INTRODUCTION
- Food contains substances and energy the body needs to construct all cell components. The food must be broken down through digestion to molecular size before it can be absorbed by the digestive system and used by the cells.
- The organs that collectively perform these functions compose the digestive system.
- The medical professions that study the structures, functions, and disorders of the digestive tract are gastroenterology for the upper end of the system and proctology for the lower end.

OVERVIEW OF THE DIGESTIVE SYSTEM
- Structure
  - Gross Anatomy
  - Histology
- Function
  - Mechanical
  - Chemical
- Development
- Disorders

Organization
- The two major sections of the digestive system perform the processes required to prepare food for use in the body (Figure 24.1).
- The gastrointestinal tract is the tube open at both ends for the transit of food during processing. The functional segments of the GI tract include the mouth, esophagus, stomach, small intestine, and large intestine.
- The accessory structures that contribute to the food processing include the teeth, tongue, salivary glands, liver, gallbladder, and pancreas.
Digestion

- Digestion includes six basic processes.
- Ingestion is taking food into the mouth (eating).
- Secretion is the release, by cells within the walls of the GI tract and accessory organs, of water, acid, buffers, and enzymes into the lumen of the tract.
- Mixing and propulsion result from the alternating contraction and relaxation of the smooth muscles within the walls of the GI tract.
- Digestion
- Mechanical digestion consists of movements of the GI tract that aid chemical digestion.
- Chemical digestion is a series of catabolic (hydrolysis) reactions that break down large carbohydrate, lipid, and protein food molecules into smaller molecules that are usable by body cells.
- Absorption is the passage of end products of digestion from the GI tract into blood or lymph for distribution to cells.
- Defecation is emptying of the rectum, eliminating indigestible substances from the GI tract.

LAYERS OF THE GI TRACT

- The basic arrangement of layers in the gastrointestinal tract from the inside outward includes the mucosa, submucosa, muscularis, and serosa (visceral peritoneum) (Figure 24.2).

Layers of the GI Tract

1. Mucosal layer
2. Submucosal layer
3. Muscularis layer
4. Serosa layer

Mucosa

- Epithelium
  - Stratified squamous (in mouth, esophagus & anus) = tough
  - Simple columnar in the rest
    - secretes enzymes and absorbs nutrients
    - specialized cells (goblet) secrete mucus onto cell surfaces
    - enteroendocrine cells—secrete hormones controlling organ function
- Lamina propria
  - thin layer of loose connective tissue
  - contains BV and lymphatic tissue
- Muscularis mucosae—thin layer of smooth muscle
  - causes folds to form in mucosal layer
  - increases local movements increasing absorption with exposure to “new” nutrients

Submucosa

- Loose connective tissue
  - containing BV, glands and lymphatic tissue
- Meissner’s plexus—
  - parasympathetic
  - innervation
  - vasoconstriction
  - local movement by muscularis mucosa smooth muscle

LAYERS OF THE GI TRACT

- The submucosa consists of aerolar connective tissue. It is highly vascular, contains a part of the submucosal plexus (plexus of Meissner), and contains glands and lymphatic tissue.
- The submucosal plexus is a part of the autonomic nervous system.
- It regulates movements of the mucosa, vasoconstriction of blood vessels, and innervates secretory cells of mucosal glands.
**Skeletal muscle** = voluntary control
- in mouth, pharynx, upper esophagus and anus
- control over swallowing and defecation

**Smooth muscle** = involuntary control
- inner circular fibers & outer longitudinal fibers
- mixes, crushes & propels food along by peristalsis

*Auerbach’s plexus (myenteric)* --
- both parasympathetic & sympathetic innervation of circular and longitudinal smooth muscle layers

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**Enteric Nervous System**

- ENS consists of neurons that extend from the esophagus to the gut (Figure 24.2)
- Located in the myenteric plexus and the submucosal plexus.
- Consists of motor neurons, interneurons, and sensory neurons (Figure 24.3)
- Myenteric neurons control gastric motility while the submucosal neurons control the secretory cells.
- Can function independently of the CNS

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**Serosa**

- An example of a serous membrane
- Covers all organs and walls of cavities not open to the outside of the body
- Secretes slippery fluid
- Consists of connective tissue covered with simple squamous epithelium

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**NEURAL INNERVATION OF THE GI TRACT**
Autonomic Nervous System (ANS)

- Vagus nerve (X) supplies parasympathetic fibers. These fibers synapse with neurons in the ENS and increase their action.
- Sympathetic nerves arise from the thoracic and upper lumbar regions of the spinal cord. These fibers also synapse with neurons in the ENS. However, they inhibit the ENS neurons.
- Gastrointestinal Reflex Pathways
  - Regulate secretions and motility in response to stimuli present in the lumen.
  - The reflexes begin with receptors associated with sensory neurons of the ENS.

Peritoneum

- Peritoneum
  - visceral layer covers organs
  - parietal layer lines the walls of body cavity
  - Peritoneal cavity
  - potential space containing a bit of serous fluid

Parts of the Peritoneum

- Mesentery
- Mesocolon
- Lesser omentum
- Greater omentum
- Peritonitis = inflammation
  - trauma
  - rupture of GI tract
  - appendicitis
  - perforated ulcer

Greater Omentum, Mesentery & Mesocolon

Clinical Application

- Peritonitis is an acute inflammation of the peritoneum.
- Cause
  - contamination by infectious microbes during surgery or from rupture of abdominal organs
Introduction

- The **mouth** (oral or buccal cavity) is formed by the cheeks, hard and soft palate, lips, and tongue (Figure 24.5).
- The **vestibule** of the oral cavity is bounded externally by the cheeks and lips and internally by the gums and teeth.
- The **oral cavity proper** is a space that extends from the gums and teeth to the **fauces**, the opening between the oral cavity and the pharynx or throat.

Mouth

- Lips and cheeks contain buccinator muscle that keeps food between upper & lower teeth
- Vestibule is the area between cheeks and teeth
- Oral cavity proper is the roof
  - hard, soft palate and uvula
  - floor = the tongue

Pharyngeal Arches

- Two skeletal muscles
  - Palatoglossal muscle
    - extends from palate to tongue
    - forms the first arch
    - posterior limit of the mouth
  - Palatopharyngeal muscle
    - extends from palate to pharyngeal wall
    - forms the second arch
    - behind the palatine tonsil

Salivary Glands

- Parotid below your ear and over the masseter
- Submandibular is under lower edge of mandible
- Sublingual is deep to the tongue in floor of mouth
- All have ducts that empty into the oral cavity

Composition and Functions of Saliva

- Wet food for easier swallowing
- Dissolves food for tasting
- Bicarbonate ions buffer acidic foods
  - bulemia — vomiting hurts the enamel on your teeth
- Chemical digestion of starch begins with enzyme (salivary amylase)
- Enzyme (lysozyme) — helps destroy bacteria
- Protects mouth from infection with its rinsing action — 1 to 1 1/2 qts/day
Salivary Gland Cellular Structure

- Cells in acini (clusters)
- Serous cells secrete a watery fluid
- Mucous cells (pale staining) secrete a slimy, mucus secretion

Salivation

- Increase salivation
  - sight, smell, sounds, memory of food, tongue stimulation—rock in mouth
  - cerebral cortex signals the salivatory nuclei in brainstem—(CN 7 & 9)
- Stop salivation
  - dry mouth when you are afraid
  - sympathetic nerves

Mumps

- Myxovirus that attacks the parotid gland
- Symptoms
  - inflammation and enlargement of the parotid
  - fever, malaise & sour throat (especially swallowing sour foods)
  - swelling on one or both sides
  - Sterility rarely possible in males with testicular involvement (only one side involved)
- Vaccine available since 1967

Mumps

Structure and Function of the Tongue

- The tongue, together with its associated muscle, forms the floor of the oral cavity. It is composed of skeletal muscle covered with mucous membrane.
- Extrinsic and intrinsic muscles permit the tongue to be moved to participate in food manipulation for chewing and swallowing and in speech.
- The lingual frenulum is a fold of mucous membrane that attaches to the midline of the undersurface of the tongue.
- The upper surface and sides of the tongue are covered with papillae. Some papillae contain taste buds.
- On the dorsum of the tongue are glands that secrete lingual lipase, which initiates digestion of triglycerides.

Mumps

Structure and Function of the Teeth

- The teeth project into the mouth and are adapted for mechanical digestion (Figure 24.7).
- A typical tooth consists of three principal portions: crown, root, and neck.
- Teeth are composed primarily of dentin, a calcified connective tissue that gives the tooth its basic shape and rigidity; the dentin of the crown is covered by enamel, the hardest substance in the body, which protects the tooth from the wear of chewing.
- The dentin of the root is covered by cementum, another bone-like substance, which attaches the root to the periodontal ligament (the fibrous connective tissue lining of the tooth sockets in the mandible and maxillae).
- The dentin encloses the pulp cavity in the crown and the root canals in the root.
Tooth Structure
- Crown
- Neck
- Roots
- Pulp cavity

Composition of Teeth
- Enamel
- hardest substance in body
  calcium phosphate or carbonate
- Dentin
  calcified connective tissue
- Cementum
  bone-like
  periodontal ligament penetrates it

What is the gingiva?

Dentition
- There are two dentitions, or sets of teeth, in an individual's lifetime: deciduous (primary), milk teeth, or baby teeth, and permanent (secondary) teeth (Figure 24.8 a,b).
- Primary or baby teeth
  20 teeth that start erupting at 6 months
  1 new pair of teeth per month
- Permanent teeth
  32 teeth that erupt between 6 and 12 years of age
  differing structures indicate function
  incisors for biting
  canines or cusps for tearing
  premolars & molars for crushing and grinding food

Dentistry
- In root canal therapy all traces of pulp tissue are removed from the pulp cavity and root canal of a badly diseased tooth
- The branch of dentistry that is concerned with the prevention, diagnosis, and treatment of diseases that affect the pulp, root, periodontal ligament, and alveolar bone is known as endodontics.
- Orthodontics is a dental branch concerned with the prevention and correction of abnormally aligned teeth.
- Periodontics is a dental branch concerned with the treatment of abnormal conditions of tissues immediately around the teeth.

Digestion in the Mouth
- Table 24.1 summarizes digestion in the mouth.
- Mechanical digestion (mastication or chewing)
  - breaks into pieces
  - mixes with saliva so it forms a bolus
- Chemical digestion
  - amylase
    - begins starch digestion at pH of 6.5 or 7.0 found in mouth
    - when bolus & enzyme hit the pH 2.5 gastric juices hydrolysis ceases
  - lingual lipase
    - secreted by glands in tongue
    - begins breakdown of triglycerides into fatty acids and glycerol
PHARYNX

- The pharynx is a funnel-shaped tube that extends from the internal nares to the esophagus posteriorly and the larynx anteriorly (Figure 24.4).
- It is composed of skeletal muscle and lined by mucous membrane.
- The nasopharynx functions in respiration only, whereas the oropharynx and laryngopharynx have digestive as well as respiratory functions.

ESOPHAGUS

- The esophagus is a collapsible, muscular tube that lies behind the trachea and connects the pharynx to the stomach (Figure 24.1).
- The wall of the esophagus contains mucosa, submucosa, and muscularis layers. The outer layer is called the adventitia rather than the serosa due to structural differences (Figure 24.9).
- The role of the esophagus is to secrete mucus and transport food to the stomach.

DEGLUTITION

- Moves a bolus from the mouth to the stomach. It is facilitated by saliva and mucus and involves the mouth, pharynx, and tongue (Figure 24.10).
- It consists of a voluntary stage, pharyngeal stage (involuntary) and esophageal stage.
- Voluntary stage begins when the bolus is forced into the oropharynx by tongue movement.
- Receptors in the oropharynx stimulate the deglutition center in the medulla. This begins the pharyngeal stage which moves food from the pharynx to the esophagus.
- The esophageal stage begins when the bolus enters the esophagus. During this stage the peristalsis moves the bolus from the esophagus to the stomach.
- Table 24.2 summarizes the digestion related activities of the pharynx and esophagus.
Swallowing

- **Voluntary phase**—tongue pushes food to back of oral cavity
- **Involuntary phase**—pharyngeal stage
  - breathing stops & airways are closed
  - soft palate & uvula are lifted to close off nasopharynx
  - vocal cords close
  - epiglottis is bent over airway as larynx is lifted

**Upper sphincter relaxes when larynx is lifted**
- Peristalsis pushes food down
  - circular fibers behind bolus
  - longitudinal fibers in front of bolus shorten the distance of travel
- Travel time is 4-8 seconds for solids and 1 sec for liquids
- Lower sphincter relaxes as food approaches

Gastroesophageal Reflex Disease

- If lower sphincter fails to open
  - distension of esophagus feels like chest pain or heart attack
- If lower esophageal sphincter fails to close
  - stomach acids enter esophagus & cause heartburn (GERD)
  - for a weak sphincter—don’t eat a large meal and lay down in front of TV
  - smoking and alcohol make the sphincter relax worsening the situation
- Control the symptoms by avoiding
  - coffee, chocolate, tomatoes, fatty foods, onions & mint
  - take Tagamet HB or Pepcid AC 60 minutes before eating
  - neutralize existing stomach acids with Tums

STOMACH

Introduction

- The stomach is a J-shaped enlargement of the GI tract that begins at the bottom of the esophagus and ends at the pyloric sphincter (Figure 24.11).
- It serves as a mixing and holding area for food, begins the digestion of proteins, and continues the digestion of triglycerides, converting a bolus to a liquid called chyme. It can also absorb some substances.

Anatomy of the Stomach

- The gross anatomical subdivisions of the stomach include the **cardia**, **fundus**, **body**, and **pyloris** (Figure 24.11).
- When the stomach is empty, the mucosa lies in folds called **rugae**.
- **Pylorospasm** and **pyloric stenosis** are two abnormalities of the pyloric sphincter that can occur in newborns. Both functionally block or partially block the exit of food from the stomach into the duodenum and must be treated with drugs or surgery (Clinical Application).
Anatomy of the Stomach

- At the greater curvature, the visceral peritoneum becomes the greater omentum.

Anatomy of Stomach

- Which side is it on?
- Size when empty?
  - large sausage
  - stretches due to rugae

Parts of stomach

- cardia
- fundus—air in x-ray
- body
- pylorus—starts to narrow as approaches pyloric sphincter
- Empties as small squirts of chyme leave the stomach through the pyloric valve

Histology of the Stomach

- The surface of the mucosa is a layer of simple columnar epithelial cells called mucous surface cells (Figure 24.12a).
- Epithelial cells extend down into the lamina propria forming gastric pits and gastric glands.
- The gastric glands consist of three types of exocrine glands: mucous neck cells (secrete mucus), chief or zymogenic cells (secrete pepsinogen and gastric lipase), and parietal or oxyntic cells (secrete HCl).
- Gastric glands also contain enteroendocrine cells which are hormone producing cells. G cells secrete the hormone gastrin into the bloodstream.
- Zollinger-Ellison Syndrome is a syndrome in which an individual produces too much HCl. It is caused by excessive gastrin which stimulates the secretion of gastric juice.

Pylorospasm and Pyloric Stenosis

- Abnormalities of the pyloric sphincter in infants
- Pylorospasm
  - muscle fibers of sphincter fail to relax trapping food in the stomach
  - vomiting occurs to relieve pressure
- Pyloric stenosis
  - narrowing of sphincter indicated by projectile vomiting
  - must be corrected surgically
Mucosa & Gastric Glands

- Hydrochloric acid converts pepsinogen from chief cell to pepsin
- Intrinsic factor
  - absorption of vitamin B12 for RBC production
- Gastrin hormone (g cell)
  - "get it out of here"
  - release more gastric juice
  - increase gastric motility
  - relax pyloric sphincter
  - constrict esophageal sphincter preventing entry

Histology of the Stomach

- The submucosa is composed of areolar connective tissue.
- The muscularis has three layers of smooth muscle: longitudinal, circular, and an inner oblique layer.
- The serosa is a part of the visceral peritoneum.
- At the lesser curvature, the visceral peritoneum becomes the lesser omentum.

Muscularis

- Three layers of smooth muscle—outer longitudinal, circular & inner oblique
- Permits greater churning & mixing of food with gastric juice

Serosa

- Simple squamous epithelium over a bit of connective tissue
- Also known as visceral peritoneum
Physiology--Mechanical Digestion

- Gentle mixing waves
  - every 15 to 25 seconds
  - mixes bolus with 2 quarts/day of gastric juice to turn it into chyme (a thin liquid)
- More vigorous waves
  - travel from body of stomach to pyloric region
- Intense waves near the pylorus
  - open it and squirt out 1-2 teaspoons full with each wave

Physiology--Chemical Digestion

- Protein digestion begins
  - HCl denatures (unfolds) protein molecules
  - HCl transforms pepsinogen into pepsin that breaks peptides bonds between certain amino acids
- Fat digestion continues
  - gastric lipase splits the triglycerides in milk fat
    - most effective at pH 5 to 6 (infant stomach)
  - HCl kills microbes in food
  - Mucous cells protect stomach walls from being digested with 1-3mm thick layer of mucous

Gastric pH

Application

- Vomiting is the forcible expulsion of the contents of the upper GI tract (stomach and sometimes duodenum) through the mouth. Prolonged vomiting, especially in infants and elderly people, can be serious because the loss of gastric juice and fluids can lead to disturbances in fluid and acid-base balance.

PANCREAS

- The pancreas is divided into a head, body, and tail and is connected to the duodenum via the pancreatic duct (duct of Wirsung) and accessory duct (duct of Santorini) (Figure 24.14).
- Pancreatic islets (islets of Langerhans) secrete hormones and acini secrete a mixture of fluid and digestive enzymes called pancreatic juice (Figure 18.23).

Anatomy of the Pancreas

- 5” long by 1” thick
- Head close to curve in C-shaped duodenum
- Main duct joins common bile duct from liver
- Sphincter of Oddi on major duodenal papilla
- Opens 4” below pyloric sphincter
Pancreatic Duct

- Main duct joins common bile duct from liver
- Sphincter of Oddi on major duodenal papilla
- Opens 4” below pyloric sphincter

Histology of the Pancreas

- Acini - dark clusters
  - 99% of gland
  - produce pancreatic juice
- Islets of Langerhans
  - 1% of gland
  - pale staining cells
  - produce hormones

Pancreas - Overview

- Pancreatic juice contains enzymes that digest starch (pancreatic amylase), proteins (trypsin, chymotrypsin, and carboxypeptidase), fats (pancreatic lipase), and nucleic acids (ribonuclease and deoxyribonuclease).
- It also contains sodium bicarbonate which converts the acid stomach contents to a slightly alkaline pH (7.1-8.2), halting stomach pepsin activity and promoting activity of pancreatic enzymes.
- Inflammation of the pancreas is called pancreatitis and can result in trypsin beginning to digest pancreatic cells.
- Pancreatic cancer is nearly always fatal and in the fourth most common cause of cancer death in the United States.

Composition and Functions of Pancreatic Juice

- 1 & 1/2 Quarts/day at pH of 7.1 to 8.2
- Contains water, enzymes & sodium bicarbonate
- Digestive enzymes
  - pancreatic amylase, pancreatic lipase, proteases
    - trypsinogen---activated by enterokinase (a brush border enzyme)
    - chymotrypsinogen---activated by trypsin
    - procarboxypeptidase---activated by trypsin
    - proelastase---activated by trypsin
    - trypsin inhibitor---combines with any trypsin produced inside pancreas
  - ribonuclease----to digest nucleic acids
  - deoxyribonuclease

Regulation of Pancreatic Secretions

- Secretin
  - acidity in intestine causes increased sodium bicarbonate release
- GIP
  - fatty acids & sugar causes increased insulin release
- CCK
  - fats and proteins cause increased digestive enzyme release

Pancreatitis

- Pancreatitis---inflammation of the pancreas occurring with the mumps
- Acute pancreatitis---associated with heavy alcohol intake or biliary tract obstruction
  - result is patient secretes trypsin in the pancreas & starts to digest himself
LIVER AND GALLBLADDER

- The liver is the heaviest gland in the body and the second largest organ in the body after the skin.
- Anatomy of the Liver and Gallbladder
  - The liver is divisible into left and right lobes, separated by the falciform ligament. Associated with the right lobe are the caudate and quadrate lobes (Figure 24.14).
  - The gallbladder is a sac located in a depression on the posterior surface of the liver (Figure 24.14).

Anatomy of the Liver and Gallbladder

- Liver
  - weighs 3 lbs.
  - below diaphragm
  - right lobe larger
  - gallbladder on right lobe
  - size causes right kidney to be lower than left
- Gallbladder
  - fundus, body & neck

Histology of the Liver - Introduction

- Hepatocytes arranged in lobules
- Sinusoids in between hepatocytes are blood-filled spaces
- Kupffer cells phagocytize microbes & foreign matter

Histology of the Liver

- The lobes of the liver are made up of lobules that contain hepatic cells (liver cells or hepatocytes), sinusoids, stellate reticuloendothelial (Kupffer’s) cells, and a central vein (Figure 24.15).
- Bile is secreted by hepatocytes.
- Bile passes into bile canaliculi to bile ducts to the right and left hepatic ducts which unite to form the common hepatic duct (Figure 24.14).
- Common hepatic duct joins the cystic duct to form the common bile duct which enters the hepatopancreatic ampulla.

Histology of the Gallbladder

- Simple columnar epithelium
- No submucosa
- Three layers of smooth muscle
- Serosa or visceral peritoneum

Application

- Jaundice is a yellowish coloration of the sclera, skin, and mucous membranes due to a buildup of bilirubin. The main categories of jaundice are prehepatic, hepatic, and enterohepatic.
Blood Supply

- The liver receives a double supply of blood from the hepatic artery and the hepatic portal vein. All blood eventually leaves the liver via the hepatic vein (Figure 24.16).

## Blood Supply to the Liver

- **Hepatic portal vein**
  - nutrient rich blood from stomach, spleen & intestines
- **Hepatic artery from branch off the aorta**

## Flow of Fluids Within the Liver

1. **Oxygenated blood from hepatic artery**
2. **Nutrient-rich, deoxygenated blood from hepatic portal vein**
3. Liver sinusoids
4. Central vein
5. Hepatic vein
6. Inferior vena cava
7. Right atrium of heart

## Bile - Overview

- Hepatic cells (hepatocytes) produce bile that is transported by a duct system to the gallbladder for concentration and temporary storage.
- Bile is partially an excretory product (containing components of worn-out red blood cells) and partially a digestive secretion.
- Bile's contribution to digestion is the emulsification of triglycerides.
- The fusion of individual crystals of cholesterol is the beginning of 95% of all gallstones. Gallstones can cause obstruction to the outflow of bile in any portion of the duct system. Treatment of gallstones consists of using gallstone-dissolving drugs, lithotripsy, or surgery.
- The liver also functions in carbohydrate, lipid, and protein metabolism; removal of drugs and hormones from the blood; excretion of bilirubin; synthesis of bile salts; storage of vitamins and minerals; phagocytosis; and activation of vitamin D.
- In a liver biopsy a sample of living liver tissue is removed to diagnose a number of disorders.

## Bile Production

- One quart of bile/day is secreted by the liver
  - yellow-green in color & pH 7.6 to 8.6
- **Components**
  - water & cholesterol
  - bile salts = Na & K salts of bile acids
  - bile pigments (bilirubin) from hemoglobin molecule
    - globin = a reusable protein
    - heme = broken down into iron and bilirubin
Regulation of Bile Secretion

Liver Functions — Carbohydrate Metabolism
- Turn proteins into glucose
- Turn triglycerides into glucose
- Turn excess glucose into glycogen & store in the liver
- Turn glycogen back into glucose as needed

Liver Functions — Lipid Metabolism
- Synthesize cholesterol
- Synthesize lipoproteins — HDL and LDL (used to transport fatty acids in bloodstream)
- Stores some fat
- Breaks down some fatty acids

Liver Functions — Protein Metabolism
- Deamination = removes NH₂ (amine group) from amino acids so can use what is left as energy source
- Converts resulting toxic ammonia (NH₃) into urea for excretion by the kidney
- Synthesizes plasma proteins utilized in the clotting mechanism and immune system
- Convert one amino acid into another

Other Liver Functions
- Detoxifies the blood by removing or altering drugs & hormones (thyroid & estrogen)
- Removes the waste product — bilirubin
- Releases bile salts help digestion by emulsification
- Stores fat soluble vitamins — A, B₁₂, D, E, K
- Stores iron and copper
- Phagocytizes worn out blood cells & bacteria
- Activates vitamin D (the skin can also do this with 1 hr of sunlight a week)

Summary of Digestive Hormones
- Gastrin
  - stomach, gastric & ileocecal sphincters
- Gastric inhibitory peptide — GIP
  - stomach & pancreas
- Secretin
  - pancreas, liver & stomach
- Cholecystokinin — CCK
  - pancreas, gallbladder, sphincter of Oddi, & stomach
Introduction

- The major events of digestion and absorption occur in the small intestine.
- The small intestine extends from the pyloric sphincter to the ileocecal sphincter.
- Anatomy of the Small Intestine
- The small intestine is divided into the duodenum, jejunum, and ileum (Figure 24.17).
- Projections called circular folds, or plicae circulares, are permanent ridges in the mucosa that enhance absorption by increasing surface area and causing chyme to spiral as it passes through the small intestine (Figure 24.17).

Anatomy of the Small Intestine

- 20 feet long — 1 inch in diameter
- Large surface area for majority of absorption
- 3 parts
  - duodenum — 10 inches
  - jejunum — 8 feet
  - ileum — 12 feet
    - ends at ileocecal valve

Surface area of the small intestine

- plica circularis
  - permanent ½ inch tall folds that contain part of submucosal layer
  - not found in lower ileum
  - can not stretch out like rugae in stomach
- villi
  - 1 Millimeter tall
  - Core is lamina propria of mucosal layer
  - Contains vascular capillaries and lacteals (lymphatic capillaries)
- microvilli
  - cell surface feature known as brush border

Small Intestine - Overview

- The mucosa forms fingerlike villi which increase the surface area of the epithelium available for absorption and digestion (Figure 24.18a).
- Embedded in the villus is a lacteal (lymphatic capillary) for fat absorption.
- The cells of the mucosal epithelium include absorptive cells, goblet cells, enteroendocrine cells, and Paneth cells (Figure 24.18b).
- The free surface of the absorptive cells feature microvilli, which increase the surface area (Figure 24.19d). They form the brush border which also contains several enzymes.
- The mucosa contains many cavities lined by glandular epithelium. These cavities form the intestinal glands (crypts of Lieberkuhn).
- The submucosa of the duodenum contains duodenal (Brunner’s) glands which secrete an alkaline mucus that helps neutralize gastric acid in chyme. The submucosa of the ileum contains aggregated lymphatic nodules (Peyer’s patches) (Figure 24.19a).
- The muscularis consists of 2 layers of smooth muscles

Histology of Small Intestine
Functions of Microvilli
- Absorption and digestion
- Digestive enzymes found at cell surface on microvilli
- Digestion occurs at cell surfaces
- Significant cell division within intestinal glands produces new cells that move up
- Once out of the way—rupturing and releasing their digestive enzymes & proteins

Cells of Intestinal Glands
- Absorptive cell
- Goblet cell
- Enteroendocrine
  - secretin
  - cholecystokinin
  - gastric inhibitory peptide
- Paneth cells
  - secretes lysozyme

Goblet Cells of GI epithelium
- Unicellular glands that are part of simple columnar epithelium

Roles of Intestinal Juice & Brush-Border Enzymes
- Submucosal layer has duodenal glands
  - secretes alkaline mucus
- Mucosal layer contains intestinal glands = Crypts of Lieberkuhn (deep to surface)
  - secretes intestinal juice
  - 1-2 qt./day—— at pH 7.6
- brush border enzymes
- paneth cells secrete lysozyme kills bacteria

Intestinal Juice and Brush Border Enzymes
- Intestinal juice provides a vehicle for absorption of substances from chyme as they come in contact with the villi.
- Some intestinal enzymes (brush border enzymes) break down foods inside epithelial cells of the mucosa on the surfaces of their microvilli.
- Some digestion also occurs in the lumen of the small intestine.

Mechanical Digestion in the Small Intestine
- Segmentation, the major movement of the small intestine, is a localized contraction in areas containing food.
- Peristalsis propels the chyme onward through the intestinal tract.
Mechanical Digestion in the Small Intestine

- Weak peristalsis in comparison to the stomach—chyme remains for 3 to 5 hours
- Segmentation—local mixing of chyme with intestinal juices—sloshing back & forth

Chemical Digestion in the Small Intestine

- Carbohydrates are broken down into monosaccharides for absorption.
- Intestinal enzymes break down starches into maltose, maltotriose, and alpha-dextrins (pancreatic amylase); alpha-dextrins into glucose (alphadestrinase); maltose to glucose (maltase); sucrose to glucose and fructose (sucrase); and lactose to glucose and galactose (lactase).

Chemical Digestion in Small Intestine

- Chart page 853—groups enzymes by region where they are found
- Need to trace breakdown of nutrients
  - carbohydrates
  - proteins
  - lipids

Review: Digestion of Carbohydrates

- Mouth—salivary amylase
- Esophagus & stomach—nothing happens
- Duodenum—pancreatic amylase
- Brush border enzymes (maltase, sucrase & lactose) act on disaccharides
  - produces monosaccharides—fructose, glucose & galactose
  - lactose intolerance (no enzyme; bacteria ferment sugar)—gas & diarrhea

Lactose Intolerance

- Mucosal cells of small intestine fail to produce lactase
  - essential for digestion of lactose sugar in milk
  - undigested lactose retains fluid in the feces
  - bacterial fermentation produces gases
- Symptoms
  - diarrhea, gas, bloating & abdominal cramps
- Dietary supplements are helpful

Review: Digestion of Proteins

- Stomach
  - HCl denatures or unfolds proteins
  - pepsin turns proteins into peptides
- Pancreas
  - digestive enzymes—split peptide bonds between different amino acids
  - brush border enzymes—aminopeptidase or dipeptidase
    - enzymes break peptide bonds that attach terminal amino acids to carboxyl ends of peptides (carboxypeptidases)
    - enzymes break peptide bonds that attach terminal amino acids to amino ends of peptides (aminopeptidases)
  - enzymes split dipeptides to amino acids (dipeptidase)
Review: Digestion of Lipids

- Mouth—lingual lipase
- Most lipid digestion, in an adult, occurs in the small intestine.
- Emulsification by bile of globules of triglycerides
- Pancreatic lipase—splits triglycerides into fatty acids & monoglycerides
- No enzymes in brush border

Digestion of Nucleic Acids

- Nucleic acids are broken down into nucleotides for absorption.
- Pancreatic juice contains 2 nucleases
  - Ribonuclease which digests RNA
  - Deoxyribonuclease which digests DNA
- Nucleotides produced are further digested by brush border enzymes (nucleosidase and phosphatase)
  - Pentose, phosphate & nitrogenous bases
- Absorbed by active transport

A summary of digestive enzymes in terms of source, substrate acted on, and product is presented in Table 24.5.

Regulation of Secretion & Motility

- Enteric reflexes that respond to presence of chyme
  - Increase intestinal motility
  - VIP (vasoactive intestinal polypeptide) stimulates the production of intestinal juice
  - Segmentation depends on distention which sends impulses to the enteric plexus & CNS
  - Distention produces more vigorous peristalsis
  - 10 cm per second
  - Sympathetic impulses decrease motility

Absorption in the Small Intestine

- Absorption is the passage of the end products of digestion from the GI tract into blood or lymph and occurs by diffusion, facilitated diffusion, osmosis, and active transport.
Where will the absorbed nutrients go?

Absorption of Monosaccharides
- Essentially all carbohydrates are absorbed as **monosaccharides**.
- They are absorbed into blood capillaries (Figure 24.19 a,b).
- Absorption of Amino Acids, Dipeptides, and Tripeptides
- Most proteins are absorbed as **amino acids** by active transport processes.
- They are absorbed into the blood capillaries in the villus (Figure 24.22a,b).

Absorption of Amino Acids & Dipeptides
- Absorption into epithelial cell
  - active transport with Na⁺ or H⁺ ions (symporters)
  - Movement out of epithelial cell into blood
    - diffusion

Absorption of Lipids
- Small fatty acids enter cells & then blood by simple diffusion
- Larger lipids exist only within micelles (bile salts coating)
- Lipids enter cells by simple diffusion leaving bile salts behind in gut
- Bile salts reabsorbed into blood & reformed into bile in the liver
- Fat-soluble vitamins enter cells since were within micelles
Absorption of Lipids
- Inside epithelial cells fats are rebuilt and coated with protein to form chylomicrons.
- Chylomicrons leave intestinal cells by exocytosis into a lacteal.
- Travel in lymphatic system to reach veins near the heart.
- Removed from the blood by the liver and fat tissue.

Absorption of Electrolytes
- Many of the electrolytes absorbed by the small intestine come from gastrointestinal secretions and some part of digested foods and liquids.
- Enter epithelial cells by diffusion & secondary active transport.
- Sodium & potassium move = Na+/K+ pumps (active transport).
- Chloride, iodide, nitrate = passively follow.
- Iron, magnesium, & phosphate ions = active transport.
- Intestinal Ca²⁺ absorption requires vitamin D & parathyroid hormone.

Absorption of Vitamins
- Fat-soluble vitamins (A, D, E, and K) are included along with ingested dietary lipids.
- Travel in micelles & are absorbed by simple diffusion.
- Water-soluble vitamins (B and C) absorbed by diffusion.
- B₁₂ combines with intrinsic factor before it is transported into the cells.
- Receptor mediated endocytosis.

Absorption of Water
- Figure 24.24 reviews the fluid input to the GI tract.
- All water absorption in the GI tract occurs by osmosis from the lumen of the intestines through epithelial cells and into blood capillaries.
- The absorption of water depends on the absorption of electrolytes and nutrients to maintain an osmotic balance with the blood.
- Table 24.5 summarizes the digestive and absorptive activities of the small intestine and associated accessory structures.

Absorption of Water
- 9 liters of fluid dumped into GI tract each day.
- Small intestine reabsorbs 8 liters.
- Large intestine reabsorbs 90% of the last liter.
- Absorption is by osmosis through cell walls into vascular capillaries inside villi.

LARGE INTESTINE
Anatomy of the Large Intestine
(Figure 24.25b)
- The large intestine (colon) extends from the ileocecal sphincter to the anus.
- Its subdivisions include the cecum, colon, rectum, and anal canal (Figure 24.25a).
- Hanging inferior to the cecum is the appendix.
  - Inflammation of the appendix is called appendicitis.
  - A ruptured appendix can result in gangrene or peritonitis, which can be life-threatening conditions.

Appendicitis
- Inflammation of the appendix due to blockage of the lumen by chyme, foreign body, carcinoma, stenosis, or kinking
- Symptoms
  - high fever, elevated WBC count, neutrophil count above 75%
  - referred pain, anorexia, nausea and vomiting
  - pain localizes in right lower quadrant
  - Infection may progress to gangrene and perforation within 24 to 36 hours

Histology of the Large Intestine
- The mucosa of the large intestine has no villi or permanent circular folds. It does have a simple columnar epithelium with numerous goblet cells (Figure 24.26).
- The muscularis contains specialized portions of the longitudinal muscles called taeniae coli, which contract and gather the colon into a series of pouches called haustra (Figure 24.25a).
- Polyps in the colon are generally slow growing and benign. They should be removed because they may become cancerous.
Mechanical Digestion in Large Intestine

- Mechanical movements of the large intestine include haustral churning, peristalsis, and mass peristalsis.

- Peristaltic waves (3 to 12 contractions/minute)
  - haustral churning—relaxed pouches are filled from below by muscular contractions (elevator)
  - gastriotic reflex = when stomach is full, gastrin hormone relaxes ileocecal sphincter so small intestine will empty and make room
  - gastrocolic reflex = when stomach fills, a strong peristaltic wave moves contents of transverse colon into rectum

Chemical Digestion in Large Intestine

- No enzymes are secreted only mucous
- Bacteria ferment
  - undigested carbohydrates into carbon dioxide & methane gas
  - undigested proteins into simpler substances (indoles)----odor
  - turn bilirubin into simpler substances that produce color
- Bacteria produce vitamin K and B in colon

Absorption & Feces Formation in the Large Intestine

- Some electrolytes—Na+ and Cl-
- After 3 to 10 hours, 90% of H2O has been removed from chyme
- Feces are semisolid by time reaches transverse colon
- Feces = dead epithelial cells, undigested food such as cellulose, bacteria (live & dead)

Absorption and Feces Formation in the Large Intestine

- The large intestine absorbs water, electrolytes, and some vitamins.
- Feces consist of water, inorganic salts, sloughed-off epithelial cells, bacteria, products of bacterial decomposition, and undigested parts of food.
- Although most water absorption occurs in the small intestine, the large intestine absorbs enough to make it an important organ in maintaining the body’s water balance.

Defecation Reflex

- The elimination of feces from the rectum is called defecation.
- Defecation is a reflex action aided by voluntary contractions of the diaphragm and abdominal muscles. The external anal sphincter can be voluntarily controlled (except in infants) to allow or postpone defecation.

Defecation

- Gastrocolic reflex moves feces into rectum
- Stretch receptors signal sacral spinal cord
- Parasympathetic nerves contract muscles of rectum & relax internal anal sphincter
- External sphincter is voluntarily controlled
Defecation Problems

- **Diarrhea** = chyme passes too quickly through intestine
  - H₂O not reabsorbed
- **Constipation** = decreased intestinal motility
  - too much water is reabsorbed
  - remedy = fiber, exercise and water

Applications

- Dietary fiber may be classified as insoluble (does not dissolve in water) and soluble (dissolves in water).
  - Both types affect the speed of food passage through the GI tract
  - Insoluble fiber
    - woody parts of plants (wheat bran, veggie skins)
    - may help protect against colon cancer
  - Soluble fiber
    - gel-like consistency = beans, oats, citrus white parts, apples
    - lowers blood cholesterol by preventing reabsorption of bile salts so liver has to use cholesterol to make more

  Colonoscopy is the visual examination of the lining of the colon using an elongated, flexible, fiberoptic endoscope.
  - Occult blood test is to screen for colorectal cancer.

Review

- Table 24.6 summarizes the digestive activities in the large intestine while Table 24.7 summarizes the organs of the digestive system and their functions.

Regulation of Gastric Secretion and Motility

- Cephalic phase
- Gastric phase
- Intestinal phase

Gastric Secretion and Motility
Cephalic phase

- The cephalic phases is initiated by sensory receptors in the head; prepares the mouth and stomach for food that is about to be eaten.
- Cerebral cortex =sight, smell, taste & thought
  - stimulate parasympathetic nervous system
- The facial and glossopharyngeal nerves stimulate the salivary glands.
- Vagus nerve increases stomach muscle and glandular activity

Gastric Phase = “Stomach Working”

- Nervous control keeps stomach active
  - stretch receptors & chemoreceptors provide information
  - vigorous peristalsis and glandular secretions continue
  - chyme is released into the duodenum
- Endocrine influences over stomach activity
  - distention and presence of caffeine or protein cause G cells secretion of gastrin into bloodstream
  - gastrin hormone increases stomach glandular secretion
  - gastrin hormone increases stomach churning and sphincter relaxation

Intestinal phase

- The intestinal phase begins when food enters the small intestine.
  - Stretch receptors, fatty acids or sugar signals medulla
    - sympathetic nerves slow stomach activity & increase intestinal activity
  - The enterogastric reflex inhibits gastric motility and increases the contraction of the pyloric sphincter to decrease gastric emptying.
  - Hormonal influences
    - secretin stimulates the flow of pancreatic juice rich in bicarbonate, and inhibits the secretion of gastric juice.
    - cholecystokinin (CCK) decreases stomach emptying and stimulates the secretion of pancreatic juice rich in digestive enzymes, and increase the flow of bile
    - gastric inhibitory peptide (GIP) decreases stomach secretions, motility & emptying

Absorption of Nutrients by the Stomach

- Water especially if it is cold
- Electrolytes
- Some drugs (especially aspirin) & alcohol
- Fat content in the stomach slows the passage of alcohol to the intestine where absorption is more rapid
- Gastric mucosal cells contain alcohol dehydrogenase that converts some alcohol to acetaldehyde — more of this enzyme found in males than females
- Females have less total body fluid that same size male so end up with higher blood alcohol levels with same intake of alcohol

Regulation of Gastric Emptying

- Release of chyme is regulated by neural and hormonal reflexes
  - Distention & stomach contents increase secretion of gastrin hormone & vagal nerve impulses
    - stimulate contraction of esophageal sphincter and stomach and relaxation of pyloric sphincter
  - Enterogastric reflex regulates amount released into intestines
    - distension of duodenum & contents of chyme
    - sensory impulses sent to the medulla inhibit parasympathetic stimulation of the stomach but increase secretion of cholecystokinin and stimulate sympathetic impulses
    - inhibition of gastric emptying

Vomiting (emesis)

- Forceful expulsion of contents of stomach & duodenum through the mouth
  - Cause
    - irritation or distension of stomach
    - unpleasant sights, general anesthesia, dizziness & certain drugs
    - Sensory input from medulla cause stomach contraction & complete sphincter relaxation
  - Contents of stomach squeezed between abdominal muscles and diaphragm and forced through open mouth
  - Serious because loss of acidic gastric juice can lead to alkalosis
Other hormones

- Other hormones that have effects on the GI tract are motilin, substance P, bombesin, vasoactive intestinal polypeptide (VIP), gastrin-releasing peptide, and somatostatin.
- Table 24.8 summarizes the major hormones that control digestion.

DEVELOPMENT OF THE DIGESTIVE SYSTEM

- The endoderm of the primitive gut forms the epithelium and glands of most of the gastrointestinal tract (Figure 24.12).
- The mesoderm of the primitive gut forms the smooth muscle and connective tissue of the GI tract.

Endoderm forms primitive gut with help from the splanchnic mesoderm resulting tube is made up of epithelial, glandular, muscle & connective tissue
- Differentiates into foregut, midgut & hindgut
- Endoderm grows into the mesoderm to form salivary glands, liver, gallbladder & pancreas
- Stomodeum develops into oral cavity
- oral membrane ruptures
- Proctodeum develops into anus
- cloacal membrane ruptures

Aging and the Digestive System

- Changes that occur
  - decreased secretory mechanisms
  - decreased motility
  - loss of strength & tone of muscular tissue
  - changes in neurosensory feedback
  - diminished response to pain & internal stimuli
- Symptoms
  - sores, loss of taste, peridontal disease, difficulty swallowing, hernia, gastritis, ulcers, malabsorption, jaundice, cirrhosis, pancreatitis, hemorrhoids and constipation
  - Cancer of the colon or rectum is common

Diseases of the GI Tract

- Dental caries and periodontal disease
- Peptic Ulcers
- Diverticulitis
- Colorectal cancer
- Hepatitis
- Anorexia nervosa
Disorders: Homeostatic Imbalances

Dental caries, or tooth decay, is started by acid-producing bacteria that reside in dental plaque, act on sugars, and demineralize tooth enamel and dentin with acid.

Periodontal diseases are characterized by inflammation and degeneration of the gingivae (gums), alveolar bone, periodontal ligament, and cementum.

Peptic ulcers are crater-like lesions that develop in the mucous membrane of the GI tract in areas exposed to gastric juice. The most common complication of peptic ulcers is bleeding, which can lead to anemia if blood loss is serious. The three well-defined causes of peptic ulcer disease (PUD) are the bacterium Helicobacter pylori; nonsteroidal anti-inflammatory drugs, such as aspirin; and hypersecretion of HCl.

Diverticula are saclike outpouchings of the wall of the colon in places where the muscularis has become weak. The development of diverticula is called diverticulosis. Inflammation within the diverticula, known as diverticulitis, may cause pain, nausea, vomiting, and either constipation or an increased frequency of defecation. High fiber diets help relieve the symptoms.

Hepatitis is an inflammation of the liver and can be caused by viruses, drugs, and chemicals, including alcohol.

Hepatitis A (infectious hepatitis) is caused by hepatitis A virus and is spread by fecal contamination. It does not cause lasting liver damage.

Hepatitis B is caused by hepatitis B virus and is spread primarily by sexual contact and contaminated syringes and transfusion equipment. It can produce cirrhosis and possibly cancer of the liver. Vaccines are available to prevent hepatitis B infection.

Hepatitis C is caused by the hepatitis C virus. It is clinically similar to hepatitis B and is often spread by blood transfusions. It can cause cirrhosis and possibly liver cancer.

Hepatitis D is caused by hepatitis D virus. It is transmitted like hepatitis B and, in fact, a person must be co-infected with hepatitis B before contracting hepatitis D. It results in severe liver damage and has a high fatality rate.

Hepatitis E is caused by hepatitis E virus and is spread like hepatitis A. It is responsible for a very high mortality rate in pregnant women.

Anorexia nervosa is a chronic disorder characterized by self-induced weight loss, body-image and other perceptual disturbances, and physiologic changes that result from nutritional depletion. The disorder is found predominantly in young, single females and may be inherited. Individuals may become emaciated and may ultimately die of starvation or one of its complications. Treatment consists of psychotherapy and dietary regulation.