



# Physiology of Digestive System

By

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3<sup>rd</sup> Year/ Lecture 4

# The Small Intestine

- ▶ Nearly all chemical digestion and nutrient absorption occurs in the small intestine
- ▶ The longest part of the digestive tract
  - ▶ 2.7 to 4.5 m long in a living person
  - ▶ 4 to 8 m long in a cadaver where there is no muscle tone
- ▶ “Small” intestine refers to the diameter—not length
  - ▶ 2.5 cm (1 in.)

# The Small Intestine

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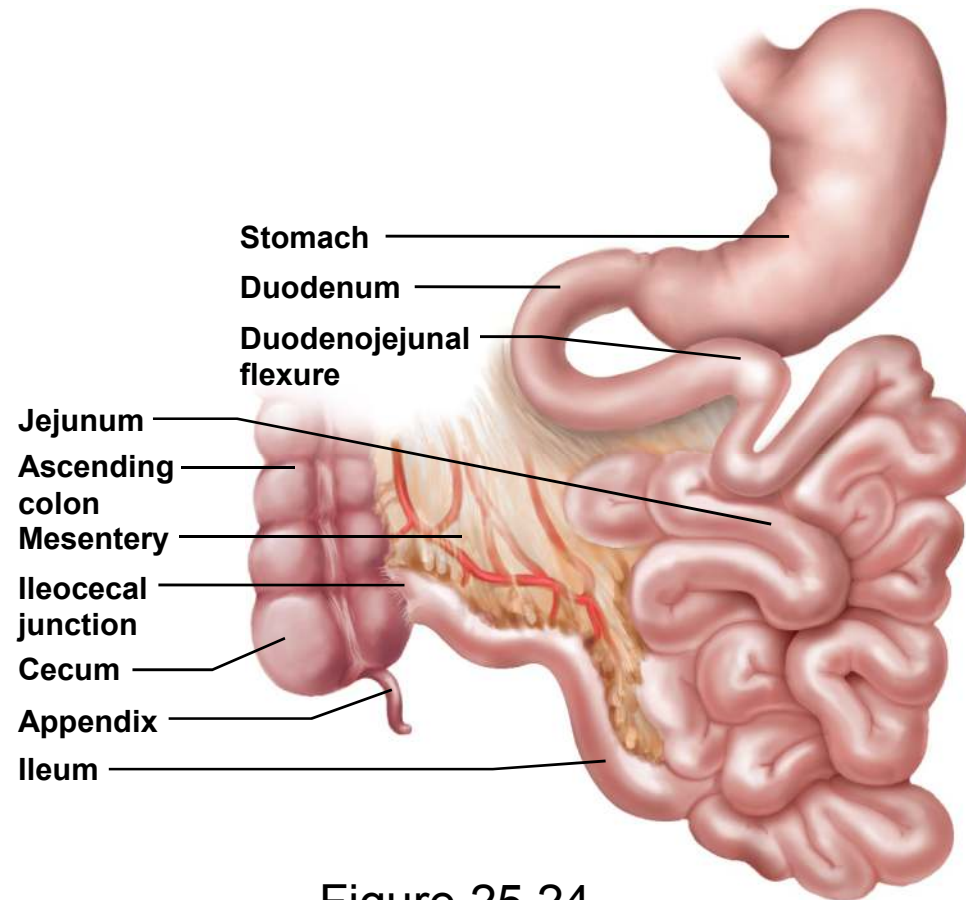


Figure 25.24

# Gross Anatomy

- ▶ Small intestine—coiled mass filling most of the abdominal cavity inferior to the stomach and the liver
- ▶ Small intestine divided into three regions
  - ▶ Duodenum: first 25 cm (10 in.)
    - ▶ Begins at the pyloric valve
      - ▶ Major and minor duodenal papilla distal to pyloric valve
      - ▶ Receives major and minor pancreatic ducts respectively
    - ▶ Arches around the head of the pancreas
    - ▶ Ends at a sharp bend called the duodenojejunal flexure

# Gross Anatomy

Cont.

- ▶ Most is retroperitoneal
- ▶ Receives stomach contents, pancreatic juice, and bile
- ▶ Stomach acid is neutralized here
- ▶ Fats are physically broken up (emulsified) by the bile acids
- ▶ Pepsin is inactivated by increased pH
- ▶ Pancreatic enzymes take over the job of chemical digestion

# Gross Anatomy

## ▶ Three regions

- ▶ Jejunum: follows duodenum = 40% of small intestine beyond duodenum
  - ▶ Roughly 1.0 to 1.7 m in a living person
  - ▶ Has large, tall, closely spaced circular folds
  - ▶ Its wall is relatively thick and muscular
  - ▶ Especially rich blood supply which gives it a red color
  - ▶ Most digestion and nutrient absorption occurs here

# Gross Anatomy

Cont.

- ▶ Ileum: forms the last 60% of the postduodenal small intestine
  - ▶ About 1.6 to 2.7 m
  - ▶ Thinner, less muscular, less vascular, and paler pink color
  - ▶ Peyer patches—prominent lymphatic nodules in clusters on the side opposite the mesenteric attachment
    - ▶ Readily visible with the naked eye
    - ▶ Become progressively larger approaching the large intestine

# Gross Anatomy

- ▶ Ileocecal junction—end of the small intestine
  - ▶ Where the ileum joins the cecum of the large intestine
- ▶ Ileocecal valve—a sphincter formed by the thickened muscularis of the ileum
  - ▶ Protrudes into the cecum
  - ▶ Regulates passage of food residue into the large intestine
- ▶ Both jejunum and ileum are intraperitoneal and covered with serosa



# Microscopic Anatomy

- ▶ Tissue layers have modifications for nutrient digestion and absorption
  - ▶ Lumen lined with simple columnar epithelium
  - ▶ Muscularis externa is notable for a thick inner circular layer and a thinner outer longitudinal layer
  - ▶ Large internal surface area for effective digestion and absorption: by great length and three types of internal folds or projections
    - ▶ Circular folds (plicae circulares)—increase surface area by a factor of 2 to 3
    - ▶ Villi—increase surface area by a factor of 10
    - ▶ Microvilli—increase the surface area by a factor of 20

# Microscopic Anatomy

- ▶ Circular folds (plicae circulares)—largest folds of intestinal wall
  - ▶ Up to 10 mm high
  - ▶ Involve only mucosa and submucosa
  - ▶ Occur from the duodenum to the middle of the ileum
  - ▶ Cause chyme flow in spiral path causing more contact with mucosa
  - ▶ Promotes more thorough mixing and nutrient absorption
  - ▶ Relatively small and sparse in ileum and not found in distal half
    - ▶ Most nutrient absorption is completed by this point

# Microscopic Anatomy

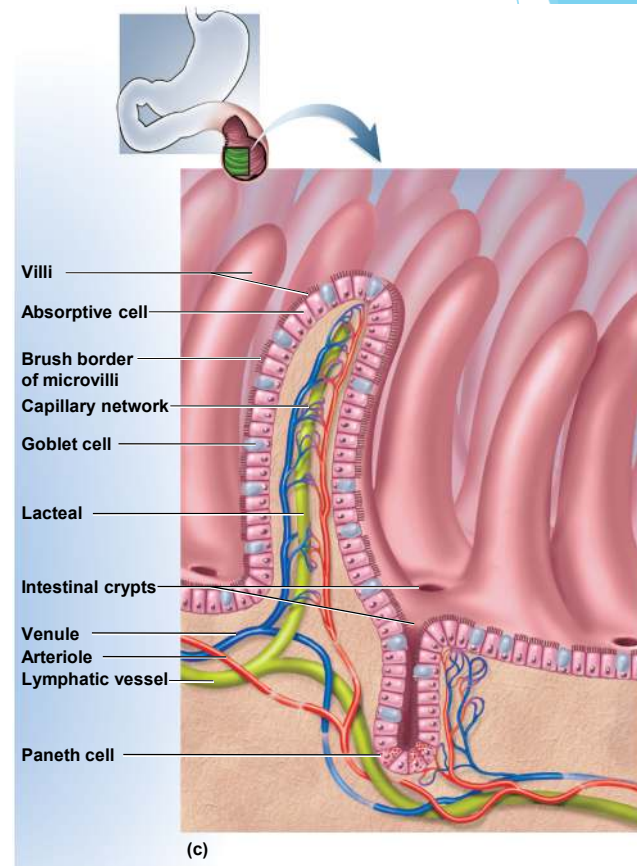
- ▶ Villi—fingerlike projections 0.5 to 1 mm tall
  - ▶ Make mucosa look fuzzy
  - ▶ Villus covered with two types of epithelial cells
    - ▶ Absorptive cells (enterocytes)
    - ▶ Goblet cells—secrete mucus
  - ▶ Epithelia joined by tight junctions that prevent digestive enzymes from seeping between them
- ▶ Core of villus filled with areolar tissue of the lamina propria
  - ▶ Embedded in this tissue are an arteriole, a capillary network, a venule, and a lymphatic capillary called a lacteal

# Microscopic Anatomy

- ▶ Microvilli—fuzzy border on apical surface of each absorptive cell
  - ▶ About 1  $\mu\text{m}$  high
  - ▶ Brush border increases absorptive surface area

Figure 25.25c

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# Microscopic Anatomy

- ▶ Brush border enzymes—  
contained in the plasma  
membrane of microvilli
  - ▶ Carry out some of the final stages of  
enzymatic digestion
  - ▶ Not released into the lumen
  - ▶ Contact digestion: chyme must contact  
the brush border for digestion to occur
  - ▶ Intestinal churning of chyme ensures  
contact with the mucosa

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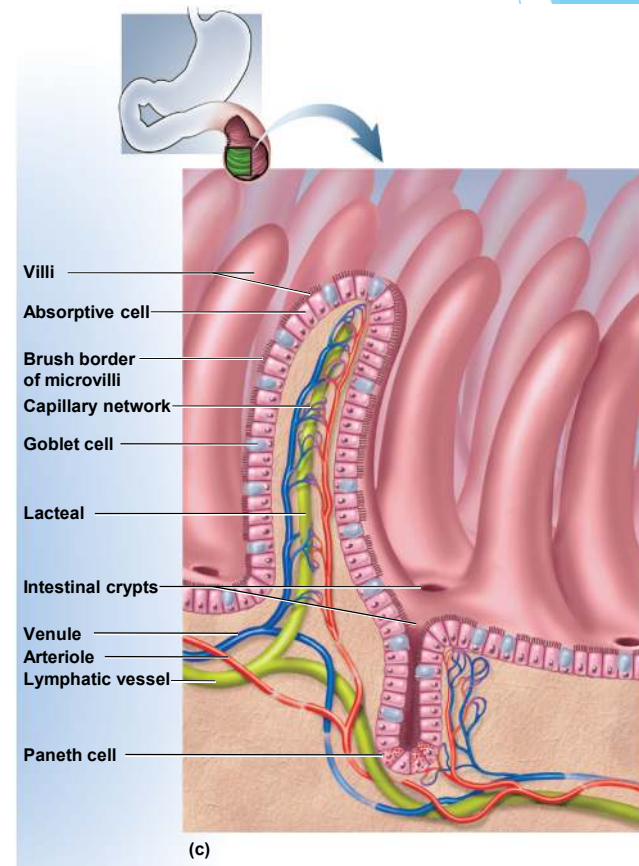


Figure 25.25c

# Microscopic Anatomy

- ▶ Intestinal crypts (crypts of Lieberkühn)—numerous pores that open into tubular glands on the floor of the small intestine between bases of the villi
  - ▶ Similar to gastric glands
  - ▶ In upper half, have enterocytes and goblet cells like the villi
  - ▶ In lower half, dominated by dividing stem cells
    - ▶ Life span of 3 to 6 days
    - ▶ New epithelial cells migrate up the crypt to the tip of the villus where it is sloughed off and digested
  - ▶ A few Paneth cells are clustered at the base of each crypt
    - ▶ Secrete lysozyme, phospholipase, and defensins—defensive proteins that resist bacterial invasion of the mucosa

# Microscopic Anatomy

- ▶ Duodenal glands—in submucosa of duodenum
  - ▶ Secrete an abundance of bicarbonate-rich mucus
  - ▶ Neutralize stomach acid and shield the mucosa from its erosive effects
- ▶ Large population of defensive lymphocytes throughout lamina propria and submucosa of small intestine
  - ▶ Intercept pathogens before they can invade the bloodstream
  - ▶ Aggregated into lymphatic nodules in ileum: Peyer patches

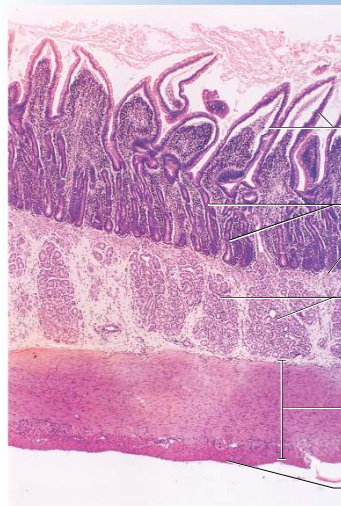


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## Intestinal Villi



(a)

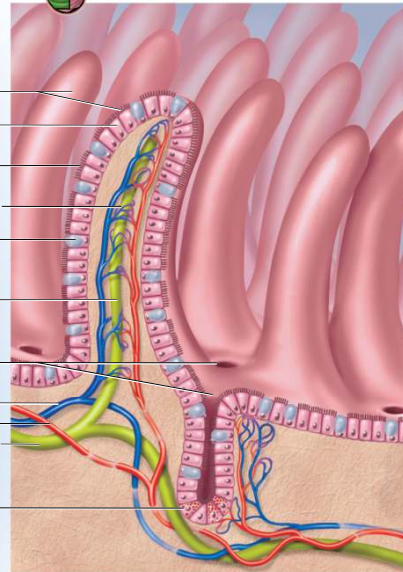


(b)

0.5 mm



Villi  
Absorptive cell  
Brush border of microvilli  
Capillary network  
Goblet cell  
Lacteal  
Intestinal crypts  
Venule  
Arteriole  
Lymphatic vessel  
Paneth cell



(c)

Villi  
Intestinal crypts  
Muscularis mucosae  
Duodenal glands  
Muscularis externa  
Serosa

Figure 25.25a–c

a: © Meckes/Ottawa/Photo Researchers, Inc.; b: © The McGraw-Hill Companies, Inc./Dennis Strete, photographer



# Intestinal Secretion

- ▶ Intestinal crypts secrete 1 to 2 L of intestinal juice per day
  - ▶ In response to acid, hypertonic chyme, and distension of the intestines
  - ▶ pH of 7.4 to 7.8
  - ▶ Contains water, mucus, and little enzyme
    - ▶ Most enzymes that function in the small intestine are found in the brush border and pancreatic juice

# Intestinal Motility

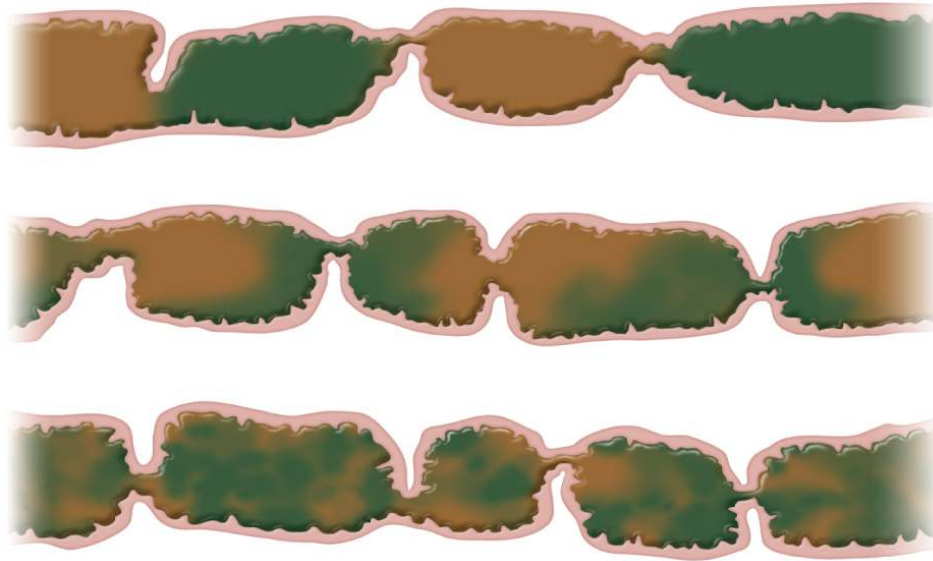
- ▶ Contractions of small intestine serve three functions
  - ▶ To mix chyme with intestinal juice, bile, and pancreatic juice
    - ▶ To neutralize acid
    - ▶ Digest nutrients more effectively
  - ▶ To churn chyme and bring it in contact with the mucosa for contact digestion and nutrient absorption
  - ▶ To move residue toward large intestine

# Intestinal Motility

- ▶ Segmentation—movement in which stationary ringlike constrictions appear in several places along the intestine
  - ▶ They relax and new constrictions form elsewhere
  - ▶ Most common kind of intestinal contraction
  - ▶ Pacemaker cells in muscularis externa set rhythm of segmentation
    - ▶ Contractions about 12 times per minute in the duodenum
    - ▶ 8 to 9 times per minute in the ileum
    - ▶ When most nutrients have been absorbed and little remains but undigested residue, segmentation declines and peristalsis begins

# Contractions of the Small Intestine

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**(a) Segmentation**

Figure 25.26a

- ▶ Purpose of segmentation is to mix and churn, not to move material along as in peristalsis

# Intestinal Motility

- ▶ Gradual movement of contents toward colon
- ▶ Peristaltic wave begins in duodenum, travels 10 to 70 cm and dies out
- ▶ Followed by another wave starting further down the tract
- ▶ Migrating motor complex—successive, overlapping waves of contraction
- ▶ Milk chyme toward colon over a period of 2 hours

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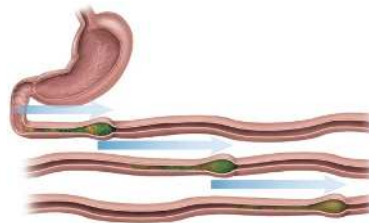


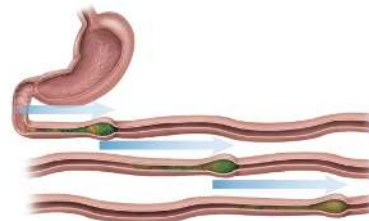
Figure 25.26b

(b) Peristalsis

# Intestinal Motility

- ▶ Ileocecal valve usually closed
  - ▶ Food in stomach triggers gastroileal reflex that enhances segmentation in the ileum and relaxes the valve
  - ▶ As cecum fills with residue, pressure pinches the valve shut
    - ▶ Prevents reflux of cecal contents into the ileum

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(b) Peristalsis

Figure 25.26b

# Chemical Digestion and Absorption



# Carbohydrates

- ▶ Starch—the most digestible carbohydrate
  - ▶ Cellulose is indigestible
  - ▶ Starch is first digested to:
    - ▶ Oligosaccharides up to eight glucose residues long
    - ▶ Then into the disaccharide maltose
    - ▶ Finally to glucose which is absorbed by the small intestine



# Carbohydrates

- ▶ Process begins in the mouth
  - ▶ Salivary amylase hydrolyzes starch into oligosaccharides
  - ▶ Amylase works best at pH of 6.8 to 7.0 of oral cavity
  - ▶ Amylase quickly denatured on contact with stomach acid and digested by pepsin

# Carbohydrates

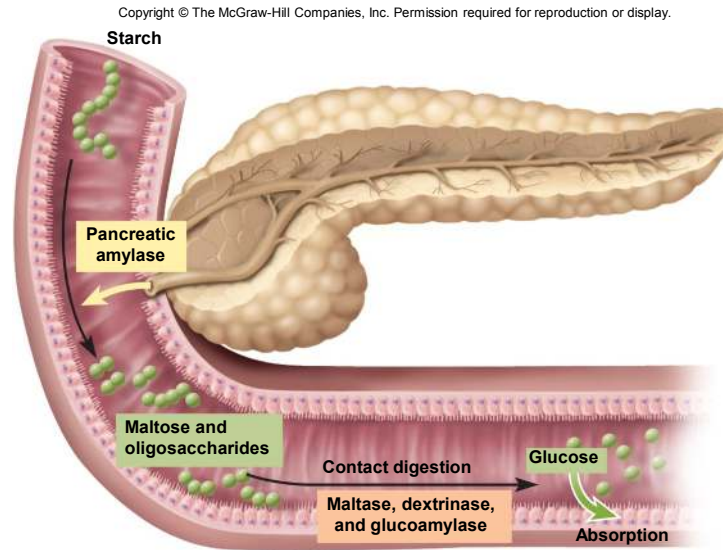


Figure 25.27

- ▶ Salivary amylase stops working in stomach at pH less than 4.5
  - ▶ 50% of dietary starch digested before it reaches small intestine

# Carbohydrates

- ▶ When reaching the small intestine, pancreatic amylase converts starch to oligosaccharides and maltose within 10 min.
- ▶ Oligosaccharides and maltose contact brush border enzymes (dextrinase, glucoamylase, maltase, sucrase, and lactase) and act upon oligosaccharides, maltose, sucrose, lactose, and fructose to glucose
  - ▶ Lactose becomes indigestible after age 4 in most humans due to decline in lactase production: lactose intolerance

# Carbohydrates

- ▶ Plasma membrane of the absorptive cells has transport proteins that absorb monosaccharides as soon as the brush border enzymes release them
- ▶ 80% of absorbed sugar is glucose
  - ▶ Taken up by sodium-glucose transport (SGLT) proteins
  - ▶ Glucose is transported out the base of absorptive cell into ECF by facilitated diffusion
  - ▶ Sugar entering ECF increases its osmolarity
  - ▶ Draws water osmotically from the lumen of the intestine, through now leaky tight junctions between epithelial cells
  - ▶ Water carries more glucose and other nutrients with it by solvent drag

# Carbohydrates

- ▶ SGLT absorbs galactose, fructose is absorbed by facilitated diffusion
- ▶ Glucose, galactose, and any remaining fructose are transported out of the base of the cell by facilitated diffusion
- ▶ Absorbed by blood capillaries in the villus
- ▶ Hepatic portal system delivers them to the liver

# Lactose Intolerance

- ▶ Lactose passes undigested into large intestine
  - ▶ Increases osmolarity of intestinal contents
  - ▶ Causes water retention in the colon and diarrhea
  - ▶ Gas production by bacterial fermentation of the lactose
- ▶ Occurs in many parts of the population
  - ▶ 15% of American whites, 90% of American blacks, 70% of Mediterraneans; and nearly all of Asian descent
- ▶ Can consume yogurt and cheese since bacteria have broken down the lactose