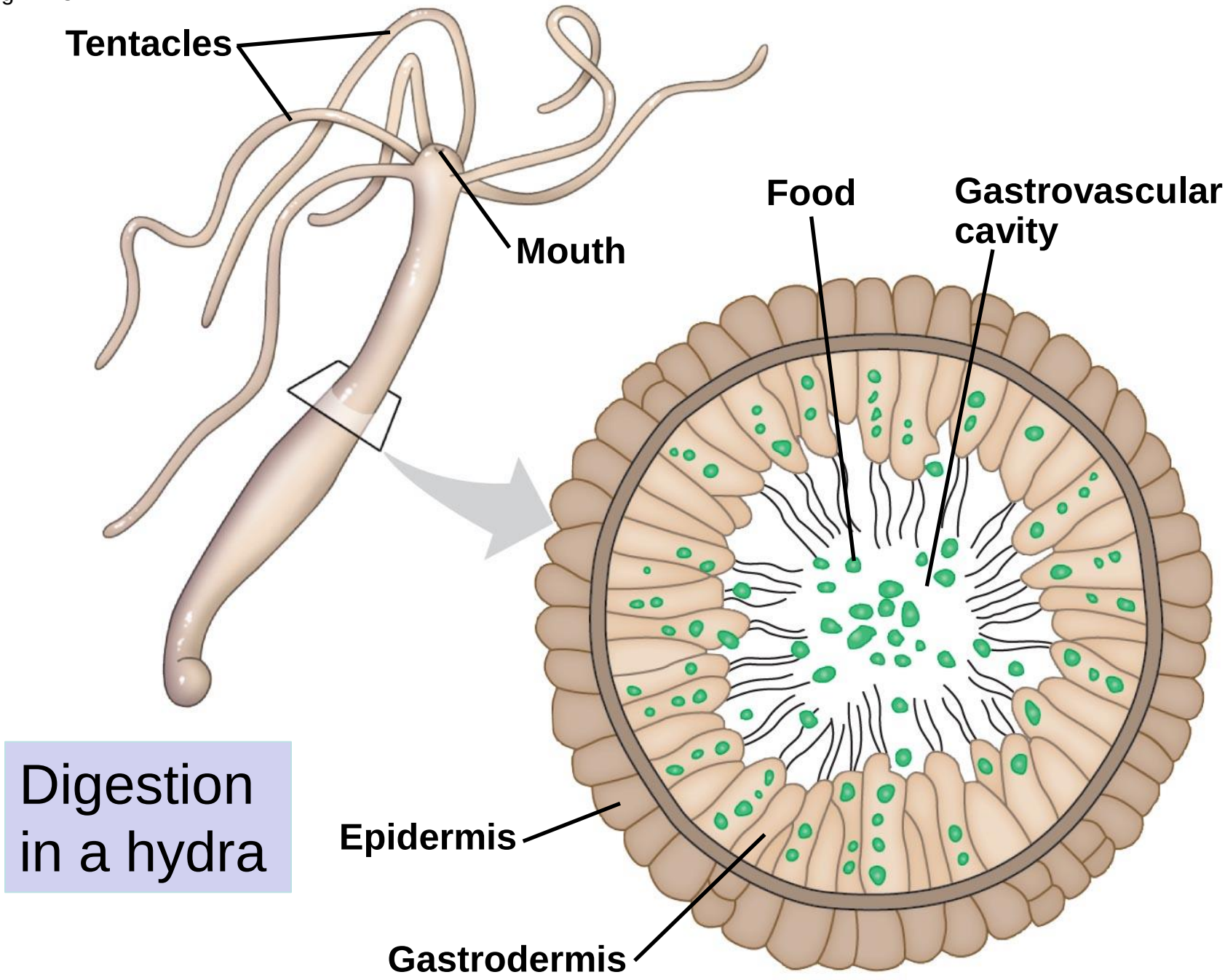
Intracellular Digestion

- In **intracellular digestion**, food particles are engulfed by endocytosis and digested within food vacuoles
- Hydrolysis of food inside vacuoles is called intracellular digestion
- Newly formed food vacuoles fuse with lysosomes

Extracellular Digestion

- **Extracellular digestion** is the breakdown of food particles outside of cells
- It occurs in compartments that are continuous with the outside of the animal's body

Fig. 41-8



Digestion in a hydra

- Animals with simple body plans have a **gastrovascular cavity** that functions in both digestion and distribution of nutrients

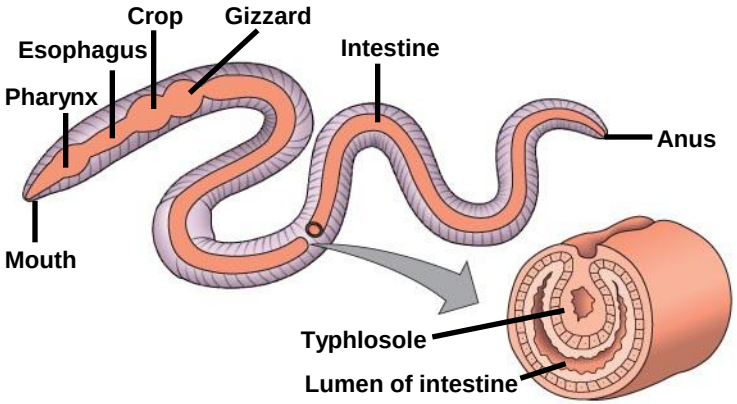
PLAY

Video: Hydra Eating Daphnia

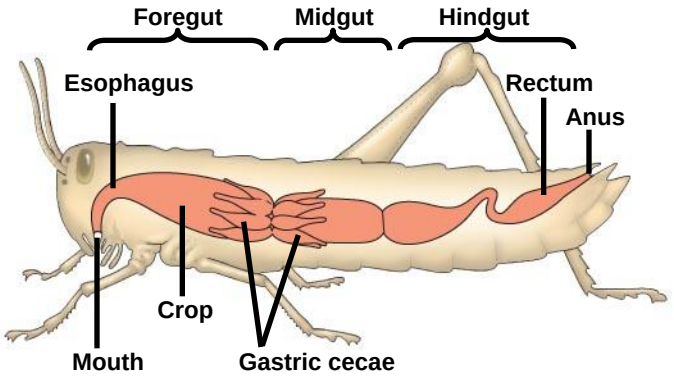
- More complex animals have a digestive tube with two openings, a mouth and an anus
- This digestive tube is called a **complete digestive tract** or an **alimentary canal**
- It can have specialized regions that carry out digestion and absorption in a stepwise fashion

Fig. 41-9

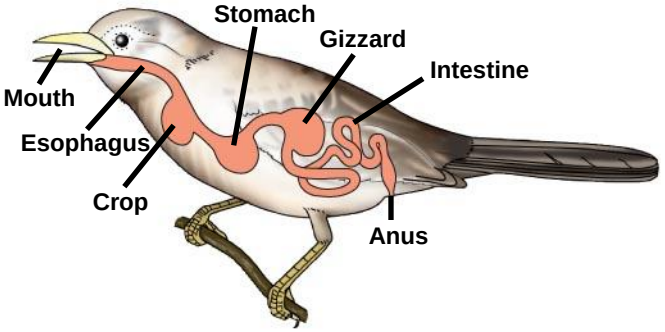
Variation in alimentary canals



(a) Earthworm

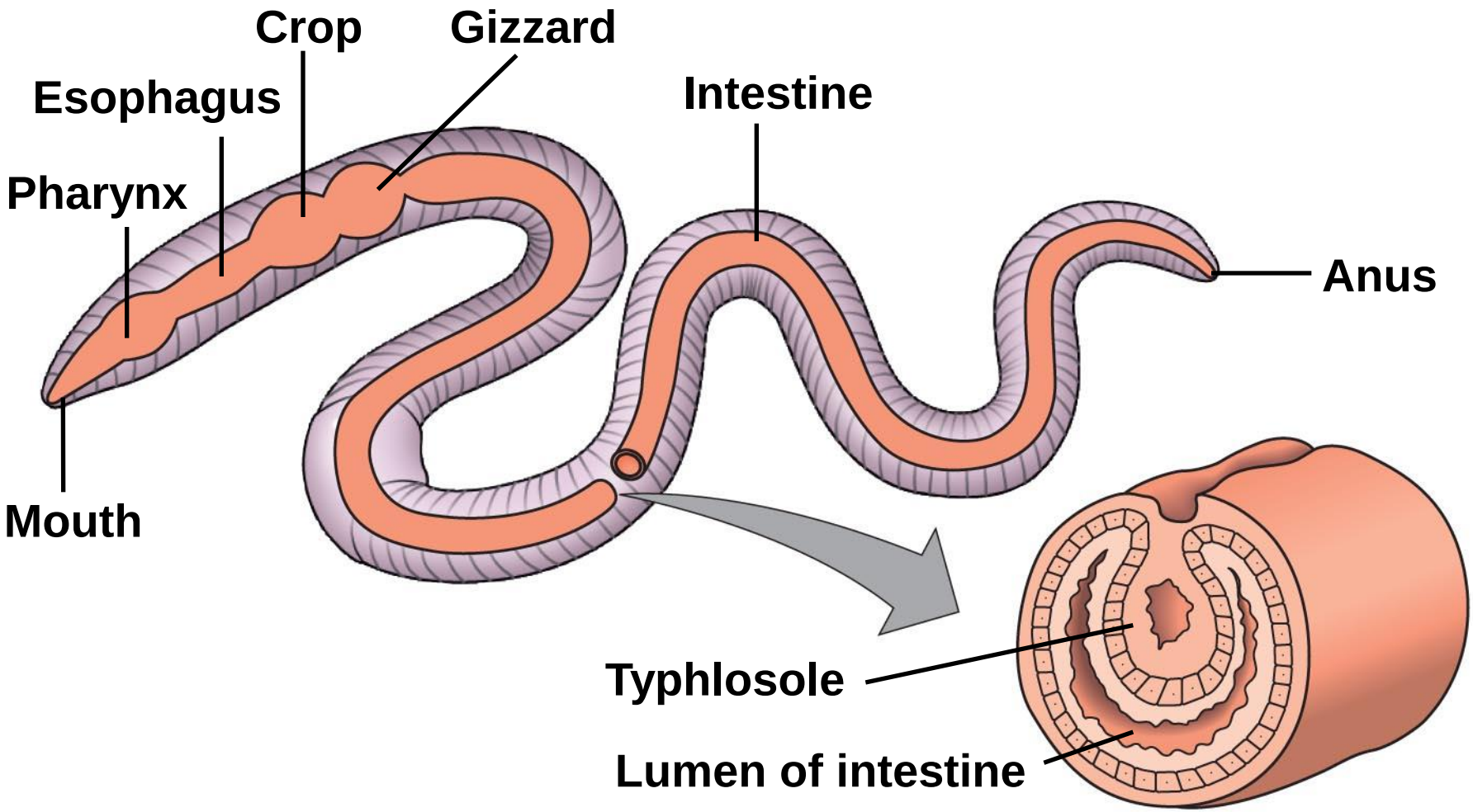


(b) Grasshopper



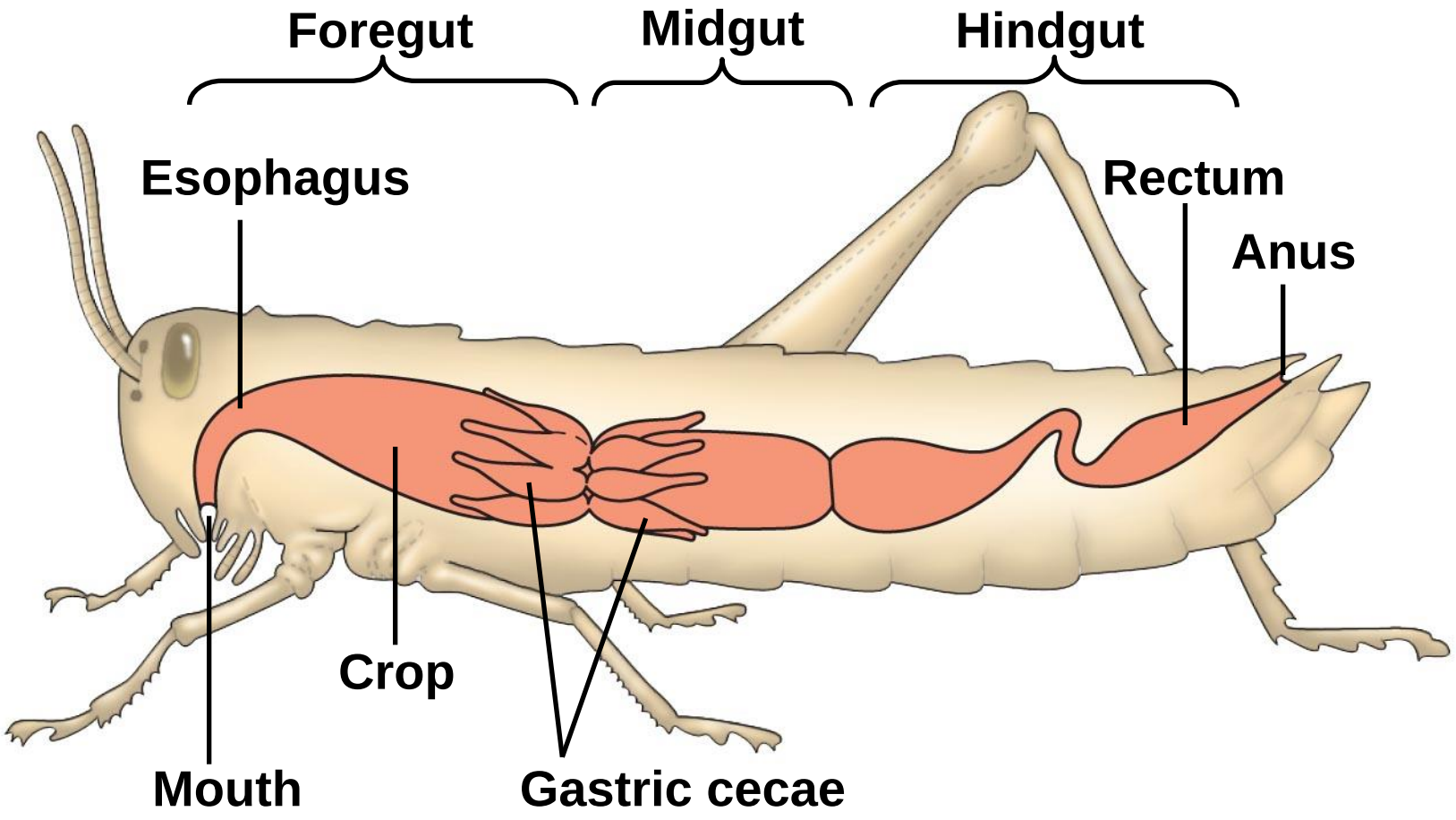
(c) Bird

Fig. 41-9a



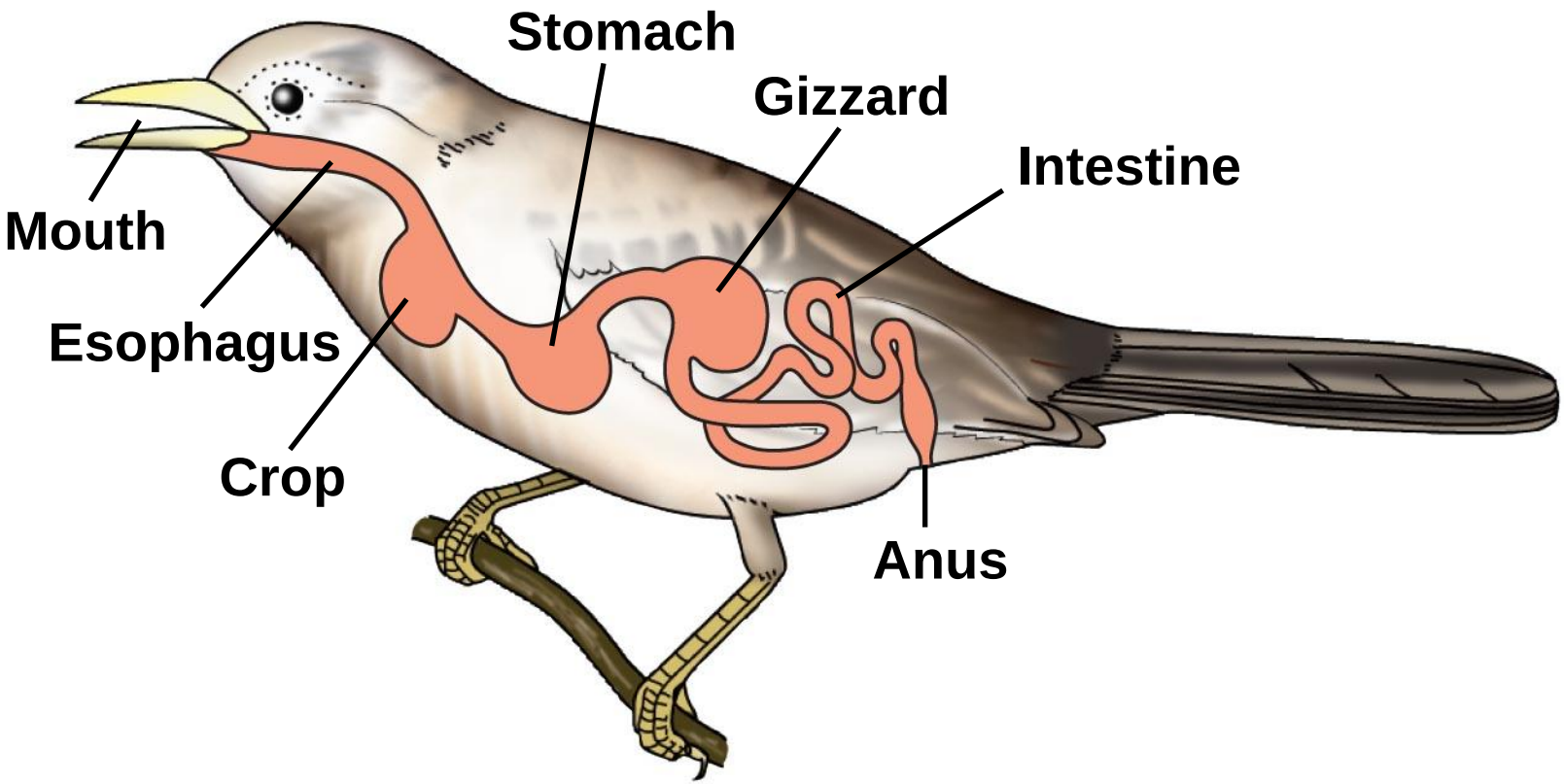
(a) Earthworm

Fig. 41-9b



(b) Grasshopper

Fig. 41-9c



(c) Bird

Concept 41.3: Organs specialized for sequential stages of food processing form the mammalian digestive system

- The mammalian digestive system consists of an alimentary canal and accessory glands that secrete digestive juices through ducts
- Mammalian accessory glands are the salivary glands, the pancreas, the liver, and the gallbladder

- Food is pushed along by **peristalsis**, rhythmic contractions of muscles in the wall of the canal
- Valves called **sphincters** regulate the movement of material between compartments

Fig. 41-10

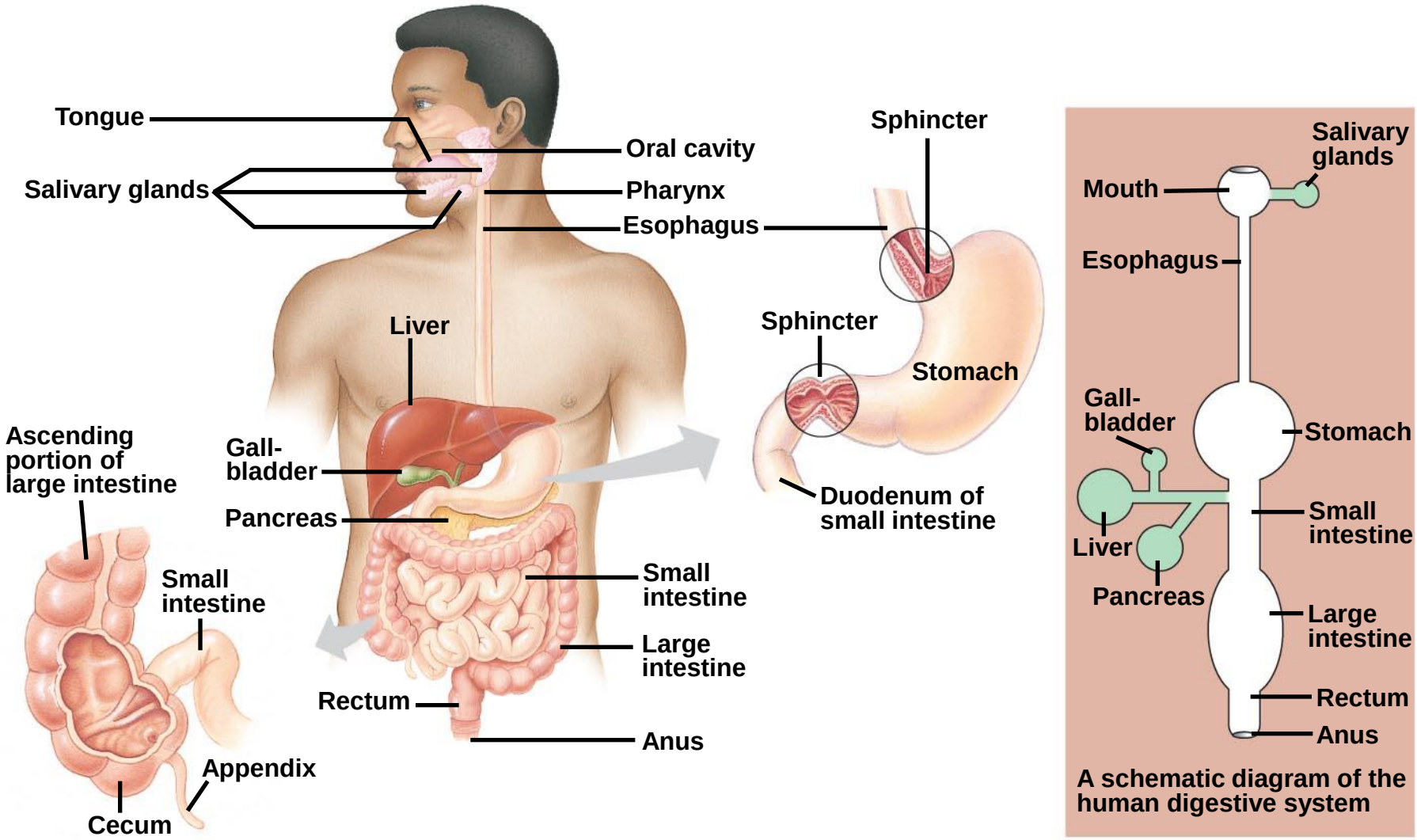


Fig. 41-10a

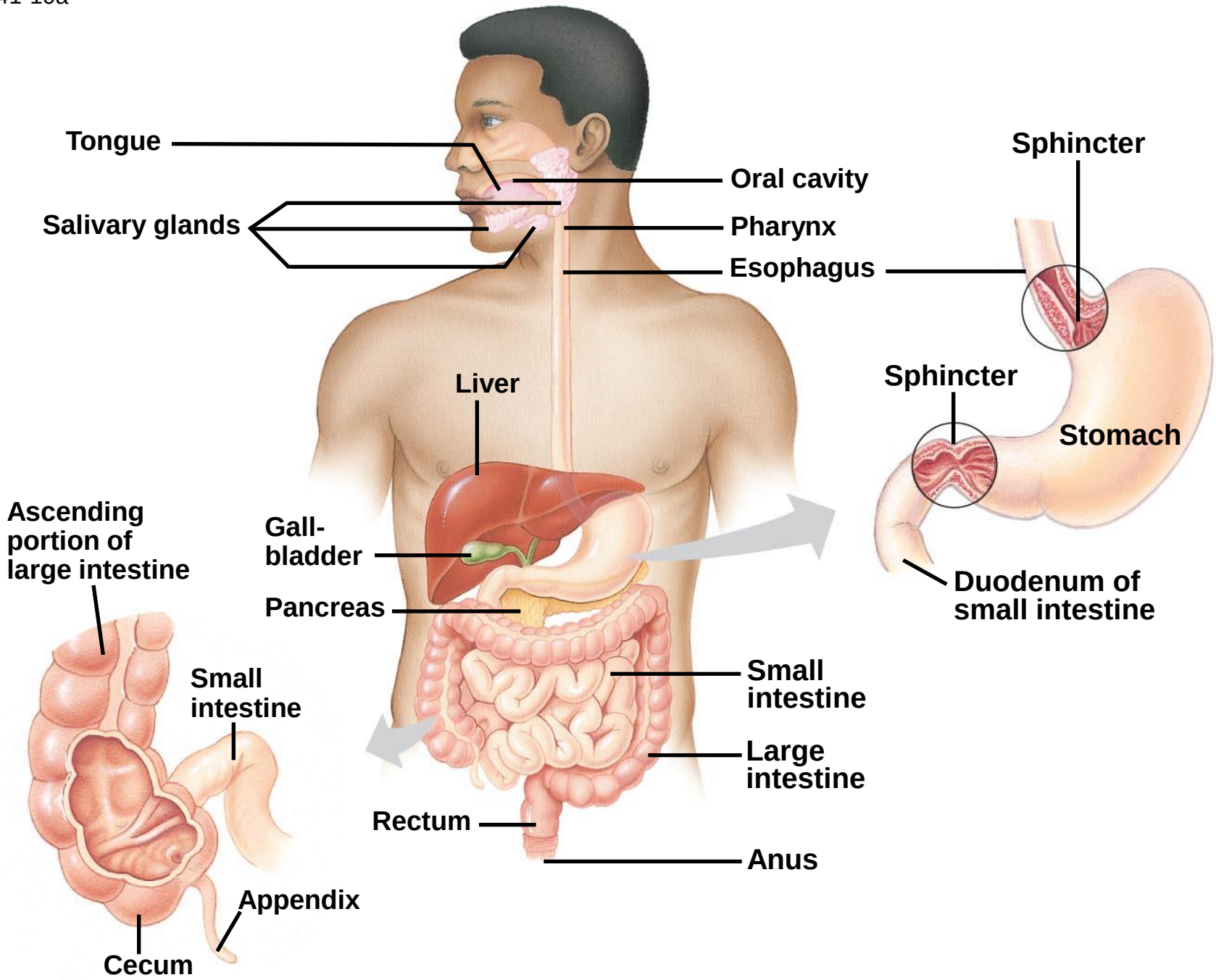
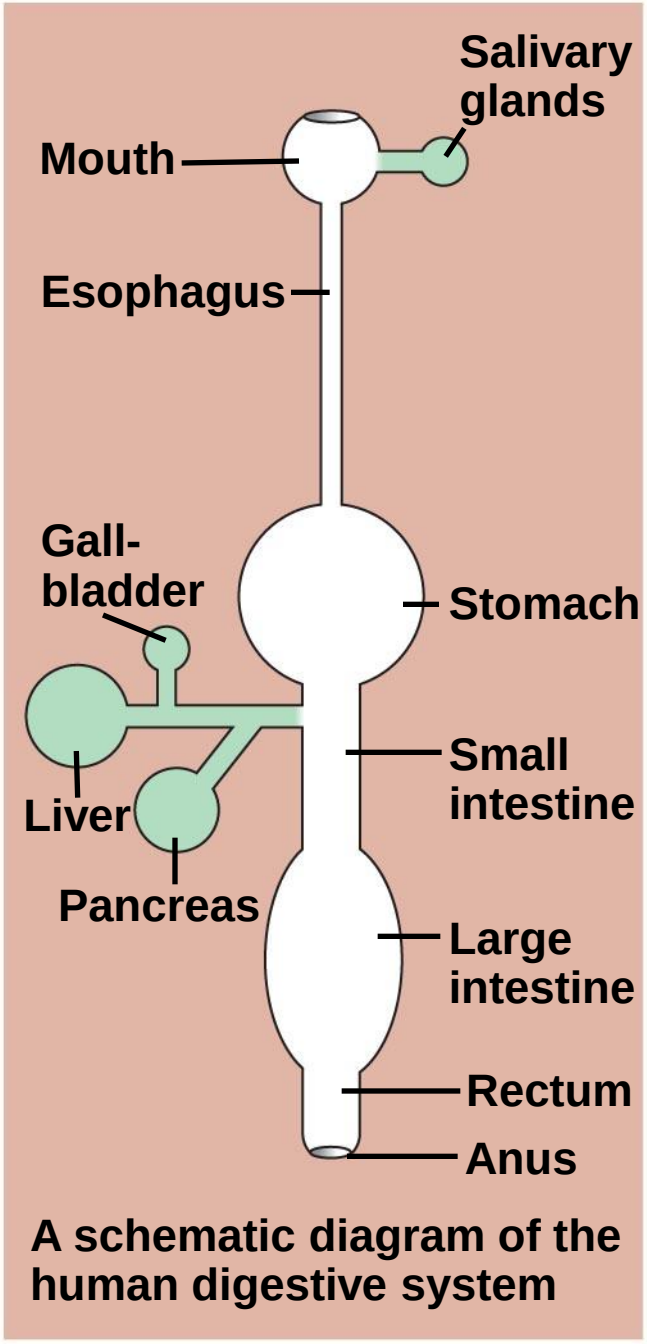


Fig. 41-10b



A schematic diagram of the human digestive system

The Oral Cavity, Pharynx, and Esophagus

- The first stage of digestion is mechanical and takes place in the **oral cavity**
- **Salivary glands** deliver saliva to lubricate food
- Teeth chew food into smaller particles that are exposed to salivary **amylase**, initiating breakdown of glucose polymers

- The tongue shapes food into a **bolus** and provides help with swallowing
- The region we call our throat is the **pharynx**, a junction that opens to both the esophagus and the trachea (windpipe)
- The trachea leads to the lungs

- The **esophagus** conducts food from the pharynx down to the stomach by peristalsis
- Swallowing causes the epiglottis to block entry to the trachea, and the bolus is guided by the larynx, the upper part of the respiratory tract
- Coughing occurs when the swallowing reflex fails and food or liquids reach the windpipe

Fig. 41-11-1

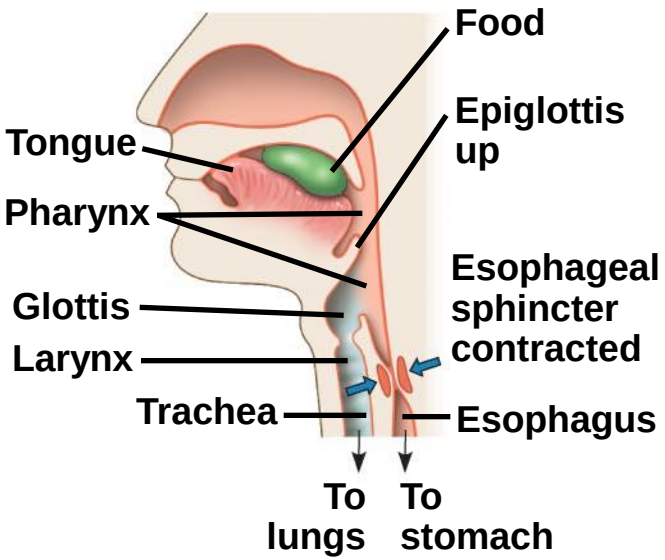


Fig. 41-11-2

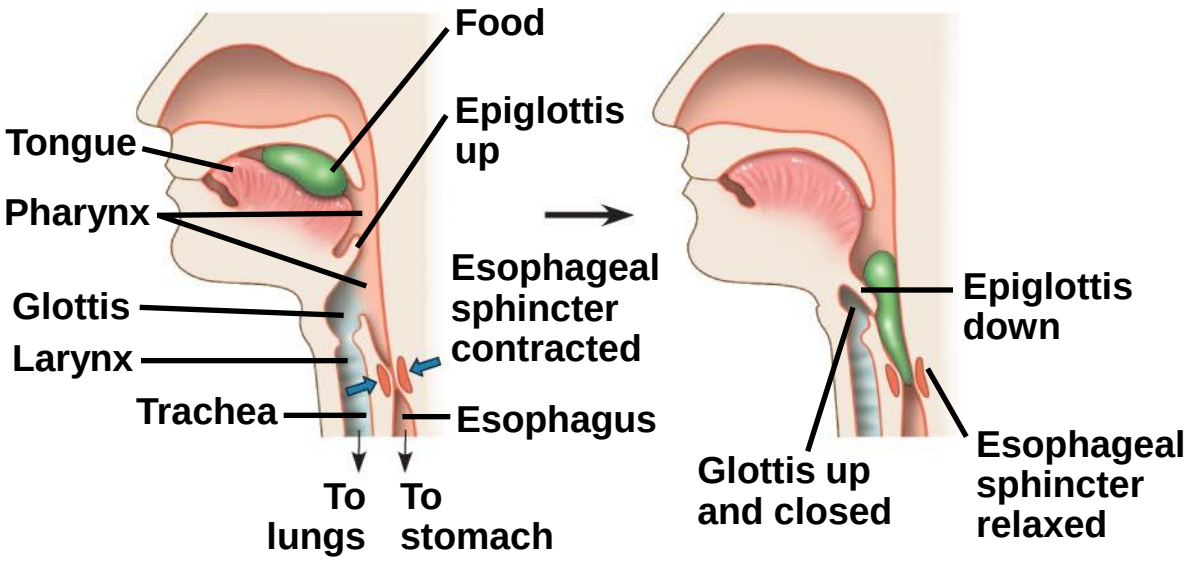
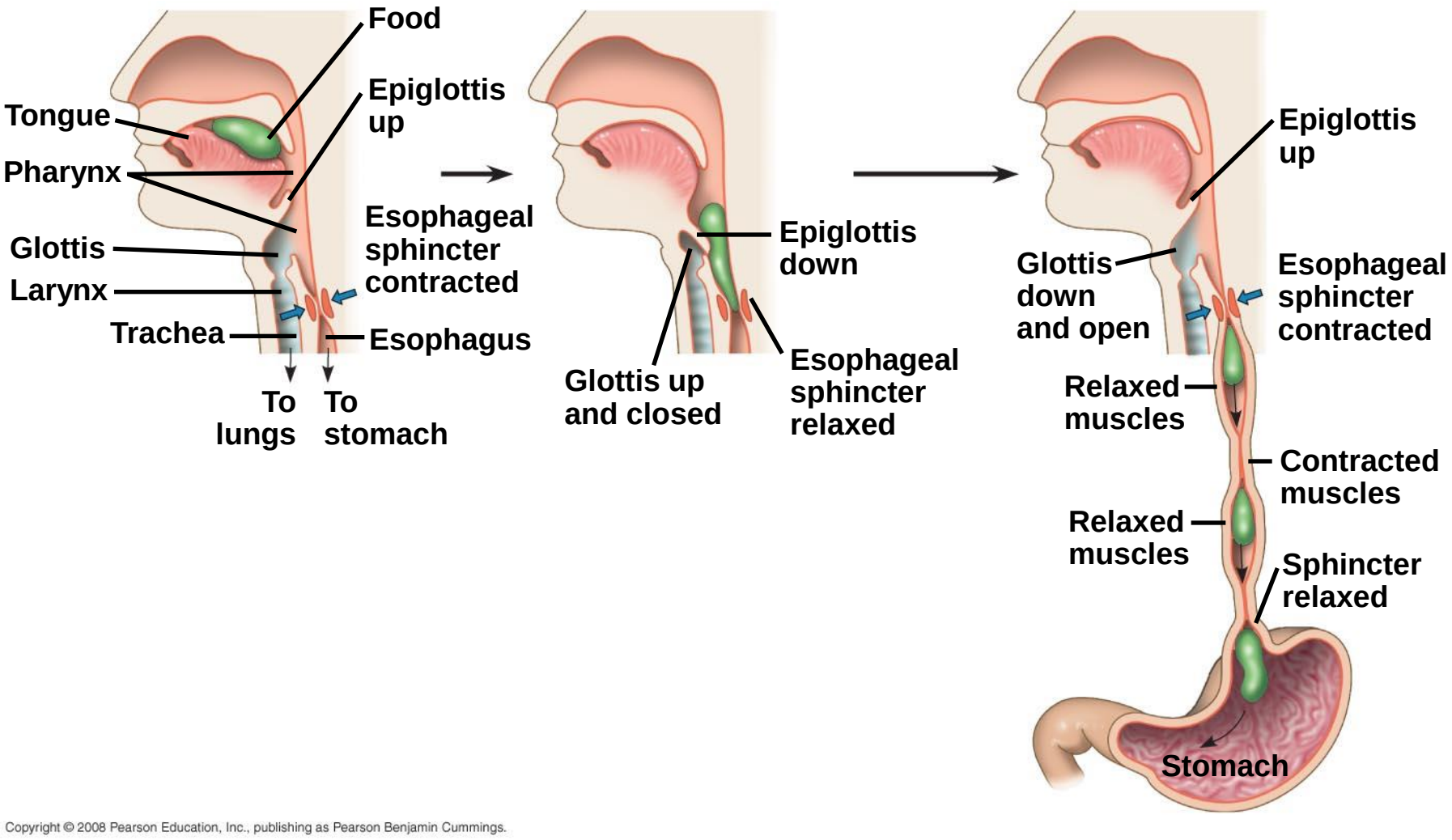


Fig. 41-11-3



Digestion in the Stomach

- The **stomach** stores food and secretes **gastric juice**, which converts a meal to acid **chyme**

Chemical Digestion in the Stomach

- Gastric juice is made up of hydrochloric acid and the enzyme **pepsin**
- *Parietal cells* secrete hydrogen and chloride ions separately
- *Chief cells* secrete inactive **pepsinogen**, which is activated to pepsin when mixed with hydrochloric acid in the stomach
- **Mucus** protects the stomach lining from gastric juice

Fig. 41-12

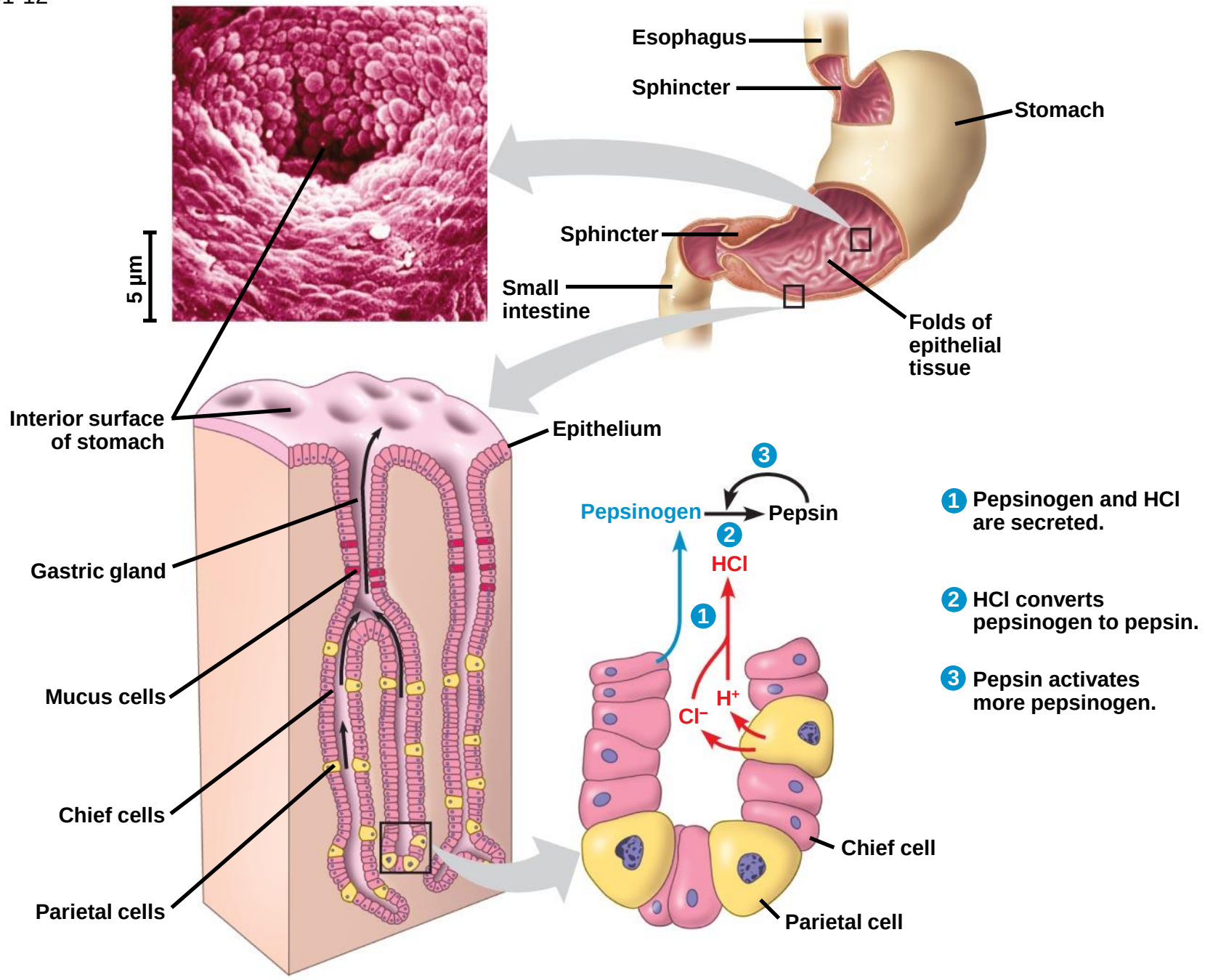


Fig. 41-12a

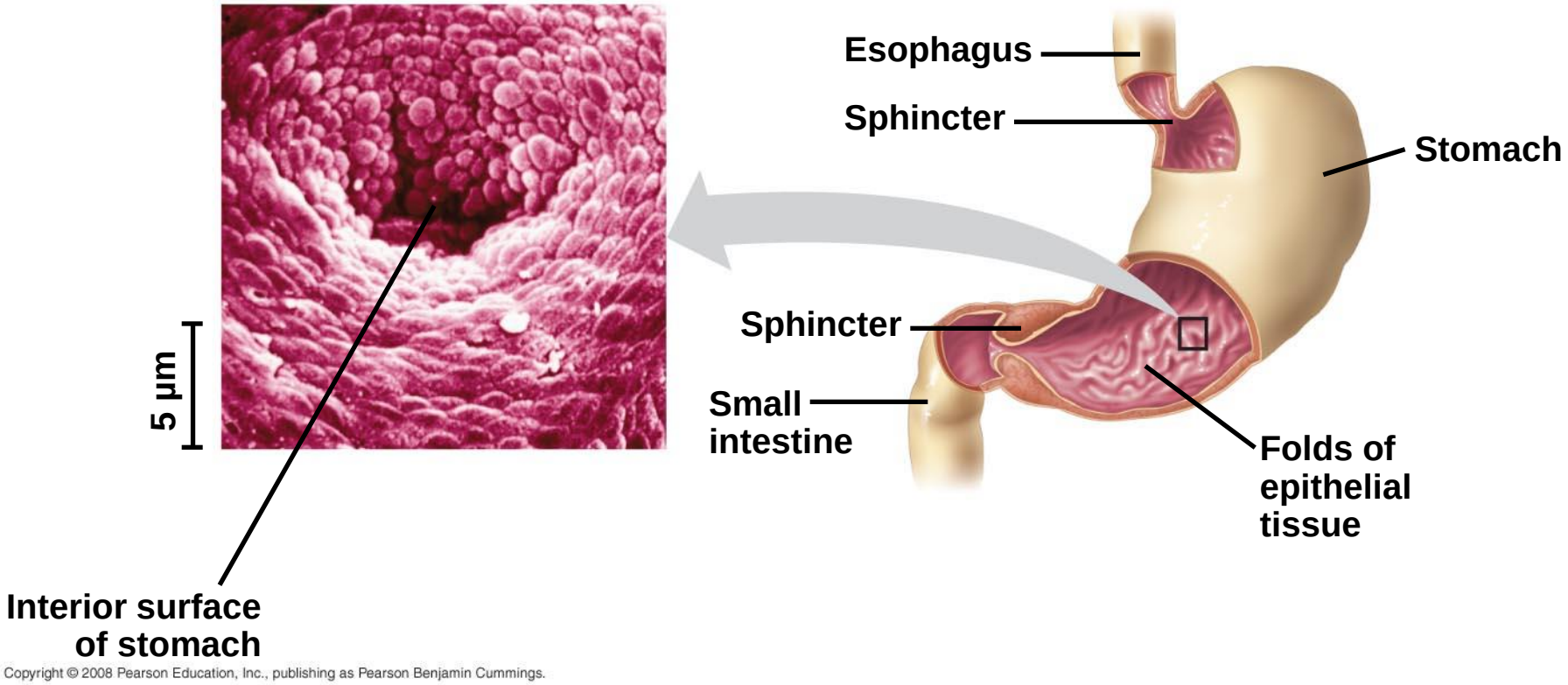
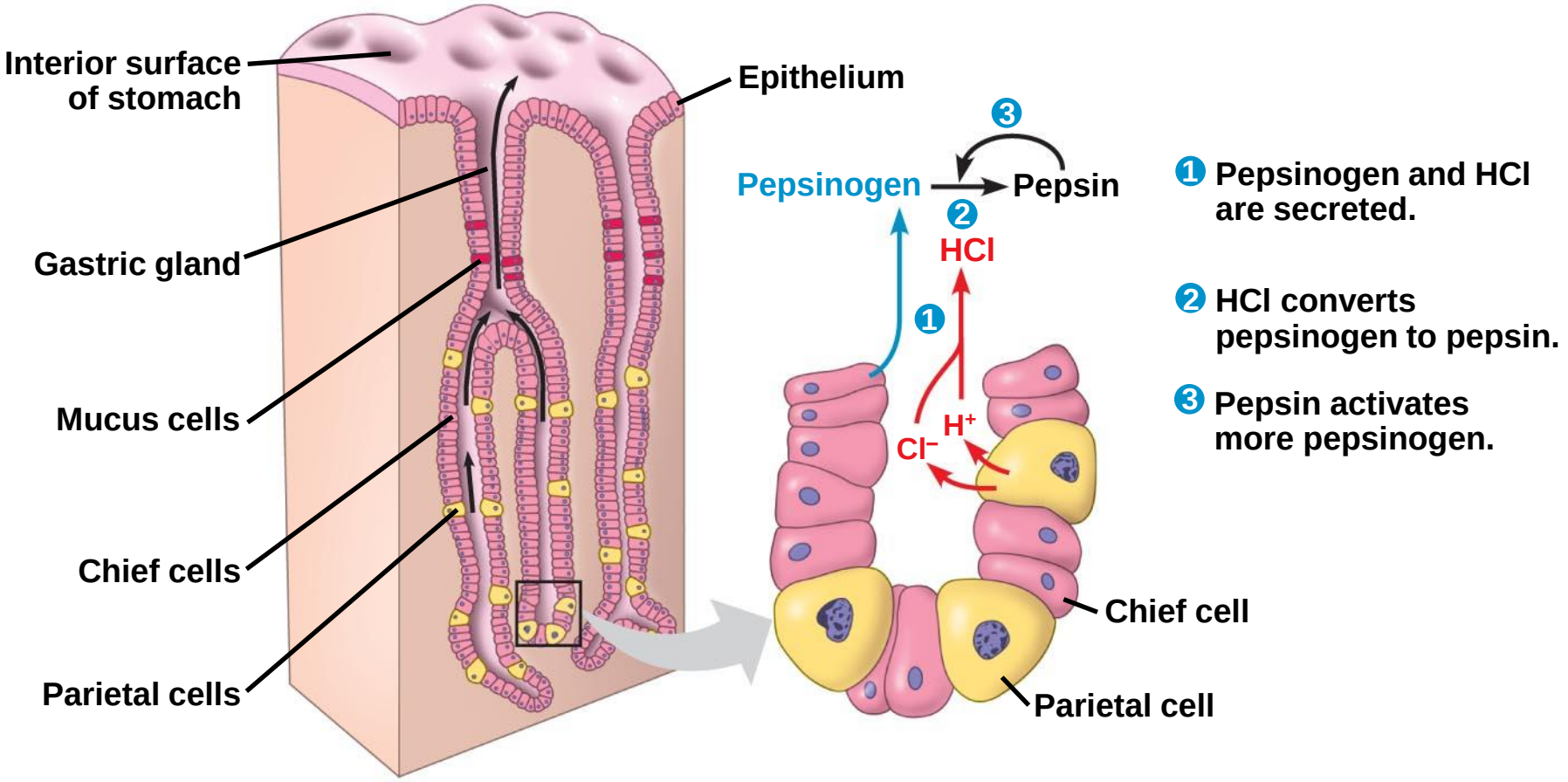


Fig. 41-12b



- Gastric ulcers, lesions in the lining, are caused mainly by the bacterium *Helicobacter pylori*

Stomach Dynamics

- Coordinated contraction and relaxation of stomach muscle churn the stomach's contents
- Sphincters prevent chyme from entering the esophagus and regulate its entry into the small intestine
- The swallowed meal is converted in stomach to an acidic and nutrient-rich broth called a chyme or acid chyme

Class activity?

- Why do not HCl and pepsin eat through the lining of the stomach?

Digestion in the Small Intestine

- The **small intestine** is the longest section of the alimentary canal
- It is the major organ of digestion and absorption

Fig. 41-13

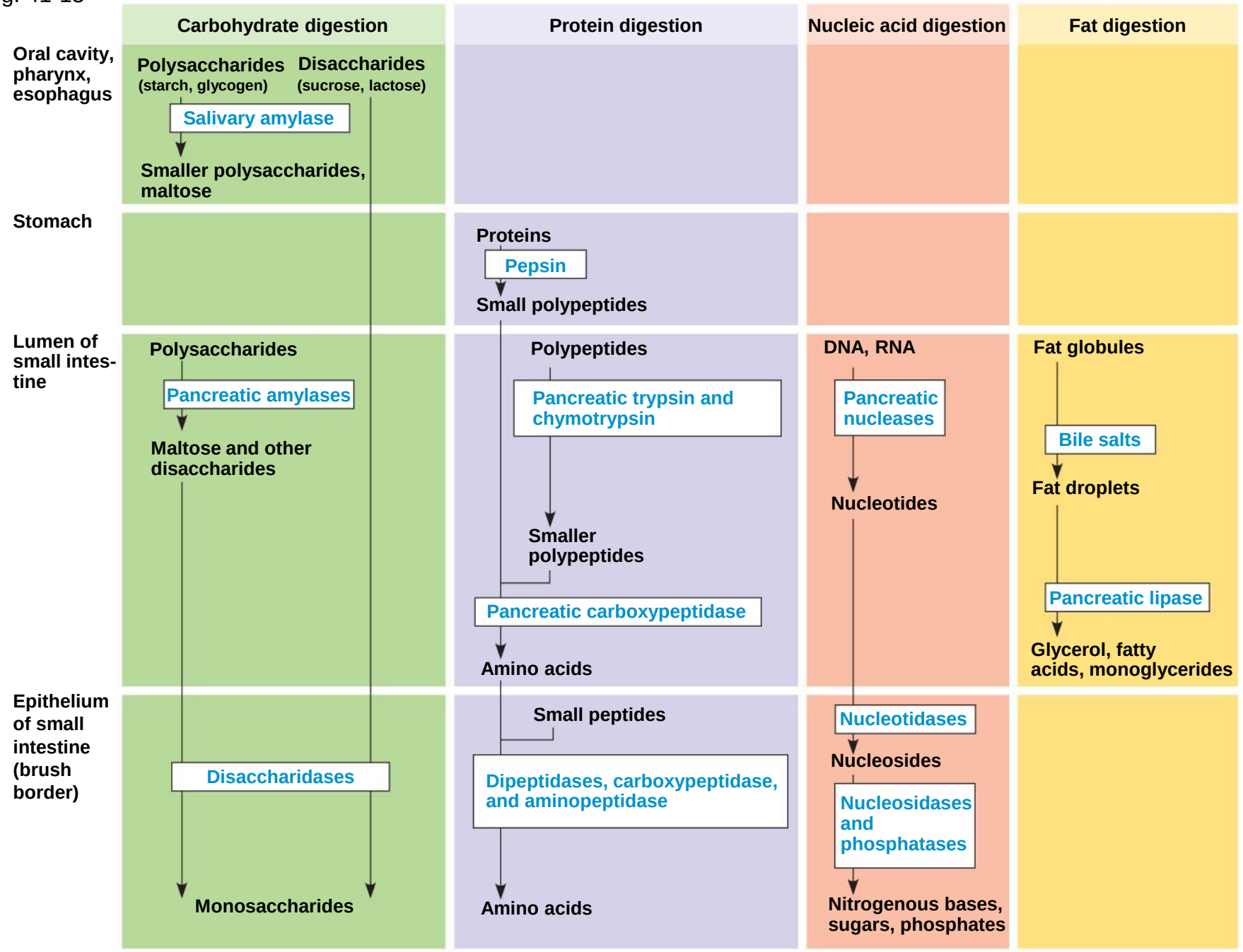


Fig. 41-13a

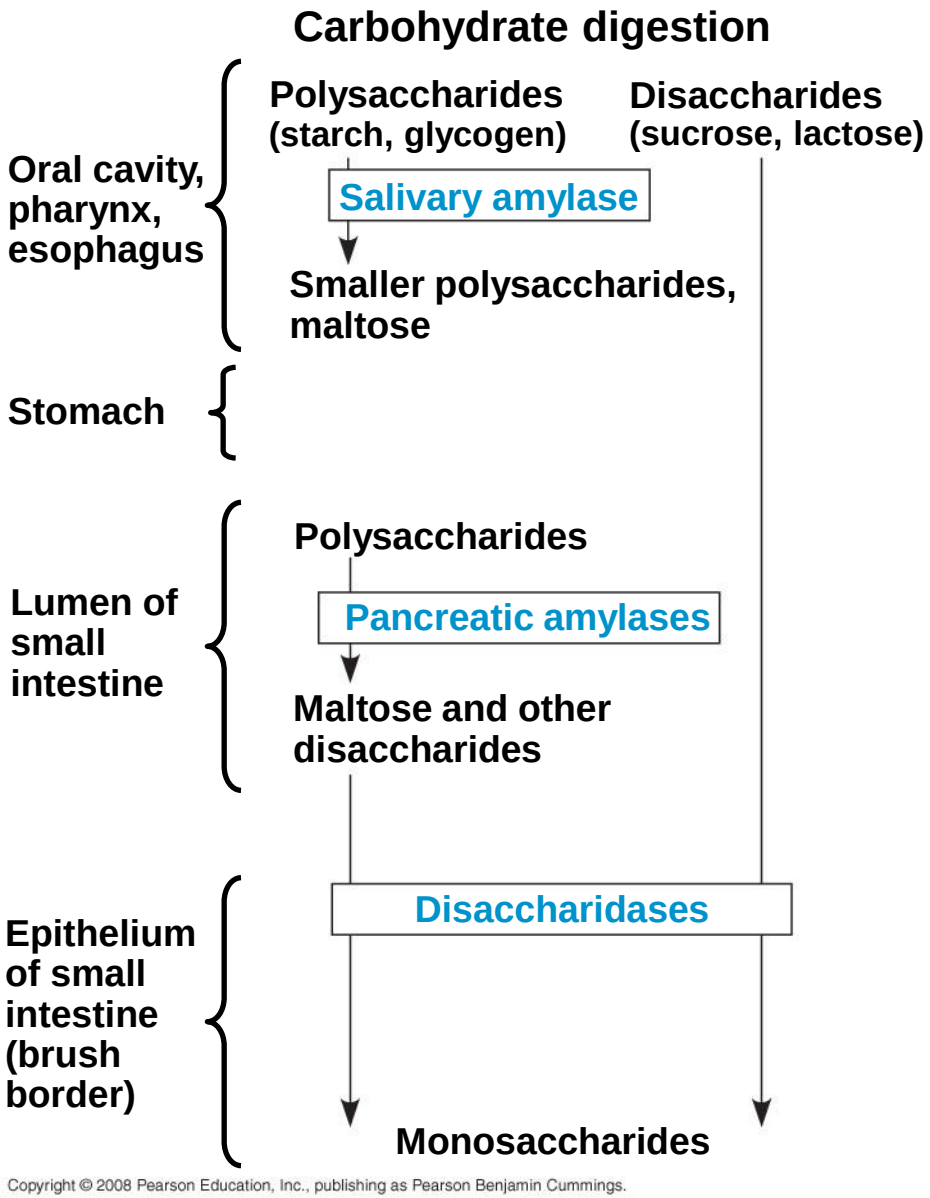


Fig. 41-13b

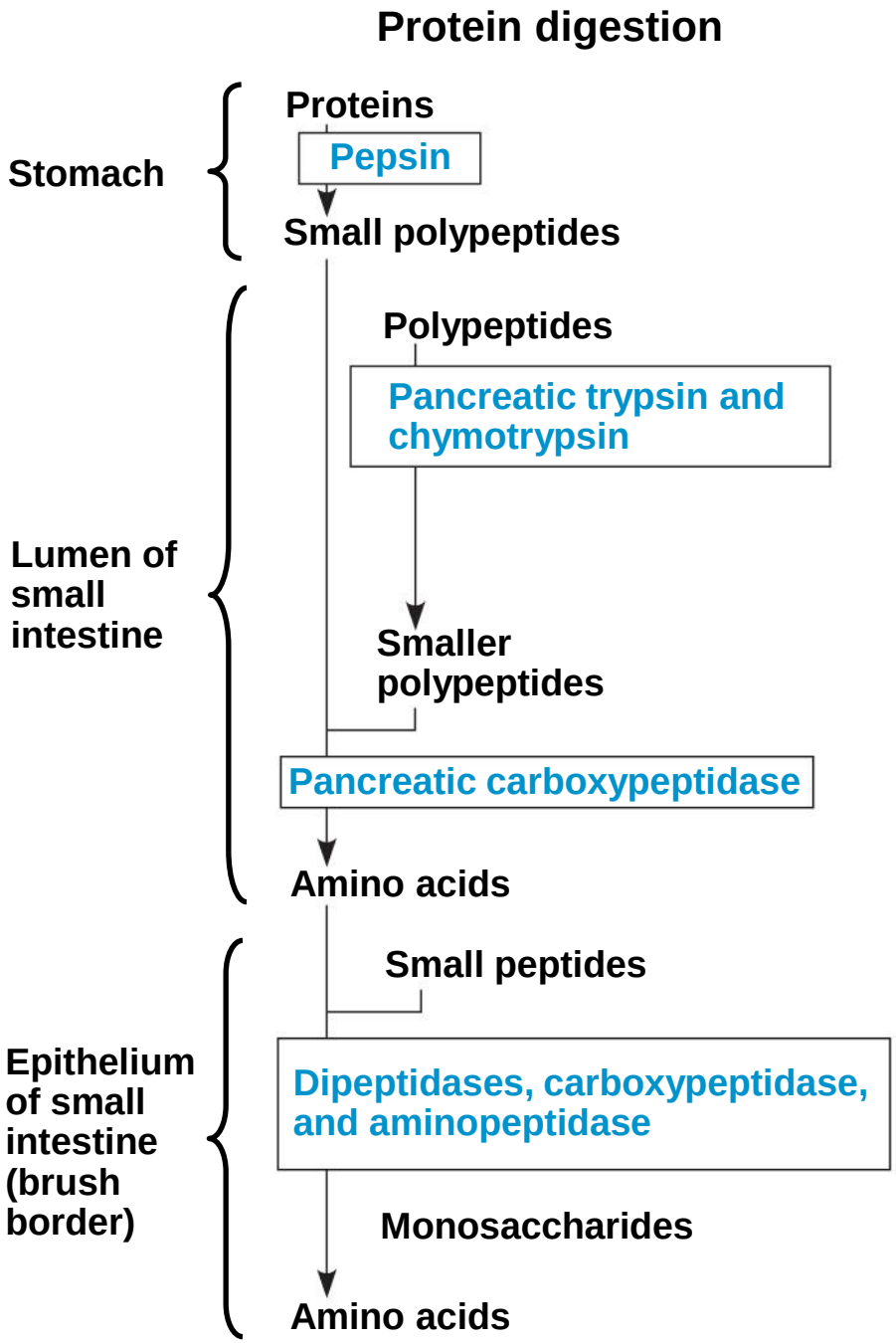


Fig. 41-13c

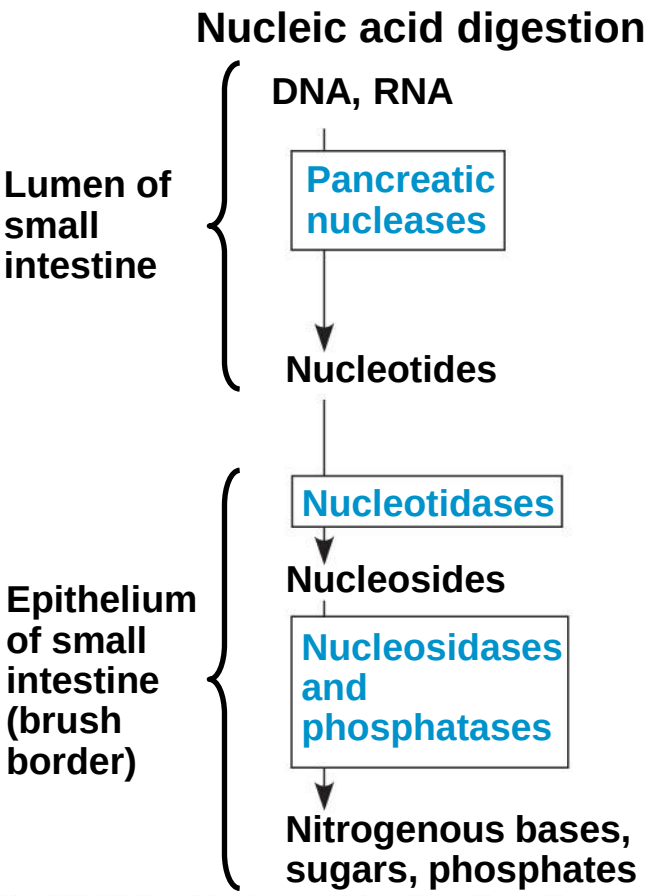


Fig. 41-13d

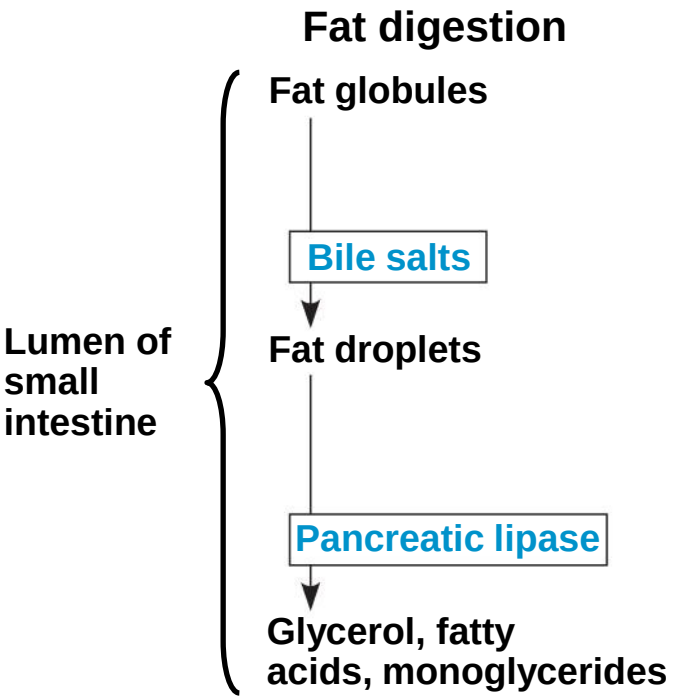
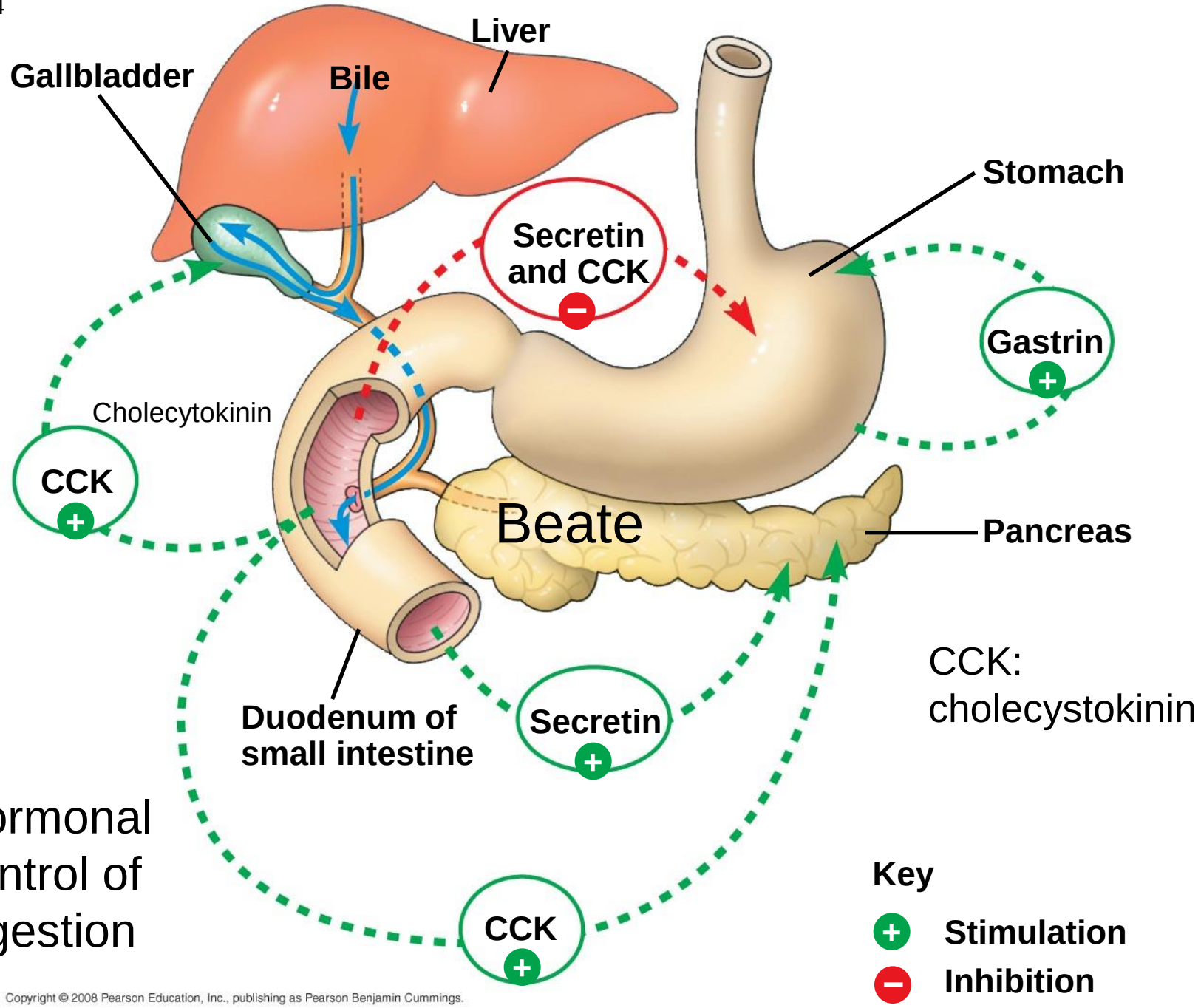


Fig. 41-14



- The first portion of the small intestine is the **duodenum**, where acid chyme from the stomach mixes with digestive juices from the pancreas, liver, gallbladder, and the small intestine itself

Pancreatic Secretions

- The **pancreas** produces proteases trypsin and chymotrypsin, protein-digesting enzymes that are activated after entering the duodenum
- Its solution is alkaline and neutralizes the acidic chyme

Bile Production by the Liver

- In the small intestine, **bile** aids in digestion and absorption of fats
- Bile is made in the **liver** and stored in the **gallbladder**

Secretions of the Small Intestine

- The epithelial lining of the duodenum, called the brush border, produces several digestive enzymes
- Enzymatic digestion is completed as peristalsis moves the chyme and digestive juices along the small intestine
- Most digestion occurs in the duodenum; the jejunum and ileum function mainly in absorption of nutrients and water

Absorption in the Small Intestine

- The small intestine has a huge surface area, due to **villi** and **microvilli** that are exposed to the intestinal lumen
- The enormous microvillar surface greatly increases the rate of nutrient absorption

Fig. 41-15

The structure of the small intestine

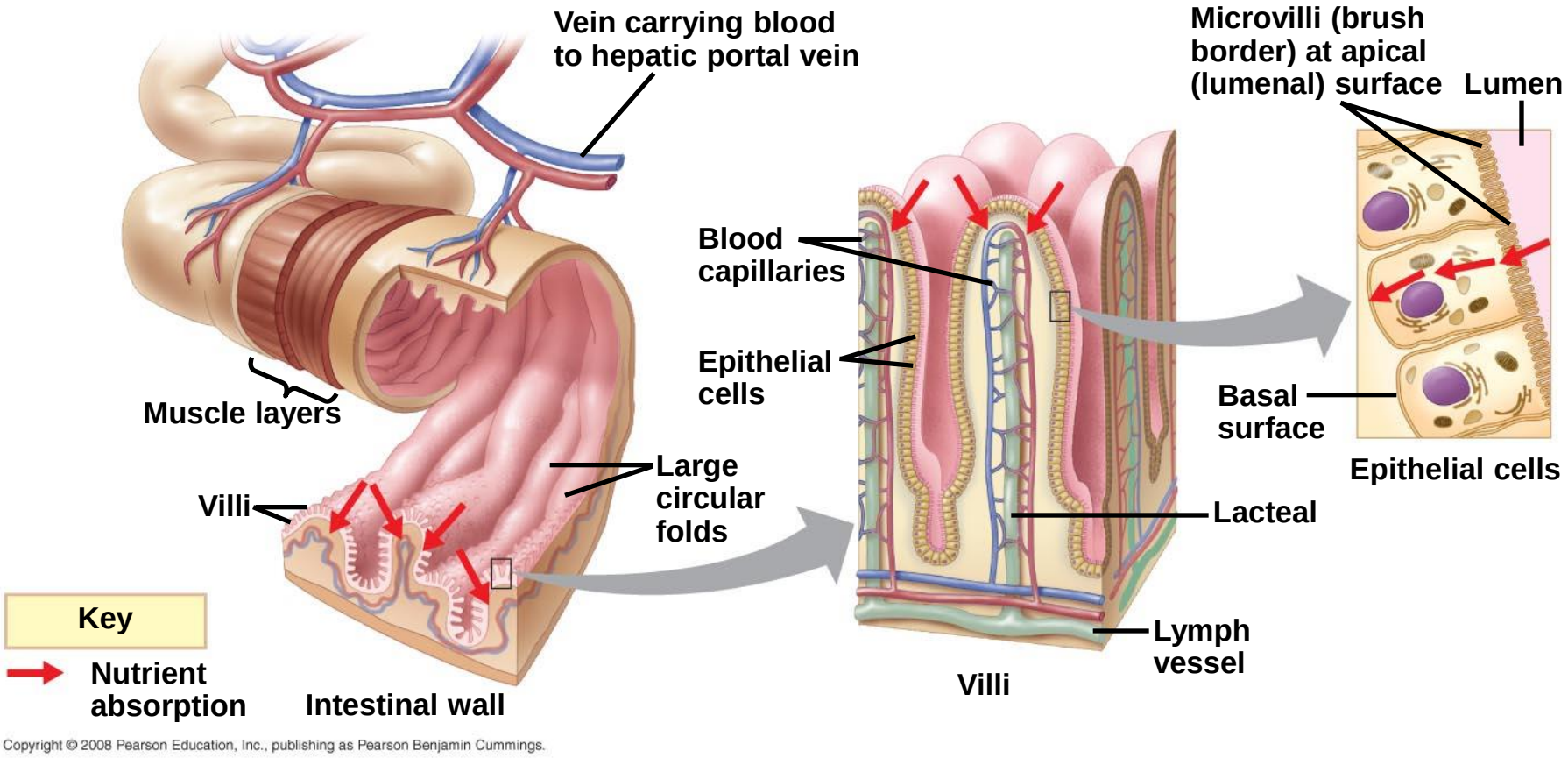


Fig. 41-15a

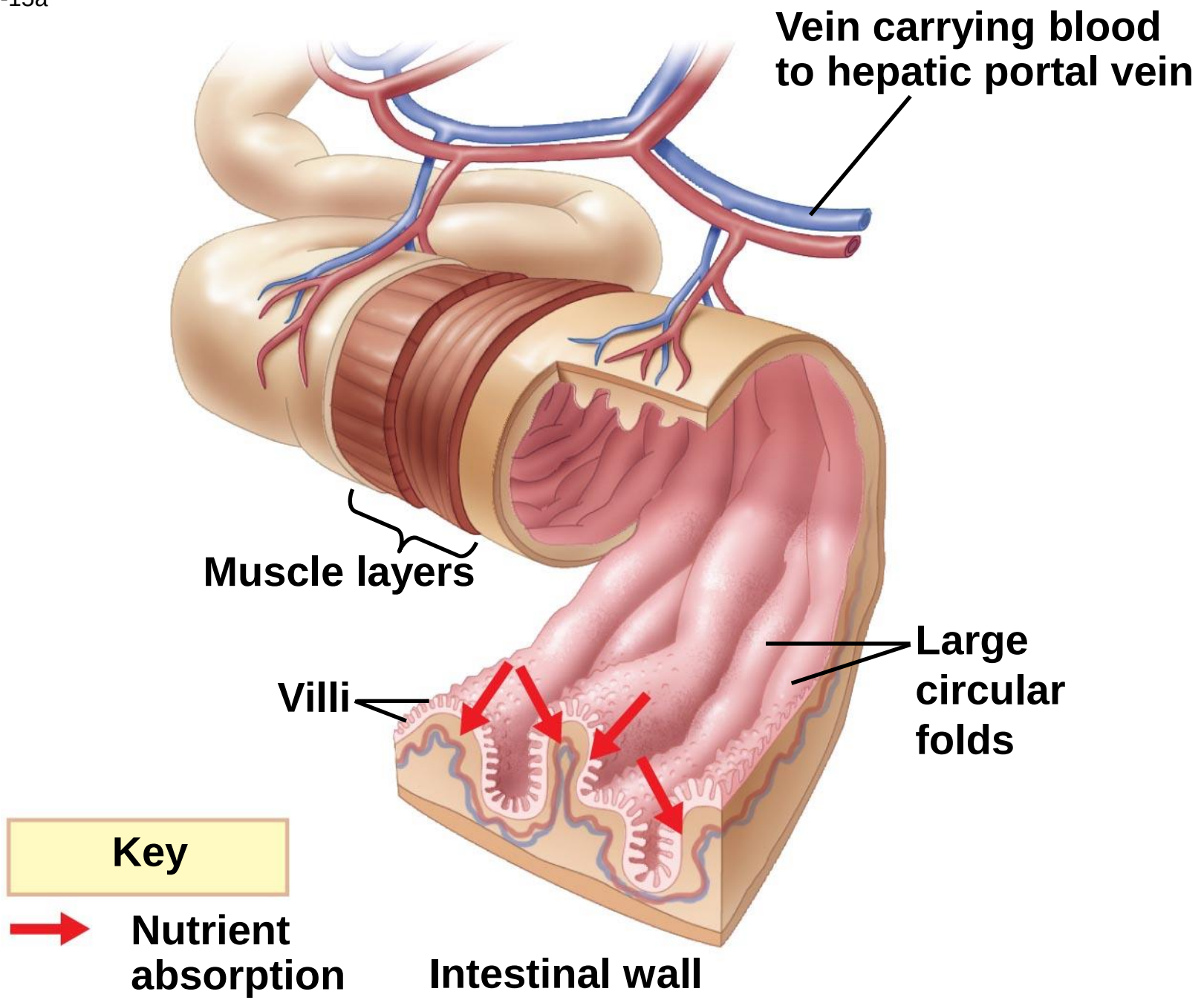
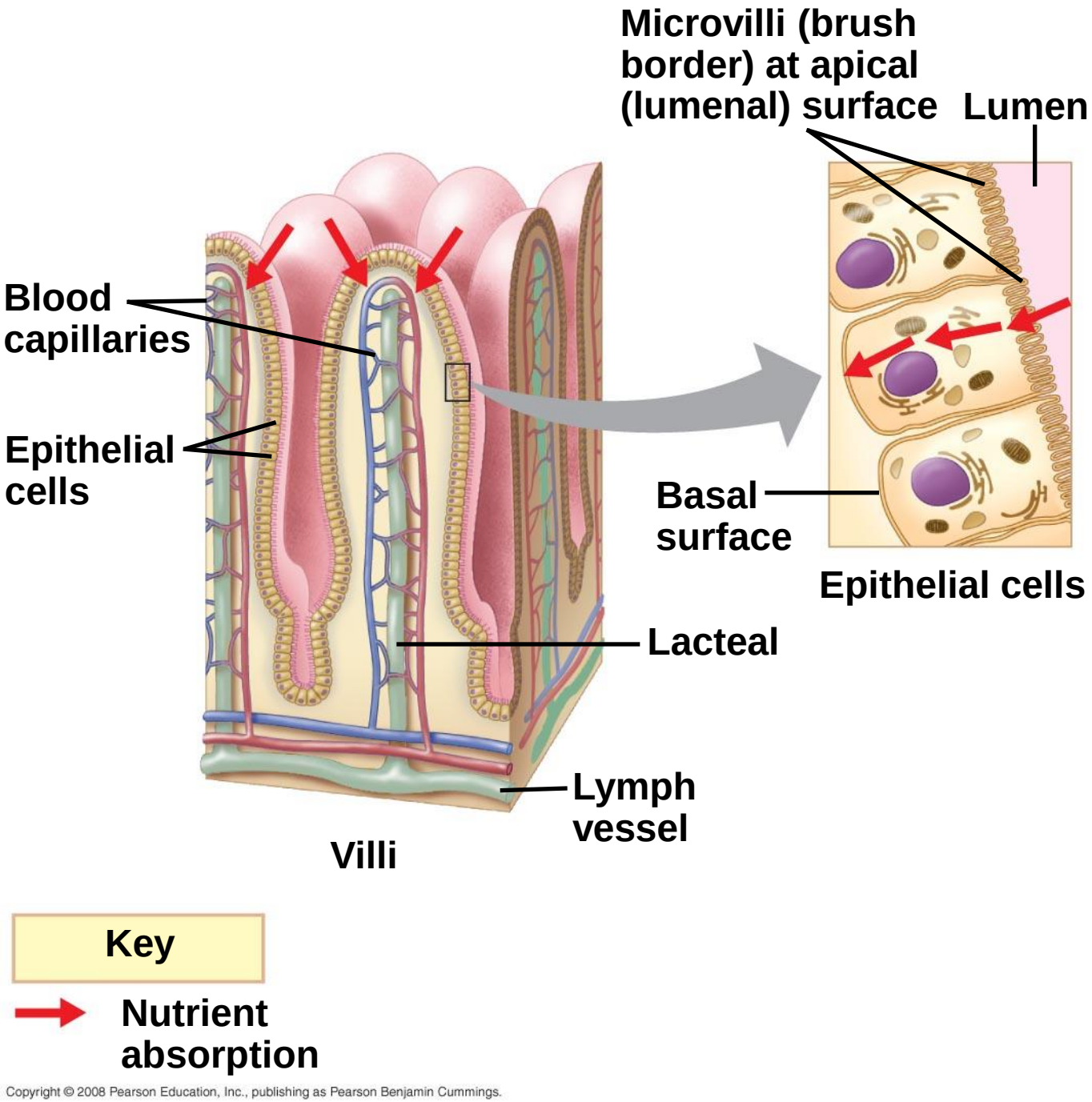


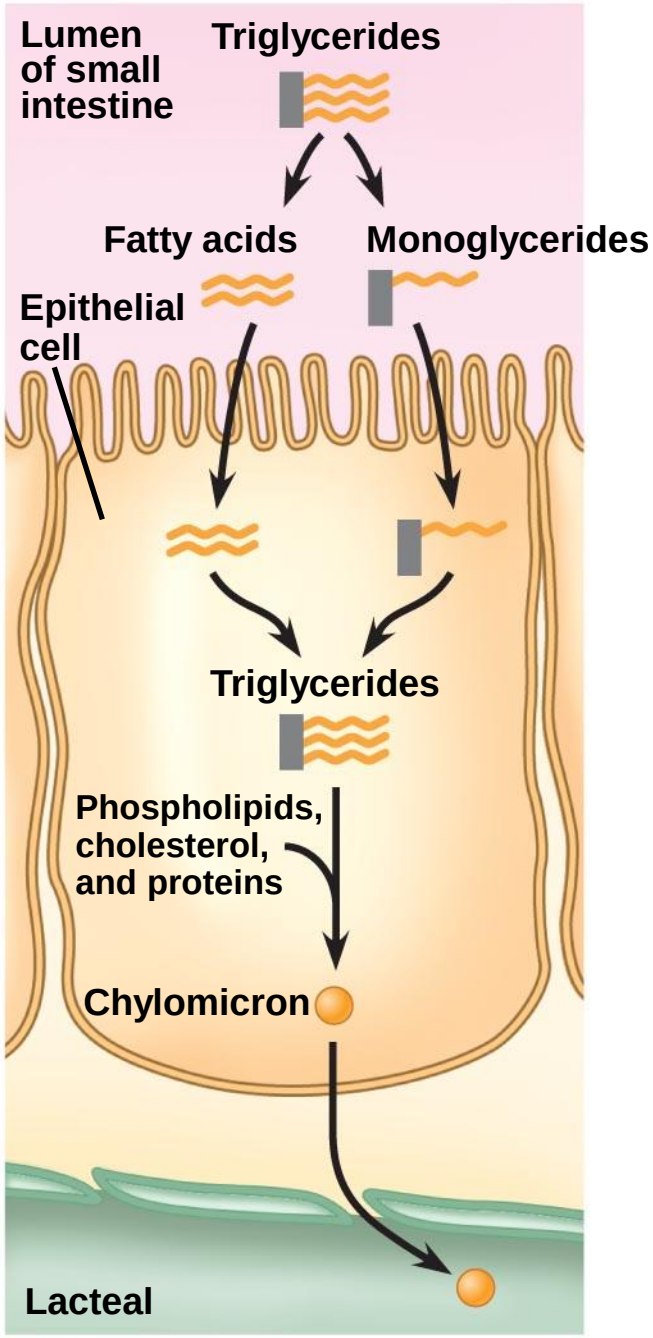
Fig. 41-15b



- Each villus contains a network of blood vessels and a small lymphatic vessel called a **lacteal**
- After glycerol and fatty acids are absorbed by epithelial cells, they are recombined into fats within these cells
- These fats are mixed with cholesterol and coated with protein, forming molecules called **chylomicrons**, which are transported into lacteals

Fig. 41-16

Absorption of fats

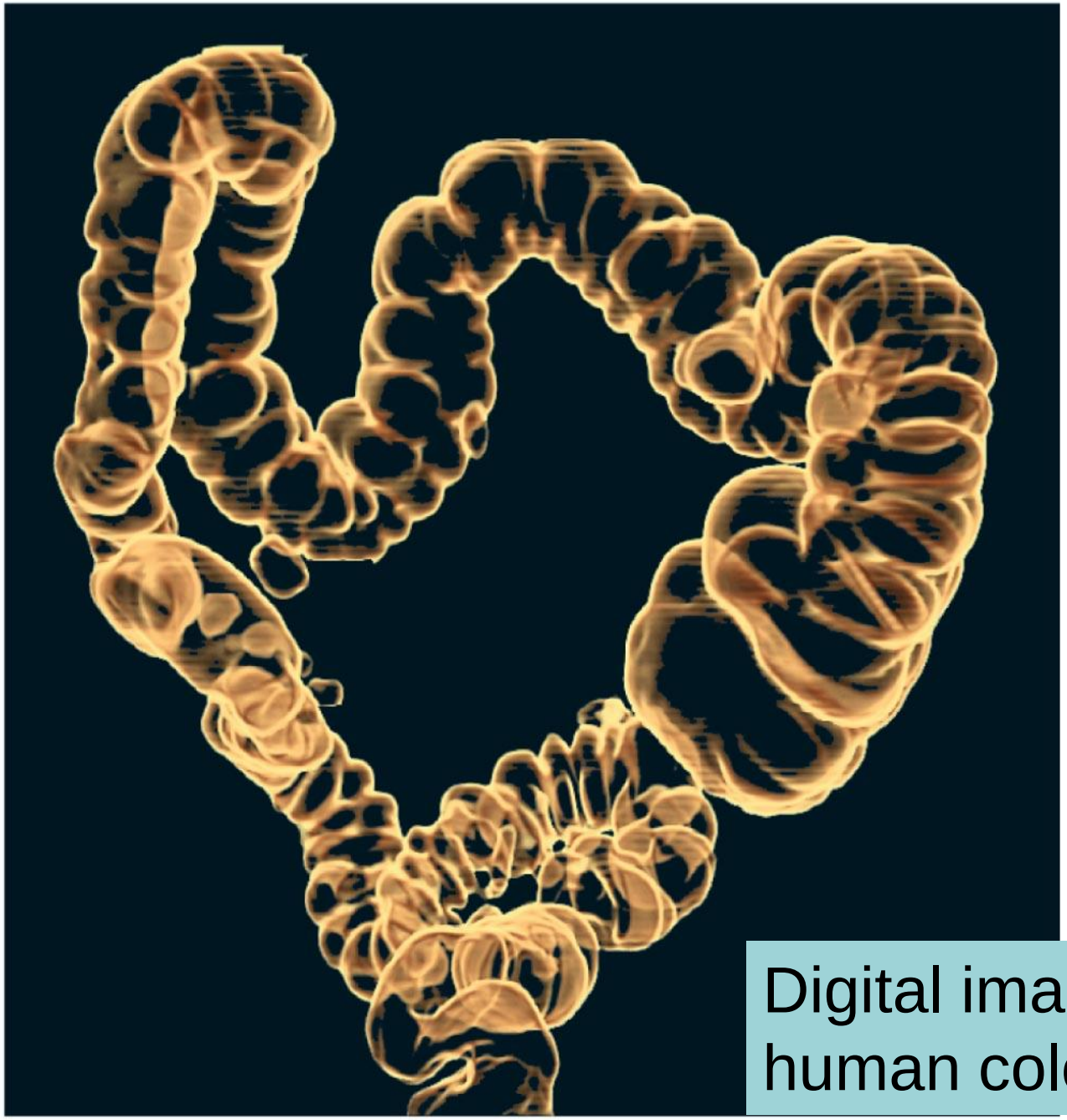


- Amino acids and sugars pass through the epithelium of the small intestine and enter the bloodstream
- Capillaries and veins from the lacteals converge in the **hepatic portal vein** and deliver blood to the liver and then on to the heart

Absorption in the Large Intestine

- The **colon** of the l**arge intestine** is connected to the small intestine
- The **cecum** aids in the fermentation of plant material and connects where the small and large intestines meet
- The human cecum has an extension called the **appendix**, which plays a very minor role in immunity

Fig. 41-17



Digital image of a human colon

- A major function of the colon is to recover water that has entered the alimentary canal
- Wastes of the digestive tract, the **feces**, become more solid as they move through the colon
- Feces pass through the rectum and exit via the anus

- The colon houses strains of the bacterium *Escherichia coli*, some of which produce vitamins
- Feces are stored in the **rectum** until they can be eliminated
- Two sphincters between the rectum and anus control bowel movements

Concept 41.4: Evolutionary adaptations of vertebrate digestive systems correlate with diet

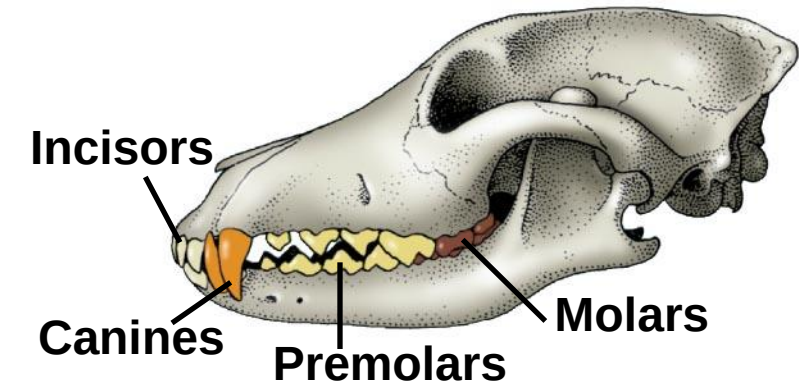
- Digestive systems of vertebrates are variations on a common plan
- However, there are intriguing adaptations, often related to diet

Skip 41.4 & move to 41.5
>>> slide 95

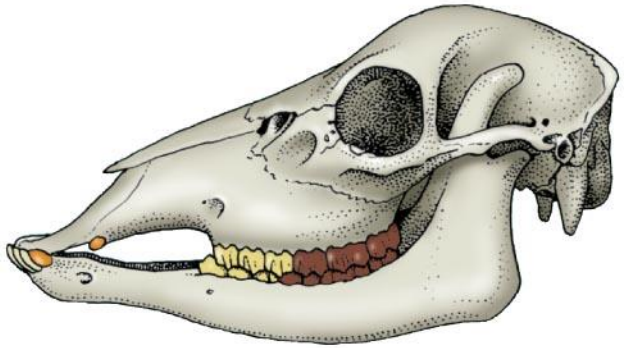
Some Dental Adaptations

- Dentition, an animal's assortment of teeth, is one example of structural variation reflecting diet
- Mammals have varying dentition that is adapted to their usual diet
- The teeth of poisonous snakes are modified as fangs for injecting venom
- All snakes can unhinge their jaws to swallow prey whole

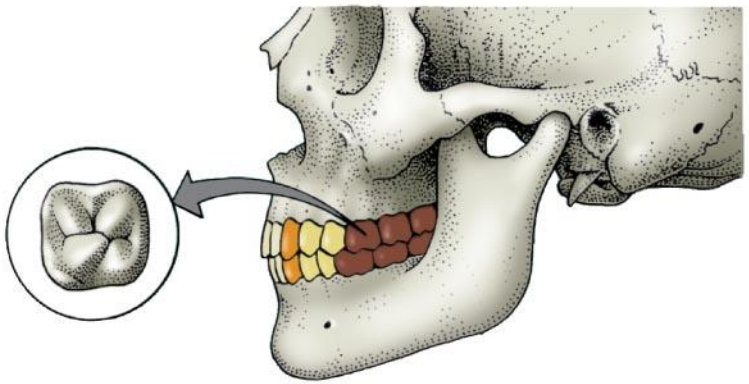
Fig. 41-18



(a) Carnivore



(b) Herbivore

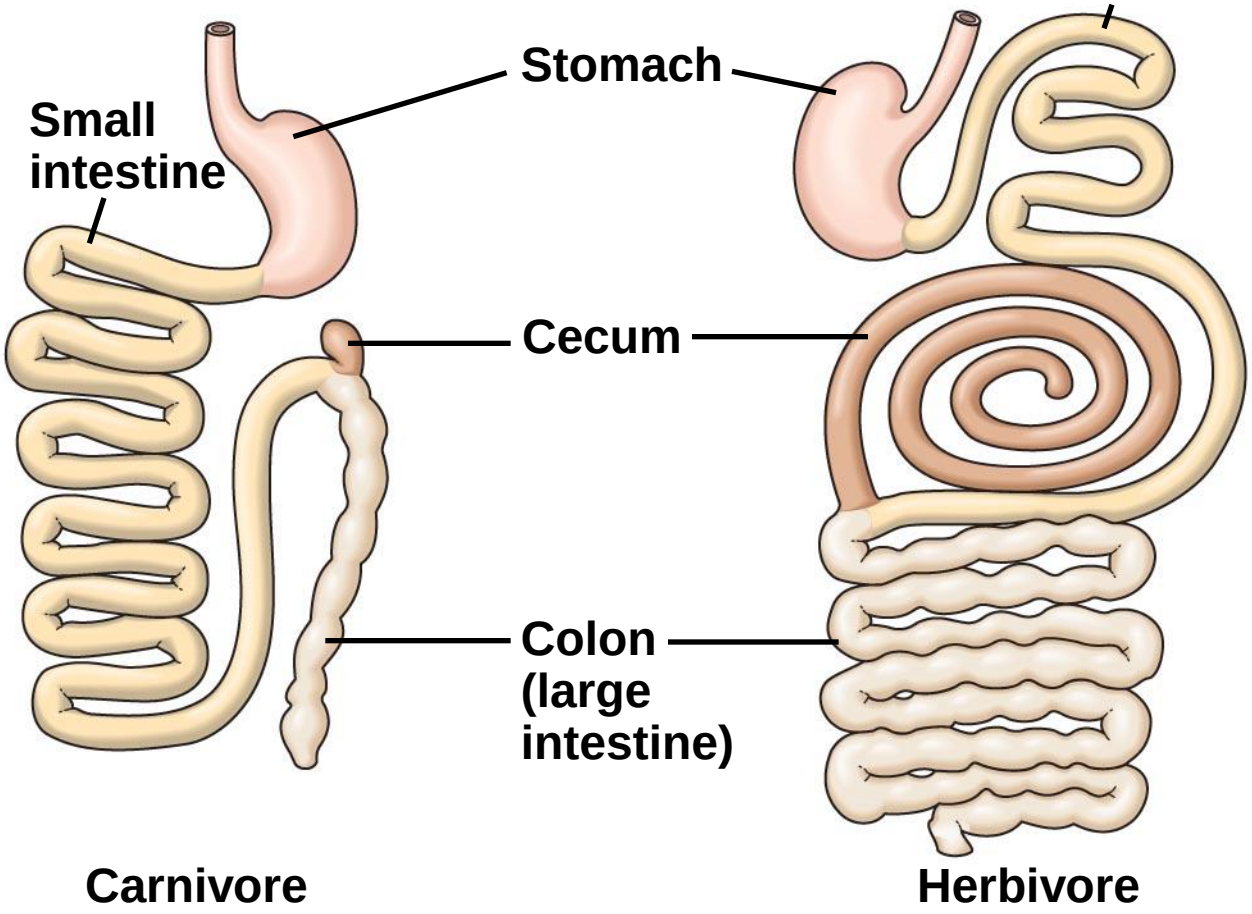


(c) Omnivore

Stomach and Intestinal Adaptations

- Herbivores generally have longer alimentary canals than carnivores, reflecting the longer time needed to digest vegetation

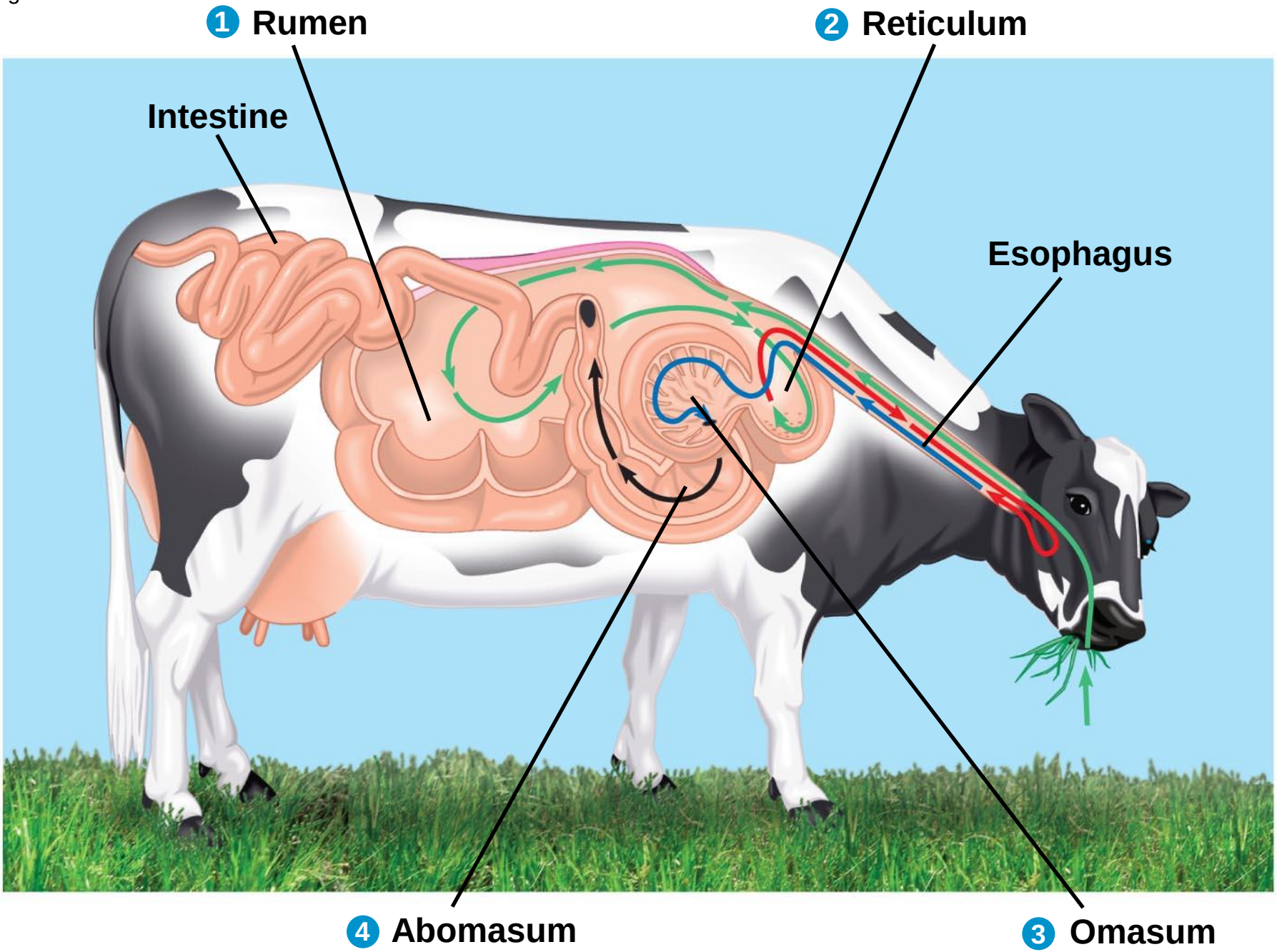
Fig. 41-19



Mutualistic Adaptations

- Many herbivores have fermentation chambers, where symbiotic microorganisms digest cellulose
- The most elaborate adaptations for an herbivorous diet have evolved in the animals called **ruminants**

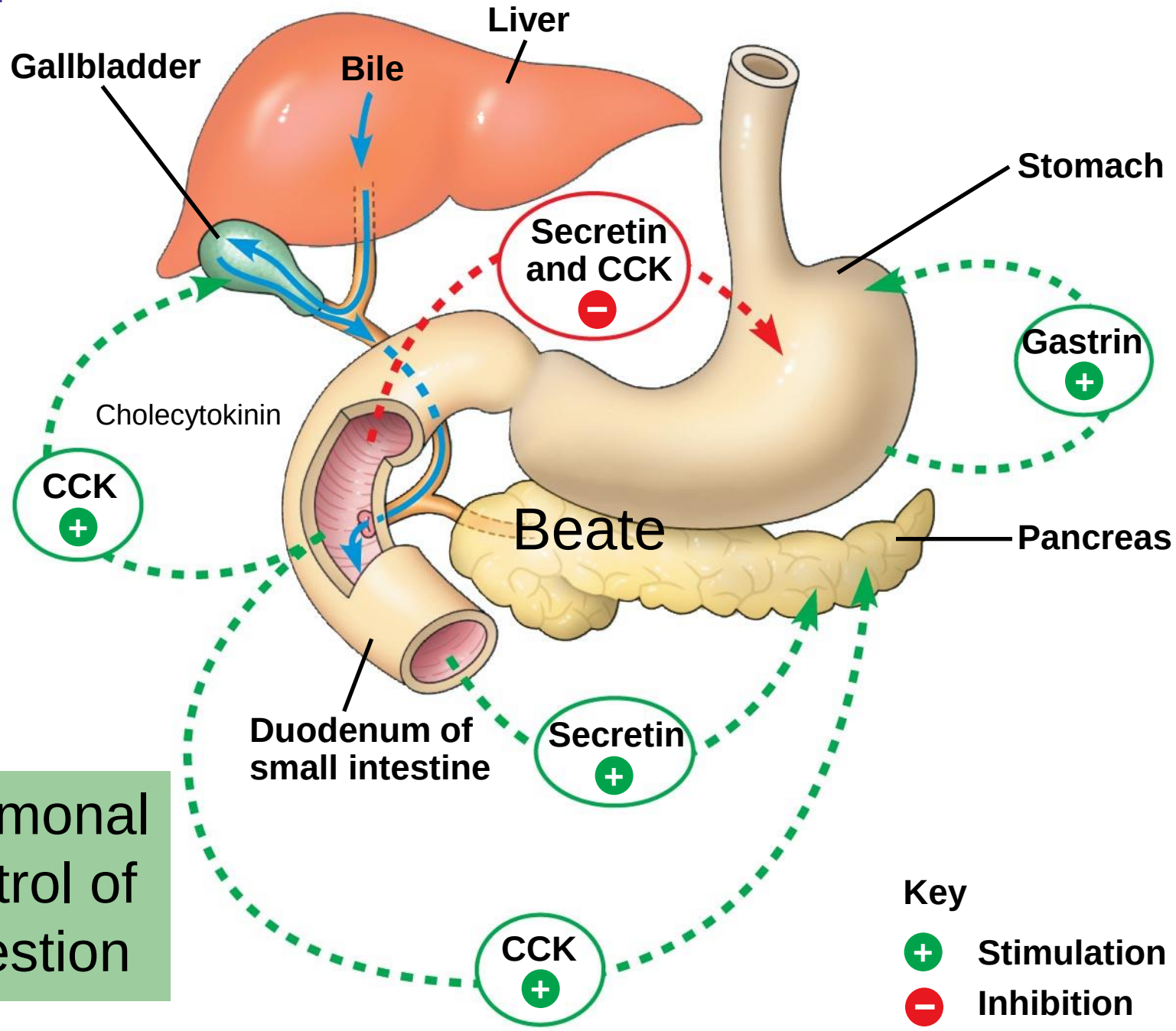
Fig. 41-20



Concept 41.5: Homeostatic mechanisms contribute to an animal's energy balance

- Food energy balances the energy from metabolism, activity, and storage

Fig. 41-14

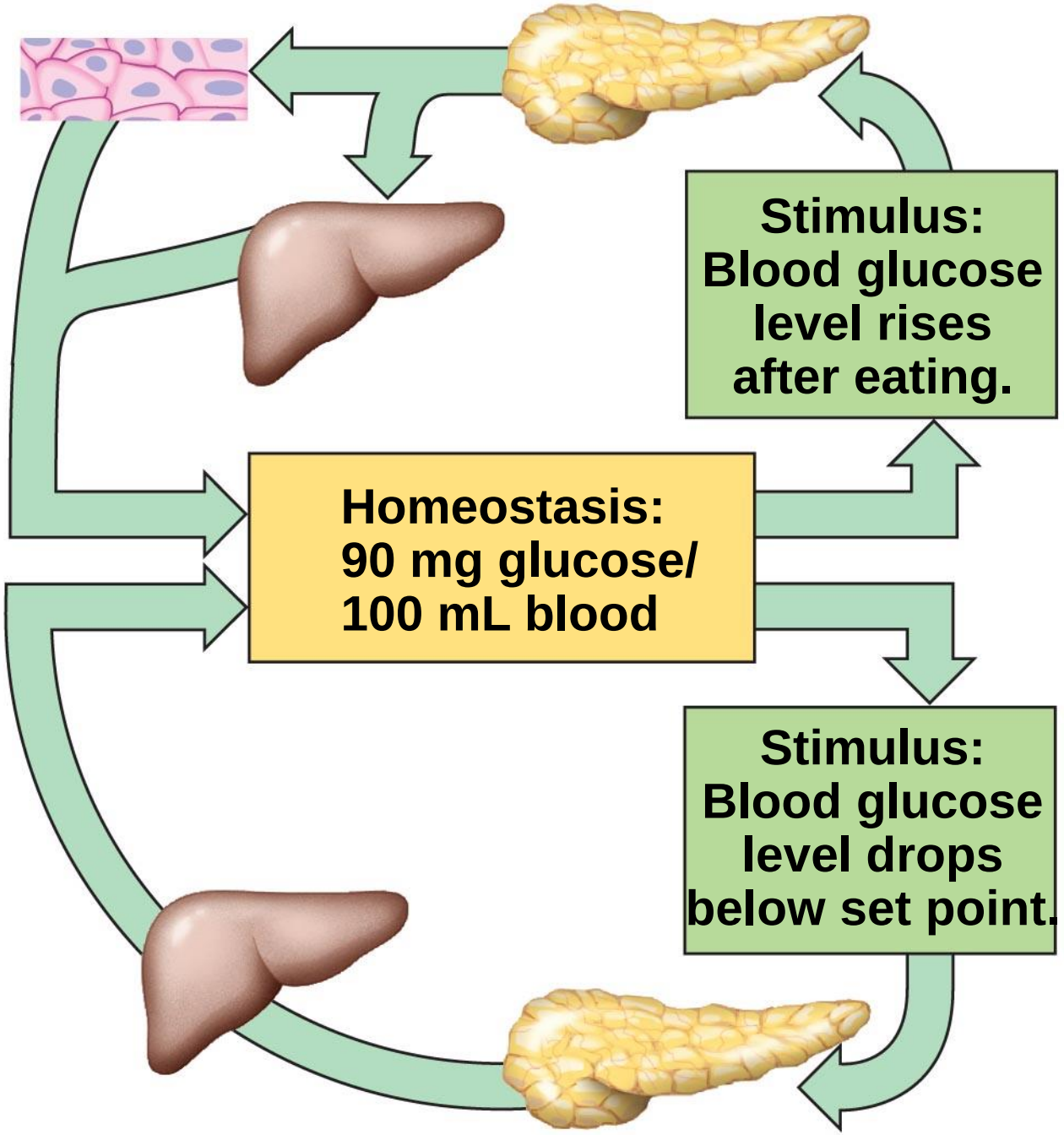


Hormonal control of digestion

Energy Sources and Stores

- Nearly all of an animal's ATP generation is based on oxidation of energy-rich molecules: carbohydrates, proteins, and fats
- Animals store excess calories primarily as glycogen in the liver and muscles
- Energy is secondarily stored as adipose, or fat, cells
- When fewer calories are taken in than are expended, fuel is taken from storage and oxidized

Fig. 41-21



Overnourishment and Obesity

- **Overnourishment** causes obesity, which results from excessive intake of food energy with the excess stored as fat
- Obesity contributes to diabetes (type 2), cancer of the colon and breasts, heart attacks, and strokes

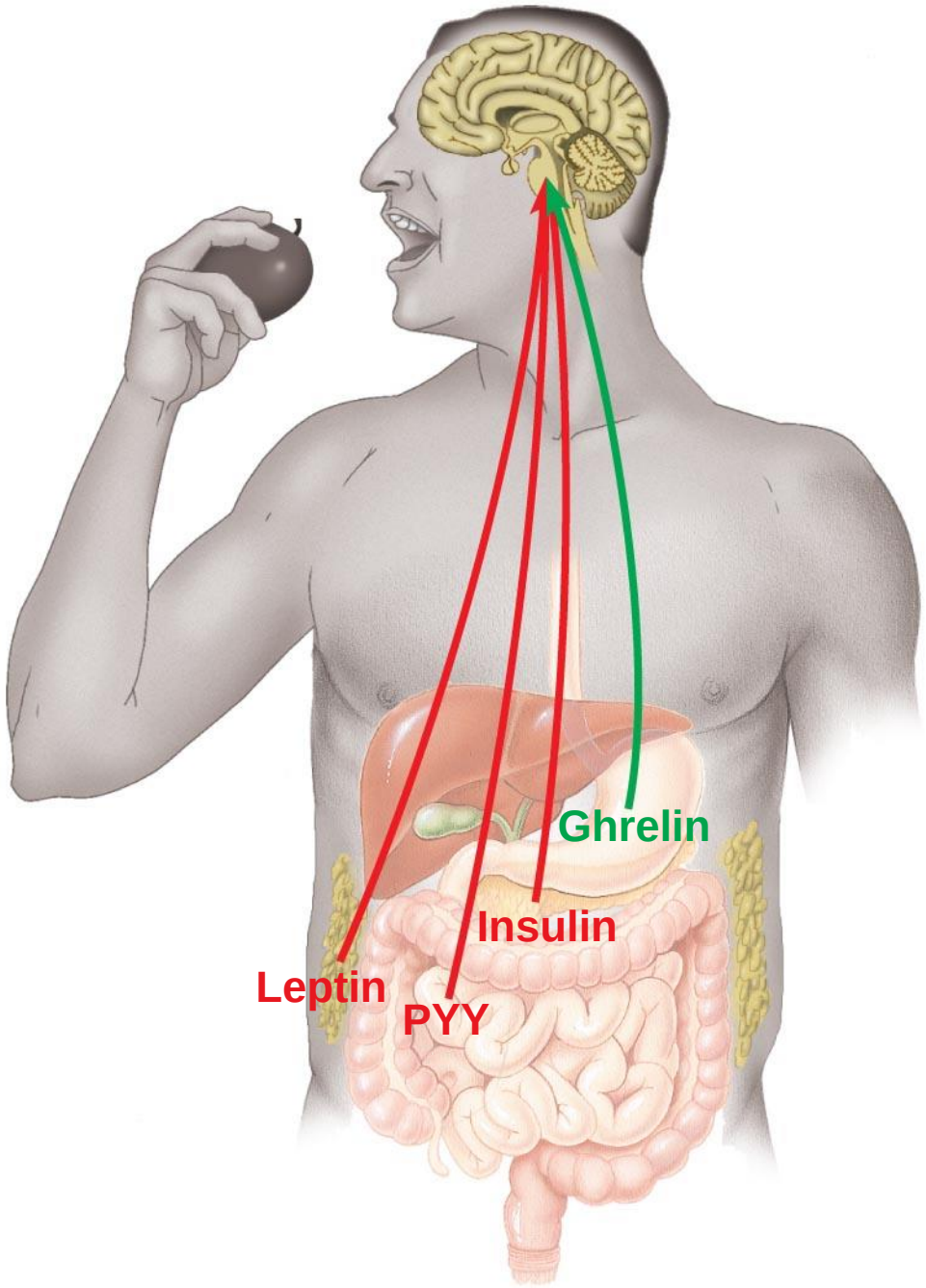
Fig. 41-22

Fat cells from the abdomen of a human

- Researchers have discovered several of the mechanisms that help regulate body weight
- Homeostatic mechanisms are feedback circuits that control the body's storage and metabolism of fat over the long-term
- Hormones regulate long-term and short-term appetite by affecting a "satiety center" in the brain

Satiety: التخمة

Fig. 41-23



- The complexity of weight control in humans is evident from studies of the hormone leptin
- Mice that inherit a defect in the gene for leptin become very obese

Fig. 41-24

EXPERIMENT

Obese mouse with mutant *ob* gene (left) next to wild-type mouse.

What are the roles of the *ob* and *db* genes in appetite regulation?

RESULTS

Genotype pairing (red type indicates mutant genes; bar indicates pairing)	Average body mass (g)	
	Starting	Ending
ob^+, db^+	20.3	23.6
ob^+, db^+	20.8	21.4
ob, db^+	27.6	47.0
ob, db^+	26.6	44.0
ob, db^+	29.4	39.8
ob^+, db^+	22.5	25.5
ob, db^+	33.7	18.8
ob^+, db	30.3	33.2

Fig. 41-24a

EXPERIMENT

Obese mouse with mutant *ob* gene (left) next to wild-type mouse.

Fig. 41-24b

RESULTS

Genotype pairing (red type indicates mutant genes; bar indicates pairing)	Average body mass (g)	
	Starting	Ending
ob^+, db^+	20.3	23.6
|		
ob^+, db^+	20.8	21.4
ob, db^+	27.6	47.0
|		
ob, db^+	26.6	44.0
ob, db^+	29.4	39.8
|		
ob^+, db^+	22.5	25.5
ob, db^+	33.7	18.8
|		
ob^+, db	30.3	33.2

Obesity and Evolution

- The problem of maintaining weight partly stems from our evolutionary past, when fat hoarding was a means of survival
- A species of birds called petrels become obese as chicks; in order to consume enough protein from high-fat food, chicks need to consume more calories than they burn

Fig. 41-25

Fig. 41-UN1

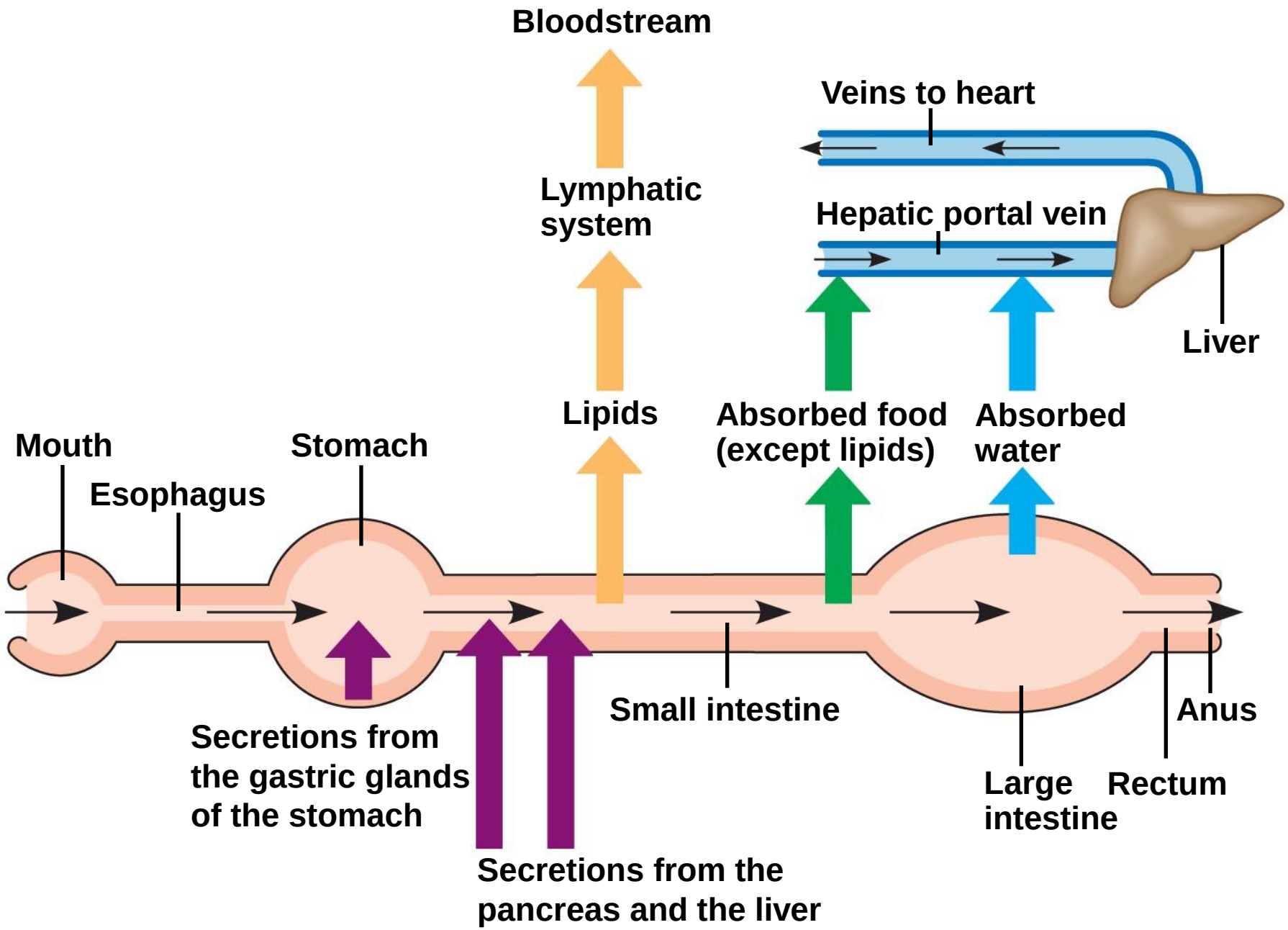
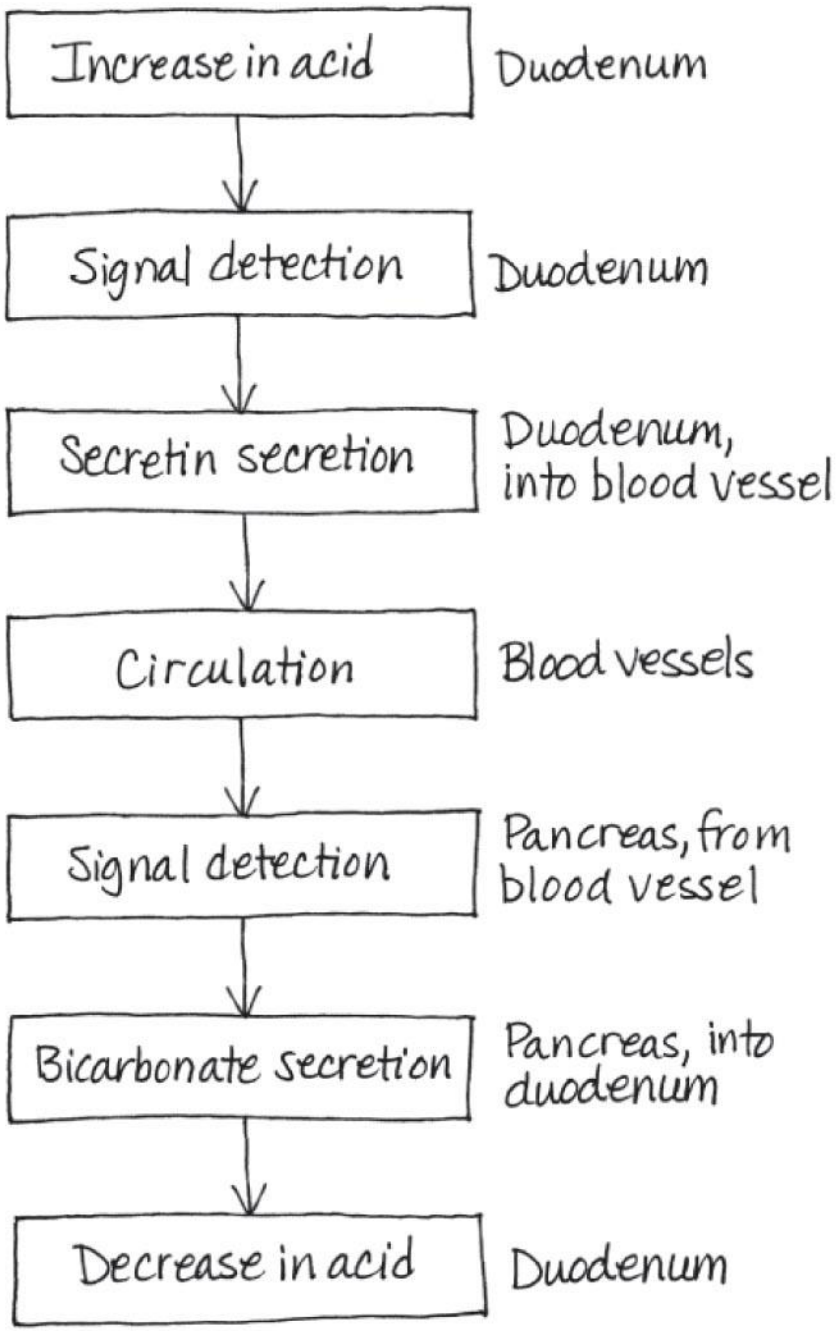


Fig. 41-UN2



You should now be able to:

1. Name the three nutritional needs that must be met by an animal's diet
2. Describe the four classes of essential nutrients
3. Distinguish among undernourishment, overnourishment, and malnourishment
4. Describe the four main stages of food processing
5. Distinguish between a complete digestive tract and a gastrovascular cavity

6. Follow a meal through the mammalian digestive system:
   - List important enzymes and describe their roles
   - Compare *where* and *how* the major types of macromolecules are digested and absorbed
7. Relate variations in dentition with different diets
8. Explain *where* and *in what form* energy-rich molecules may be stored in the human body