CAMPBELL
BIOLOGY
TENTH EDITION
Reece • Urry • Cain • Wasserman • Minorsky • Jackson

41

Animal Nutrition

Lecture Presentation by Nicole Tunbridge and Kathleen Fitzpatrick

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 plants and algae
  - **Carnivores** eat other animals
  - **Omnivores** regularly consume animals as well as plants or algae
- Most animals are also opportunistic feeders

Figure 41.1

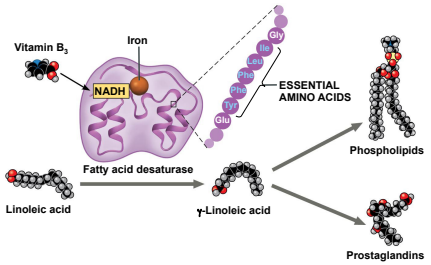
Concept 41.1: An animal's diet must supply chemical energy, organic molecules, and essential nutrients

- An animal's diet must provide
  - Chemical energy for cellular processes
  - Organic building blocks for macromolecules
  - Essential nutrients

Essential Nutrients

- Materials that an animal cannot assemble from simpler organic molecules are called **essential nutrients**
- These must be obtained from an animal's diet
- There are four classes
  - Essential amino acids
  - Essential fatty acids
  - Vitamins
  - Minerals

Figure 41.2



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
- Meat, eggs, and cheese provide all the essential amino acids and are thus "complete" proteins

- Most plant proteins are incomplete in amino acid composition
- Individuals who eat only plant proteins need to eat specific plant combinations to get all the essential amino acids
- Some animals have adaptations that help them through periods when their bodies demand extraordinary amounts of protein

Essential Fatty Acids

- Animals can synthesize most of the fatty acids they need
- The **essential fatty acids** must be obtained from the diet and include certain unsaturated fatty acids (i.e., fatty acids with one or more double bonds)
- Deficiencies in fatty acids are rare

Vitamins

- **Vitamins** are organic molecules required in the diet in very small amounts
- Thirteen vitamins are essential for humans
- 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
Water-Soluble Vitamins			
B_1 (thiamine)	Pork, legumes, peanuts, whole grains	Coenzyme used in removing CO_2 from organic compounds	Beriberi (tingling, poor coordination, reduced heart function)
B_2 (riboflavin)	Dairy products, meats, enriched grains, vegetables	Component of coenzymes FAD and FMN	Skin lesions, such as cracks at corners of mouth
B_3 (niacin)	Nuts, meats, grains	Component of coenzymes NAD^+ and $NADP^+$	Skin and gastrointestinal lesions, delusions, confusion
B_5 (pantothenic acid)	Meats, dairy products, whole grains, fruits, vegetables	Component of coenzyme A	Fatigue, numbness, tingling of hands and feet
B_6 (pyridoxine)	Meats, vegetables, whole grains	Coenzyme used in amino acid metabolism	Irritability, convulsions, muscular twitching, anemia
B_7 (biotin)	Legumes, other vegetables, meats	Coenzyme in synthesis of fat, glycogen, and amino acids	Scaly skin inflammation, neuromuscular disorders
B_9 (folic acid)	Green vegetables, oranges, nuts, legumes, whole grains	Coenzyme in nucleic acid and amino acid metabolism	Anemia, birth defects
B_{12} (cobalamin)	Meats, eggs, dairy products	Production of nucleic acids and red blood cells	Anemia, numbness, loss of balance
C (ascorbic acid)	Citrus fruits, broccoli, tomatoes	Used in collagen synthesis; antioxidant	Scurvy (degeneration of skin and teeth), delayed wound healing
Fat-Soluble Vitamins			
A (retinol)	Dark green and orange vegetables and fruits, dairy products	Component of visual pigments; maintenance of epithelial tissues	Blindness, skin disorders, impaired immunity
D	Dairy products, egg yolk	Aids in absorption and use of calcium and phosphorus	Rickets (bone deformities) in children, bone softening in adults
E (tocopherol)	Vegetable oils, nuts, seeds	Antioxidant; helps prevent damage to cell membranes	Nervous system degeneration
K (phylloquinone)	Green vegetables, tea; also made by colon bacteria	Important in blood clotting	Defective blood clotting

Minerals

- **Minerals** are simple inorganic nutrients, usually required in small amounts
- Ingesting large amounts of some minerals can upset homeostatic balance

Table 41.2

Table 41.2 Mineral Requirements of Humans*

	Mineral	Major Dietary Sources	Major Functions in the Body	Symptoms of Deficiency
More than 200 mg per day required	Calcium (Ca)	Dairy products, dark green vegetables, legumes	Bone and tooth formation, blood clotting, nerve and muscle function	Impaired growth, 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	Impaired growth, fatigue, swelling
	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	Enzyme cofactor; ATP bioenergetics	Nervous system disturbances
	Iron (Fe)	Meats, eggs, legumes, whole grains, green leafy vegetables	Component of hemoglobin and of electron carriers; enzyme cofactor	Iron-deficiency anemia, weakness, impaired immunity
	Fluorine (F)	Drinking water, tea, seafood	Maintenance of tooth structure	Higher frequency of tooth decay
	Iodine (I)	Seafood, iodized salt	Component of thyroid hormones	Goiter (enlarged thyroid gland)

*Additional minerals required in trace amounts include cobalt (Co), copper (Cu), manganese (Mn), molybdenum (Mo), selenium (Se), and zinc (Zn). All of these minerals, as well as those in the table, can be harmful in excess.

Dietary Deficiencies

- Malnutrition is a failure to obtain adequate nutrition
- Malnutrition can have negative impacts on health and survival

Deficiencies in Essential Nutrients

- Deficiencies in essential nutrients can cause deformities, disease, and death
- Cattle, deer, and other herbivores can prevent phosphorus deficiency by consuming concentrated sources of salt or other minerals
- "Golden Rice" is an engineered strain of rice with beta-carotene, which is converted to vitamin A in the body

Figure 41.3

Undernutrition

- Undernutrition results when a diet does not provide enough chemical energy
- 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

Assessing Nutritional Needs

- Many 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

Figure 41.4

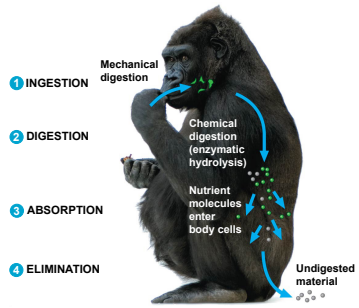
Results

Group	Number of Infants/Fetuses Studied	Infants/Fetuses with a Neural Tube Defect
Vitamin supplements (experimental group)	141	1
No vitamin supplements (control group)	204	12

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

- **Ingestion** is the act of eating or feeding
- Strategies for extracting resources from food differ widely among animal species

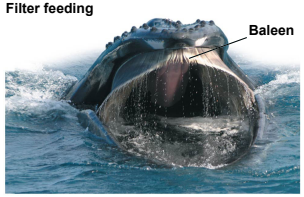
Figure 41.5



Suspension Feeders

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

Figure 41.6a



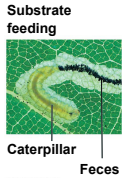
Video: Shark Eating a Seal

Video: Lobster Mouth Parts

Substrate Feeders

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

Figure 41.6b



Fluid Feeders

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

Figure 41.6c

Bulk Feeders

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

Figure 41.6d

- **Digestion** is the process of breaking food down into molecules small enough to absorb
- Mechanical digestion, such as chewing, increases the surface area of food
- Chemical digestion splits food into small molecules that can pass through membranes; these are used to build larger molecules
- 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 system

Digestive Compartments

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

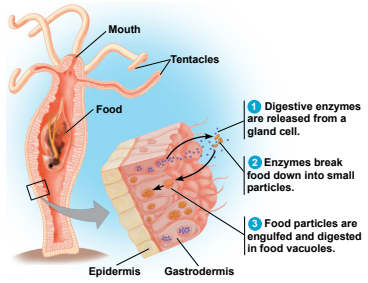
Intracellular Digestion

- In intracellular digestion, food particles are engulfed by phagocytosis
- Food vacuoles, containing food, fuse with lysosomes containing hydrolytic enzymes
- A few animals, such as sponges, digest their food entirely by this mechanism

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

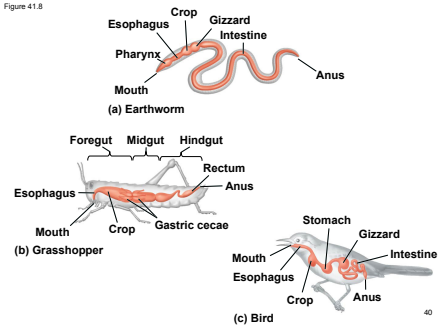
Figure 41.7



Video: Hydra Eating *Daphnia* (Time Lapse)

- 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

Figure 41.8

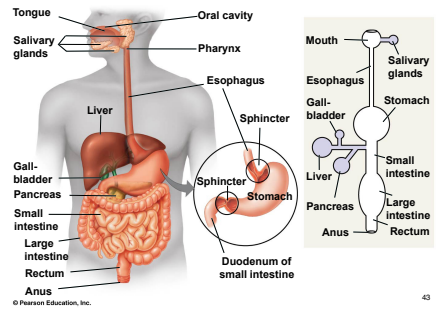


Concept 41.3: Organs specialized for sequential stages of food processing form the mammalian digestive system

- 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

Figure 41.9



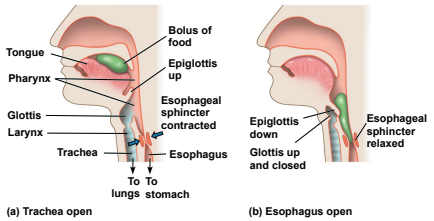
The Oral Cavity, Pharynx, and Esophagus

- 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
- Saliva also contains **mucus**, a viscous mixture of water, salts, cells, and glycoproteins

- The tongue shapes food into a **bolus** and provides help with swallowing
- The throat, or **pharynx**, is the junction that opens to both the esophagus and the trachea
- The **esophagus** connects to the stomach
- The trachea (windpipe) 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

Figure 41.10



Digestion in the Stomach

- The **stomach** stores food and begins digestion of proteins
- The stomach secretes **gastric juice**, which converts a meal to **chyme**

Chemical Digestion in the Stomach

- Gastric juice has a low pH of about 2, which kills bacteria and denatures proteins
- Gastric juice is made up of hydrochloric acid (HCl) and **pepsin**
- Pepsin is a **protease**, or protein-digesting enzyme, that cleaves proteins into smaller peptides

- Parietal cells secrete hydrogen and chloride ions separately into the lumen (cavity) of the stomach
- 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

Figure 41.11

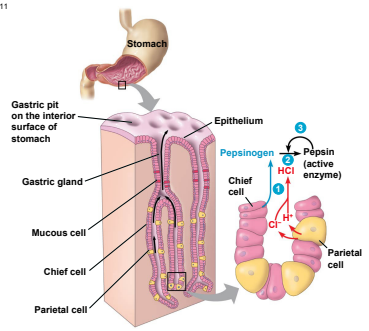


Figure 41.11a

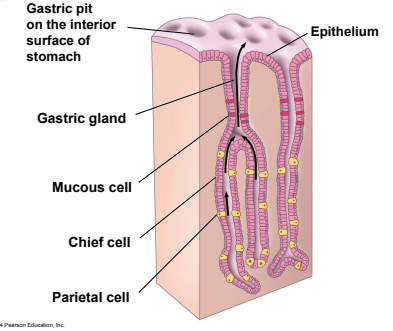


Figure 41.11b-1

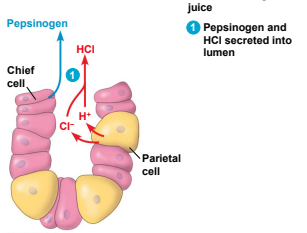


Figure 41.11b-2

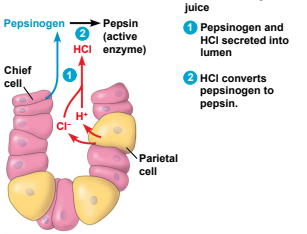
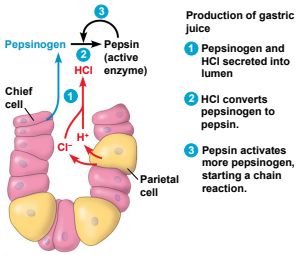


Figure 41.11b-3



- 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

Digestion in the Small Intestine

- The **small intestine** is the longest compartment of the alimentary canal
- Most enzymatic hydrolysis of macromolecules from food occurs here

Figure 41.12

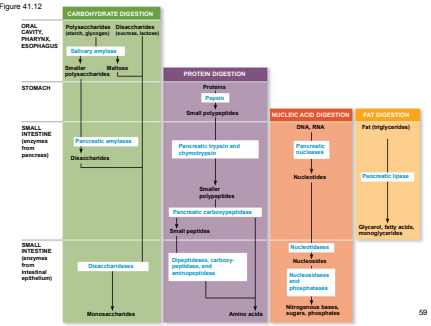


Figure 41.12a

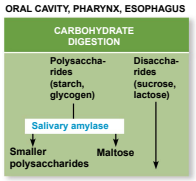


Figure 41.12b

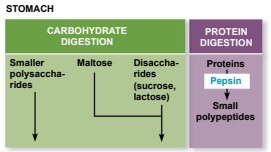


Figure 41.12c

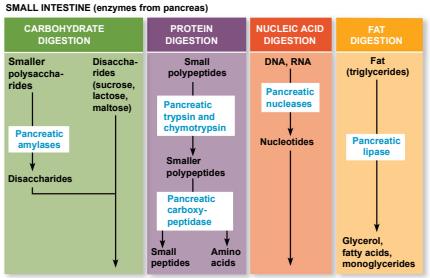
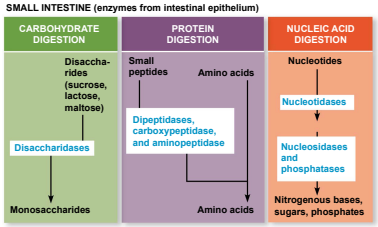


Figure 41.12d



- The first portion of the small intestine is the **duodenum**, where 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 that are activated in the lumen of 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**
- Bile also destroys nonfunctional red blood cells

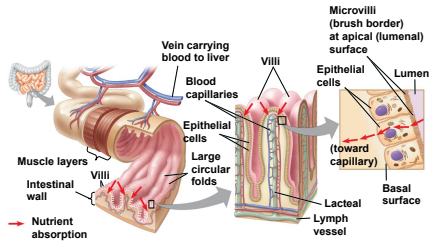
Secretions of the Small Intestine

- The epithelial lining of the duodenum 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

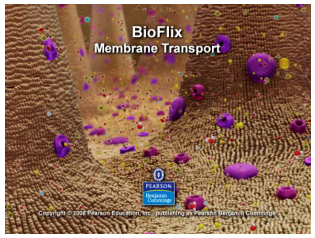
Absorption in the Small Intestine

- The small intestine has a huge surface area, due to **villi** and **microvilli** that are exposed to the intestinal lumen
- The enormous microvillar surface creates a brush border that greatly increases the rate of nutrient absorption
- Transport across the epithelial cells can be passive or active depending on the nutrient

Figure 41.13



BioFlix: Membrane Transport



- The **hepatic portal vein** carries nutrient-rich blood from the capillaries of the villi to the liver, then to the heart
- The liver regulates nutrient distribution, interconverts many organic molecules, and detoxifies many organic molecules

- Epithelial cells absorb fatty acids and monoglycerides and recombine them into triglycerides
- These fats are coated with phospholipids, cholesterol, and proteins to form water-soluble **chylomicrons**
- Chylomicrons are transported into a **lacteal**, a lymphatic vessel in each villus
- Lymphatic vessels deliver chylomicron-containing lymph to large veins that return blood to the heart

Figure 41.14

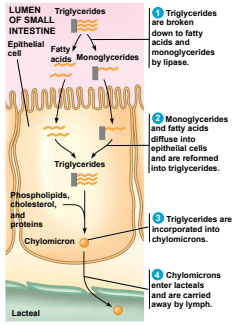


Figure 41.14a

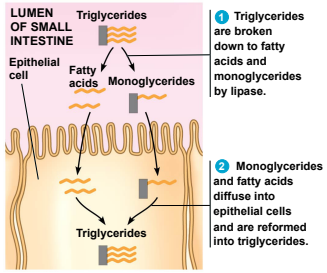
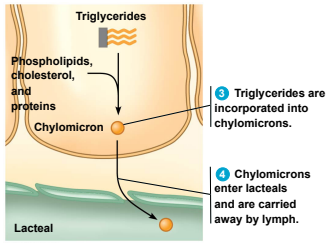


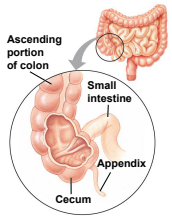
Figure 41.14b



Processing in the Large Intestine

- The **colon** of the **large 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 minor role in immunity

Figure 41.15



- The colon completes the reabsorption of water that began in the small intestine
- **Feces**, including undigested material and bacteria, become more solid as they move through the colon

- Feces are stored in the **rectum** until they can be eliminated through the anus
- Two sphincters between the rectum and anus control bowel movements

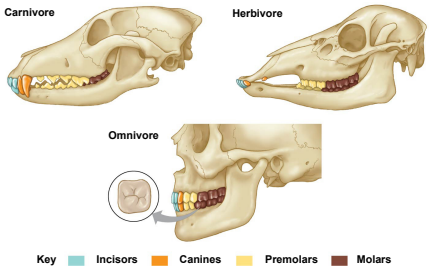
Concept 41.4: Evolutionary adaptations of vertebrate digestive systems correlate with diet

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

Dental Adaptations

- Dentition, an animal's assortment of teeth, is one example of structural variation reflecting diet
- The success of mammals is due in part to their dentition, which is specialized for different diets
- Nonmammalian vertebrates have less specialized teeth, though exceptions exist
  - For example, the teeth of poisonous snakes are modified as fangs for injecting venom

Figure 41.16



Stomach and Intestinal Adaptations

- Many carnivores have large, expandable stomachs
- Herbivores and omnivores generally have longer alimentary canals than carnivores, reflecting the longer time needed to digest vegetation

Figure 41.17

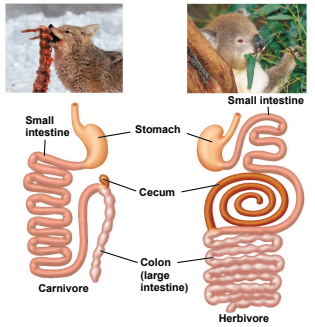


Figure 41.17a

Figure 41.17b

Mutualistic Adaptations

- The coexistence of humans and many bacteria involves mutualistic symbiosis
- Some intestinal bacteria produce vitamins; intestinal bacteria also regulate the development of the intestinal epithelium and the function of the innate immune system
- Using a DNA sequencing approach based on the polymerase chain reaction, scientists have found more than 400 bacterial species in the human digestive tract

Figure 41.18

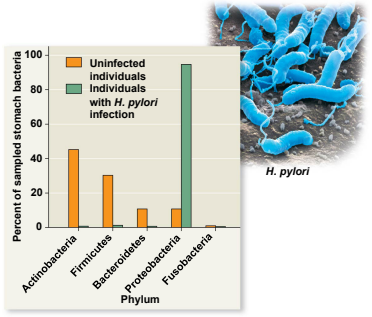


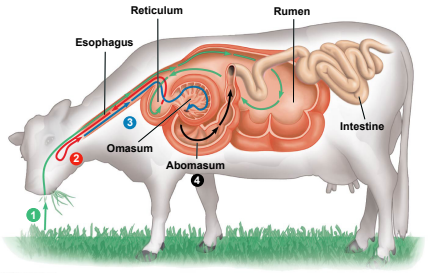
Figure 41.18a

H. pylori

Mutualistic Adaptations in Herbivores

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

Figure 41.19



Concept 41.5: Feedback circuits regulate digestion, energy storage, and appetite

- The processes that enable an animal to obtain nutrients are matched to the organism's circumstances and need for energy

Regulation of Digestion

- Each step in the digestive system is activated as needed
- The enteric division of the nervous system helps to regulate the digestive process
- The endocrine system also regulates digestion through the release and transport of hormones

Figure 41.20

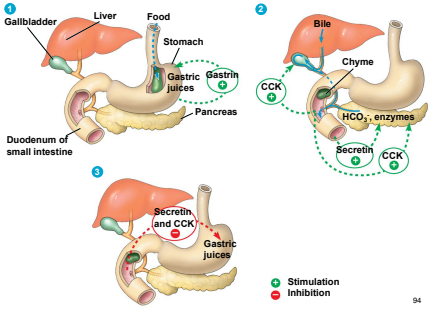


Figure 41.20a

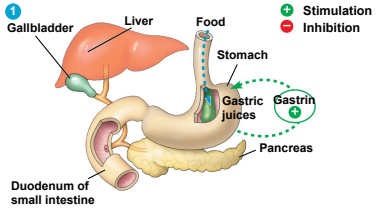


Figure 41.20b

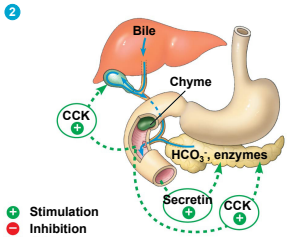
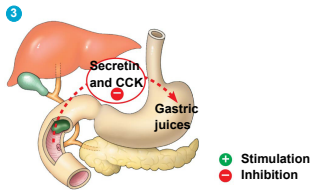


Figure 41.20c



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Regulation of Energy Storage

- The body stores energy-rich molecules that are not needed right away for metabolism
- In humans, energy is stored first in the liver and muscle cells in the polymer glycogen
- Excess energy is stored in fat in adipose cells
- When fewer calories are taken in than expended, the human body expends liver glycogen first, then muscle glycogen and fat

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Glucose Homeostasis

- Glucose is a major fuel for cellular respiration and a key source of carbon skeletons for biosynthesis
- The hormones **insulin** and **glucagon** regulate the breakdown of glycogen into glucose
- The liver is the site for glucose homeostasis
  - A carbohydrate-rich meal raises insulin levels, which triggers the synthesis of glycogen
  - Low blood sugar causes glucagon to stimulate the breakdown of glycogen and release glucose

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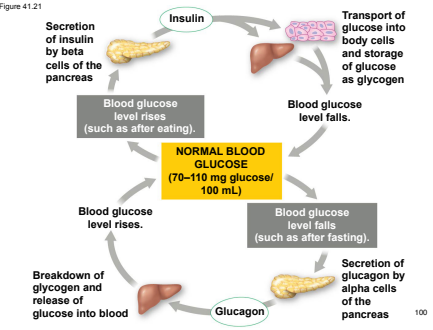
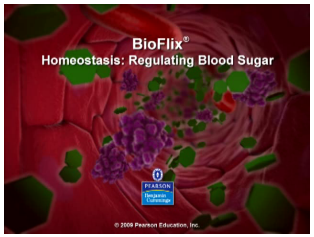
Figure 41.21



100

BioFlix: Homeostasis: Regulating Blood Sugar



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- Insulin acts on nearly all body cells to stimulate glucose uptake from blood
- Brain cells are an exception; they can take up glucose whether or not insulin is present
- Glucagon and insulin are both produced in the islets of the pancreas
- Alpha cells make glucagon and beta cells make insulin

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Diabetes Mellitus

- The disease **diabetes mellitus** is caused by a deficiency of insulin or a decreased response to insulin in target tissues
- Cells are unable to take up enough glucose to meet metabolic needs
- The level of glucose in the blood may exceed the capacity of kidneys to reabsorb it
- Sugar in the urine is one test for diabetes

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- **Type 1 diabetes** is an autoimmune disorder in which the immune system destroys the beta cells of the pancreas
- It usually appears during childhood
- **Type 2 diabetes** is characterized by a failure of target cells to respond normally to insulin
- Excess body weight and lack of exercise significantly increase the risk of type 2 diabetes
- It generally appears after age 40, but may develop earlier in younger people who are sedentary

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Regulation of Appetite and Consumption

- 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
- Researchers have discovered several of the mechanisms that help regulate body weight

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- Hormones regulate long-term and short-term appetite by affecting a "satiety center" in the brain
- Ghrelin, a hormone secreted by the stomach wall, triggers feelings of hunger before meals
- Insulin and PYY, a hormone secreted by the small intestine after meals, both suppress appetite
- Leptin, produced by adipose (fat) tissue, also suppresses appetite and plays a role in regulating body fat levels

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Figure 41.22

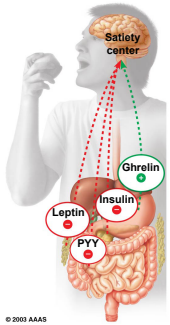

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Figure 41.UN02a

Genotype Pairing (red type indicates mutant genes)			Average Change in Body Mass Subject (g)
	Subject	Paired with	
(a)	*ob*$^+$/*ob*$^+$, *db*$^+$/*db*$^+$	*ob*$^+$/*ob*$^+$, *db*$^+$/*db*$^+$	8.3
(b)	*ob*/*ob*, *db*$^+$/*db*$^+$	*ob*/*ob*, *db*$^+$/*db*$^+$	38.7
(c)	*ob*/*ob*, *db*$^+$/*db*$^+$	*ob*$^+$/*ob*$^+$, *db*$^+$/*db*$^+$	8.2
(d)	*ob*/*ob*, *db*$^+$/*db*$^+$	*ob*$^+$/*ob*$^+$, *db*/*db*	−14.9*

* Due to pronounced weight loss and weakening, subjects in this pairing were remeasured after less than eight weeks.

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Figure 41.UN02b

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Figure 41.UN03

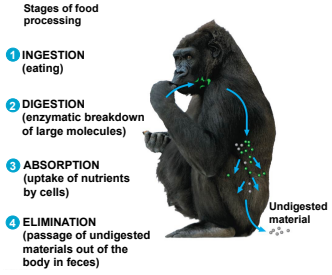

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Figure 41.UN04

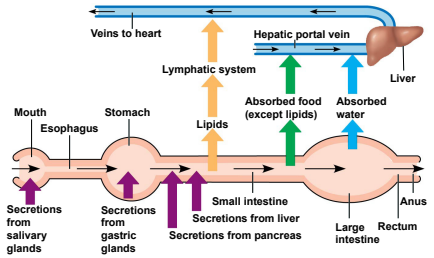

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Figure 41.UN05

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