Chapter 22 – Digestion and Nutrient Absorption

Objectives

Given the synopsis in this chapter, competence in each objective will be demonstrated by writing short essays, drawing diagrams, and responding to multiple choices or matching questions, at the level of 85% or greater proficiency for each student.

A. To describe the general organization and function of the digestive system.
B. To explain the movement of food and digestion in the mouth and esophagus.
C. To explain the movement of food and digestion in the stomach.
D. To explain the movement of food through the small intestine and the interconnection of the small intestines with the pancreas and liver.
E. To explain the digestion and absorption of carbohydrates in the small intestines.
F. To explain the digestion and absorption of proteins in the small intestines.
G. To explain the digestion and absorption of fats in the small intestines.
H. To explain the movement of food and absorption in the large intestines.
I. To explain how the parasympathetic and sympathetic nervous systems control the gastrointestinal tract, pancreas, and liver.
J. To explain how gastrointestinal hormones control the gastrointestinal tract, pancreas, and liver.

The digestive system includes the gastrointestinal tract, the mouth, pharynx, esophagus, stomach, small intestines, and large intestines; and the accessory organs, the salivary glands, liver, gallbladder, and pancreas. The primary purpose of the digestive system is to convert food into molecular forms that can be transferred along with water and minerals into the blood and used by cells of the body. Accordingly, the digestive system is concerned with digestion, the process of breaking down food; absorption, the process of moving molecules across the epithelial cells of the gastrointestinal tract; and motility, the process of moving food through the gastrointestinal tract by smooth muscle contraction. The gastrointestinal system is under the control of an enteric nervous and endocrine system and by the central nervous system.

Movement of Food, Digestion, and Absorption

Food moves through the gastrointestinal tract by way of coordinated contraction and relaxation of smooth muscle. Contractions are controlled by the enteric nervous system and by the parasympathetic and sympathetic nervous systems. The enteric nervous system is a separate and relatively independent system of neurons in the walls of the gastrointestinal tract that coordinate the contraction and relaxation of smooth muscle and the release of many gastrointestinal secretions. These neurons are modulated by the parasympathetic and sympathetic nervous systems.

Most of the food we consume is composed of large molecules such as proteins, polysaccharides, and fats which are unable to cross the intestinal epithelium. Food must therefore be dissolved and broken down into small molecules that can transfer out of the intestine and into the blood. This process is digestion and is accomplished by salivary enzymes in the mouth; hydrochloric acid and gastric enzymes in the stomach; and by bile from the liver, and a variety of intestinal and pancreatic enzymes in the small intestines.

Mouth and Esophagus

A sagittal view of the mouth, oropharynx, and esophagus is shown in Figure 22.1. The mouth is mainly involved in chewing the food, which is a mechanical process rather than a chemical process. As a matter of fact, chewing and mixing the food with saliva is not necessary for digestion, it mainly makes swallowing easier. Nonetheless saliva starts some chemical digestion in the mouth, especially the breakdown of polysaccharides.

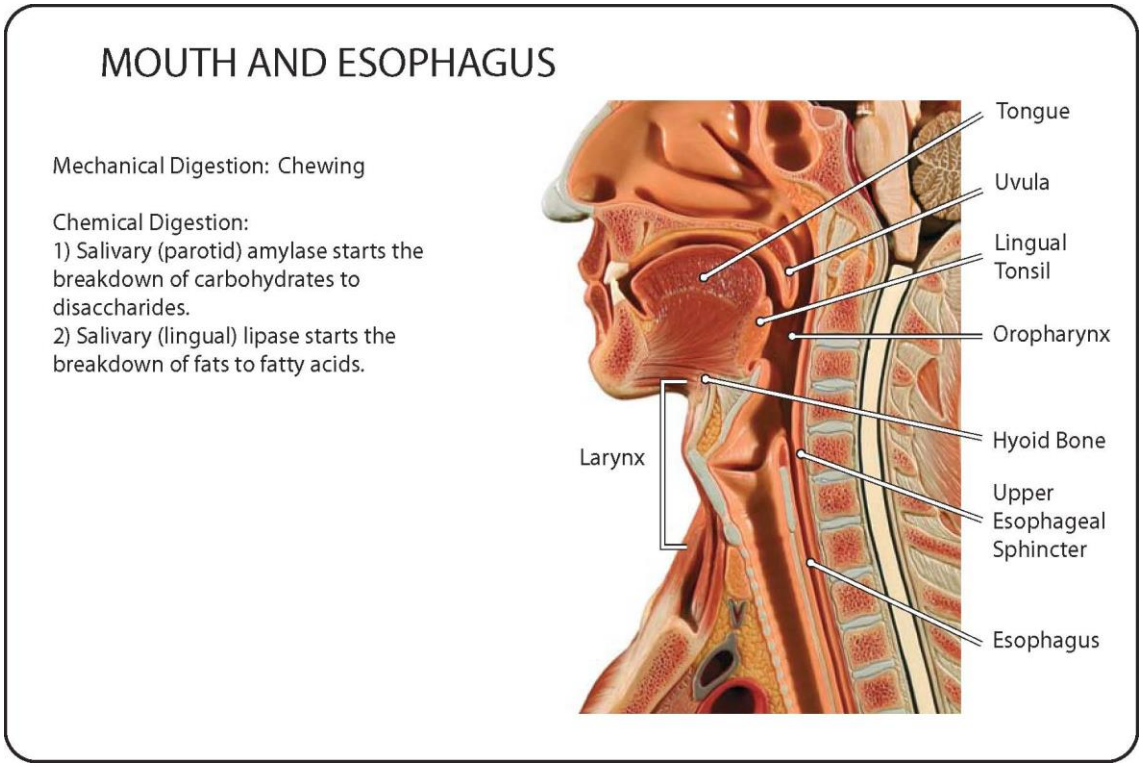

Figure 22.1 © 2007 David G. Ward, Ph.D.

The secretion of saliva is controlled by both the parasympathetic nervous system and the sympathetic nervous system, with the parasympathetic nervous system dominating. The sight or smell of food induces salivary secretion. In addition, food in the mouth stimulates chemoreceptors and pressure receptors in the walls of the mouth and on the tongue which cause reflex increases in salivary secretion.

- The salivary glands (parotid, lingual, and submandibular) secrete saliva.
- Salivary (parotid) amylase starts the breakdown of carbohydrates (polysaccharides) to simpler sugars (disaccharides and trisaccharides).
- Salivary (lingual) lipase starts the breakdown of fats to fatty acids.

When the food is pushed by the tongue into the back of the mouth and touches the oropharynx, sensory receptors are stimulated that cause a series of reflexes associated with swallowing. Signals from the sensory receptors travel into the medulla oblongata of the brainstem, inhibit respiration, and elicit contraction of muscles of the pharynx and larynx.

- As the tongue pushes food to the back of the mouth the uvula is pushed up to prevent food from entering the nasal cavity
- Elevator muscles for the larynx (including the digastricus, stylohyoid, mylohyoid, geniohyoid, and thyrohyoid) pull the larynx up and into the bottom of the tongue, obstructing the opening to the larynx (glottis).

- The upper esophageal sphincter relaxes, food is pushed into the esophagus, and the sphincter closes.
- A wave of muscle contraction (peristalsis) moves the food through the esophagus
- The lower esophageal sphincter relaxes, food moves into the stomach, and the sphincter closes (see below)

Stomach

A sagittal view of the stomach is shown in Figure 22.2. The stomach is involved in the churning and mixing of the food, a mechanical process, and in chemical digestion. Churning and mixing is mediated by coordinated contraction and relaxation of smooth muscle. Digestion is mediated by gastric secretions. About 20% of the protein in food is broken down in the stomach and a very small amount of fat digestion occurs.

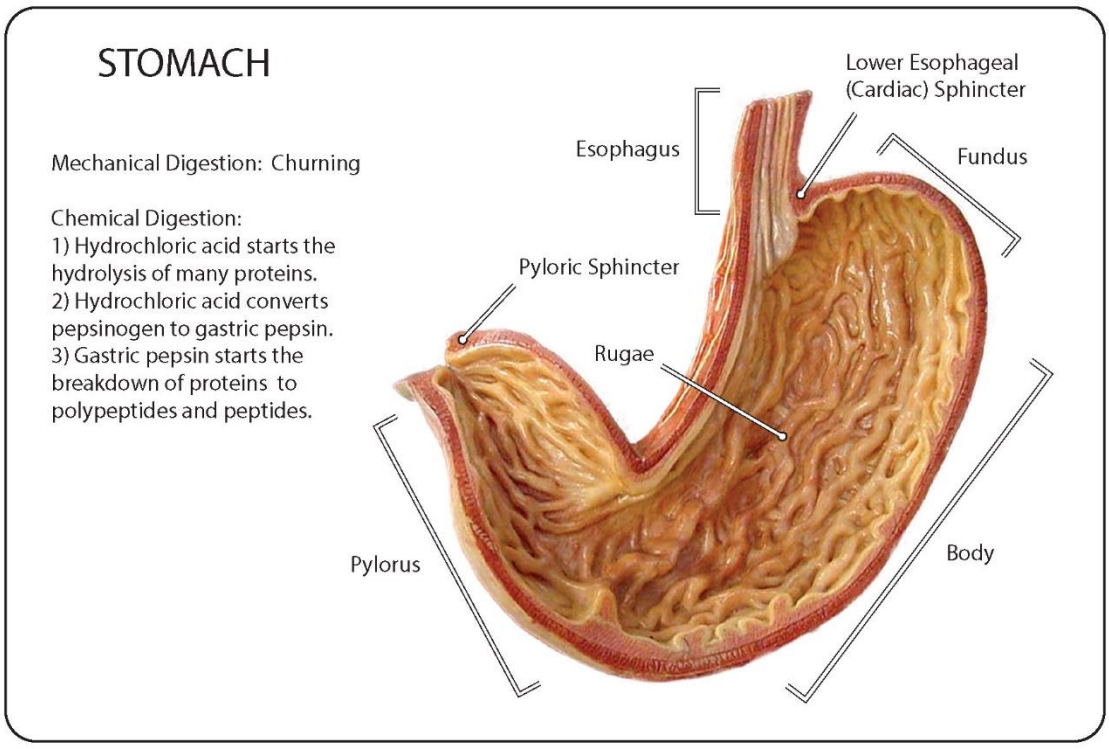

Figure 22.2 © 2018 David G. Ward, Ph.D.

As food is swallowed the medulla oblongata stimulates the parasympathetic nervous system that in turn stimulates the enteric nervous system to secrete serotonin which stimulates nitric oxide and causes relaxation of the stomach. In response to food arriving in the stomach waves of muscle contraction (peristalsis) are produced. Contractions start out weak in the body and become stronger toward the antrum (pylorus). The smooth muscle of the pyloric sphincter closes upon arrival of the peristaltic wave. Most of the chyme is forced back toward the body of the stomach, and little is expelled into the duodenum. The lower esophageal sphincter prevents the contents of the stomach from entering the esophagus.

The basic rhythm of gastric peristalsis is determined by pacemaker cells in the longitudinal layer of smooth muscle (outer longitudinal layer of the muscularis externa). A photomicrograph of the wall of the stomach, including the muscularis externa, enteric neurons, the submucosa and the mucosa is shown in Figure 22.3. The force of contraction, however, is determined by nerves and hormones. Distension of the stomach stimulates neural reflexes that increase force of contraction; high concentrations of gastrin also increase force of contraction. In contrast, distension of the duodenum, or the presence of fat, high acidity, or hypertonic fluid decrease force of gastric contractions.

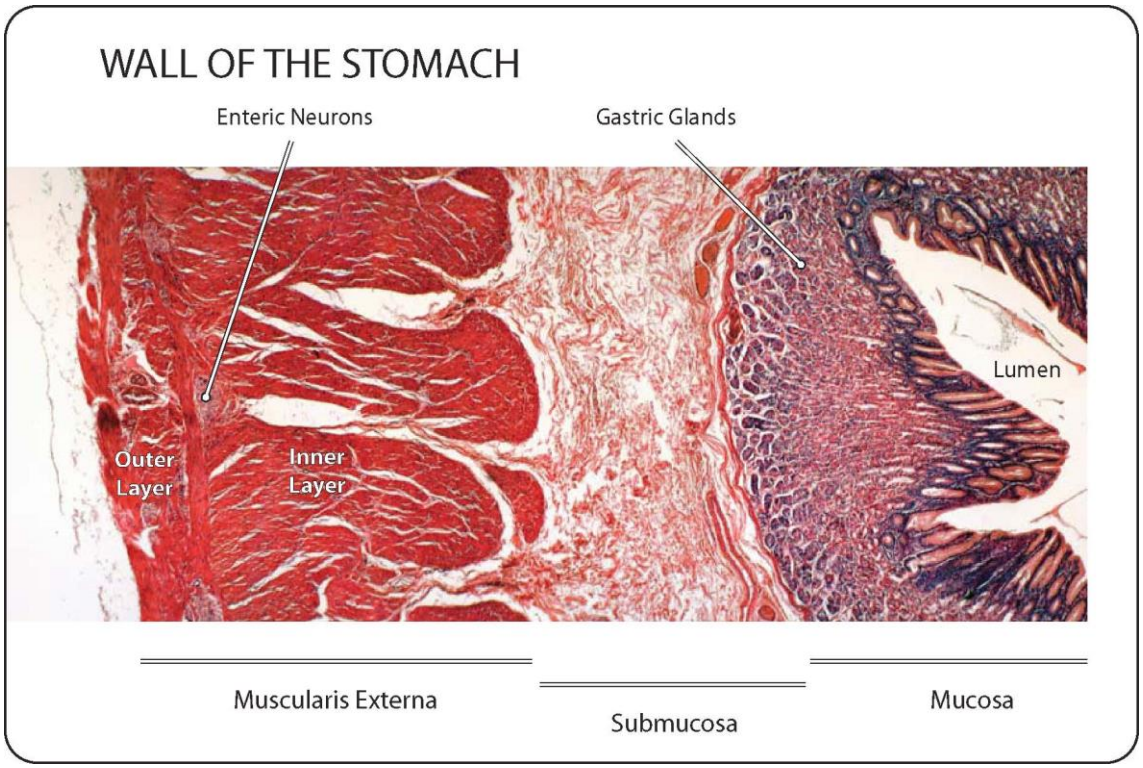

Figure 22.3 © 2007 David G. Ward, Ph.D.

A photomicrograph of the mucosa of the stomach, including the gastric glands and surface epithelium is shown in Figure 22.4. Gastric secretion from the gastric gland and epithelium is controlled by the enteric nervous system and by the parasympathetic nervous system. The sight or smell of food induces gastric secretion largely by activating the parasympathetic nervous system and causing the release of acetylcholine from enteric neurons, gastrin from gastrin secreting cells, and histamine from enterochromaffin-like cells. These chemical messengers stimulate secretion of HCl by parietal cells and pepsinogen by chief cells. Prostaglandins and acetylcholine, at least, play a role in stimulating secretion of mucus by mucus neck cells.

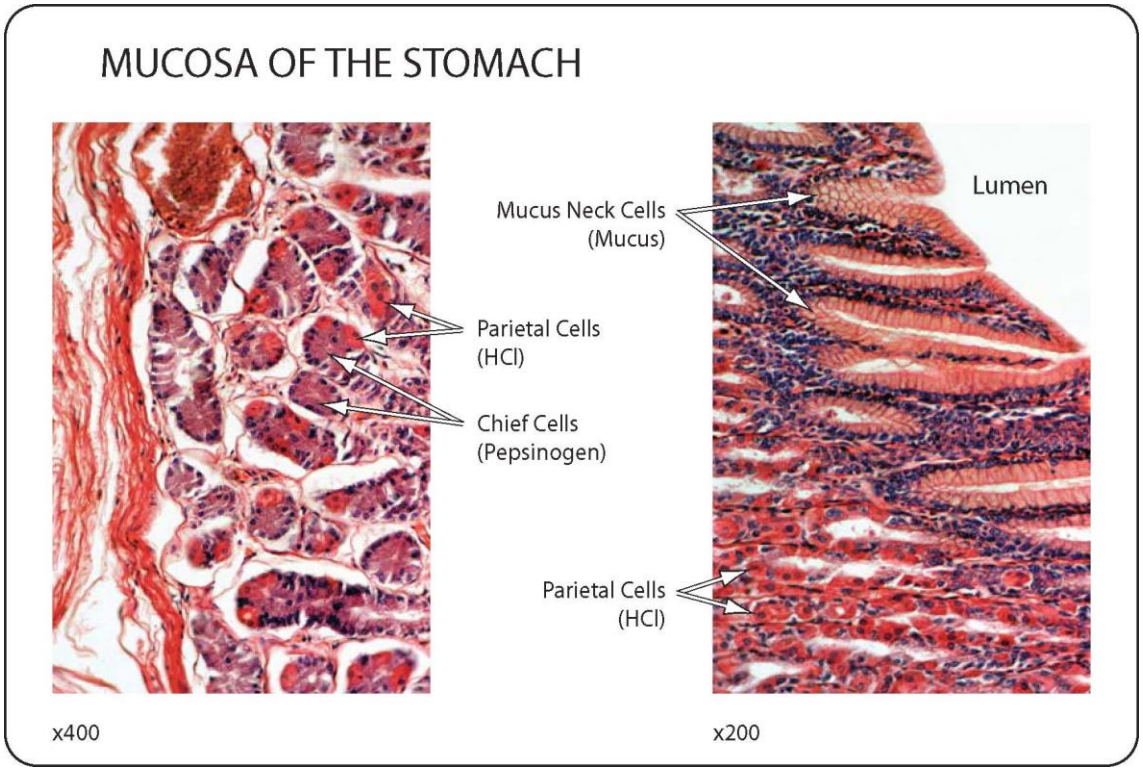

Figure 22.4 © 2007 David G. Ward, Ph.D.

When food enters the fundus of the stomach, distension of the stomach and the presence of peptides and amino acids stimulate enterochromaffin cells that act as sensory receptors. These sensory cells communicate directly with the enteric nervous system, at least in part by the secretion of serotonin, and increase the secretion of acetylcholine, gastrin, and histamine. In addition, peptides and amino acids seem to act directly on gastrin producing cells to increase gastrin production. As before, these chemical messengers stimulate secretion of HCl by parietal cells and pepsin by chief cells. Proteases (for example, trypsin) and prostaglandins stimulate secretion of mucus by the mucus neck cells.

- The gastric mucus neck cells and surface epithelium secrete mucus and bicarbonate which protects the stomach from the digestive processes within the lumen of the stomach.
- Parietal cells secrete HCl.
- Chief cells secrete pepsinogens.
- HCl hydrolyzes many proteins and cleaves pepsinogens to form pepsins.
- Pepsins breaks down proteins to peptides.

Small intestine, pancreas and liver

An anterior view of the intestines and pancreas are shown in Figure 22.5. The small intestine is involved in mixing of the food with digestive enzymes, in chemical breakdown, and in absorption of nutrients and fluid. Most of the new enzymes mixed

with the food come from the pancreas and liver. Most of the digestion of carbohydrates, proteins and fats in food occur in the small intestine.

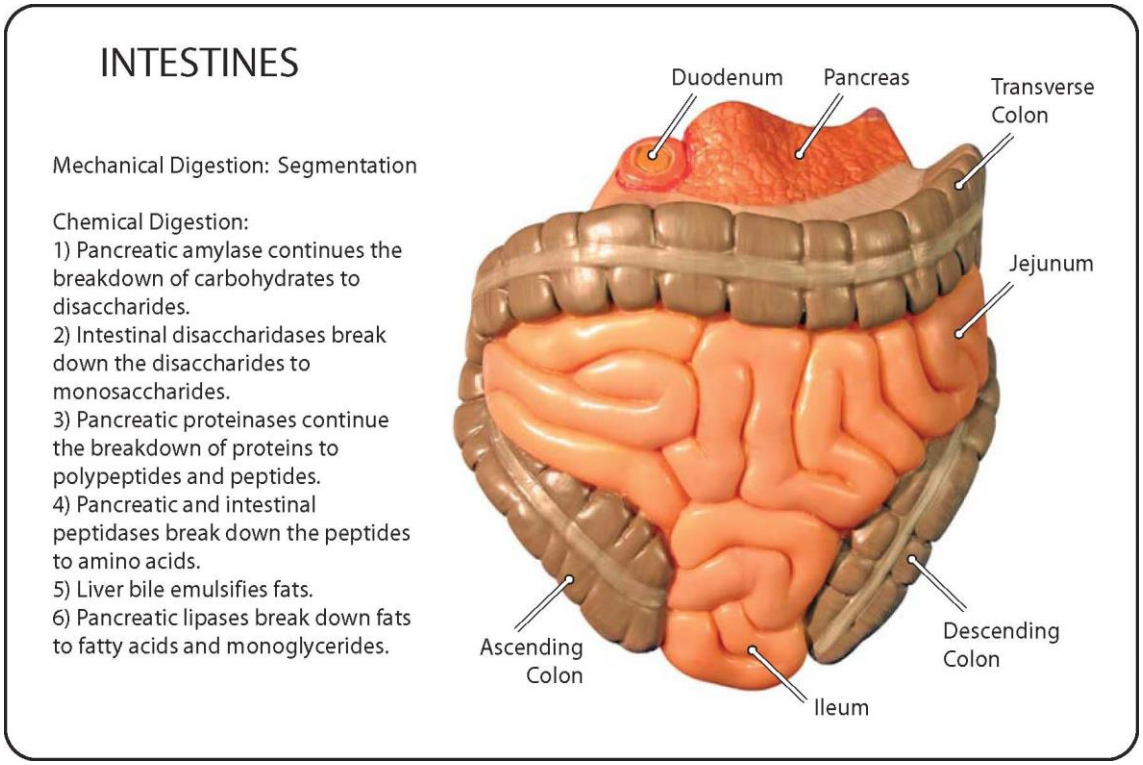

Figure 22.5 © 2007 David G. Ward, Ph.D.

In contrast to the peristaltic waves seen in the esophagus and stomach, the most common type of mechanical activity in the small intestines is stationary contraction and relaxation of intestinal segments. This sort of activity thoroughly mixes the contents of the intestines and brings them into contact with the intestinal wall.

The basic rhythms of intestinal segmentation are determined by pacemaker cells in or near the circular layer of smooth muscle (inner circular layer of the muscularis externa). A photomicrograph of the wall of the duodenum, including the muscularis externa, enteric neurons, the submucosa and the mucosa is shown in Figure 22.6. The rhythm becomes slower as we go from the duodenum to the ileum. The force of contraction, however, is determined by nerves and hormones, and involves at least serotonin and acetylcholine. The force of contraction is increased by the parasympathetic nervous system and decreased by the sympathetic nervous system.

Most of the new enzymes and related substances that are mixed with the food come from the pancreas and liver. As shown in Figure 22.7, the pancreatic duct (and sometimes an accessory pancreatic duct) and common bile duct travel to the duodenum where they merge to form the duodenal ampulla. A ring of smooth muscle forms a sphincter at the duodenum which controls the flow of pancreatic secretions from the pancreas and the flow of bile from the liver.

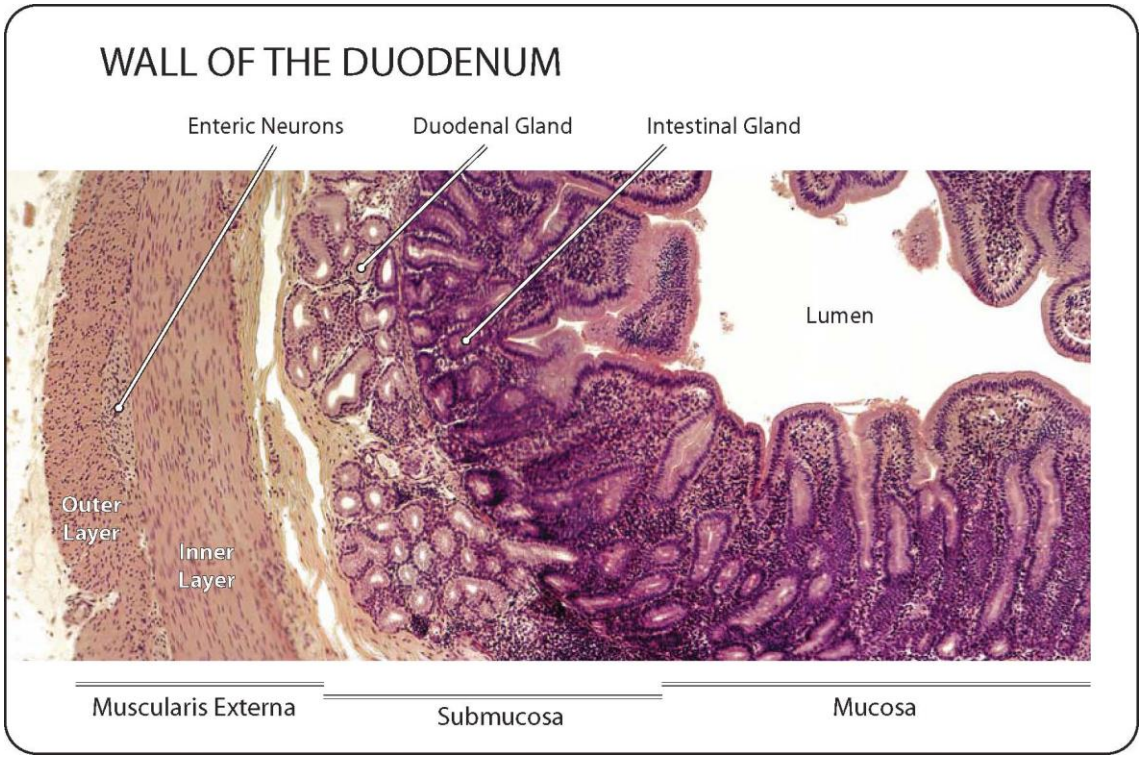

Figure 22.6 © 2007 David G. Ward, Ph.D.

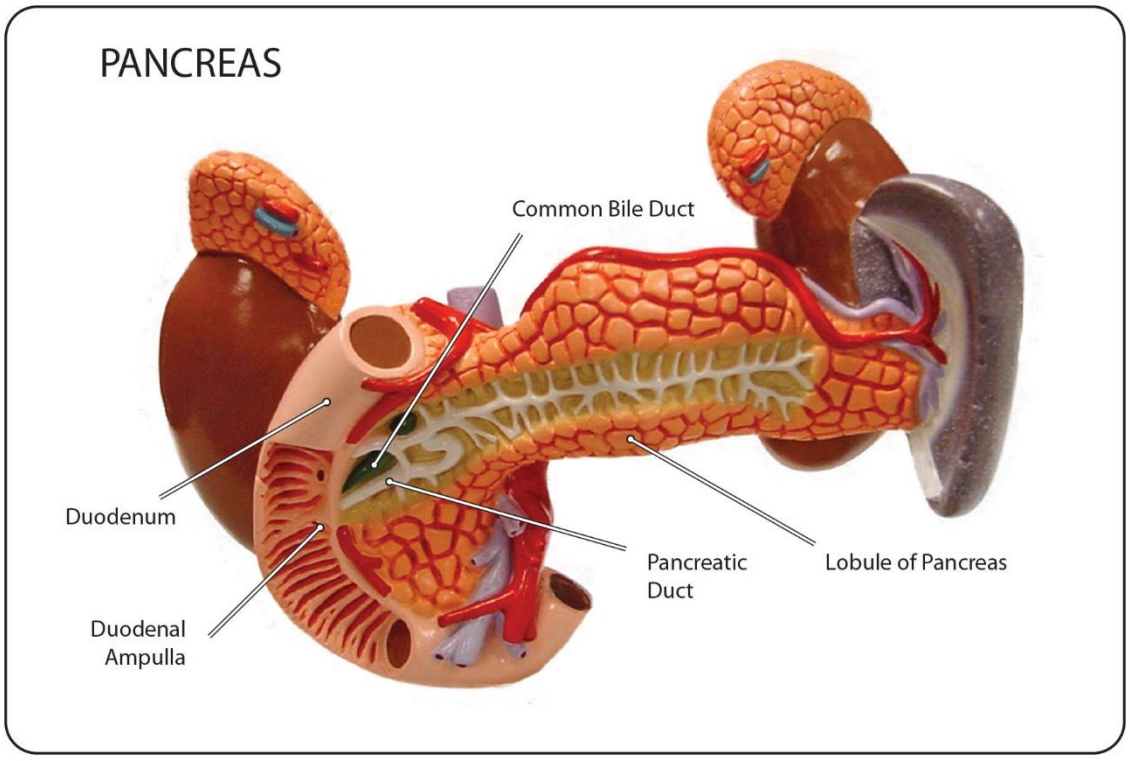

Figure 22.7 © 2007 David G. Ward, Ph.D.

Bile is produced by the liver and between meals bile is stored in the gallbladder. As shown in Figure 22.8, bile travels from the liver through hepatic ducts that merge to form the common hepatic duct. In turn, the common hepatic duct joins with the cystic duct from the gall bladder to form the common bile duct. As a result of this pattern of connection, bile can move to the duodenum directly from the liver or from storage in the gallbladder.

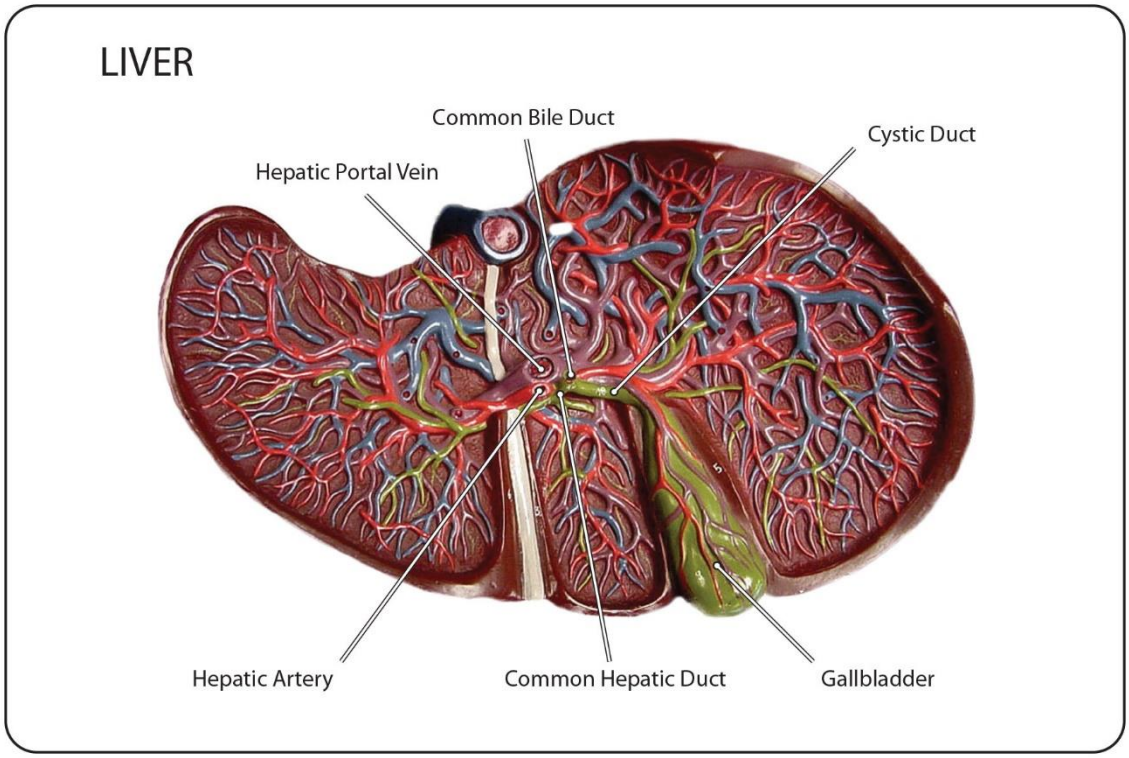

Figure 22.8 © 2007 David G. Ward, Ph.D.

Bile is a heterogeneous fluid that is composed of bicarbonate, bile salts, cholesterol, lecithin, bile pigments, metabolic end products, and certain trace metals. Bile pigments (bilirubin) are derived from the breakdown of the heme group of hemoglobin. Bile salts are amphipathic steroid molecules produced from cholesterol that emulsify fat in the small intestine.

Carbohydrate digestion and absorption

Carbohydrate digestion started in the mouth and continues in the small intestine. Most of the breakdown of carbohydrates involves amylase transported to the duodenum from the pancreas, and a variety of enzymes produced by epithelial cells of the small intestines.

- Pancreatic amylase (from the pancreas) continues the breakdown of carbohydrates (polysaccharides) to simpler sugars (disaccharides and trisaccharides)
- Maltase (from the small intestine) breaks down maltose (a disaccharide) to two glucose molecules
- Lactase (from the small intestine) breakdown lactose (a disaccharide) to glucose and galactose
- Sucrase (from the small intestine) breaks down sucrose (a disaccharide) to glucose and fructose
- Glucose, galactose, and fructose are monosaccharides that can be transported through the epithelial cells of the small intestine and thus absorbed.

Monosaccharides are absorbed through the intestinal epithelium by co-transport and facilitated diffusion, as shown in Figure 22.9.

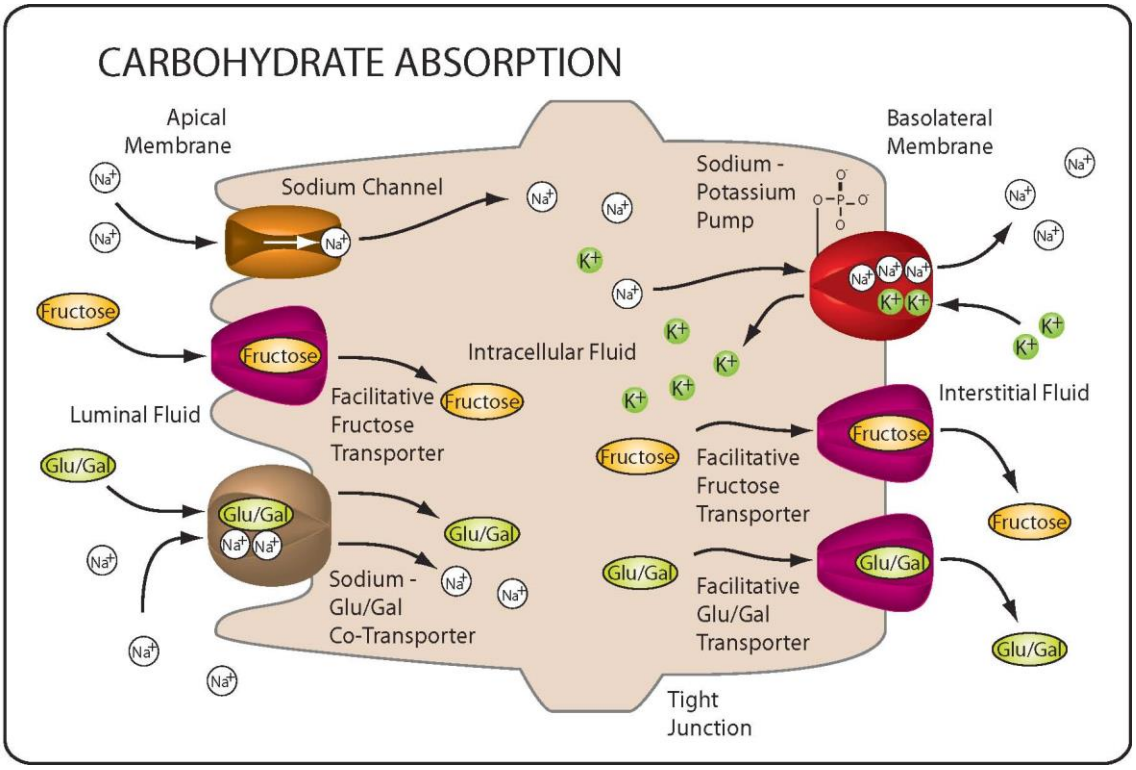

Figure 22.9 © 2007 David G. Ward, Ph.D.

- Glucose and galactose enter epithelial cells across the apical membrane via Na^+-linked secondary active transport (co-transport).
- Fructose enters epithelial cells across the apical membrane by facilitated diffusion.
- These monosaccharides diffuse through the walls of intestinal capillaries and enter the blood.

Protein digestion and absorption

Protein digestion started in the stomach with the breakdown of protein to peptide fragments using hydrochloric acid and pepsin from the stomach. Protein digestion continues in the small intestine using trypsin and chymotrypsin from the pancreas to breakdown protein to peptides. The peptides are broken down to free amino acids by carboxypeptidase from the pancreas, and by aminopeptidase from the small intestine.

- Proteinases (chymotrypsin, trypsin, elastase) from pancreas break down proteins and polypeptides to short chain peptides
- Carboxypeptidase from the pancreas breaks down dipeptides and tripeptides to amino acids
- Aminopeptidase from the small intestine breaks down dipeptides and tripeptides to amino acids
- Amino acids can be transported through the epithelial cells of the small intestine and thus absorbed into the blood.

Amino acids are absorbed through the intestinal epithelium by cotransport and facilitated diffusion, as shown in Figure 22.10.

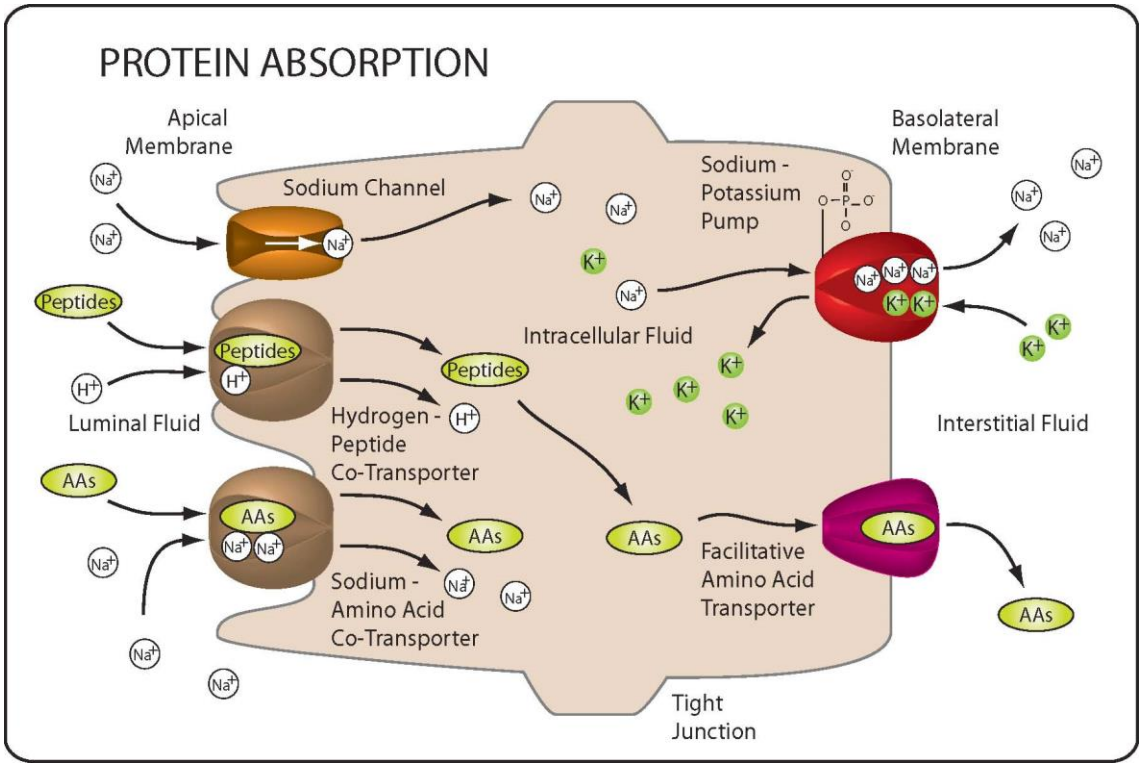

Figure 22.10 © 2007 David G. Ward, Ph.D.

- Amino acids enter epithelial cells via Na^+-linked secondary active transport (co-transport) across the apical membrane
- Peptides enter epithelial cells via H^+-linked secondary active transport (cotransport) across the apical membrane.
- Amino acids exit epithelial cells across the basolateral membrane by facilitated diffusion.
- The amino acids diffuse through the walls of intestinal capillaries and enter the blood.

Fat digestion and absorption

Only a very small amount of fat digestion started in the mouth and stomach. Almost all of the fat digestion occurs in the small intestine. Fats are insoluble in water and form large lipid droplets in the stomach. In large droplets the surface area is small relative to their volume. The digestive enzymes are water soluble and therefore only have access to the outside surface of the droplets. Fat digestion is much more efficient when the fat droplets are small and the surface area becomes large relative to their volume. Fat droplets are made smaller by the process of emulsification which requires mechanical disruption of the fat droplets and the addition of an emulsifying agent (detergent or other amphipathic compound). Rhythmic contraction of the stomach and segmental contraction of the small intestines provide the mechanical disruption. Bile salts from the liver and phospholipids from our food function as the emulsifying agents.

- Bile salts from liver help emulsify fats
- Lipase from the pancreas breaks down triglycerides to fatty acids and monoglycerides.
- Fatty acids and monoglycerides can be transported through the epithelial cells of the small intestine and thus absorbed.

Fatty acids and monoglycerides bind to bile salts to form micelles before diffusing through the intestinal epithelium, as shown in Figure 22.11.

- The lipids enter the epithelial cells by simple diffusion across the apical membrane.
- The lipids enter the smooth ER where they are rejoined as triglycerides.
- The triglycerides enter the Golgi complex where they are coated with protein to form chylomicrons and packaged in vesicles
- The chylomicrons are transported across the basolateral membrane from the vesicles by exocytosis to enter the intestinal lacteals and lymphatics.
- The lymphatic vessels connect to the thoracic duct which then empties into the systemic venous circulation at the junction of the left internal jugular and subclavian veins.

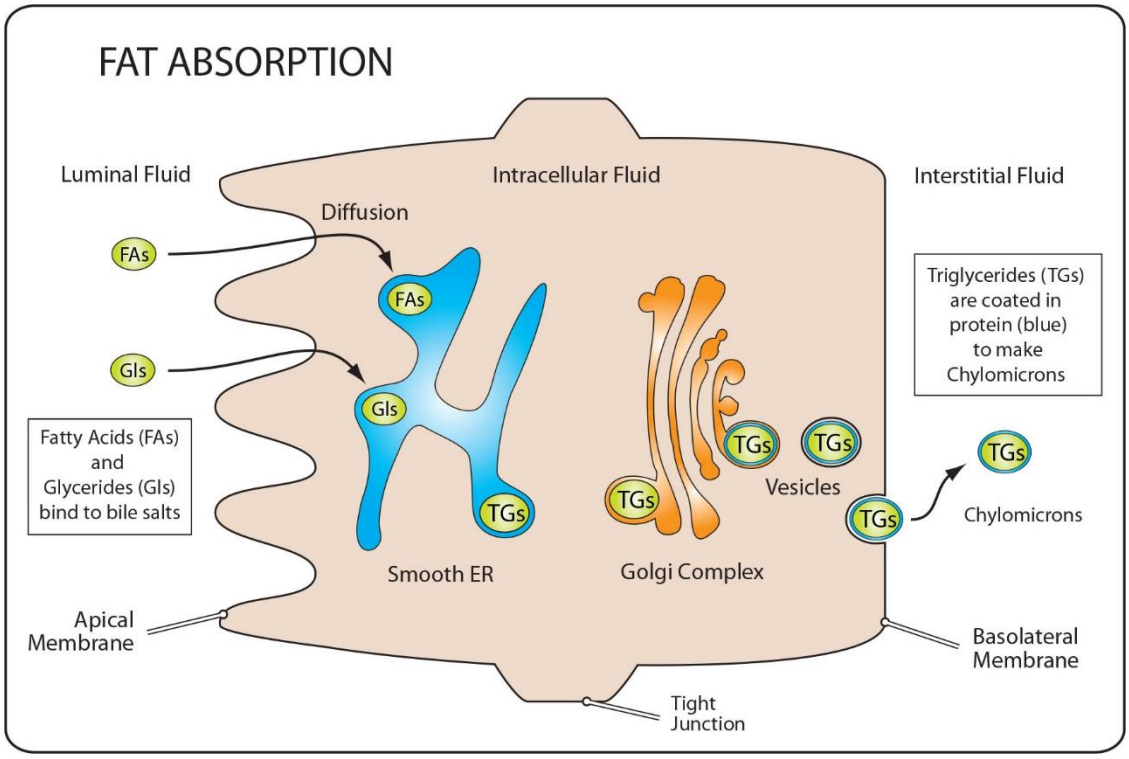

Figure 22.11 © 2014 David G. Ward, Ph.D.

Water, electrolyte and vitamin absorption

- Water and chloride are absorbed passively via channels
- Sodium is absorbed via active transport
- Bicarbonate is absorbed in the jejunum and secreted in the ileum and colon via active transport
- Fat soluble vitamins are absorbed with lipids via simple diffusion

Large intestine

Following absorption, the intestinal segmentation is replaced by slow peristaltic waves that move undigested material to the large intestine, and involves at least serotonin and acetylcholine. Little digestion occurs in the large intestine. The major function seems to be to absorb much of the fluid that enters the large intestine and to concentrate the undigested material. However, the bacteria that inhabit the large intestine are able to metabolize some undigested polysaccharides into short chain fatty acid that can be absorbed. In addition, bacteria also produce small amounts of vitamins, especially vitamin K.

Contraction of the circular muscle of the large intestines produces a slow segmentation movement. Three or four times a day an intense contraction, called a mass movement, moves from the transverse colon toward the rectum. Control of these movements is mediated by the enteric nervous system and involves, at least, serotonin and acetylcholine. Unlike peristalsis the contraction persist for a prolonged time. The force of contraction of the slow segmentation movement is increased by the parasympathetic nervous system. The force of the mass movement is decreased by the sympathetic nervous system.

Neural and Hormonal Control of Digestion

As we have seen, the gastrointestinal tract is controlled by enteric nervous and endocrine systems. These controlling systems interact with the autonomic nervous system and many gastrointestinal hormones.

Autonomic nervous system

Many contributions of the autonomic nervous system have already been considered and are summarized below and in Figure 22.12.

The parasympathetic nervous system plays a central role in preparing the gastrointestinal tract and accessory organs for eating, digestion, and absorptive metabolism. Please refer to chapter 23, for additional information about absorptive metabolism. Anticipatory, digestive, and metabolic actions include:

- Stimulation of the sphenopalatine and submandibular ganglia which causes
    - Secretion of watery saliva by the submandibular, sublingual, and parotid (salivary) glands (M-3)
- Stimulation of the abdominal intramural ganglia causes
    - Increases in secretion of HCl and pepsinogen by gastric glands (M-1)
    - Increases in secretion of fluids by pancreatic exocrine glands (M-3)
    - Increases in secretion of fluids by intestinal glands (M-3)
    - Increases in contraction of the gallbladder by stimulating smooth muscle (M-3)
    - Increases in gastrointestinal motility by stimulating the smooth muscle of the digestive tract (M_3)
    - Increases in insulin secretion by pancreatic beta cells (M-3)
- Stimulation of the pelvic intramural ganglia causes
    - Defecation by stimulation of smooth muscle (M-3)

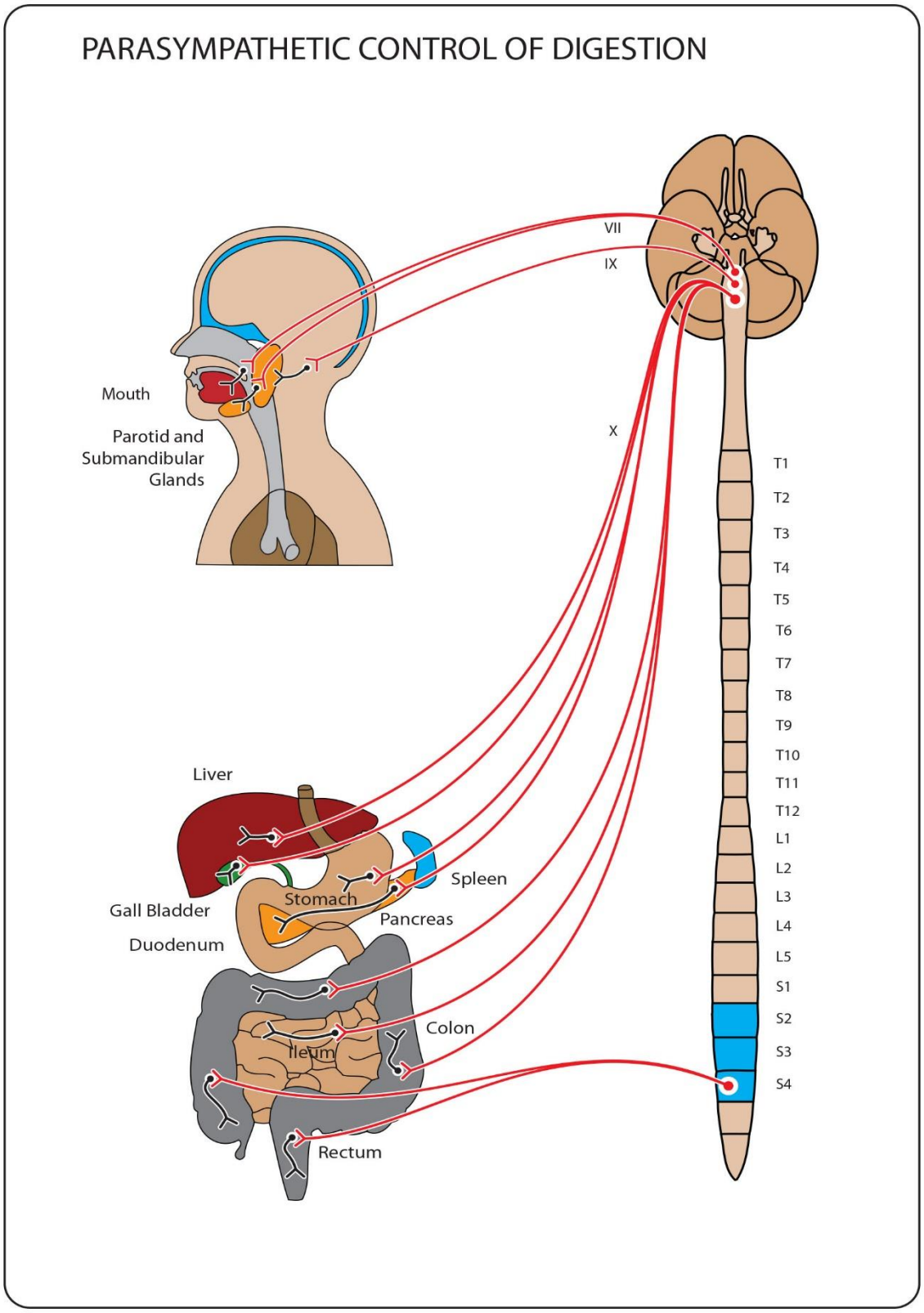

Figure 22.12 © 2014 David G. Ward, Ph.D.

The sympathetic nervous system plays a minor role in digestion, but a major role in post-absorptive metabolism. Please refer to chapter 23, for additional information about post-absorptive metabolism. Digestive and metabolic actions include:
:

- Stimulation of the superior cervical sympathetic ganglion which causes
    - Secretion of enzymes and viscous saliva by the salivary glands (Beta-1, Alpha-1)
- Stimulation of the celiac and superior mesenteric ganglia which causes
    - Decreases in blood flow to gastrointestinal organs by contracting smooth muscle (Alpha-1)
    - Decreases in gastrointestinal motility by relaxing the smooth muscle of the digestive tract (Alpha-2, Beta-2)
    - Decreases in secretion of fluids by intestinal glands (Alpha-2)
    - Decreases in secretion of fluids by pancreatic exocrine glands (Alpha)
    - Decreases in contraction of the gallbladder by relaxing smooth muscle (Beta-2)
    - Decreases in secretion of insulin by pancreatic endocrine beta cells (Alpha-2)
    - Increases in secretion of glucagon by pancreatic endocrine alpha cells (Alpha-1, Beta-1)
    - Increases in gluconeogenesis by the liver (Alpha-1, Beta-1)
    - Increases in glycogenolysis by the liver (Beta-1)

Gastrointestinal hormones

Endocrine control over digestive functions is provided by the so-called enteric endocrine system. Classic gastrointestinal hormones are secreted by epithelial cells lining the stomach and small intestine. These cells are interspersed among a much larger number of epithelial cells that secrete their products (acid, mucus, etc.) into the lumen or take up nutrients from the lumen. Gastrointestinal hormones are secreted into blood, and circulate systemically, where they affect function of other parts of the digestive tract, pancreas, liver, brain and other targets. Some of the best documented gastrointestinal hormones are summarized below and in Figure 22.13.

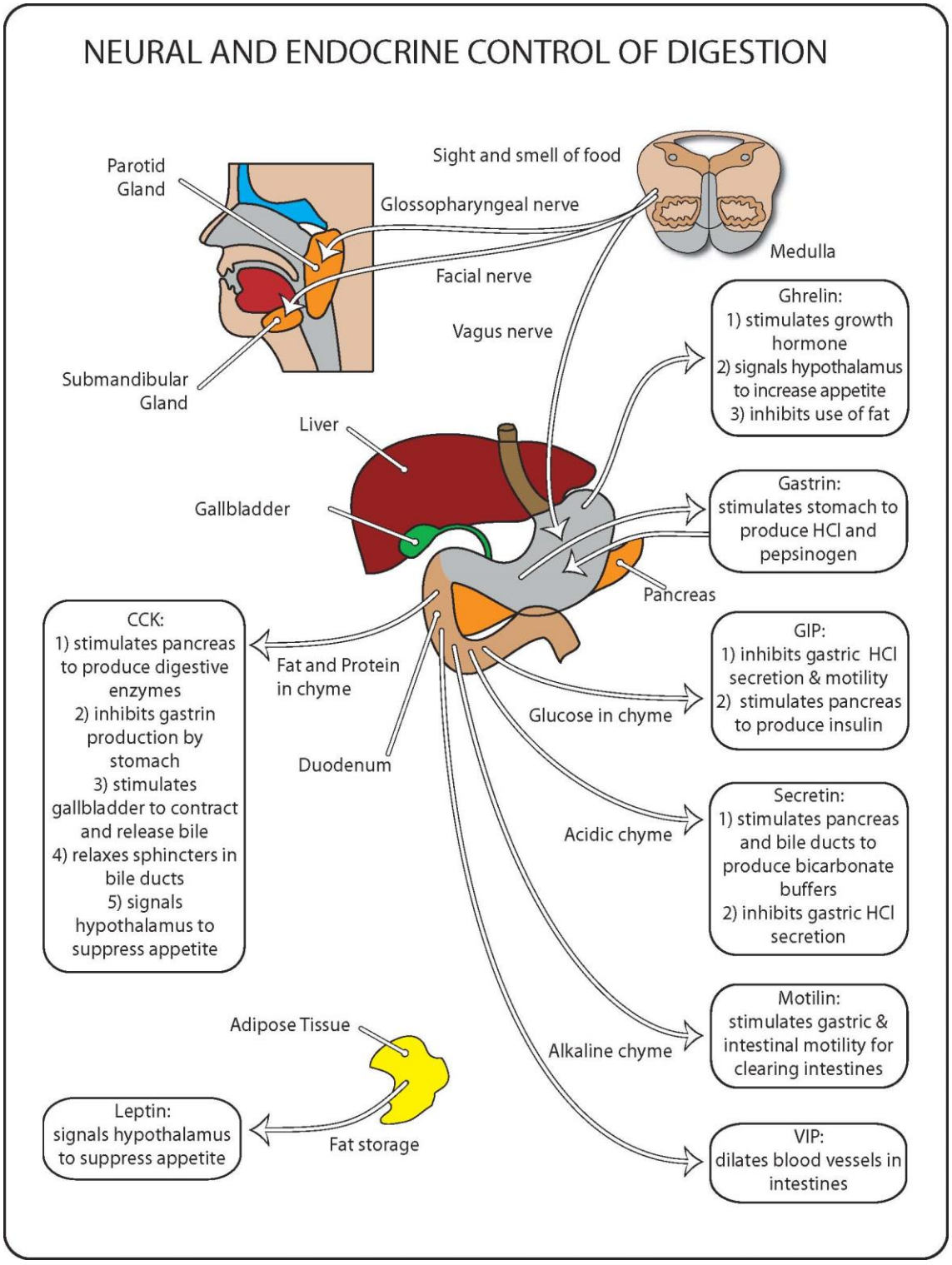

Figure 22.13 © 2007 David G. Ward, Ph.D.

- **Gastrin** is released from antrum (pyloris) of the stomach in response to parasympathetic vagal signals or the presence of peptides and amino acids in the gastric lumen, and acts on
    - Enterochromaffin-like cells to stimulate the secretion of histamine
        - Histamine is critical for hydrochloric acid (HCL) secretion by parietal cells and probably for pepsinogen secretion by chief cells
    - Gastric mucosal cells to stimulate mucosal growth
- **Ghrelin** is secreted mainly from epithelial cells lining the fundus, possibly in response to an empty stomach, and acts on
    - The somatotrophs of the anterior pituitary to stimulation the secretion of growth hormone
    - The hypothalamus to increase hunger
    - Adipose tissue to suppress fat utilization
- **Secretin** is released from duodenum in response to acidic chyme in the lumen of the small intestine and acts on
    - The pancreas to stimulate production of bicarbonate buffers
    - Hepatic bile ducts to stimulate production of bicarbonate buffers
    - The stomach possibly to inhibit secretion of HCl and pepsinogen
- **Cholecystokinin** (CCK) is released from duodenum in response to fats, peptides and amino acids in the intestinal lumen and acts on
    - The pancreas to stimulate production and secretion of pancreatic enzymes
    - The stomach possibly to inhibit Gastrin, and thus to inhibit secretion of HCl and pepsinogen
    - The gallbladder causing it to contract
    - The duodenum causing relaxation of the sphincter at the duodenal ampulla
    - The central nervous system (hypothalamus) to suppress appetite
- **Gastric Inhibitory Peptide** (GIP) [aka, Glucose Dependent Insulinotropic Hormone] is released from duodenum in response to glucose and acts on
    - The stomach to inhibit motility and acid secretion
    - The pancreas to stimulate the production and secretion of insulin
- **Motilin** is released from duodenum in response to alkaline chyme and acts on
    - The stomach and small intestine, between meals, to stimulate motility and clear these regions of undigested material
- **Vasoactive Intestinal Peptide** (VIP) is released from the pancreas and much of the gastrointestinal tract and acts on
    - The intestines to dilate blood vessels
    - The intestines to increase secretions

Although not classic gastrointestinal hormones, two additional hormones should be acknowledged because of their effects on the central nervous system

- **Insulin** is released from the pancreas in response to elevated blood glucose and acts on
    - The central nervous system (hypothalamus) to suppress appetite
    - Most cells to increase transport of glucose
- **Leptin** is secreted from adipose tissue when caloric intake exceeds the body's need and acts on
    - The central nervous system (hypothalamus) to suppress appetite

Quiz Yourself

1-5. Matching

A)	Peptidase	Emulsifies fats	1) _____
B)	Bile salts	Breaks down fats in intestine	2) _____
C)	Amylase	Breaks down protein in stomach	3) _____
D)	Pepsin	Breaks down peptides to amino acids	4) _____
E)	Lipase	Breaks down complex carbohydrates to disaccharides	5) _____

6-10. Matching

A)	Typically not absorbed through intestinal epithelium	Amino acids	6) _____
B)	Absorbed into intestinal lymphatic vessels	Triglycerides	7) _____
C)	Absorbed into intestinal capillaries	Large proteins	8) _____
		Monosaccharides	9) _____
		Complex carbohydrates	10) _____

11-15. Matching

A)	Parasympathetic N.S.	Increases salivation	11) _____
B)	Sympathetic N.S.	Increases secretion of fluids by pancreas	12) _____
C)	Somatic N. S.	Decreases blood flow of gastrointestinal tract	13) _____
		Increases motility of stomach and small intestine	14) _____
		Increases secretion of HCl and pepsinogen by stomach	15) _____

16-20.

A)	Increases secretion of exocrine pancreas	Leptin	16) _____
B)	Increases secretions of stomach	Ghrelin	17) _____
C)	Decreases appetite	Gastrin	18) _____
D)	Increases appetite	Secretin	19) _____
E)	A & C	Cholecystokinin	20) _____

Fill in

21. Swallowing raises the larynx by contraction of the _____ muscle.

22. In the stomach _____ plays a major role in disrupting phospholipids..

23. Glucose is absorbed through the apical membrane by _____ linked _____.

24. Glucose is absorbed through the basolateral membrane by _____ transporters.

25. Fatty acids and glycerol are recombined inside of digestive epithelial cells to form _____ coated in _____.

Study Questions

1. Explain how large carbohydrates, proteins, and fats are broken down into the smaller substances that are absorbed.
2. Explain how nutrients are absorbed through the digestive epithelium and into the blood
3. Explain how nerves and hormones control and coordinate the digestive process.