The Digestive System
Chapter 25

- Digestive functions and processes
- Anatomy of the Digestive System
  - Mouth, Pharynx, Esophagus
  - Gastrointestinal Tract
    - Stomach
    - Liver, Gallbladder, Pancreas
    - Small Intestine
    - Large Intestine (colon)
    - Rectum
    - Anus
Digestive System Functions

- **Ingestion** = intake of food
- **Digestion** = breakdown of complex nutrient molecules into simple nutrient molecules
- **Absorption** = uptake of nutrients into the blood and lymph
- **Defecation** = elimination of undigested material
Stages of Digestion

1. **Mechanical Digestion** is the physical breakdown of food into smaller particles by:
   - chewing with teeth
   - churning with stomach and intestines

2. **Chemical Digestion** is a series of hydrolysis reactions by acid (from the stomach) and enzymes (from saliva, stomach, pancreas, intestines) that break down nutrient macromolecules into their monomers:
   - polysaccharides → monosaccharides
   - proteins (polypeptides) → amino acids
   - fats → glycerol and fatty acids
Anatomy of the Digestive System

- **Digestive tract**
  - 30 foot long tube extending from mouth to anus

- **Accessory organs**
  - teeth, tongue, salivary glands
  - liver and gallbladder
  - pancreas
The Tongue, Pharynx and Larynx
The Tongue

- Dorsal surface is covered by a keratinized stratified squamous epithelium with numerous specialized papillae:
  - Circumvallate Papillae
  - Foliate Papillae
  - Fungiform Papillae
  - Filiform Papillae

- Circumvallate, Foliate and Fungiform papillae have taste buds. Filiform do not.

- Lingual Tonsil(s) contains lymphatic tissue in the root of the tongue

- Foramen Cecum is a shallow pouch that is a remnant of where the thyroid gland formed from the embryonic pharynx
• Circumvallate: 8-12 large, domed papillae arranged in a “V”
• Foliate: low parallel ridges on the lateral edge of tongue
• Fungiform: mushroom-shaped papillae that look like small spots
• Filiform: smallest and most numerous papillae. Conical shape with highly keratinized epithelium and no taste buds.
Filiform Papillae are covered with a keratinized stratified squamous epithelium. They are distributed over the entire anterior surface of the tongue. The stiff tips of the papillae help grip food and since they point backward they help move food towards the pharynx for swallowing.
Circumvallate papillae are covered with a slightly keratinized stratified squamous epithelium. Taste buds are embedded in the epithelium around the papilla. Serous glands (von Ebner’s glands) surround the papillae and release a watery secretion that clears the cleft so the taste buds can respond to new gustatory stimuli.
Taste Buds

- Taste buds are clusters of 50-100 columnar cells in the tongue epithelium. The taste pore is the opening of the taste bud.
- Taste cells have microvilli called “taste hairs” with specific types of taste receptors.
- Taste cells synapse with sensory nerve fibers at their base.
- Basal cells are stem cells that continually replace the sensory and supporting cells.
- Taste buds are also found on the soft palate, epiglottis, and the pharynx.
Taste Pore and Taste Hairs of a Taste Bud
Physiology of Taste

- Molecules must dissolve in saliva to be tasted.
- 5 primary taste sensations:
  1. Sweet
  2. Salty
  3. Sour
  4. Bitter
  5. Umami - meaty, savory taste of the amino acid glutamine and MSG
- Taste is influenced by food texture, aroma, temperature, and appearance.
- Mouthfeel of food is detected by branches of the lingual nerve in papillae
- Hot pepper stimulates free nerve endings sensitive to pain
One of the most dubious “facts” about taste—and one that is commonly reproduced in textbooks—is the oft-cited but misleading “tongue map” showing large regional differences in sensitivity across the human tongue. These maps indicate that sweetness is detected by taste buds on the tip of the tongue, sourness on the sides, bitterness at the back and saltiness along the edges.

Taste researchers have known for many years that these tongue maps are wrong. The maps arose early in the 20th century as a result of a misinterpretation of research reported in the late 1800s, and they have been almost impossible to purge from the literature.

In reality, all qualities of taste can be elicited from all the regions of the tongue that contain taste buds. At present, we have no evidence that any kind of spatial segregation of sensitivities contributes to the neural representation of taste quality, although there are some slight differences in sensitivity across the tongue and palate, especially in rodents.

—D.V.S. and R.F.M.

OUTDATED “TONGUE MAP” has continued to appear in textbooks even though it was based on a misinterpretation of research done in the 19th century.
• **Gingiva (gums)** is a mucous membrane on the alveolar bone around teeth
  
  • **Enamel** covers the crown
    – 90% mineral (hydroxyapatite)
    – only formed during tooth development
    – hardest material in the body
    – irreplaceable
  
  • **Dentin** is 70% mineral and is living, innervated tissue
  
  • **Cementum** surrounds the roots and is 50% mineral much like bone
  
  • **Periodontal Ligament** is composed of collagen fibers that anchors tooth to alveolus – requires Vitamin C
  
  • **Root Canal** leads into pulp cavity and contains nerves and blood vessels

**Anatomical Crown** – part of tooth covered with enamel

**Clinical Crown** – part of tooth exposed above the gingiva (increases with receding gums)
Permanent and Deciduous (Baby) Teeth

(a) Adult dentition at age 6-25 years (b) Baby teeth by 2 years old
Permanent and Deciduous Teeth
Saliva

- **Functions of Saliva**
  - Moisten food, begins digestion, cleanse teeth, inhibit bacteria, bind food together into bolus and lubricate food for swallowing

- **Saliva is a hypotonic solution of 99.5% water with the following solutes:**
  - amylase = begins starch digestion
  - lipase = helps digest fat in the stomach
  - mucus = aids in swallowing
  - lysozyme = enzyme that kills bacteria
  - immunoglobulin A = inhibits bacterial growth
  - electrolytes = $Na^+$, $K^+$, $Cl^-$, phosphate & bicarbonate

- **Saliva pH is 6.8 - 7.0**
Salivary Glands

- 3 pairs of large **extrinsic glands** are connected to the oral cavity by ducts: **parotid**, **submandibular** and **sublingual**
- Small **intrinsic glands** are found throughout the mouth under the mucous membrane of the lips, cheeks and tongue secrete a small amount of saliva all the time.
Salivary duct orifices
- Sublingual
- Submandibular
Salivation

- About 1 to 1.5 L of saliva produced per day.
- Parts of the brain that respond to the sight, smell and thoughts of food can cause salivation.
  - parasympathetic stimulation of salivary glands produces large volume of thin saliva
  - sympathetic stimulation of salivary glands produces small volume of thicker saliva, with more mucus
- Sialoliths are “stones” that can develop in salivary glands or salivary gland ducts.
Layers of the Digestive Tract

• Mucosa
  – epithelium
  – lamina propria (loose CT)
  – muscularis mucosae

• Submucosa
  – loose CT with vessels, nerves and glands

• Muscularis Externa
  – inner circular layer of smooth muscle
  – outer longitudinal layer of smooth muscle

• Adventitia or Serosa
  – areolar tissue or CT capsule
Tissue Layers of the Digestive Tract

1. **Mucosa**
   - Stratified squamous epithelium
   - Lamina propria
   - Muscularis mucosae

2. **Submucosa**
   - Esophageal gland

3. **Muscularis externa**
   - Inner circular layer
   - Outer longitudinal layer

4. **Serosa** (present only inferior to diaphragm)
   - Diaphragm
   - Myenteric nerve plexus
   - Submucosal nerve plexus
   - Lumen
   - Blood vessels
Esophagus

- Straight muscular tube from pharynx to stomach
  - nonkeratinized stratified squamous epithelium of mucosa
  - esophageal glands in submucosa release mucous during swallowing
  - skeletal muscle in upper 1/3 (voluntary control)
  - smooth muscle in lower 1/3 (involuntary control)
  - mix of muscle types in middle 1/3

- Esophagus passes through a hiatus of the diaphragm muscle fibers which forms part of the lower esophageal sphincter

Constriction of diaphragm and the muscularis externa layer of the esophagus helps close cardiac orifice of stomach – failure can result in gastroesophageal reflux of stomach contents into the esophagus. Weak esophageal sphincter can lead to a hiatal hernia.
X-ray of Esophagus during Swallowing

- Upper esophagus
- Peristaltic constriction
- Bolus of ingested matter passing down esophagus
Stomach

• Mechanically breaks up food particles, liquefies the food and begins chemical digestion of protein and fat resulting in a soupy mixture called **chyme**.

• Stomach absorbs some water, alcohol, and some drugs including aspirin.

• Stomach does not absorb a significant amount of nutrients.
Anatomy of the Stomach

• Expandable muscular sac
  – internal volume from 50 ml to 4,000 ml

• Regions of the stomach
  – **cardiac** region just inside cardiac orifice
  – **fundus** is domed portion superior to esophageal opening
  – **body** is main portion of organ
  – **pyloric** region is narrow inferior end that opens into the duodenum
    • region consists of the antrum, pyloric canal and pyloric sphincter
    • pyloric sphincter is a thick ring of smooth muscle
  – **Rugae** are wrinkles and folds of stomach lining that increase surface area for secretions and allow for expansion

  – **Gastroesophageal Junction**
    • abrupt transition from stratified squamous epithelium of the esophagus to simple columnar epithelium of the stomach
Gross Anatomy of the Stomach

- Fundus
- Cardia
- Esophagus
- Longitudinal layer (outer)
- Circular layer (middle)
- Oblique layer (inner)
- Body
- Three layers of smooth muscle
- Lesser curvature
- Greater curvature
- Duodenum
- Pyloric orifice
- Pyloric sphincter
- Pylorus
- Gastric folds
Stomach Innervation and Circulation

• Innervation by parasympathetic fibers and sympathetic fibers.
  – **parasympathetic action** (through acetylcholine) increases digestive processes and blood flow to digestive organs
  – **sympathetic action** (through epinephrine and norepinephrine) decreases digestive processes and blood flow to digestive organs (stomach ache)

• Venous blood from the stomach flows into the hepatic portal system of the liver before returning to the heart and the general circulation.
Features of the Stomach Wall

- **Mucosa**
  - epithelium of simple columnar glands (gastric pits and glands)
  - lamina propria of loose connective tissue containing vessels and nerves
  - muscularis mucosae – thin layer of smooth muscle undulates epithelium

- **Submucosa** is loose CT with vessels and nerves

- **Muscularis Externa** has 3 layers of smooth muscle for mixing chyme
  - outer longitudinal, middle circular, inner oblique

- **Serosa** is a thin smooth connective tissue capsule.
Features of the Stomach Wall

- Lumen of stomach
- Gastric pit
- Epithelium
- Lamina propria
- Mucosa
- Submucosa
- Muscularis externa
- Serosa
- Lymphatic nodule
- Muscularis mucosae
- Artery
- Vein
- Oblique layer of muscle
- Circular layer of muscle
- Longitudinal layer of muscle

(a) Stomach wall
Opening of a Gastric Pit Surrounded by Mucous Cells
Cells of the Gastric Pit and Gastric Glands

- **Mucous Cells** secrete mucus that protects the mucosa.
- **Parietal Cells** secrete HCl and Intrinsic Factor
- **Chief Cells** secrete inactive pepsinogen which must be converted into the active enzyme pepsin by HCl or more pepsin
- **Enteroendocrine Cells** (G Cells) secrete the hormones gastrin and histamine into blood and paracrine messengers that regulate digestion.
- **Regenerative Cells** in base of pit and neck of gland divide rapidly to produce new cells that migrate upwards towards surface and replace old cells. These are not shown in this illustration.
Functions of Gastric Hydrochloric Acid (HCl)

- Stomach pH can be as low as 0.8
- HCl cleaves inactive pepsinogen into the active enzyme pepsin.
- HCl converts ingested ferric ions (Fe$^{+3}$) to nutritious ferrous ions (Fe$^{+2}$) that can be absorbed and used for hemoglobin synthesis.
- HCl breaks up connective tissues in meat and the cellulose cell walls of plants.
- HCl destroys many ingested bacteria and other pathogenic microbes. (one *E. coli* bacterium ingested in the morning can divide into 2 billion cells by 2:00 in the afternoon)
Gastric HCl Secretion

- Parietal cells contain the enzyme carbonic anhydrase (CAH) that speeds up production of carbonic acid:
  \[
  \text{CAH} \quad \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \rightarrow \text{HCO}_3^- + \text{H}^+
  \]
- H⁺/K⁺ ATPase (proton pump) exchanges H⁺ (out) and K⁺ (in).
- HCO₃⁻ exchanged for Cl⁻ (chloride shift)
- Cl⁻ pumped into stomach combines with H⁺ to form HCl
- ↑ HCO₃⁻ in blood causes alkaline tide (↑ blood pH)
- Parietal cells are inhibited by proton pump inhibitors (Prilosec and Nexium, Prevacid) and some antihistamines (H₂ receptor blockers like Pepcid, Tagamet, Zantac)
**Gastric Enzymes and Intrinsic Factor**

- **Pepsin** (from chief cells)
  - pepsin is an enzyme for protein digestion
  - pepsin is secreted as pepsinogen (an inactive enzyme)
  - HCl cleaves pepsinogen into pepsin (active form)
    - pepsin then activates more pepsinogen

- **Gastric Lipase** (from chief cells)
  - lipase digests fats (important in milk digestion in infants)

- **Chymosin** (from chief cells)
  - chymosin coagulates proteins (curdles milk)

- **Intrinsic Factor** (from parietal cells) binds to Vitamin $B_{12}$
  - essential for absorption of $B_{12}$ by small intestine
  - necessary for RBC and Hb production
  - pernicious anemia results when intrinsic factor is lacking
Production and Action of Pepsin in the Stomach

- Parietal cell
  - Produces HCl
- Chief cell
  - Produces pepsinogen (zymogen)
- Pepsinogen
  - Converted to pepsin (active enzyme)
  - Acts on dietary proteins to partially digest them
- Removed peptide
3 Phases of Gastric Function

1. Cephalic Phase
   - sight, smell, taste or thoughts of food trigger vagus nerve to stimulate gastric secretions and motility

2. Gastric Phase
   - activated by presence of food in stomach that stretches the stomach and starts to dilute the stomach acid (chyme becomes more alkaline)
   - gastric secretion is stimulated by activation of parietal cells and chief cells that bind to histamine and gastrin from gastric enteroendocrine cells
   - histamine and gastrin have a paracrine effect on chief cells and parietal cells
3. Intestinal Phase

– duodenum regulates gastric activity through hormones and nervous reflexes

– at first, when the duodenum is stimulated by chyme, it stimulates the stomach by releasing gastrin into the blood stream and the gastrin stimulates chief cells and parietal cells

– later at the end of a meal, the last chyme entering the duodenum stimulates duodenal cells to release 3 hormones that inhibit the stomach and suppress gastric secretions:
  
  • secretin
  
  • gastric inhibitory peptide (GIP)
  
  • cholecystokinin (CCK)
1. **Cephalic phase**
   - Vagus nerve stimulates gastric secretion even before food is swallowed.

2. **Gastric phase**
   - Food stretches the stomach and activates myenteric and vagovagal reflexes. These reflexes stimulate gastric secretion. Histamine and gastrin also stimulate acid and enzyme secretion.

3. **Intestinal phase**
   - Intestinal gastrin briefly stimulates the stomach, but then secretin, GIP, CCK, and the enterogastric reflex inhibit gastric secretion and motility while the duodenum processes the chyme already in it. Sympathetic nerve fibers suppress gastric activity, while vagal (parasympathetic) stimulation of the stomach is now inhibited.
Food moves from the Stomach into the Small Intestine

- Most chemical digestion and nutrient absorption occurs in the small intestine
Gross Anatomy of Small Intestine

• Duodenum curves around head of pancreas
  – approximately 10 inches or “12 fingers” long
    • Greek 14th Century “intestinum duodenum digitorum”
  – retroperitoneal along with pancreas
  – receives stomach contents, pancreatic juice and bile

• Jejunum is next 8 ft. (in upper abdomen)
  – covered with serosa and suspended by mesentery

• Ileum is last 12 ft. (in lower abdomen)
  – covered with serosa and suspended by mesentery
  – ends at ileocecal junction with large intestine
Gross Anatomy of the Small Intestine

- Duodenum
- Duodenojejunal flexure
- Jejunum
- Ileocelecal valve
- Ileum
Surface Area of Small Intestine

- Plicae Circulares (circular folds) up to 10 mm tall
  - increase surface area 3 x vs a smooth tube
- Villi are fingerlike projections 1 mm tall on the plicae circulares
  - covered with absorptive epithelium and contain blood vessels, lymphatics (lacteals), smooth muscle fibers
  - increase SA 10 x
- Microvilli 1 micron tall
  - folds of plasma membrane on absorptive cells forms a brush border supported by actin microfilaments
  - increase SA 20 x
Plicae Circulaires, Villi and Microvilli

- Inner Circular Smooth Muscle
- Outer Longitudinal Smooth Muscle
- Submucosa
- Plica Circularis
- Villus
- Goblet cell
- Mucous
- Absorptive Cells
- Microvilli
- Goblet cell
Intestinal Crypts

• Pores opening between villi lead to intestinal crypts (of Lieberkuhn)
  – crypts are lined with absorptive cells, goblet cells, Paneth cells and rapidly dividing cells at the base
  – life span of cells is 3-6 days as cells migrate up to surface and get sloughed off and digested
  – Paneth cells produce antibacterial secretions
Liver, Gallbladder and Pancreas

• Liver and Pancreas are vital accessory glands to the intestines.
• Liver and Pancreas release important secretions into the duodenum.
• Liver and Pancreas secretions continue the digestion process.
Liver

- 3 lb. organ with 4 lobes located right upper quadrant of abdomen
- blood supply from hepatic portal vein and hepatic arteries
- produces bile (stored in gall bladder) and plasma proteins (coagulation factors, albumen and many others)
- liver cells store minerals, vitamins, glycogen that can be released into blood as needed
- detoxifies blood from ammonia, plant toxins, poisons, alcohol and other drugs
- Can regenerate after some diseases or surgical removal of part.
Veins of Hepatic Portal System

- Liver
- Hepatic portal v.
- Gallbladder
- Inferior vena cava
- Colon
- Rectum
- Hepatic vv.
- Spleen
- Splenic v.
- R. gastroepiploic v.
- Inferior mesenteric v.
- Superior mesenteric v.
- Ileum

{(b)}
Liver functional units are tiny cylinders called lobules (about 1mm diameter).

Blood, from portal vein and hepatic artery mixes and flows through capillaries over hepatocytes on way to central vein.

Hepatocytes secrete bile into tiny canaliculi that flow into bile ductules that flow toward the gall bladder.
Ducts of Gallbladder, Liver, Pancreas

• Hepatocytes secrete bile into **bile canaliculi** in between the hepatocytes. All the bile from the canaliculi eventually flows into the **right and left hepatic ducts**.

• Right and left hepatic ducts join to form **common hepatic duct**.

• **Cystic duct** from gallbladder joins common hepatic duct to form the **common bile duct**.

• **Pancreatic duct** and common bile duct merge at the **hepatopancreatic ampulla** that empties into the duodenum at the major duodenal papilla
  – sphincter of Oddi (hepatopancreatic sphincter) regulates release of bile and pancreatic fluid (juice)
Ducts of Liver, Gallbladder and Pancreas

1) left and right hepatic ducts merge to form a common hepatic duct

2) common hepatic duct and cystic duct merge to form a common bile duct

3) pancreatic duct merges with common bile duct at hepatopancreatic ampulla

4) bile and pancreatic fluid enter duodenum through major duodenal papilla
Gallbladder and Bile

- Liver produces about 500 to 1000 ml bile each day.
- Gallbladder stores and concentrates bile
  - Bile backs up into the gallbladder between meals when the hepatopancreatic sphincter (sphincter of Oddi) is closed.
  - Between meals, bile is concentrated by 20 x by a highly folded mucosa.
- Bile is a yellow-green fluid containing minerals, fats, bile pigments, and bile acids.
  - **bile pigments** are from the breakdown of hemoglobin from old RBCs destroyed by macrophages in the liver. Bilirubin is the primary pigment and is green-yellow in color. Bile pigments are excreted as waste.
    - intestinal bacteria convert bile pigments into the brown pigment, urobilinogen which gives a brown color to feces. In the absence of bile secretion, as in liver disease, feces are grayish white and streaked with undigested fat.
  - **bile acids (bile salts)** emulsify fats and aid in their digestion
    - enterohepatic circulation recycles 80% of the bile from the ileum
  - **cholesterol, phospholipids, lecithin** in the bile help make lipids more soluble in water.
Fat Emulsification and Absorption

1) Fat globules are broken up into emulsification droplets by the lecithin and bile acids in the bile.

2) Emulsification droplets are hydrolyzed (digested) by pancreatic lipase into simpler fatty acids and smaller fat droplets coated with bile acids called micelles.

3) Micelles are absorbed through the brush border of intestinal absorptive cells. Intestinal cells resynthesize triglycerides and package them with cholesterol and phospholipids into chylomicrons.

4) The Golgi of intestinal cells packages chylomicrons into secretory vesicles that are release from their basal surface and then absorbed into lymphatic lacteals.
Fat Emulsification

Fat globule

Lecithin

Hydrophilic region
Hydrophobic region
Bile acid

Emulsification droplets

Fat globule is broken up and coated by lecithin and bile acids.
Fat Digestion and Micelle Formation

Fat hydrolysis
- Pancreatic lipase
- Lecithin
- Bile acid
- Dietary lipid

Pancreatic lipase
- Triglyceride → Monoglyceride → Free fatty acid

Emulsification droplets are acted upon by pancreatic lipase, which hydrolyzes the first and third fatty acids from triglycerides, usually leaving the middle fatty acid.

Micelle formation
- Monoglycerides
- Cholesterol
- Fatty acids
- Fat-soluble vitamins

Lipid core
- Several types of lipids form micelles coated with bile acids.
Fat Absorption

Chylomicron formation

- Fatty acids
- Monoglycerides
- Triglycerides
- Phospholipids
- Cholesterol
- Protein shell
- Chylomicron

Micelles
Brush border
Absorptive cell

Intestinal cells absorb lipids from micelles, resynthesize triglycerides, and package triglycerides, cholesterol, and phospholipids into protein-coated chylomicrons.

Chylomicron exocytosis and lymphatic uptake

- Chylomicrons in secretory vesicles
- Lacteal
- Chylomicrons in lymph
- Golgi complex packages chylomicrons into secretory vesicles; chylomicrons are released from basal cell membrane by exocytosis and enter the lacteal (lymphatic capillary) of the villus.
Gallstones
Gross Anatomy of the Pancreas

• Retroperitoneal gland posterior to stomach
  – head, body and tail regions

• Contains Endocrine and Exocrine tissue
  – secretes insulin and glucagon into the blood
  – secretes 1500 ml exocrine fluid into duodenum per day that contains water, enzymes, and bicarbonate

• Pancreatic Duct runs length of gland and opens at the major duodenal papilla when the hepatopancreatic sphincter relaxes
  – accessory duct (if present) opens independently in duodenum
Hormonal Control of the Liver and Pancreas

- **Cholecystokinin** released from duodenum into blood in response to arrival of acid and fat
  - causes secretion of pancreatic enzymes, contraction of gallbladder, and relaxation of hepatopancreatic sphincter

- **Secretin** released from duodenum into blood in response to acidic chyme
  - stimulates pancreatic ducts to secrete more bicarbonate

- **Gastrin** released from stomach and duodenum into blood also stimulates gallbladder contraction and pancreatic enzyme secretion
Pancreatic Acinar Cells

- Acinar Cells release Zymogen Granules of:
  - trypsinogen
  - chymotrypsinogen
  - procarboxypeptidase
  - amylase
  - lipase
  - ribonuclease and deoxyribonuclease
Activation of Pancreatic Enzymes by the Brush Border of the Small Intestine
Protein Digestion in Stomach

- Pepsin has optimal pH of 1.5 to 3.5 and is inactivated when it passes into the duodenum and mixes with alkaline pancreatic fluid (pH 8)

Pepsin (▲) hydrolyzes certain bonds peptide and breaks protein down into smaller polypeptides.
Pancreatic enzymes (trypsin, chymotrypsin and carboxypeptidase) continue to digest proteins in the intestines by hydrolyzing polypeptides into shorter polypeptides
Protein Digestion and Absorption in Small Intestine

- Brush border enzymes (Peptidases) cleave small proteins into simple amino acids that are absorbed into the intestinal epithelial cells.
- Cotransporters move amino acids into epithelial cells and facilitated diffusion moves amino acids into the blood stream.
Carbohydrate Digestion in Small Intestine

- Salivary amylase stops working in acidic stomach (at pH < 4.5)
- Pancreatic amylase completes starch digestion in intestines.
- Brush border enzymes break down polysaccharides including sucrose and lactose
  - Most humans produce less lactase after age 4 making lactose less digestible (lactose intolerance)
Monosaccharide Sugar Absorption

- membrane transport proteins absorb monosaccharides from the intestines
- Some transport proteins move sugars via sodium-glucose transporters (SGLT)
- Some sugar is absorbed with water between cells
Vitamins and Minerals

- Vitamins are absorbed unchanged
  - A, D, E, K are absorbed with other lipids
  - B complex and Vitamin C are absorbed by simple diffusion
  - $\text{B}_{12}$ is only absorbed if bound to intrinsic factor
- Minerals are absorbed throughout the intestines.
Intestinal Motility

• Movement of intestines mixes chyme with intestinal secretions, bile and pancreatic fluid and increases contact with mucosa for absorption and digestion.
  – segmentation is random ring-like constrictions that mix and churn contents about 12 times per minute
  – peristaltic waves push chyme through small intestines towards colon. Takes *about* 2 hours

• Food in stomach causes gastroileal reflex (relaxes ileocecal valve between small and large intestine) and may cause the urge to defecate as the colon fills.
Segmentation in the Small Intestine

Purpose of segmentation is to mix intestinal contents, not to move material along as in peristalsis.
Peristalsis

- Waves of contraction that gradually move contents towards the colon
- Begin after absorption starts
Gross Anatomy of Large Intestine

- Right colic flexure
- Transverse colon
- Superior mesenteric artery
- Hastrum
- Ascending colon
- Ileocecal valve
- Ileum
- Cecum
- Vermiform appendix
- Rectum
- Anal canal
- Greater Omentum
- Left colic flexure
- Epiploic appendages
- Descending colon
- Tenia coli
- Sigmoid colon
- External anal sphincter
Gross Anatomy of Large Intestine

- Large intestine is also called the colon
- 5 feet long and 2.5 inches in diameter
- Begins at cecum in lower right quadrant and leads to ascending, transverse, descending and sigmoid portions.
- Sigmoid colon is S-shaped portion leading down to the rectum in the pelvis
- Rectum is straight portion ending at anus
- Lining of colon is smooth with only a few folds and no villi.
- Muscularis Externa
  - longitudinal muscle fibers called teniae coli run the length of the colon
  - haustra coli are lateral pouches along the length of the colon
Microscopic Anatomy of Large Intestine

• Mucosa is simple columnar epithelium
  – epithelium consists of absorptive cells and goblet cells
  – epithelium transitions to a stratified squamous epithelium at the anus

• Intestinal Glands produce mucus only
**Water Balance**

- Water is absorbed by osmosis through absorptive cells following a gradient established by the absorption of salts, vitamins and organic nutrients.

- Diarrhea occurs when too little water is absorbed from the feces. Diarrhea occurs when:
  - feces pass through too quickly when the mucosa is irritated.
  - feces may contain high concentrations of a solute, like lactose (from lactose intolerance) that osmotically keeps water in the feces.
Bacterial and Intestinal Gas

- Bacteria, including *Escherichia coli* and many others, live symbiotically in the large intestine.
  - synthesize vitamins B and K
  - ferment some cellulose and other undigested carbohydrates
  - average person produces 500 mL per day of gas (flatus)
  - most is swallowed air but it can contain gases produced by bacteria including odorless methane and odorous gasses including hydrogen sulfide, indole and skatole.
Colon Absorption and Motility

• Transit time is 12 to 24 hours
  – reabsorbs water and electrolytes

• Feces consist of water and solids (bacteria, mucus, undigested fiber, fat, sloughed epithelial cells)

• Contractions occur about every 30 minutes
  – distension of the colon stimulates it to contract

• Mass movements usually occur 1 to 3 times a day
Appendix

- The appendix is a thin, closed tube attached to the cecum.
- The submucosa contains numerous lymphoid follicles that contain abundant lymphocytes that play a role in immunity.
- The appendix receives small amounts of processed food and can respond to dangerous antigens.
- Infection and inflammation of the mucosa of the appendix can lead to pain, swelling and possible rupture that could lead to peritonitis.
- The appendix contains a diverse population of intestinal bacteria, and many types are beneficial to human health.
- After severe, chronic diarrhea, as caused by diseases such as cholera or amoebic dysentery, the gut may be cleared of bacteria except in the appendix and those bacteria can help repopulate the colon with a normal flora faster than individuals without an appendix.
- http://www.dukemagazine.duke.edu/issues/030408/depqa.html
McBurney’s point (on spinoumbilical line)

Variations in position of appendix
Anatomy of the Rectum and Anus

- Anal canal is about 3 cm total length
- Anal columns are longitudinal ridges separated by mucus secreting anal sinuses
- Hemorrhoids are distended veins in the lamina propria
END