Chapter 14
The Digestive System and Body Metabolism

Slides 14.1 – 14.14
The Digestive System and Body

- Digestion
  - Breakdown of ingested food
  - Absorption of nutrients into the blood
- Metabolism
  - Production of cellular energy (ATP)
  - Constructive and degradative cellular activities
Organs of the Digestive System

- Two main groups
  - Alimentary canal – continuous coiled hollow tube
  - Accessory 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

Figure 14.2a

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Mouth (Oral Cavity) Anatomy

- Vestibule – space between lips externally and teeth and gums internally
- Oral cavity – area contained by the teeth
- Tongue – attached at hyoid and styloid processes of the skull, and by the lingual frenulum
Mouth (Oral Cavity) Anatomy

- Tonsils
  - Palatine tonsils
  - Lingual tonsil

Figure 14.2a

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Processes of the Mouth

- Mastication (chewing) of food
- Mixing masticated food with saliva
- Initiation of swallowing by the tongue
- Allowing 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
Pharynx Function

- 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

- Runs from pharynx to stomach through the diaphragm
- Conducts food by peristalsis (slow rhythmic squeezing)
- Passageway for food only (respiratory system branches off after the pharynx)
Layers of Alimentary Canal Organs

- Mucosa
  - Innermost layer
  - Moist membrane
    - Surface epithelium
    - Small amount of connective tissue (lamina propria)
  - Small smooth muscle layer
Layers of Alimentary Canal Organs

- **Submucosa**
  - Just beneath the mucosa
  - Soft connective tissue with blood vessels, nerve endings, and lymphatics
Layers of Alimentary Canal Organs

- **Muscularis externa** – smooth muscle
  - Inner circular layer
  - Outer longitudinal layer
- **Serosa**
  - Outermost layer – visceral peritoneum
  - Layer of serous fluid-producing cells
Layers of Alimentary Canal Organs

Visceral peritoneum

Intrinsic nerve plexuses:

- Myenteric nerve plexus
- Submucosal nerve plexus

Submucosal glands

Mucosa:
- Surface epithelium
- Lamina propria
- Muscle layer

Submucosa

Muscularis externa:
- Longitudinal muscle layer
- Circular muscle layer

Serosa:
- (visceral peritoneum)

Mesentery

Nerve Artery Vein

Gland in mucosa

Duct of gland outside alimentary canal

Lumen

Lymph nodule

Figure 14.3

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Slide 14.13
Alimentary Canal Nerve Plexuses

- All are part of the autonomic nervous system
- Three separate networks of nerve fibers
  - Submucosal nerve plexus
  - Myenteric nerve plexus
  - Subserous plexus
Stomach Anatomy

- Located on the left side of the abdominal cavity
- Food enters at the cardioesophagaeal sphincter
Stomach Anatomy

- Regions of the stomach
  - Cardiac region – near the heart
  - Fundus
  - Body
  - Phylorus – funnel-shaped terminal end

- Food empties into the small intestine at the pyloric sphincter
Stomach Anatomy

- Rugae – internal folds of the mucosa
- External regions
  - Lesser curvature
  - Greater curvature
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
  - Contains fat to insulate, cushion, and protect abdominal organs
Stomach Anatomy

Figure 14.4a

Esophagus
Muscularis externa
- Longitudinal layer
- Circular layer
- Oblique layer

Cardioesophageal sphincter
Fundus
Serosa
Body
Rugae of mucosa
Greater curvature
Lesser curvature
Pylorus
Duodenum
Pyloric sphincter

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Slide 14.17
Stomach Functions

- Acts as a storage tank for food
- Site of food breakdown
- Chemical breakdown of protein begins
- Delivers chyme (processed food) to the small intestine
Specialized Mucosa of the Stomach

- Simple columnar epithelium
  - Mucous neck cells – produce a sticky alkaline mucus
  - Gastric glands – secrete gastric juice
  - Chief cells – produce protein-digesting enzymes (pepsinogens)
  - Parietal cells – produce hydrochloric acid
  - Endocrine cells – produce gastrin
Structure of the Stomach Mucosa

- Gastric pits formed by folded mucosa
- Glands and specialized cells are in the gastric gland region
Structure of the Stomach Mucosa

Figure 14.4b, c

Slide 14.20b
Small Intestine

- The body’s major digestive organ
- Site of nutrient absorption into the blood
- Muscular tube extending from the pyloric sphincter to the ileocecal 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

- Source of enzymes that are mixed with chyme
  - Intestinal cells
  - Pancreas
- Bile enters from the gall bladder
Chemical Digestion in the Small Intestine

Figure 14.6
Villi of the Small Intestine

- Fingerlike structures formed by the mucosa
- Give the small intestine more surface area

Figure 14.7a
Microvilli of the Small Intestine

- Small projections of the plasma membrane
- Found on absorptive cells

Figure 14.7c
Structures Involved in Absorption of Nutrients

- Absorptive cells
- Blood capillaries
- Lacteals (specialized lymphatic capillaries)
Folds of the Small Intestine

- Called circular folds or plicae circulares
- Deep folds of the mucosa and submucosa
- Do not disappear when filled with food
- The submucosa has Peyer’s patches (collections of lymphatic tissue)
Large Intestine

- Larger in diameter, but shorter than the small intestine
- Frames the internal abdomen
Large Intestine

Figure 14.8

- Right colic (hepatic) flexure
- Transverse colon
- Haustra
- Ascending colon
- Ileum (cut)
- Ileocecal valve
- Cecum
- Vermiform appendix
- Rectum
- Anal canal
- External anal sphincter
- Left colic (splenic) flexure
- Transverse mesocolon
- Descending colon
- Cut edge of mesentery
- Teniae coli
- Sigmoid colon

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Functions of the Large Intestine

- Absorption of water
- Eliminates indigestible food from the body as feces
- Does not participate in digestion of food
- Goblet cells produce mucus to act as a lubricant
Structures of the Large Intestine

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

- Colon
  - Ascending
  - Transverse
  - Descending
  - S-shaped sigmoidal
- Rectum
- Anus – external body opening
Modifications to the Muscularis Externa in the Large Intestine

- Smooth muscle is reduced to three bands (teniae coli)
- Muscle bands have some degree of tone
- Walls are formed into pocketlike sacs called haustra
Accessory Digestive Organs

- Salivary glands
- Teeth
- Pancreas
- Liver
- Gall bladder
Salivary Glands

- Saliva-producing glands
  - Parotid glands – located anterior to ears
  - Submandibular glands
  - Sublingual glands
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
Teeth

- The role is to masticate (chew) food
- Humans have two sets of teeth
  - Deciduous (baby or milk) teeth
  - 20 teeth are fully formed by age two
Teeth

- Permanent teeth
  - Replace deciduous teeth beginning between the ages of 6 to 12
  - A full set is 32 teeth, but some people do not have wisdom teeth
Classification of Teeth

- Incisors
- Canines
- Premolars
- Molars
Classification of Teeth

- **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)

**Deciduous (milk) teeth**

- **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)

**Permanent teeth**

Figure 14.9
Regions of a Tooth

- **Crown** – exposed part
  - Outer enamel
  - Dentin
  - Pulp cavity
- **Neck**
  - Region in contact with the gum
  - Connects crown to root

Figure 14.10

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Slide 14.37a
Regions of a Tooth

- Root
  - Periodontal membrane attached to the bone
  - Root canal carrying blood vessels and nerves

Figure 14.10
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
- Endocrine products of pancreas
  - Insulin
  - Glucagons
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 gall bladder via the common hepatic duct
Bile

- Produced by cells in the liver

Composition

- Bile salts
- Bile pigment (mostly bilirubin from the breakdown of hemoglobin)
- Cholesterol
- Phospholipids
- Electrolytes
Gall Bladder

- Sac found in hollow fossa of liver
- Stores bile from the liver by way of the cystic duct
- Bile is introduced into the duodenum in the presence of fatty food
- Gallstones can cause blockages
Processes of the Digestive System

- Ingestion – getting food into the mouth
- Propulsion – moving foods from one region of the digestive system to another
Processes of the Digestive System

- Peristalsis – alternating waves of contraction
- Segmentation – moving materials back and forth to aid in mixing

Figure 14.12

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Processes of the Digestive System

- Mechanical digestion
  - Mixing of food in the mouth by the tongue
  - Churning of food in the stomach
  - Segmentation in the small intestine
Processes of the Digestive System

- 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
Processes 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 as feces
Processes of the Digestive System

Figure 14.11

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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
  - Breaking of starch 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-esophogeal phase (continued)
  - Peristalsis moves the bolus toward the stomach
  - The cardioesophageal sphincter is opened when food presses against it
Deglutition (Swallowing)

Figure 14.13
Food Breakdown in the Stomach

- Gastric juice is regulated by neural and hormonal factors
- Presence of food or falling pH causes the release of gastrin
- Gastrin causes stomach glands to produce protein-digesting enzymes
- Hydrocholoric acid makes the stomach contents very acidic
Necessity of an Extremely Acid Environment in the Stomach

- 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
- The only absorption that occurs in the stomach is of alcohol and aspirin
Propulsion in the Stomach

- Food must first be well mixed
- Rippling peristalsis occurs in the lower stomach
Propulsion in the Stomach

- The pylorus meters out chyme into the small intestine (30 ml at a time)
- The stomach empties in four to six hours
Digestion in the Small Intestine

- Enzymes from the brush border
  - Break double sugars into simple sugars
  - Complete some protein digestion
- Pancreatic enzymes play the major digestive function
  - Help complete digestion of starch (pancreatic amylase)
  - Carry out about half of all protein digestion (trypsin, etc.)
Digestion in the Small Intestine

- Pancreatic enzymes play the major digestive function (continued)
  - Responsible for fat digestion (lipase)
  - Digest nucleic acids (nucleases)
  - Alkaline content neutralizes acidic chyme
Stimulation of the Release of Pancreatic Juice

- Vagus nerve
- Local hormones
  - Secretin
  - Cholecystokinin

Figure 14.15

Stimulation by vagal nerve fibers causes release of pancreatic juice.

1. Chyme entering duodenum causes the duodenal mucosal cells to release secretin and cholecystokinin.
2. Cholecystokinin and secretin enter bloodstream.
3. Upon reaching the pancreas, cholecystokinin 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
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

- Categories of nutrients
  - Carbohydrates
  - Lipids
  - Proteins
  - Vitamins
  - Mineral
  - Water
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
  • Legumes and beans also have proteins, but are incomplete

• Vitamins
  • Most vitamins are used as cofactors and act with enzymes
  • 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
  - Anabolism – larger molecules are built from smaller ones
- Energy is released during catabolism
Carbohydrate Metabolism

- The body’s preferred source to produce cellular energy (ATP)
- Glucose (blood sugar) is the major breakdown product and fuel to make ATP

Figure 14.16
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 that it can be split into two pyruvic acid molecules and yield ATP
Figure 14.17

Metabolic Pathways Involved in Cellular Respiration

1. Glycolysis
   - Glucose → Pyruvic acid
   - Cytosol of cell → Mitochondrial cristae
   - Resulting in ATP

2. Krebs cycle
   - Chemical energy (high-energy electrons)
   - Chemical energy
   - Mitochondrion

3. Electron transport chain and oxidative phosphorylation
   - H₂O
   - Via oxidative phosphorylation
   - Resulting in ATP

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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
Metabolic Pathways Involved in Cellular Respiration

- Electron transport chain

- Hydrogen atoms removed during glycolysis and the Krebs cycle are delivered to protein carriers.
Metabolic Pathways Involved in Cellular Respiration

- Electron transport chain (continued)
  - Hydrogen is split into hydrogen ions and electrons in the mitochondria
Metabolic Pathways Involved in Cellular Respiration

- Electron transport chain (continued)
  - Electrons give off energy in a series of steps to enable the production of ATP

Figure 14.18
Fat Metabolism

- Handled mostly by the liver
  - Use some fats to make ATP
  - Synthesize lipoproteins, thromboplastin, and cholesterol
  - Release 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.
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
Role of the Liver in Metabolism

- Several roles in digestion
- Detoxifies drugs and alcohol
- Degrades hormones
- Produce cholesterol, blood proteins (albumin and clotting proteins)
- Plays a central role in metabolism
Metabolic Functions of the Liver

- **Glycogenesis**
  - Glucose molecules are converted to glycogen
  - Glycogen molecules are stored in the liver

- **Glycogenolysis**
  - Glucose is released from the liver after conversion from glycogen

- **Gluconeogenesis**
  - Glucose is produced from fats and proteins
Metabolic Functions of the Liver

Figure 14.20

- Glucogenesis: Glucose converted to glycogen and stored
- Rising blood glucose level
- Imbalance
- Homeostatic blood sugar
- Glycogenolysis: Stored glycogen converted to glucose
- Falling blood glucose level
- Imbalance
- Gluconeogenesis: Amino acids and fats converted to glucose

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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

- 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 and is not from diet
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
  - 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 liberated during food oxidation
  - Energy output
    - Heat is usually about 60%
    - Storage energy is in the form of 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

- Factors that influence BMR
  - Surface area – small body usually has higher BMR
  - Gender – males tend to have higher BMR
Metabolic Rate and Body Heat Production

- Factors that influence BMR (continued)
  - Age – children and adolescents have a higher BMR
  - The amount of thyroxine produced is the most important control factor
    - More thyroxine means higher metabolic rate
Total Metabolic Rate (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° to 37.8°C (96° to 100° F)
- The body’s thermostat is in the hypothalamus
  - Initiates heat-loss or heat-promoting mechanisms
Heat Promoting Mechanisms

- Vasoconstriction of blood vessels
  - Blood is rerouted to deeper, more vital body organs
- Shivering – contraction of muscles produces heat
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
Body Temperature Regulation

Figure 14.21

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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

- Teething begins around age six months
- Metabolism decreases with old age
- Middle age digestive problems
  - Ulcers
  - Gall bladder problems
Developmental Aspects of the Digestive System

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