The Digestive System Functions

- Ingestion—taking in food
- Digestion—breaking food down both physically and chemically
- Absorption—movement of nutrients into the bloodstream
- Defecation—rids the body of indigestible waste
Organs of the Digestive System

• Two main groups of organs
  • Alimentary canal (gastrointestinal or GI tract)—continuous coiled hollow tube
    • These organs ingest, digest, absorb, defecate
  • Accessory digestive organs
    • Includes teeth, tongue, and other large digestive organs
Organs of the Alimentary Canal

- Mouth
- Pharynx
- Esophagus
- Stomach
- Small intestine
- Large intestine
- Anus
Mouth (Oral Cavity) Anatomy

- Lips (labia)—protect the anterior opening
- Cheeks—form the lateral walls
- Hard palate—forms the anterior roof
- Soft palate—forms the posterior roof
- Uvula—fleshy projection of the soft palate
Mouth (Oral Cavity) Anatomy

• Vestibule—space between lips externally and teeth and gums internally
• Oral cavity proper—area contained by the teeth
• Tongue—attached at hyoid bone and styloid processes of the skull, and by the lingual frenulum to the floor of the mouth
• Tonsils
  • Palatine—located at posterior end of oral cavity
  • Lingual—located at the base of the tongue
Figure 14.2b

- Upper lip
- Gingivae (gums)
- Hard palate
- Soft palate
- Uvula
- Palatine tonsil
- Oropharynx
- Tongue

(b)
Mouth Physiology

- Mastication (chewing) of food
- Mixing masticated food with saliva
- Initiation of swallowing by the tongue
- Allows for the sense of taste
Pharynx Anatomy

- Nasopharynx—not part of the digestive system
- Oropharynx—posterior to oral cavity
- Laryngopharynx—below the oropharynx and connected to the esophagus
Figure 14.2a

- Nasopharynx
- Soft palate
- Uvula
- Palatine tonsil
- Lingual tonsil
- Oropharynx
- Epiglottis
- Laryngopharynx
- Esophagus
- Hard palate
- Oral cavity
- Lips (labia)
- Vestibule
- Lingual frenulum
- Tongue
- Hyoid bone
- Trachea
Pharynx Physiology

- Serves as a passageway for air and food
- Food is propelled to the esophagus by two muscle layers
  - Longitudinal inner layer
  - Circular outer layer
- Food movement is by alternating contractions of the muscle layers (peristalsis)
Esophagus Anatomy and Physiology

• Anatomy
  • About 10 inches long
  • Runs from pharynx to stomach through the diaphragm

• Physiology
  • Conducts food by peristalsis (slow rhythmic squeezing)
  • Passageway for food only (respiratory system branches off after the pharynx)
Layers of Tissue in the Alimentary Canal Organs

- Four layers from deep to superficial:
  - Mucosa
  - Submucosa
  - Muscularis externa
  - Serosa
Layers of Tissue in the Alimentary Canal Organs

• Mucosa
  • Innermost, moist membrane consisting of
    • Surface epithelium
    • Small amount of connective tissue (lamina propria)
    • Small smooth muscle layer
  • Lines the cavity (known as the lumen)
Visceral peritoneum

Intrinsic nerve plexuses
- Myenteric nerve plexus
- Submucosal nerve plexus

Submucosal glands

Submucosa
- Longitudinal muscle layer
- Circular muscle layer

Mucosa
- Surface epithelium
- Lamina propria
- Muscle layer

Muscularis externa

Serosa (visceral peritoneum)

Lumen

Duct of gland outside alimentary canal

Vein

Artery

Nerve

Mesentery

Gland in mucosa

Lymphoid tissue
Layers of Tissue in the Alimentary Canal Organs

• Submucosa
  • Just beneath the mucosa
  • Soft connective tissue with blood vessels, nerve endings, mucosa-associated lymphoid tissue, and lymphatics
Figure 14.3

Visceral peritoneum

Intrinsic nerve plexuses
- Myenteric nerve plexus
- Submucosal nerve plexus

Submucosal glands

Submucosa
- Muscularis externa
  - Longitudinal muscle layer
  - Circular muscle layer

Mucosa
- Surface epithelium
- Lamina propria
- Muscle layer

Serosa (visceral peritoneum)

Lumen

Lymphoid tissue

Duct of gland outside alimentary canal

Gland in mucosa

Nerve
Artery
Vein

Mesentery
Layers of Tissue in the Alimentary Canal

- **Muscularis externa**—smooth muscle
  - Inner circular layer
  - Outer longitudinal layer

- **Serosa**—outermost layer of the wall contains fluid-producing cells
  - Visceral peritoneum—outermost layer that is continuous with the innermost layer
  - Parietal peritoneum—innermost layer that lines the abdominopelvic cavity
Figure 14.3

Visceral peritoneum

Intrinsic nerve plexuses
- Myenteric nerve plexus
- Submucosal nerve plexus

Submucosal glands

Submucosa

Muscularis externa
- Longitudinal muscle layer
- Circular muscle layer

Mucosa
- Surface epithelium
- Lamina propria
- Muscle layer

Serosa (visceral peritoneum)

Gland in mucosa

Duct of gland outside alimentary canal

Vein

Artery

Nerve

Mesentery

Lumen

Lymphoid tissue
Figure 14.5

(a)

Diaphragm
Falciform ligament
Liver
Spleen
Gallbladder
Stomach
Visceral peritoneum
Greater omentum
Parietal peritoneum
Small intestine
Uterus
Large intestine
Cecum
Urinary bladder

(b)

Lesser omentum
Pancreas
Duodenum
Transverse colon
Mesenteries
Peritoneal cavity
Rectum
Anus
Alimentary Canal Nerve Plexuses

• Two important nerve plexuses serve the alimentary canal
• Both are part of the autonomic nervous system
  • Submucosal nerve plexus
  • Myenteric nerve plexus
• Function is to regulate mobility and secretory activity of the GI tract organs
Stomach Anatomy

- Located on the left side of the abdominal cavity
- Food enters at the cardioesophageal sphincter
- Food empties into the small intestine at the pyloric sphincter (valve)
Stomach Anatomy

• Regions of the stomach
  • Cardiac region—near the heart
  • Fundus—expanded portion lateral to the cardiac region
  • Body—midportion
  • Pylorus—funnel-shaped terminal end
Stomach Anatomy

• Rugae—internal folds of the mucosa
  • Stomach can stretch and hold 4 L (1 gallon) of food when full

• External regions
  • Lesser curvature—concave medial surface
  • Greater curvature—convex lateral surface
Figure 14.4a

- **Cardioesophageal sphincter**
- **Fundus**
- **Serosa**
- **Body**
- **Rugae of mucosa**
- **Greater curvature**
- **Lesser curvature**
- **Esophagus**
- **Muscularis externa**
  - Longitudinal layer
  - Circular layer
  - Oblique layer
- **Pylorus**
- **Duodenum**
- **Pyloric Sphincter (valve)**
- **Pyloric antrum**
Figure 14.4b

- Fundus
- Body
- Rugae of mucosa
- Pyloric sphincter
- Pyloric antrum
Stomach Anatomy

- Layers of peritoneum attached to the stomach
  - Lesser omentum—attaches the liver to the lesser curvature
  - Greater omentum—attaches the greater curvature to the posterior body wall
    - Embedded fat insulates, cushions, and protects abdominal organs
    - Lymph follicles contain macrophages

- Muscularis externa has a third layer
  - Oblique layer helps to churn, mix, and pummel the food
Stomach Physiology

• Temporary storage tank for food
• Site of food breakdown
• Chemical breakdown of protein begins
• Delivers chyme (processed food) to the small intestine
Structure of the Stomach Mucosa

- Mucosa is simple columnar epithelium
- Mucous neck cells—produce a sticky alkaline mucus
- Gastric glands—situated in gastric pits and secrete gastric juice
- Chief cells—produce protein-digesting enzymes (pepsinogens)
- Parietal cells—produce hydrochloric acid
- Enteroendocrine cells—produce gastrin
Figure 14.4c

- Gastric pits
- Surface epithelium
- Mucous neck cells
- Parietal cells
- Gastric glands
- Chief cells
- Pyloric sphincter
- Gastric pit
- Gastric gland

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Figure 14.4d

- Pepsinogen
- HCl
- Pepsin

- Parietal cells
- Chief cells
- Enteroendocrine cell

(d)
Small Intestine

• The body’s major digestive organ
• Site of nutrient absorption into the blood
• Muscular tube extending from the pyloric sphincter to the ileocecval valve
• Suspended from the posterior abdominal wall by the mesentery
Subdivisions of the Small Intestine

• Duodenum
  • Attached to the stomach
  • Curves around the head of the pancreas

• Jejunum
  • Attaches anteriorly to the duodenum

• Ileum
  • Extends from jejunum to large intestine
Chemical Digestion in the Small Intestine

- Chemical digestion begins in the small intestine
  - Enzymes are produced by
    - Intestinal cells
    - Pancreas
  - Pancreatic ducts carry enzymes to the small intestine
  - Bile, formed by the liver, enters via the bile duct
Small Intestine Anatomy

• Three structural modifications that increase surface area
  • Microvilli—tiny projections of the plasma membrane (create a brush border appearance)
  • Villi—fingerlike structures formed by the mucosa
  • Circular folds (plicae circulares)—deep folds of mucosa and submucosa
Blood vessels serving the small intestine

Muscle layers

Villi

Lumen

Circular folds (plicae circulares)

(a) Small intestine
Figure 14.7b

- Absorptive cells
- Lacteal
- Blood capillaries
- Lymphoid tissue
- Intestinal crypt
- Muscularis mucosae
- Villus
- Venule
- Lymphatic vessel
- Submucosa

(b) Villi
(c) Absorptive cells

Microvilli
(brush border)
Large Intestine

• Larger in diameter, but shorter in length, than the small intestine
• Extends from the ileocecal valve to the anus
• Subdivisions:
  • Cecum
  • Appendix
  • Colon
  • Rectum
  • Anal canal
Large Intestine Anatomy

- **Cecum**—saclike first part of the large intestine
- **Appendix**
  - Accumulation of lymphatic tissue that sometimes becomes inflamed (appendicitis)
  - Hangs from the cecum
Large Intestine Anatomy

• Colon
  • Ascending—travels up right side of abdomen
  • Transverse—travels across the abdominal cavity
  • Descending—travels down the left side
  • Sigmoid—S-shaped region; enters the pelvis

• Rectum and anus also are located in the pelvis
Large Intestine Anatomy

• **Anus**—opening of the large intestine
  - External anal sphincter—formed by skeletal muscle and under voluntary control
  - Internal involuntary sphincter—formed by smooth muscle
  - These sphincters are normally closed except during defecation
Large Intestine Anatomy

• No villi present
• Goblet cells produce alkaline mucus which lubricates the passage of feces
• Muscularis externa layer is reduced to three bands of muscle called teniae coli
• These bands cause the wall to pucker into haustra (pocketlike sacs)
Accessory Digestive Organs

• Teeth
• Salivary glands
• Pancreas
• Liver
• Gallbladder
Teeth

- Function is to masticate (chew) food
- Humans have two sets of teeth
  - Deciduous (baby or “milk”) teeth
  - A baby has 20 teeth by age two
  - First teeth to appear are the lower central incisors
Teeth

• **Permanent teeth**
  - Replace deciduous teeth between the ages of 6 and 12
  - A full set is 32 teeth, but some people do not have wisdom teeth (third molars)
  - If they do emerge, the wisdom teeth appear between ages of 17 and 25
Classification of Teeth

- Incisors—cutting
- Canines (eyeteeth)—tearing or piercing
- Premolars (bicuspids)—grinding
- Molars—grinding
Incisors
- Central (6–8 mo)
- Lateral (8–10 mo)
- Canine (eyetooth) (16–20 mo)

Molars
- First molar (10–15 mo)
- Second molar (about 2 yr)

Incisors
- Central (7 yr)
- Lateral (8 yr)
- Canine (eyetooth) (11 yr)

Premolars (bicuspids)
- First premolar (11 yr)
- Second premolar (12–13 yr)

Molars
- First molar (6–7 yr)
- Second molar (12–13 yr)
- Third molar (wisdom tooth) (17–25 yr)

Deciduous (milk) teeth
- First molar (10–15 mo)
- Second molar (about 2 yr)
- Third molar (wisdom tooth) (17–25 yr)

Permanent teeth
Regions of a Tooth

• Crown—exposed part
  • Enamel—hardest substance in the body
  • Dentin—found deep to the enamel and forms the bulk of the tooth
  • Pulp cavity—contains connective tissue, blood vessels, and nerve fibers
  • Root canal—where the pulp cavity extends into the root
Regions of a Tooth

- **Neck**
  - Region in contact with the gum
  - Connects crown to root

- **Root**
  - Cementum—covers outer surface and attaches the tooth to the periodontal membrane
Figure 14.10

- Enamel
- Dentin
- Pulp cavity
- Gum (gingiva)
- Periodontal membrane
- Bone
- Cement
- Root canal
- Blood vessels and nerves in pulp

- Crown
- Neck
- Root
Salivary Glands

- Three pairs of salivary glands empty secretions into the mouth
  - Parotid glands
    - Found anterior to the ears
  - Submandibular glands
  - Sublingual glands
    - Both submandibular and sublingual glands empty saliva into the floor of the mouth through small ducts
Figure 14.1

Mouth (oral cavity)
Tongue
Esophagus
Liver
Gallbladder
Small intestine
Duodenum
Jejunum
Ileum
Anus

Parotid gland
Sublingual gland
Submandibular gland
Salivary glands
Pharynx
Stomach
Pancreas (Spleen)

Transverse colon
Descending colon
Ascending colon
Cecum
Sigmoid colon
Rectum
Appendix
Anal canal

Large intestine
Saliva

- Mixture of mucus and serous fluids
- Helps to form a food bolus
- Contains salivary amylase to begin starch digestion
- Dissolves chemicals so they can be tasted
Pancreas

• Found posterior to the parietal peritoneum
  • Its location is retroperitoneal
• Extends across the abdomen from spleen to duodenum
Pancreas

- Produces a wide spectrum of digestive enzymes that break down all categories of food
- Enzymes are secreted into the duodenum
- Alkaline fluid introduced with enzymes neutralizes acidic chyme coming from stomach
- Hormones produced by the pancreas
  - Insulin
  - Glucagon
Mouth (oral cavity) → Tongue → Esophagus → Liver → Gallbladder → Small intestine: Duodenum, Jejunum, Ileum → Anus

Parotid gland → Sublingual gland → Submandibular gland (Salivary glands)

Pharynx → Stomach → Pancreas (Spleen) → Large intestine: Descending colon, Transverse colon, Ascending colon, Cecum, Sigmoid colon, Rectum, Appendix, Anal canal

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Liver

- Largest gland in the body
- Located on the right side of the body under the diaphragm
- Consists of four lobes suspended from the diaphragm and abdominal wall by the falciform ligament
- Connected to the gallbladder via the common hepatic duct
Bile

- Produced by cells in the liver
- Bile leaves the liver through the common hepatic duct
- Composition is
  - Bile salts
  - Bile pigments (mostly bilirubin from the breakdown of hemoglobin)
  - Cholesterol
  - Phospholipids
  - Electrolytes
Bile

- Function—emulsify fats by physically breaking large fat globules into smaller ones
Gallbladder

- Sac found in hollow fossa of liver
- When no digestion is occurring, bile backs up the cystic duct for storage in the gallbladder
- When digestion of fatty food is occurring, bile is introduced into the duodenum from the gallbladder
- Gallstones are crystallized cholesterol which can cause blockages
- Gallbladder
- Duodenal papilla
- Hepatopancreatic ampulla and sphincter
- Duodenum
- Right and left hepatic ducts from liver
- Cystic duct
- Common hepatic duct
- Bile duct and sphincter
- Accessory pancreatic duct
- Pancreas
- Jejunum
- Main pancreatic duct and sphincter

Figure 14.6
Functions of the Digestive System

• Ingestion—placing food into the mouth
• Propulsion—moving foods from one region of the digestive system to another
  • Peristalsis—alternating waves of contraction and relaxation that squeezes food along the GI tract
  • Segmentation—moving materials back and forth to aid with mixing in the small intestine
Ingestion

Mechanical digestion

- Chewing (mouth)
- Churning (stomach)
- Segmentation (small intestine)

Chemical digestion

- Swallowing (oropharynx)
- Peristalsis (esophagus, stomach, small intestine, large intestine)

Propulsion

Absorption

Defecation

Food

Pharynx

Esophagus

Stomach

Small intestine

Lymph vessel

Blood vessel

Mainly H₂O

Feces

Anus

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Figure 14.11
Functions of the Digestive System

• Food breakdown as mechanical digestion
  • Examples:
    • Mixing food in the mouth by the tongue
    • Churning food in the stomach
    • Segmentation in the small intestine
  • Mechanical digestion prepares food for further degradation by enzymes
Functions of the Digestive System

• Food breakdown as *chemical* digestion
  • Enzymes break down food molecules into their building blocks
  • Each major food group uses different enzymes
    • Carbohydrates are broken to simple sugars
    • Proteins are broken to amino acids
    • Fats are broken to fatty acids and alcohols
Carbohydrate digestion

Starch and disaccharides

Enzyme(s) and source

Salivary amylase
Pancreatic amylase

Site of action

Mouth
Small intestine

Oligosaccharides*
and disaccharides

Lactose
Maltose
Sucrose

Galactose
Glucose
Fructose

Brush border enzymes in small intestine (dextrinase, glucoamylase, lactase, maltase, and sucrase)

Small intestine

Carbohydrate absorption

The monosaccharides glucose, galactose, and fructose enter the capillary blood in the villi and are transported to the liver via the hepatic portal vein.

*Oligosaccharides consist of a few linked monosaccharides.
Figure 14.13 (2 of 3)

Protein digestion

Foodstuff

Protein

- Large polypeptides

- Small polypeptides, small peptides

- Amino acids (some dipeptides and tripeptides)

Enzyme(s) and source

- Pepsin (stomach glands) in the presence of HCl
- Pancreatic enzymes (trypsin, chymotrypsin, carboxypeptidase)
- Brush border enzymes (aminopeptidase, carboxypeptidase, and dipeptidase)

Site of action

- Stomach
- Small intestine
- Small intestine

Protein absorption

Amino acids enter the capillary blood in the villi and are transported to the liver via the hepatic portal vein.
Fat digestion

Unemulsified fats

- Emulsified by the detergent action of bile salts from the liver
- Pancreatic lipase

Site of action:
- Small intestine

Foodstuff

Enzyme(s) and source

Fat absorption

Monoglycerides and fatty acids

Glycerol and fatty acids

Fatty acids and monoglycerides enter the lacteals of the villi and are transported to the systemic circulation via the lymph in the thoracic duct. (Glycerol and short-chain fatty acids are absorbed into the capillary blood in the villi and transported to the liver via the hepatic portal vein.)
Functions of the Digestive System

• Absorption
  • End products of digestion are absorbed in the blood or lymph
  • Food must enter mucosal cells and then into blood or lymph capillaries

• Defecation
  • Elimination of indigestible substances from the GI tract in the form of feces
Ingestion

Mechanical digestion
- Chewing (mouth)
- Churning (stomach)
- Segmentation (small intestine)

Chemical digestion

Propulsion
- Swallowing (oropharynx)
- Peristalsis (esophagus, stomach, small intestine, large intestine)

Absorption
- Lymph vessel
- Blood vessel
- Mainly H₂O

Defecation
- Feces
- Anus

Figure 14.11
Control of Digestive Activity

- Mostly controlled by reflexes via the parasympathetic division
- Chemical and mechanical receptors are located in organ walls that trigger reflexes
Control of Digestive Activity

• **Stimuli include**
  - Stretch of the organ
  - pH of the contents
  - Presence of breakdown products

• **Reflexes include**
  - Activation or inhibition of glandular secretions
  - Smooth muscle activity
Digestive Activities of the Mouth

• Mechanical breakdown
  • Food is physically broken down by chewing

• Chemical digestion
  • Food is mixed with saliva
  • Starch is broken down into maltose by salivary amylase
Activities of the Pharynx and Esophagus

• These organs have no digestive function
• Serve as passageways to the stomach
Deglutition (Swallowing)

• Buccal phase
  • Voluntary
  • Occurs in the mouth
  • Food is formed into a bolus
  • The bolus is forced into the pharynx by the tongue
Deglutition (Swallowing)

• Pharyngeal-esophageal phase
  • Involuntary transport of the bolus
  • All passageways except to the stomach are blocked
    • Tongue blocks off the mouth
    • Soft palate (uvula) blocks the nasopharynx
    • Epiglottis blocks the larynx
Deglutition (Swallowing)

- Pharyngeal-esophageal phase (continued)
  - Peristalsis moves the bolus toward the stomach
  - The cardioesophageal sphincter is opened when food presses against it
(a) Upper esophageal sphincter contracted
(b) Upper esophageal sphincter relaxed
(c) Upper esophageal sphincter contracted
(d) Cardioresophageal sphincter relaxed
Food Breakdown in the Stomach

• Gastric juice is regulated by neural and hormonal factors
• Presence of food or rising pH causes the release of the hormone gastrin
• Gastrin causes stomach glands to produce
  • Protein-digesting enzymes
  • Mucus
  • Hydrochloric acid
Food Breakdown in the Stomach

• Hydrochloric acid makes the stomach contents very acidic

• Acidic pH
  • Activates pepsinogen to pepsin for protein digestion
  • Provides a hostile environment for microorganisms
Digestion and Absorption in the Stomach

• Protein digestion enzymes
  • Pepsin—an active protein-digesting enzyme
  • Rennin—works on digesting milk protein in infants, not adults
• Alcohol and aspirin are the only items absorbed in the stomach
Propulsion in the Stomach

- Food must first be well mixed
- Rippling peristalsis occurs in the lower stomach
  - Propulsion
  - Grinding
  - Retropulsion
- The pylorus meters out chyme into the small intestine (3 mL at a time)
- The stomach empties in 4–6 hours
1. Propulsion: Peristaltic waves move from the fundus to the pylorus.

2. Grinding: The most vigorous peristalsis and mixing action occur close to the pylorus.

3. Retropulsion: The pyloric end of the stomach pumps small amounts of chyme into the duodenum, while simultaneously forcing most of its contents backward into the stomach.
Digestion in the Small Intestine

- Enzymes from the brush border function to:
  - Break double sugars into simple sugars
  - Complete some protein digestion
Digestion in the Small Intestine

• Pancreatic enzymes play the major digestive function
  • Help complete digestion of starch (pancreatic amylase)
  • Carry out about half of all protein digestion
  • Digest fats using lipases from the pancreas
  • Digest nucleic acids using nucleases

• Alkaline content neutralizes acidic chyme
Regulation of Pancreatic Juice Secretion

- Release of pancreatic juice into the duodenum is stimulated by:
  - Vagus nerve
  - Local hormones
    - Secretin
    - Cholecystokinin (CCK)

- Hormones travel the blood to stimulate the pancreas to release enzyme- and bicarbonate-rich product
Regulation of Pancreatic Juice Secretion

- Secretin causes the liver to increase bile output
- CCK causes the gallbladder to release stored bile
  - Bile is necessary for fat absorption and absorption of fat-soluble vitamins (K, D, A)
Upon reaching the pancreas, CCK induces secretion of enzyme-rich pancreatic juice; secretin causes secretion of bicarbonate-rich pancreatic juice.

Stimulation by vagal nerve fibers causes release of pancreatic juice and weak contractions of the gallbladder.

Secretin causes the liver to secrete more bile; CCK stimulates the gallbladder to release stored bile and the hepatopancreatic sphincter to relax (allows bile to enter the duodenum).

Chyme entering duodenum causes the enteroendocrine cells of the duodenum to release secretin and cholecystokinin (CCK).

CCK (red dots) and secretin (blue dots) enter bloodstream.

Upon reaching the pancreas, CCK induces secretion of enzyme-rich pancreatic juice; secretin causes secretion of bicarbonate-rich pancreatic juice.

Figure 14.16
Chyme entering duodenum causes the enteroendocrine cells of the duodenum to release secretin and cholecystokinin (CCK).
Chyme entering duodenum causes the enteroendocrine cells of the duodenum to release secretin and cholecystokinin (CCK).

CCK (red dots) and secretin (blue dots) enter bloodstream.
Upon reaching the pancreas, CCK induces secretion of enzyme-rich pancreatic juice; secretin causes secretion of bicarbonate-rich pancreatic juice.

1. Chyme entering duodenum causes the enteroendocrine cells of the duodenum to release secretin and cholecystokinin (CCK).

2. CCK (red dots) and secretin (blue dots) enter bloodstream.

3. Upon reaching the pancreas, CCK induces secretion of enzyme-rich pancreatic juice; secretin causes secretion of bicarbonate-rich pancreatic juice.
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Upon reaching the pancreas, CCK induces secretion of enzyme-rich pancreatic juice; secretin causes secretion of bicarbonate-rich pancreatic juice.
Absorption in the Small Intestine

• Water is absorbed along the length of the small intestine

• End products of digestion
  • Most substances are absorbed by active transport through cell membranes
  • Lipids are absorbed by diffusion

• Substances are transported to the liver by the hepatic portal vein or lymph
Propulsion in the Small Intestine

- Peristalsis is the major means of moving food
- Segmental movements
  - Mix chyme with digestive juices
  - Aid in propelling food
Food Breakdown and Absorption in the Large Intestine

• No digestive enzymes are produced
• Resident bacteria digest remaining nutrients
  • Produce some vitamin K and B
  • Release gases
• Water and vitamins K and B are absorbed
• Remaining materials are eliminated via feces
Food Breakdown and Absorption in the Large Intestine

- Feces contains
  - Undigested food residues
  - Mucus
  - Bacteria
  - Water
Propulsion in the Large Intestine

- Sluggish peristalsis
- Mass movements
  - Slow, powerful movements
  - Occur three to four times per day
- Presence of feces in the rectum causes a defecation reflex
  - Internal anal sphincter is relaxed
  - Defecation occurs with relaxation of the voluntary (external) anal sphincter
Nutrition

• Nutrient—substance used by the body for growth, maintenance, and repair

• Major nutrients
  • Carbohydrates
  • Lipids
  • Proteins
  • Water

• Minor nutrients
  • Vitamins
  • Minerals
Dietary Sources of Major Nutrients

• Carbohydrates
  • Most are derived from plants
  • Exceptions: lactose from milk and small amounts of glycogens from meats

• Lipids
  • Saturated fats from animal products
  • Unsaturated fats from nuts, seeds, and vegetable oils
  • Cholesterol from egg yolk, meats, and milk products
Dietary Sources of Major Nutrients

• Proteins
  • Complete proteins—contain all essential amino acids
    • Most are from animal products
    • Essential amino acids are ones that our bodies cannot make
    • We must obtain essential amino acids through our diet
  • Legumes and beans also have proteins, but are incomplete
Figure 14.18

- Corn and other grains
  - Tryptophan
  - Methionine
  - Valine
  - Threonine
  - Phenylalanine
  - Leucine
  - Isoleucine
  - Lysine

- Beans and other legumes
Dietary Sources of Major Nutrients

• Vitamins
  • Most vitamins are used as coenzymes
  • Found in all major food groups
Dietary Sources of Major Nutrients

• Minerals
  • Play many roles in the body
  • Most mineral-rich foods are vegetables, legumes, milk, and some meats
Metabolism

• Chemical reactions necessary to maintain life
  • Catabolism—substances are broken down to simpler substances; energy is released
  • Anabolism—larger molecules are built from smaller ones
Carbohydrate Metabolism

• Carbohydrates are the body’s preferred source to produce cellular energy (ATP)
• Glucose (blood sugar)
  • Major breakdown product of carbohydrate digestion
  • Fuel used to make ATP
Cellular Respiration

- Oxygen-using events take place within the cell to create ATP from ADP
- Carbon leaves cells as carbon dioxide (CO$_2$)
- Hydrogen atoms are combined with oxygen to form water
- Energy produced by these reactions adds a phosphorus to ADP to produce ATP
- ATP can be broken down to release energy for cellular use
Metabolic Pathways Involved in Cellular Respiration

- Glycolysis—energizes a glucose molecule so it can be split into two pyruvic acid molecules and yield ATP
During glycolysis, each glucose molecule is broken down into two molecules of pyruvic acid as hydrogen atoms containing high-energy electrons are removed.

The pyruvic acid enters the mitochondrion where Krebs cycle enzymes remove more hydrogen atoms and decompose it to CO₂. During glycolysis and the Krebs cycle, small amounts of ATP are formed.

Energy-rich electrons picked up by coenzymes are transferred to the electron transport chain, built into the cristae membrane. The electron transport chain carries out oxidative phosphorylation, which accounts for most of the ATP generated by cellular respiration, and finally unites the removed hydrogen with oxygen to form water.
During glycolysis, each glucose molecule is broken down into two molecules of pyruvic acid as hydrogen atoms containing high-energy electrons are removed.
Metabolic Pathways Involved in Cellular Respiration

• Krebs cycle
  - Produces virtually all the carbon dioxide and water resulting from cell respiration
  - Yields a small amount of ATP
During glycolysis, each glucose molecule is broken down into two molecules of pyruvic acid as hydrogen atoms containing high-energy electrons are removed.

The pyruvic acid enters the mitochondrion where Krebs cycle enzymes remove more hydrogen atoms and decompose it to CO₂. During glycolysis and the Krebs cycle, small amounts of ATP are formed.
Metabolic Pathways Involved in Cellular Respiration

- Electron transport chain
  - Hydrogen atoms removed during glycolysis and the Krebs cycle are delivered to protein carriers
  - Hydrogen is split into hydrogen ions and electrons in the mitochondria
  - Electrons give off energy in a series of steps to enable the production of ATP
During glycolysis, each glucose molecule is broken down into two molecules of pyruvic acid as hydrogen atoms containing high-energy electrons are removed. The pyruvic acid enters the mitochondrion where Krebs cycle enzymes remove more hydrogen atoms and decompose it to CO₂. During glycolysis and the Krebs cycle, small amounts of ATP are formed. Energy-rich electrons picked up by coenzymes are transferred to the electron transport chain, built into the cristae membrane. The electron transport chain carries out oxidative phosphorylation, which accounts for most of the ATP generated by cellular respiration, and finally unites the removed hydrogen with oxygen to form water.
\[ \text{NADH} \rightarrow \text{NAD}^+ + \text{H}^+ \]

Energy released and now available for making ATP

Energy released as heat and light

Protein carriers of the electron transport chain

Electron flow

O_2

Figure 14.21a-b
Metabolism of Carbohydrates

• Hyperglycemia—excessively high levels of glucose in the blood
• Excess glucose is stored in body cells as glycogen
• If blood glucose levels are still too high, excesses are converted to fat
(a) Carbohydrates: polysaccharides, disaccharides; composed of simple sugars (monosaccharides)

Polysaccharides

GI digestion to simple sugars

Monosaccharides

Cellular uses

To capillary

ATP

Glycogen and fat broken down for ATP formation

Excess stored as glycogen or fat

Broken down to glucose and released to blood
Metabolism of Carbohydrates

- Hypoglycemia—low levels of glucose in the blood
- Liver breaks down stored glycogen and releases glucose into the blood
Fat Metabolism

• Handled mostly by the liver
  • Uses some fats to make ATP
  • Synthesizes lipoproteins, thromboplastin, and cholesterol
  • Releases breakdown products to the blood

• Body cells remove fat and cholesterol to build membranes and steroid hormones
Use of Fats for ATP Synthesis

• Fats must first be broken down to acetic acid
• Within mitochondria, acetic acid is completely oxidized to produce water, carbon dioxide, and ATP
(d) ATP formation (fueling the metabolic furnace): all categories of food can be oxidized to provide energy molecules (ATP)

- Monosaccharides
- Fatty acids
- Amino acids (amine first removed and combined with CO₂ by the liver to form urea)

Cellular metabolic "furnace": Krebs cycle and electron transport chain

- Carbon dioxide
- Water
- ATP
Fat Metabolism

• Acidosis (ketoacidosis) results from incomplete fat oxidation in which acetoacetic acid and acetone accumulate in the blood
  • Breath has a fruity odor
  • Common with
    • “No carbohydrate” diets
    • Uncontrolled diabetes mellitus
    • Starvation
(b) Fats: composed of 1 glycerol molecule and 3 fatty acids; triglycerides

- **Lipid (fat)**
- **Fatty acids**
- **GI digestion to fatty acids and glycerol**
- **Metabolized by liver to acetic acid, etc.**
- **Cellular uses**
- **Insulation and fat cushions to protect body organs**
- **ATP**

Fats are the primary fuels in many cells

- Fats build myelin sheaths and cell membranes
Protein Metabolism

- Proteins are conserved by body cells because they are used for most cellular structures
- Ingested proteins are broken down to amino acids
Protein Metabolism

- Cells remove amino acids to build proteins
  - Synthesized proteins are actively transported across cell membranes
- Amino acids are used to make ATP only when proteins are overabundant or there is a shortage of other sources
Production of ATP from Protein

• Amine groups are removed from proteins as ammonia
• The rest of the protein molecule enters the Krebs cycle in mitochondria
• The liver converts harmful ammonia to urea which can be eliminated in urine
Proteins: polymers of amino acids

GI digestion to amino acids

ATP formation if inadequate glucose and fats or if essential amino acids are lacking

ATP

Functional proteins (enzymes, antibodies, hemoglobin, etc.)

Structural proteins (connective tissue fibers, muscle proteins, etc.)

Protein

Amino acids

Normally infrequent

Cellular uses
Role of the Liver in Metabolism

• Several roles in digestion
  • Manufactures bile
  • Detoxifies drugs and alcohol
  • Degrades hormones
  • Produces cholesterol, blood proteins (albumin and clotting proteins)
  • Plays a central role in metabolism

• Can regenerate if part of it is damaged or removed
Metabolic Functions of the Liver

- **Glycogenesis**—“glycogen formation”
  - Glucose molecules are converted to glycogen
  - Glycogen molecules are stored in the liver
- **Glycogenolysis**—“glucose splitting”
  - Glucose is released from the liver after conversion from glycogen
- **Gluconeogenesis**—“formation of new sugar”
  - Glucose is produced from fats and proteins
Stimulus: Rising blood glucose level

Glycogenesis: Glucose converted to glycogen and stored

Stimulus: Falling blood glucose level

Glycogenolysis: Stored glycogen converted to glucose

Gluconeogenesis: Amino acids and fats converted to glucose

Figure 14.23
Metabolic Functions of the Liver

• Fats and fatty acids are picked up by the liver
  • Some are oxidized to provide energy for liver cells
  • The rest are broken down into simpler compounds and released into the blood
Cholesterol Metabolism

• Cholesterol is not used to make ATP

• Functions of cholesterol
  • Serves as a structural basis of steroid hormones and vitamin D
  • Is a major building block of plasma membranes

• Most cholesterol is produced in the liver (85 percent) and is not from diet (15 percent)
Cholesterol Transport

- Cholesterol and fatty acids cannot freely circulate in the bloodstream
- They are transported by lipoproteins (lipid-protein complexes)
  - Low-density lipoproteins (LDLs) transport to body cells
    - Rated “bad lipoproteins” since they can lead to atherosclerosis
  - High-density lipoproteins (HDLs) transport from body cells to the liver
Body Energy Balance

• Energy intake = total energy output

  (heat + work + energy storage)

  • Energy intake is the energy liberated during food oxidation
    • Energy produced during glycolysis, Krebs cycle and the electron transport chain
  • Energy output
    • Energy we lose as heat (60 percent)
    • Energy stored as fat or glycogen
Regulation of Food Intake

- Body weight is usually relatively stable
  - Energy intake and output remain about equal
- Mechanisms that may regulate food intake
  - Levels of nutrients in the blood
  - Hormones
  - Body temperature
  - Psychological factors
Metabolic Rate and Body Heat Production

- Basic metabolic rate (BMR)—amount of heat produced by the body per unit of time at rest
- Average BMR is about 60 to 72 kcal/hour
- Kilocalorie (kcal) is the unit of measure for the energy value of foods and the amount of energy used by the body
Metabolic Rate and Body Heat Production

• Factors that influence BMR

  • Surface area—a small body usually has a higher BMR
  • Gender—males tend to have higher BMRs
  • Age—children and adolescents have higher BMRs
  • The amount of thyroxine produced is the most important control factor
    • More thyroxine means a higher metabolic rate
Total Metabolic Rate (TMR)

- TMR = Total amount of kilocalories the body must consume to fuel ongoing activities
- TMR increases with an increase in body activity
- TMR must equal calories consumed to maintain homeostasis and maintain a constant weight
Body Temperature Regulation

• Most energy is released as foods are oxidized
• Most energy escapes as heat
Body Temperature Regulation

• The body has a narrow range of homeostatic temperature
  • Must remain between 35.6°C to 37.8°C (96°F to 100°F)
  • The body’s thermostat is in the hypothalamus
    • Initiates heat-loss or heat-promoting mechanisms
Body Temperature Regulation

• Heat-promoting mechanisms
  • Vasoconstriction of blood vessels
    • Blood is rerouted to deeper, more vital body organs
  • Shivering—contraction of muscles produces heat
Body Temperature Regulation

- Heat-loss mechanisms
  - Heat loss from the skin via radiation and evaporation
    - Skin blood vessels and capillaries are flushed with warm blood
    - Evaporation of perspiration cools the skin
Figure 14.24

Activates heat-loss center in hypothalamus

Blood warmer than hypothalamic set point

Stimulus:
Increased body temperature (e.g., when exercising or the climate is hot)

Body temperature increases: Blood temperature rises and hypothalamus heat-promoting center “shuts off”

Skeletal muscles activated when more heat must be generated; shivering begins

Skin blood vessels dilate: Capillaries become flushed with warm blood; heat radiates from skin surface

Sweat glands activated: Secrete perspiration, which is vaporized by body heat, helping to cool the body

Body temperature decreases: Blood temperature declines and hypothalamus heat-loss center “shuts off”

Sweat glands activated: Secrete perspiration, which is vaporized by body heat, helping to cool the body

Skin blood vessels constrict: Blood is diverted from skin capillaries and withdrawn to deeper tissues; minimizes overall heat loss from skin surface

Blood cooler than hypothalamic set point

Stimulus:
Decreased body temperature (e.g., due to cold environmental temperatures)

HOMEOSTASIS = normal body temperature (35.6°C–37.8°C)

IMBALANCE
Stimulus: Increased body temperature (e.g., when exercising or the climate is hot)
Activates heat-loss center in hypothalamus

Blood warmer than hypothalamic set point

Stimulus: Increased body temperature (e.g., when exercising or the climate is hot)

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Stimulus: Decreased body temperature (e.g., due to cold environmental temperatures)

HOMEOSTASIS = normal body temperature (35.6°C–37.8°C)
Figure 14.24, step 7

HOMEOSTASIS = normal body temperature (35.6°C–37.8°C)

Stimulus: Decreased body temperature (e.g., due to cold environmental temperatures)

Blood cooler than hypothalamic set point

Activates heat-promoting center in hypothalamus
Skeletal muscles activated when more heat must be generated; shivering begins

Stimulus: Decreased body temperature (e.g., due to cold environmental temperatures)

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HOMEOSTASIS = normal body temperature (35.6°C–37.8°C)
Body Temperature Regulation

- Fever—controlled hyperthermia
  - Results from infection, cancer, allergic reactions, CNS injuries
  - If the body thermostat is set too high, body proteins may be denatured and permanent brain damage may occur
Developmental Aspects of the Digestive System

• The alimentary canal is a continuous tube by the fifth week of development
• Digestive glands bud from the mucosa of the alimentary tube
• The developing fetus receives all nutrients through the placenta
• In newborns, feeding must be frequent, peristalsis is inefficient, and vomiting is common
Developmental Aspects of the Digestive System

• Newborn reflexes
  • Rooting reflex helps the infant find the nipple
  • Sucking reflex helps the infant hold on to the nipple and swallow
• Teething begins around age six months
Developmental Aspects of the Digestive System

• Problems of the digestive system
  • Gastroenteritis—inflammation of the gastrointestinal tract
  • Appendicitis—inflammation of the appendix

• Metabolism decreases with old age

• Middle-age digestive problems
  • Ulcers
  • Gallbladder problems
Developmental Aspects of the Digestive System

• Activity of the digestive tract in old age
  • Fewer digestive juices
  • Peristalsis slows
  • Diverticulosis and cancer are more common