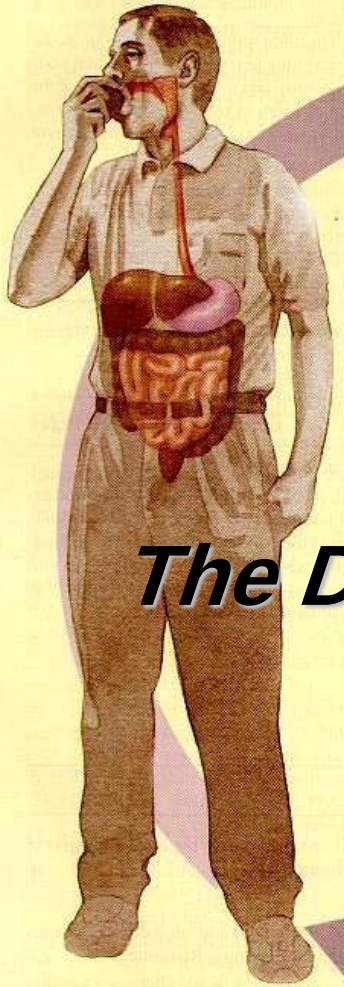
بسم الله الرحمن الرحيم

Digestive System



Homeostasis
The digestive system contributes to homeostasis by transferring nutrients, water, and electrolytes from the external environment to the internal environment.

Body systems maintain homeostasis

Homeostasis is essential for survival of cells

Cells
Cells need a constant supply of nutrients to support their energy-generating chemical reactions.

$Food + O_2 \rightarrow CO_2 + H_2O + Energy$

Also, proper cell function depends on maintaining the availability of water and various electrolytes.

Cells make up body systems

Chapter 16

The Digestive System

Part I

Prepared by
Jamil Mohanna

To maintain homeostasis, nutrient molecules used for energy production must continually be replaced by new, energy-rich nutrients. Similarly, water and electrolytes that are constantly lost in urine and sweat and through other avenues must be replenished regularly. The digestive system contributes to homeostasis by transferring nutrients, water, and electrolytes from the external environment to the internal environment. The **digestive system** does not directly regulate the concentration of any of these constituents in the internal environment. It does not vary nutrient, water, or electrolyte uptake based on body needs (with few exceptions); rather, it optimizes conditions for digesting and absorbing what is ingested.

Introduction

- The primary function of the **digestive system** is to transfer nutrients, water, and electrolytes, as energy source; to produce ATP to carry out their particular energy-dependent activities, such as active transport, contraction, synthesis, and secretion.
- The food first must be digested, or biochemically broken down, into small, simple molecules that can be absorbed.

The digestive system performs four basic digestive processes

- There are four basic digestive processes: ***motility***, ***secretion***, ***digestion***, ***and absorption***.

➢ **Motility:**

- The muscular contractions that mix and move forward the contents of the digestive tract. The smooth muscle in the walls maintains a constant low level of contraction known as **tone**.

- Two basic types of digestive motility are:

(1) ***Propulsive movements***, propel or push the contents. The rate of propulsion depending on the functions accomplished by the different regions; e.g. transit of food through the esophagus is rapid. In comparison, in the small intestine, the contents are moved forward slowly.

(2) ***Mixing movements***, serve a twofold function. ***First***, by mixing food with the digestive juices, these movements promote digestion of the food. ***Second***, they facilitate absorption by exposing all portions of the intestinal contents to the absorbing surfaces of the digestive tract.

- With the exceptions of the ends of the tract - the mouth through the early portion of the esophagus at the beginning and the external anal sphincter at the end – where motility involves skeletal muscle rather than smooth muscle activity. Accordingly, the acts of chewing, swallowing, and defecation have voluntary components.

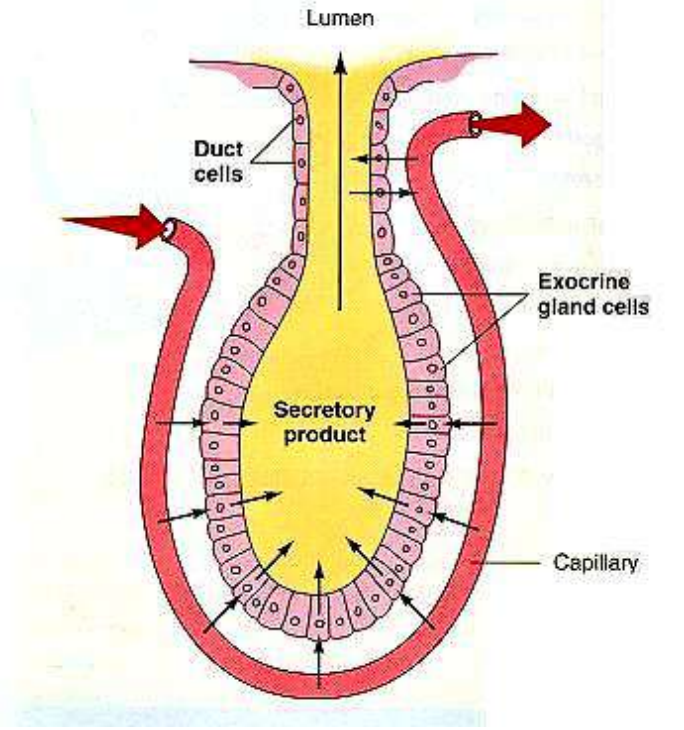
➢Secretion:

- A number of digestive juices (secretions) are secreted into the digestive tract lumen by exocrine glands located along the digestive route. **Digestive secretions** ; consists of water, electrolytes, and specific organic constituents such as enzymes, bile salts, or mucus, (fig. 16-1). Secretion of all digestive juices requires energy, both for active transport of some of the raw materials into the cell and for synthesis of secretary products by the endoplasmic reticulum. On appropriate neural or hormonal stimulation, the secretions are released into the digestive tract lumen, reabsorbed back into the blood after their participation in digestion.

● FIGURE 16-1

General mode of exocrine gland secretion

Exocrine gland cells extract from the plasma by both active and passive means the raw materials that they need to produce their secretory product. This product is emptied into ducts, which lead, in the case of the digestive system, to the lumen of the digestive tract. Frequently, the secretion is modified as it moves through the duct by active and passive transport mechanisms within the membranes of the cells lining the duct.



➢**Digestion** ; is the biochemical breakdown of the structurally complex foodstuffs of the diet into smaller, absorbable units by the enzymes produced within the digestive system as follows:

- **Cellulose**, another dietary polysaccharide cannot be digested by the digestive juices secreted in humans; thus it represents the undigested ***fiber*** or "bulk" of our diets.
- Digestion is accomplished by enzymatic **hydrolysis** (break down by water). By adding H2O at the bond site, enzymes in the digestive secretions break down the bonds that hold the small molecular subunits within the nutrient molecules together, thus setting the small molecules free (fig.16-2).

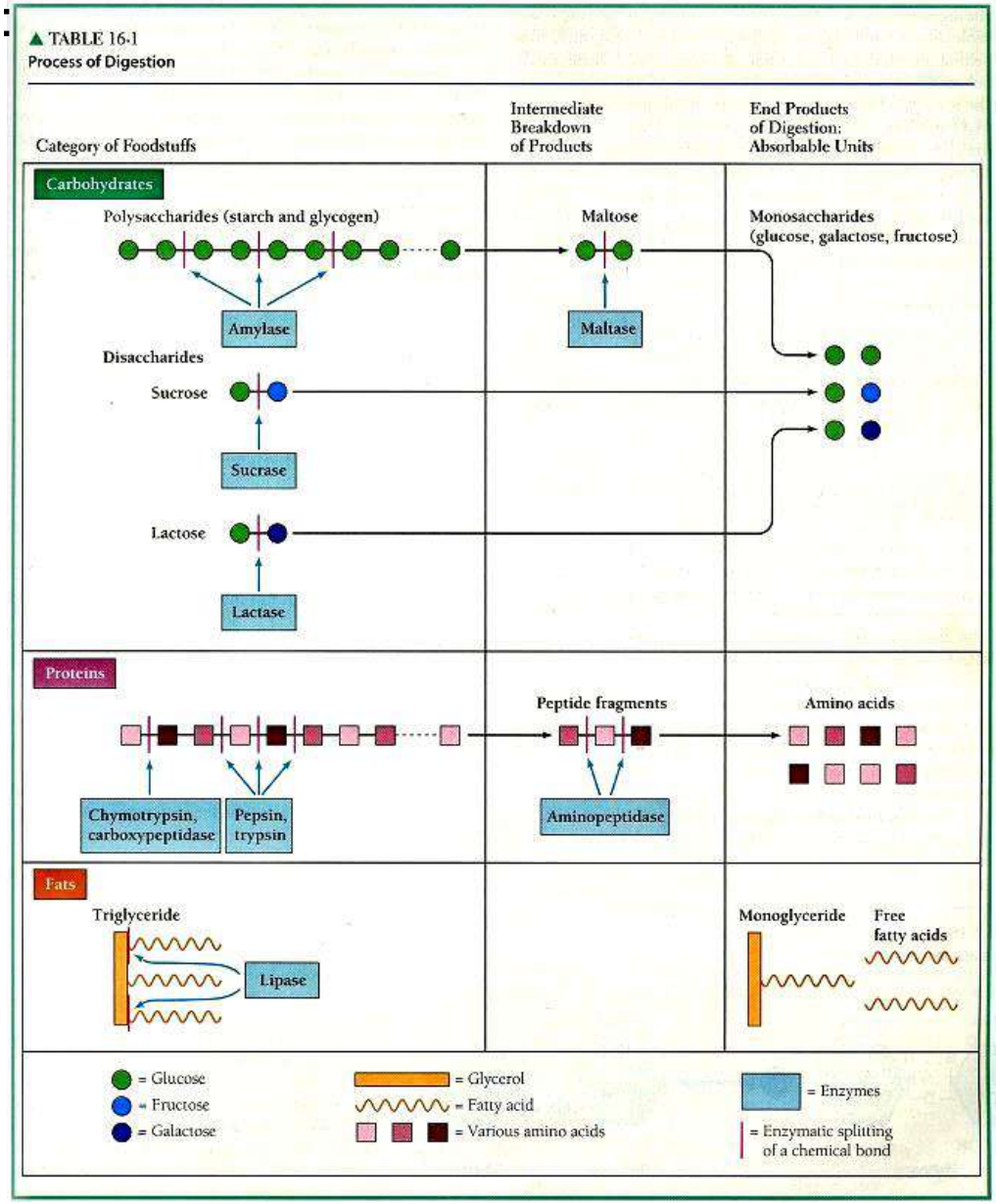
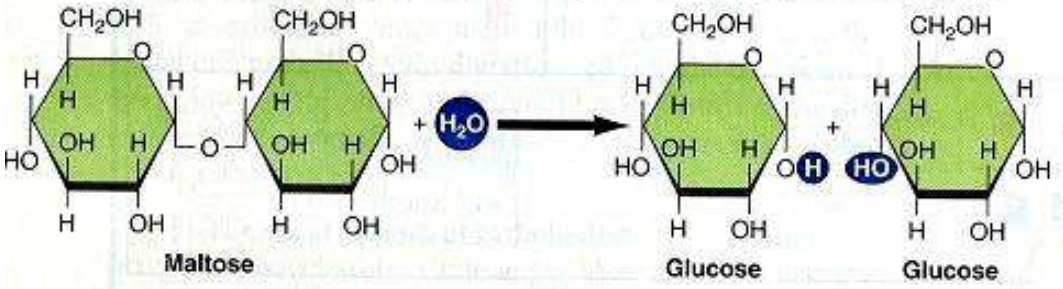


FIGURE 16-2

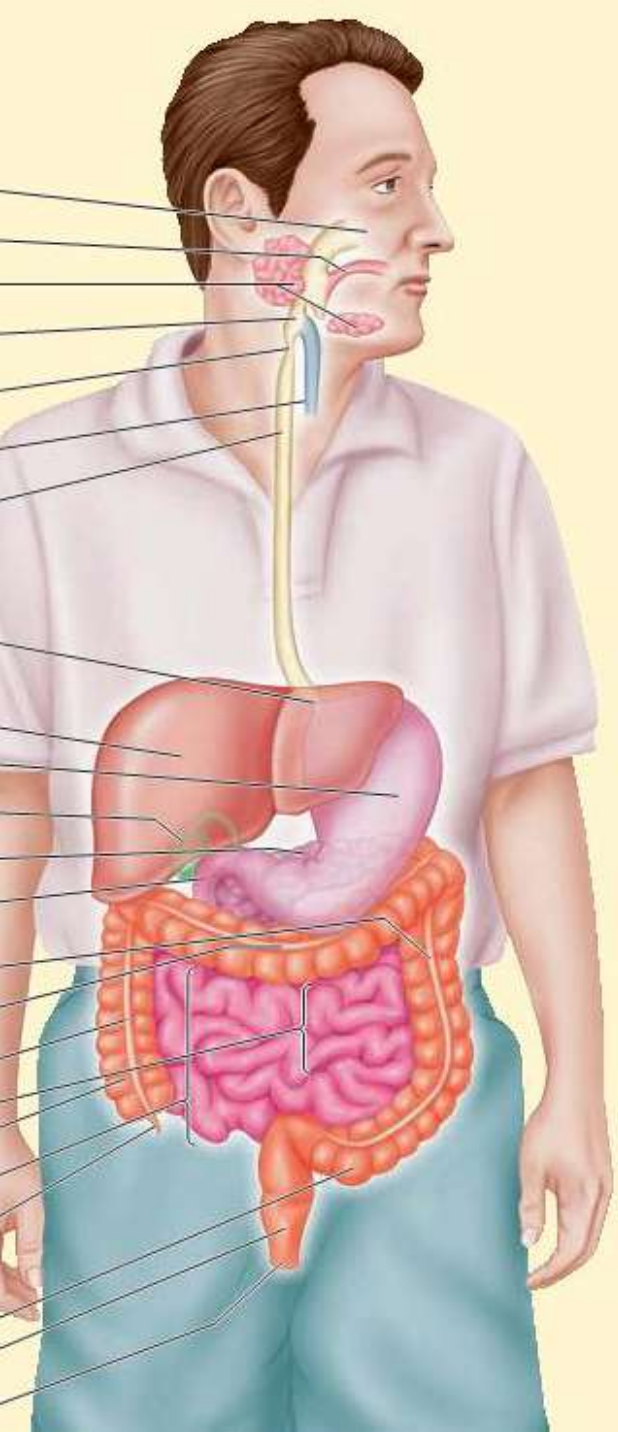
An example of hydrolysis

In this example, the disaccharide maltose (the intermediate breakdown product of polysaccharides) is broken down into two glucose molecules by the addition of H_2O at the bond site.



➢Absorption

- In the small intestine, digestion is completed and most absorption occurs, along with water, vitamins, and electrolytes, are transferred from the digestive tract lumen into the blood or lymph.
- Table 16-2 discuss the pour processes of motility, secretion, digestion, and absorption as they take place within each digestive organ.



Digestive Organ	Motility	Secretion	Digestion	Absorption
Mouth and Salivary Glands	Chewing	Saliva ■ Amylase ■ Mucus ■ Lysozyme	Carbohydrate digestion begins	No foodstuffs; a few medications—for example, nitroglycerin
Pharynx and Esophagus	Swallowing	Mucus	None	None
Stomach	Receptive relaxation; peristalsis	Gastric juice ■ HCl ■ Pepsin ■ Mucus ■ Intrinsic factor	Carbohydrate digestion continues in body of stomach; protein digestion begins in antrum of stomach	No foodstuffs; a few lipid-soluble substances, such as alcohol and aspirin
Exocrine Pancreas	Not applicable	Pancreatic digestive enzymes ■ Trypsin, chymotrypsin, carboxypeptidase ■ Amylase ■ Lipase Pancreatic aqueous $NaHCO_3$ secretion	These pancreatic enzymes accomplish digestion in duodenal lumen	Not applicable
Liver	Not applicable	Bile ■ Bile salts ■ Alkaline secretion ■ Bilirubin	Bile does not digest anything, but bile salts facilitate fat digestion and absorption in duodenal lumen	Not applicable
Small Intestine	Segmentation; migrating motility complex	Succus entericus ■ Mucus ■ Salt (Small intestine enzymes—disaccharidases and aminopeptidases—are not secreted but function within the brush-border membrane)	In lumen, under influence of pancreatic enzymes and bile, carbohydrate and protein digestion continues and fat digestion is completely accomplished; in brush border, carbohydrate and protein digestion completed	All nutrients, most electrolytes, and water
Large Intestine	Haustral contractions, mass movements	Mucus	None	Salt and water, converting contents to feces

The digestive tract and accessory digestive organs make up the digestive system

- The digestive system consists of the ***digestive tract*** (or *gastrointestinal*), about 4.5 m, plus the ***accessory digestive organs*** include the *salivary glands, the exocrine pancreas,* and the *biliary system*, which is composed of the *liver* and *gallbladder*.
- Because the digestive tract is continuous from the mouth to the anus, the lumen of this tube, like a straw, is continuous with the external environment.
- Only after a substance has been absorbed from the lumen across the intestinal wall is it considered to have become a part of the body. This fact is important, because conditions essential to the digestive process can be tolerated in the digestive tract lumen that could not be tolerated in the body proper. Consider the following examples:

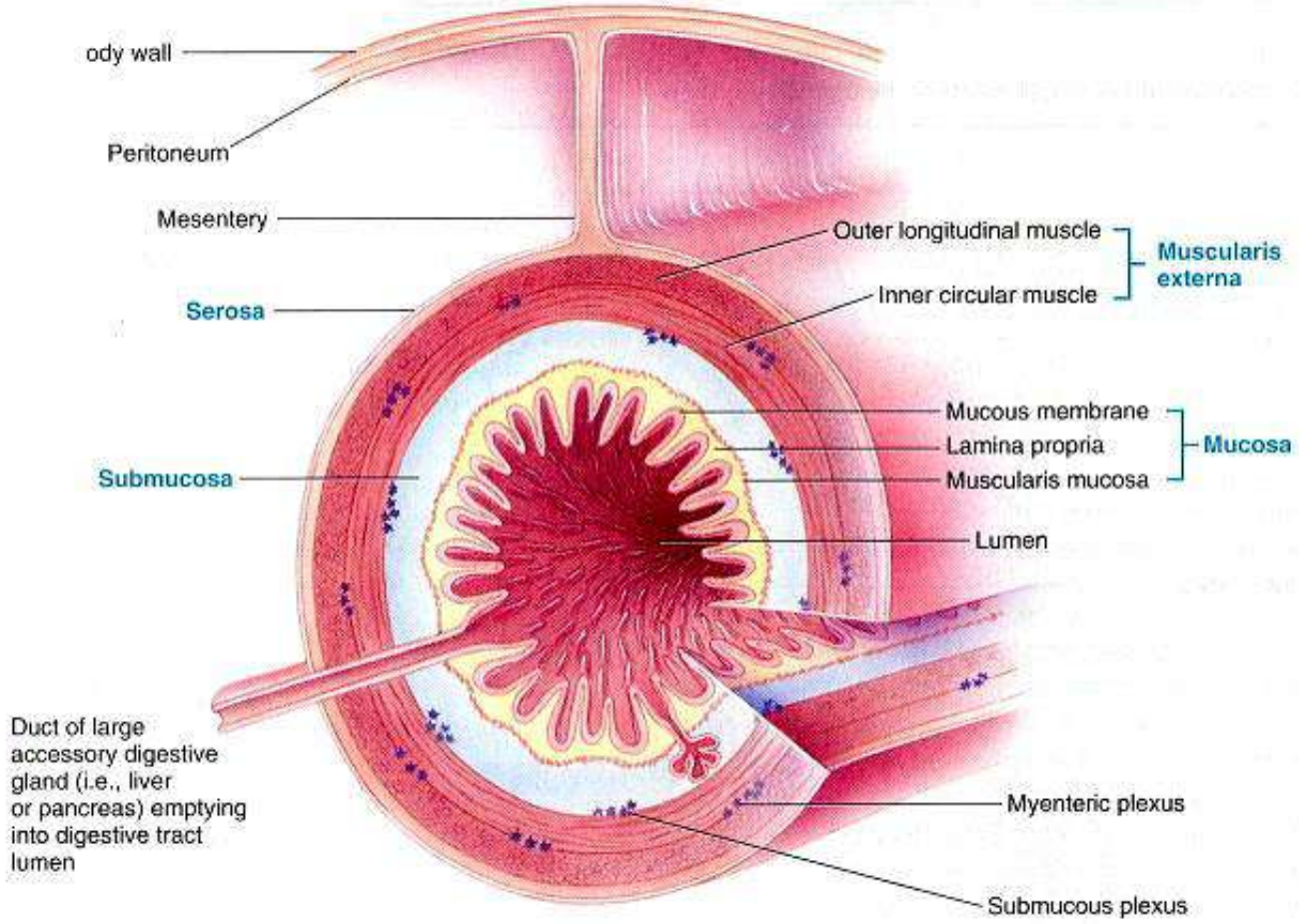
➢ The pH of the stomach contents falls as low as 2, yet in the body fluids the range of pH compatible with life is 6.8 to 8.0.

➢ The harsh digestive enzymes that hydrolyze the protein in food could also destroy the body's own tissues that produce them.

➢ The lower portion of the intestine is inhabited by millions of living micro-organisms that are normally harmless and even beneficial.

The digestive tract wall has four layers

- The digestive tract wall has the same general structure throughout most of its length from the esophagus to the anus, with some local variations characteristic for each region, (fig.16-3).
- From the innermost layer outward they are the ***mucosa***, the ***submucosa***, the ***muscularis externa***, and the ***serosa.***



➢ Mucosa

- highly folded with many ridges and valleys that greatly increase the surface area available for absorption, and varies in different areas of the digestive tract. The pattern it is divided into three layers:
- ***Mucous membrane :*** serves as a protective surface modified in particular areas for secretion, contains *exocrine* cells for secretion of digestive juices, *endocrine cells* for secretions of gastrointestinal hormones, and *epithelial cells* specialized for absorption.
- ***Lamina propria***; a thin middle layer of connective tissue. It houses the **gut-associated lymphoid tissue (GALT)**, which is important in the defense against intestinal bacteria.
- ***Muscularis mucosa***, a sparse layer of smooth muscle, and can modify the pattern of surface folding.

➢ Submucosa

- Is a thick layer of connective tissue that provides dispensability and elasticity. It contains the larger blood and lymph vessels, branches inward to the mucosal layer and outward to the surrounding thick muscle layer. Also, a nerve network known as the *submucous plexus* lies within the submucosa.

➢ Muscularis externa

- The major smooth-muscle coat of the digestive tube. In most parts it consists of two layers: an *inner circular layer* and an *outer longitudinal layer*. Contraction of circular fibers constricts of decrease the diameter of the lumen, while the longitudinal shortening of the tube. Together, produces the propulsive and mixing movements.
- Another nerve network, the *myenteric plexus*, lies between the two muscle layers. Together, help regulate local gut activity.

➢ Serosa

- The outer connective tissue, secretes a watery serous fluid that lubricates and prevents friction between the digestive organs and the surrounding viscera.
- Serosa is continuous with the **mesentery**, which suspends the digestive organs from the inner wall of the abdominal cavity like a sling (fig16-3).

Regulation of digestive function is complex and synergistic

- Four factors are involved in the regulation of digestive system function

1. **Autonomous smooth muscle function,**
2. **Intrinsic nerve plexuses,**
3. **Extrinsic nerves, and**
4. **Gastrointestinal hormones.**

➢ **(1) Autonomous smooth-muscle function**

- Some smooth muscle cells are “pacesetter” cells that display rhythmic, spontaneous variations in membrane potential. The prominent type is **slow wave potentials**, referred as the digestive tract’s **basic electrical rhythm (BER)** or **pacesetter potential**.
- Muscle-like but noncotractile cells known as the **interstitial cells of Cajal**, responsible for instigating cyclic slow-wave activity, located at the boundary between the longitudinal and circular smooth-muscle layers.
- Slow waves are not action potential and do not directly induce muscle contraction; they are rhythmic, bring the membrane closer to or farther from threshold, due to cyclical variations in Ca^{2+} release from the endoplasmic reticulum and Ca^{2+} uptake by the mitochondria of the pacesetter cell.
- If the starting point is nearer the threshold level, the depolarizing slow-wave peak reaches threshold, so a volley of action potentials is triggered at each peak, resulting in rhythmic cycles of muscle contraction.

- Smooth muscle cells are connected by gap junctions, so electrical activity initiated in a digestive-tract pacesetter cell can spread, smooth-muscle cells and the whole muscle sheet behaves like a functional syncytium.
- **The *rate* (frequency)** of rhythmic digestive contractile activities, depends of the inherent rate established by the involved pacesetter cells.
- **The *intensity*** of these contractions depends on the number of action potentials that occur when the slow-wave potential reaches threshold, which in turn depends on how long threshold is sustained.
- At threshold, voltage-gated Ca^{2+} channels are activated,

(1) resultant Ca^{2+} responsible for the rising phase of an action potential, with the falling phase being brought about as usual by K^{+} efflux, and

(2) It triggers a contractile response.

➢ In short, the greater the number of action potentials, the higher the cytosolic Ca^{2+} concentration, the greater the cross-bridge activity, and the stronger the contraction.

➢ (2) Intrinsic nerve plexuses (enteric nervous system)

- Are the **myenteric plexus** and the **submucous plexus** located entirely within the digestive tract wall and run its entire length, endows the tract with a considerable degree of self regulation.
- The intrinsic plexus have sensory neurons, which possess receptors that respond to specific local stimuli in the digestive tract. Other local neurons innervate the smooth muscle cells and exocrine and endocrine cells of the digestive tract to directly affect digestive tract motility, secretion of digestive juices, and secretion of gastrointestinal hormones.
- These inputs and outputs linked by interneurons, some of the output neurons are excitatory, and some are inhibitory. For example, neurons that release *acetylcholine* as a neurotransmitter promote contraction, whereas the neurotransmitters *nitric oxide* and *vasoactive intestinal peptide* act in concert to cause its relaxation, for coordinating local activity within the digestive tract, e.g. if a large piece of food gets stuck in the esophagus, local contractile responses coordinated by the intrinsic plexuses.

➢ (3) Extrinsic nerves

- The autonomic nerves influence digestive tract motility and secretion either by modifying ongoing activity in the intrinsic plexuses, altering the level of gastrointestinal hormone secretion, or in some instances, acting directly on the smooth muscle and glands.
- The sympathetic system, which dominates in fight-or-flight situations, tends to inhibit or slow down digestive tract contraction and secretion. The parasympathetic nervous system, by contrast, dominates in quiet, relaxed situations, which arrive primarily by way of the vagus nerve, tend to increase smooth muscle motility and promote secretion of digestive enzymes and hormones. The postganglionic nerve plexuses.
- Accordingly, acetylcholine is released in response to local reflexes coordinated entirely by the intrinsic plexuses as well as to vagal stimulation, which acts through the intrinsic plexuses.
- One of the major purposes of specific activation of extrinsic innervations is the coordination of activity between different regions of the digestive system. For example, the act of chewing food reflexly increases not only salivary secretion but also stomach, pancreatic, and liver secretion via vagal reflexes in anticipation of the arrival of food.

➢ (4) Gastrointestinal hormones

- Tucked within the mucosa, endocrine gland cells that release hormones into the blood, carried to other areas of the digestive tract, where they exert either excitatory or inhibitory influences on smooth muscle and exocrine gland cells. Interestingly, many of these same hormones are released from neurons in the brain.

➢ Receptor activation alters digestive activity through neural reflexes and hormonal pathways

- The digestive tract wall contains three types of sensory receptors

(1) *Chemoreceptors*; sensitive to chemical components within the lumen.

(2) *Mechanoreceptors* (pressure receptors) sensitive to stretch or tension within the wall.

(3) *Osmoreceptrs*, sensitive to the osmolarity of the lumen content.

Receptor activation alters digestive activity through neural reflexes and hormonal pathways

- Receptor activation may bring about two types of neural reflexes; short and long reflexes (fig.16-4).
- From this overview, you can see that regulation of gastrointestinal function is very complex, being influenced by many synergistic, interrelated pathways designed to ensure that the appropriate responses occur to digest and absorb the ingested food.

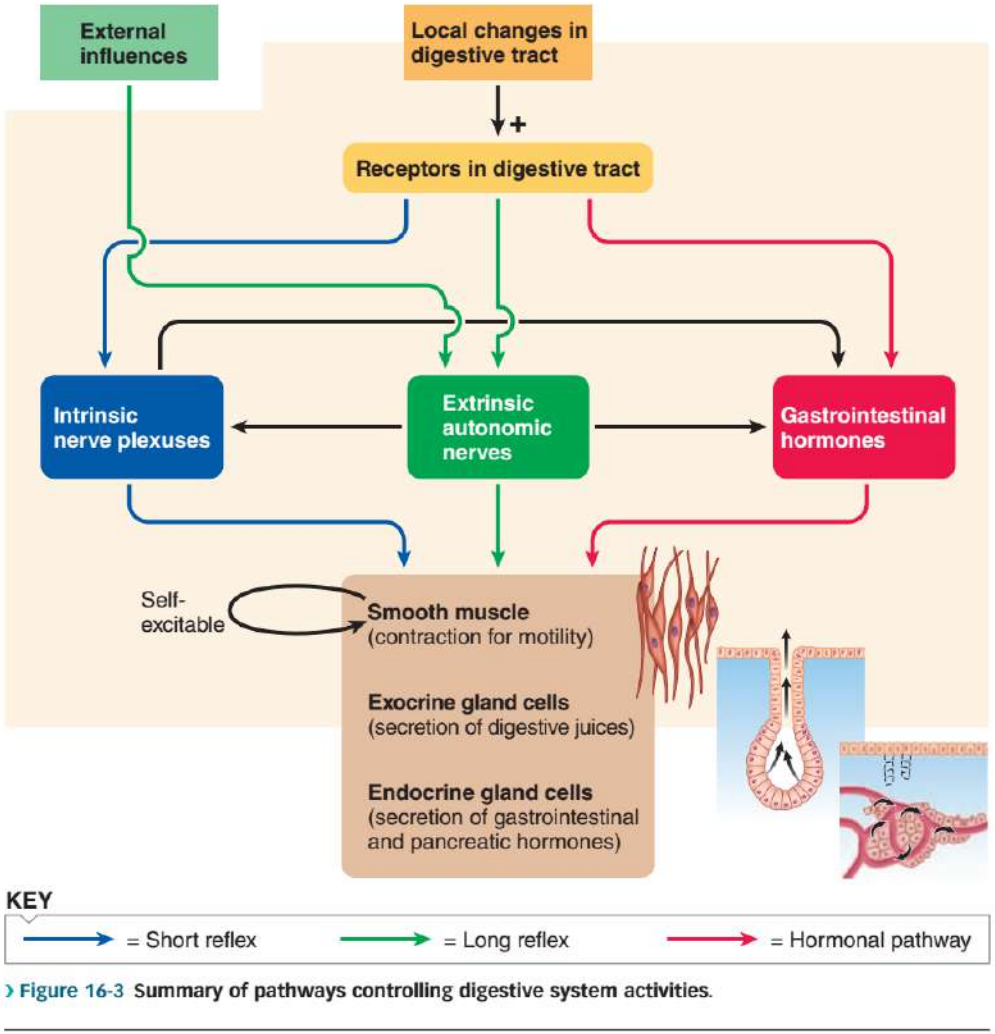


Figure 16-3 Summary of pathways controlling digestive system activities.

Saliva begins carbohydrate digestion, is important in oral hygiene, and facilitates speech

- **Saliva**, produced by three pairs of salivary glands, is composed of about 99.5% H_2O and 0.5 electrolytes and protein. The salivary NaCl (salt) concentration is only one-seventh of that in the plasma, a fact important in the perception of safety tastes. Similarly, discrimination of sweet tastes is enhanced by the absence of glucose in the saliva. The most important salivary proteins are *amylase*, *mucus* and *lysozyme.* They contribute to the functions of saliva as follows:

1. Saliva begins digestion of carbohydrates through action of **salivary amylase,** an enzyme that breaks polysaccharides down into **maltose.**
2. Saliva facilitates swallowing by moistening food particles, holding them together by **mucus**, which is thick and slippery.
3. Saliva exerts some antibacterial action (1) by **lysozyme**, (2) by rinsing away material that may serve as a food source for bacteria.
4. Saliva serves as a solvent for molecules that stimulate the taste buds.
5. Saliva aids speech by facilitating movements of the lips and tongue.
6. Saliva plays an important role in oral hygiene by helping keep the mouth and teeth clean.
7. Saliva is rich in bicarbonate buffers, which neutralize acids in food as well as acids produced by bacterial in the mouth, thereby helping to prevent **dental caries** (cavities).

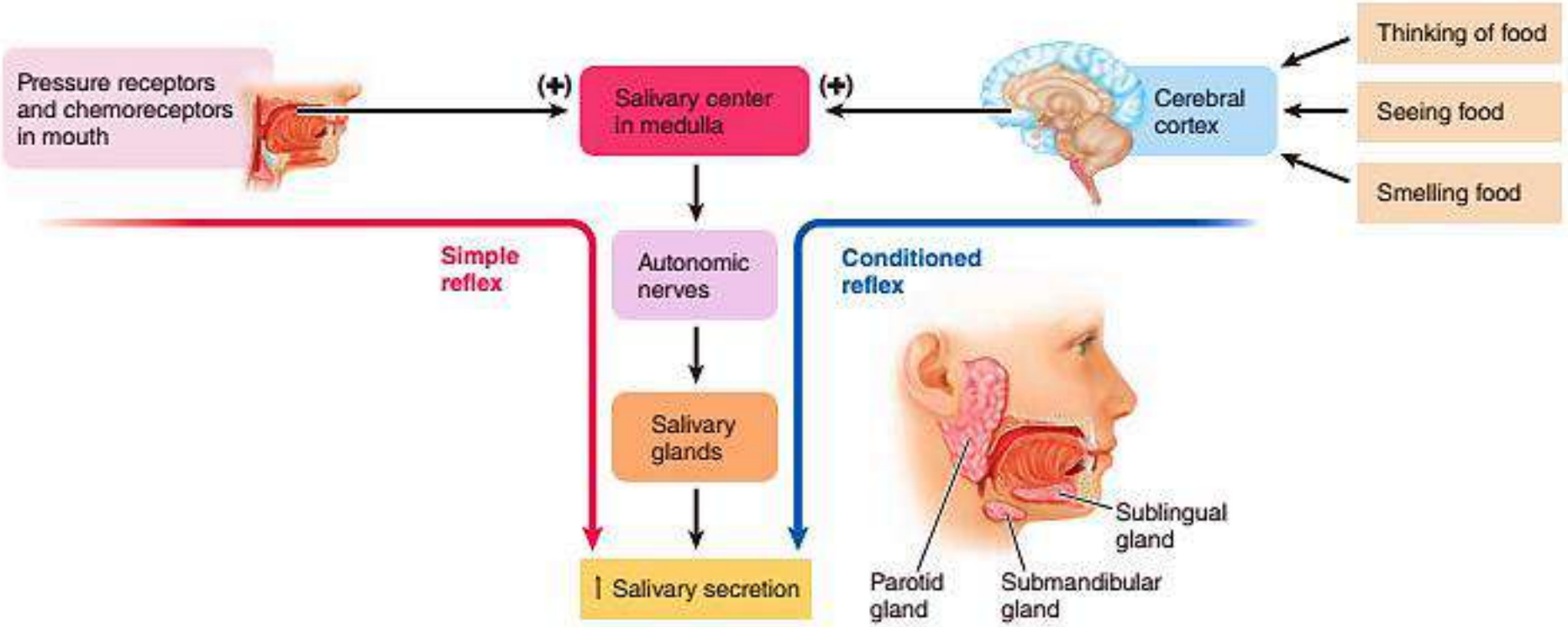
- Saliva is not essential for digesting and absorbing foods. The main problems known as **xerostomia**, are difficulty in chewing and swallowing, inarticulate speech.

Salivary secretion is continuous and can be reflexly increased

- On the average, about 1-2liters of saliva are secreted per day; 0.5-5ml/min in response to a potent stimulus such as sucking on a lemon. The continuous spontaneous secretion of saliva, is brought about by constant low-level stimulation by the parasympathetic nerve endings that terminate in the salivary glands.
- In addition salivary secretion may be enhanced by two types of salivary reflexes, the simple and the acquired salivary reflexes (fig.16-5).

➢**Simple and acquired salivary reflexes**

The **simple**, or **unconditioned, salivary reflex** occurs when chemoreceptors and pressure receptors within the oral cavity respond to the presence of food. These receptors initiate impulses in afferent nerve fibers that carry the information to the **salivary center**, which is located in the medulla of the brain stem, in turn sends impulses via the extrinsic autonomic nerves to the salivary glands to promote increased salivation.



› Figure 16-4 Salivary glands and control of salivary secretion.

- With the **acquired**, or **conditioned, salivary reflex**, salivation occurs without oral stimulation. Just thinking about, seeing, smelling, or hearing the preparation of pleasant food initiates salivation through this reflex. This reflex is a learned response based on previous experience, act through the cerebral cortex to stimulate the medullary salivary center.

➢ **Autonomic influence on salivary secretion**

- Unlike the ANS elsewhere in the body, both sympathetic and parasympathetic stimulation increase salivary secretion, but the quantity, characteristics, and mechanisms are different. Parasympathetic stimulation, produces a prompt and abundant flow of watery saliva that is rich in enzymes. Sympathetic stimulation, by contrast, produces a much smaller volume of thick saliva that is rich in mucus.
- Thus people experience a dry feeling in the mouth when they are nervous about giving a speech

➢ **Digestion in the mouth is minimal; no absorption of nutrients occurs**

- Digestion in the mouth involves the hydrolysis of polysaccharides into disaccharides by amylase, while acid inactivates amylase in stomach. No absorption of foodstuff occurs from the mouth, but some therapeutic agents can be absorbed by the oral mucosa, a prime example being a vasodilator drug, ***nitroglycerin***, which is used by certain cardiac patients to relieve anginal attacks associated with myocardial ischemia.

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Digestive System

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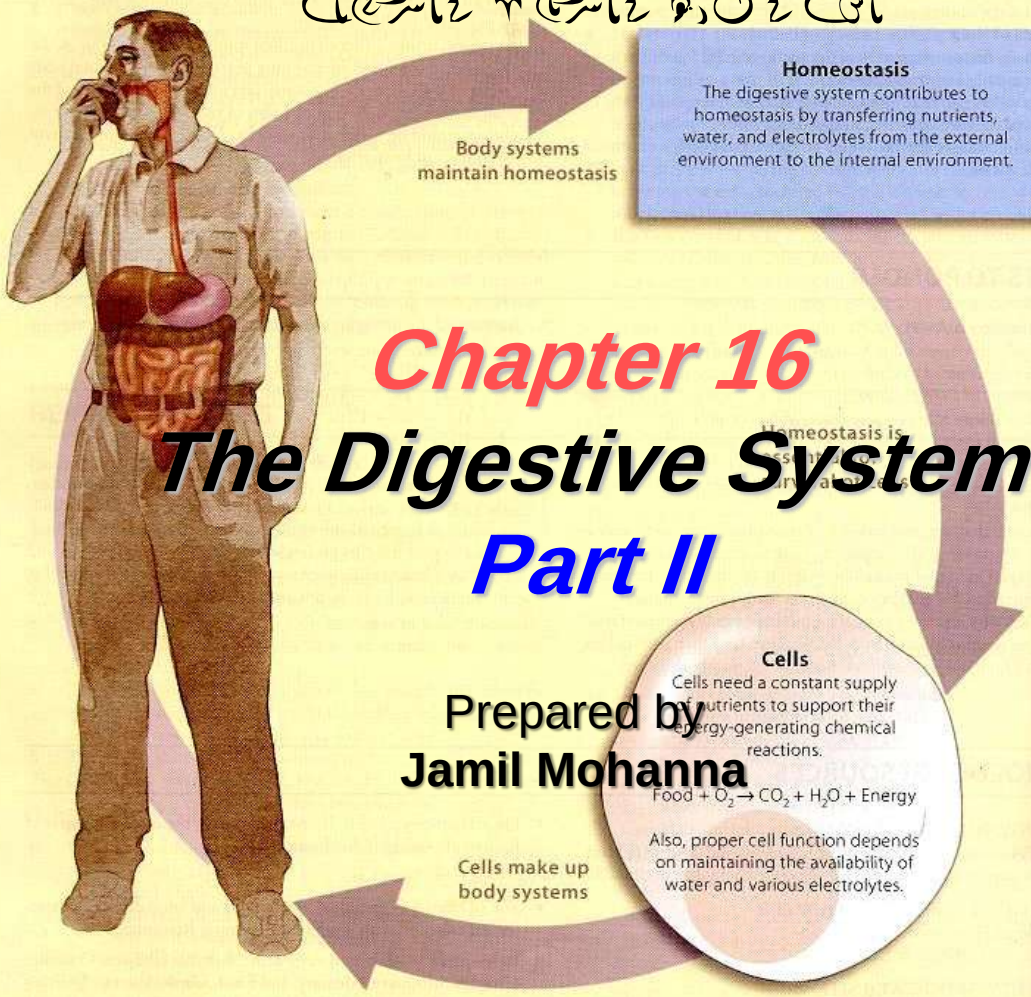

Chapter 16

The Digestive System

Part II

Prepared by
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To maintain homeostasis, nutrient molecules used for energy production must continually be replaced by new, energy-rich nutrients. Similarly, water and electrolytes that are constantly lost in urine and sweat and through other avenues must be replenished regularly. The digestive system contributes to homeostasis by transferring nutrients, water, and electrolytes from the external environment to the internal environment. The **digestive system** does not directly regulate the concentration of any of these constituents in the internal environment. It does not vary nutrient, water, or electrolyte uptake based on body needs (with few exceptions); rather, it optimizes conditions for digesting and absorbing what is ingested.

Stomach

- It is arbitrarily divided into three sections based on anatomical, histological, and functional distinctions. The **fundus** is the portion of the stomach that lies above the esophageal opening. The middle or main part of the stomach is the **body**. Then the lower portion of the stomach, the **antrum**, which has much heavier musculature. The terminal portion of the stomach consists of the **pyloric sphincter**.

➢ **The stomach stores food and begins protein digestion**

- The stomach performs three main functions:

1. The stomach's most important function is to store ingested food until it can be emptied into the small intestine at a rate appropriate for optimal digestion and absorption.
2. The stomach secretes HCl and enzymes that begin protein digestion.
3. The ingested food is pulverized and mixed with gastric secretions to produce a thick liquid mixture known as **chyme**.

- The four aspects of gastric motility are

(1) **Filling**, (2) **Storage**, (3) **Mixing**, (4) **Emptying**.

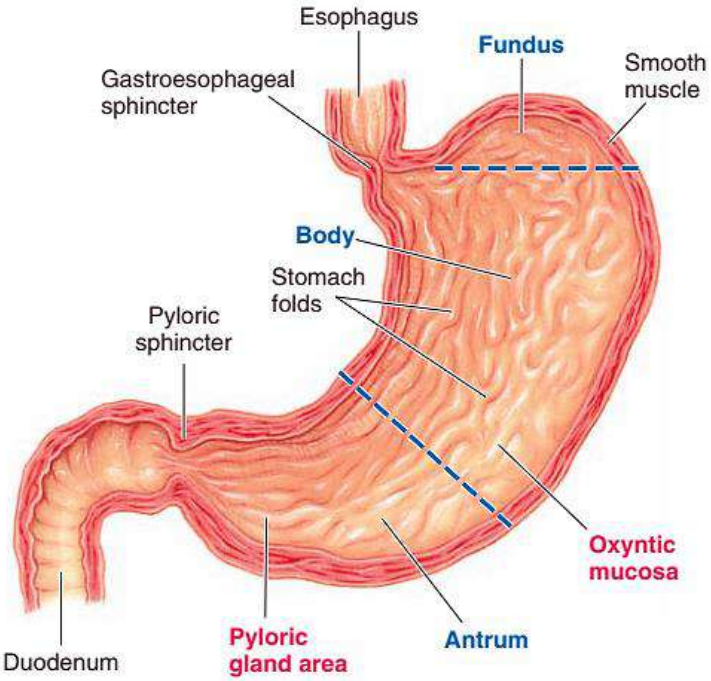


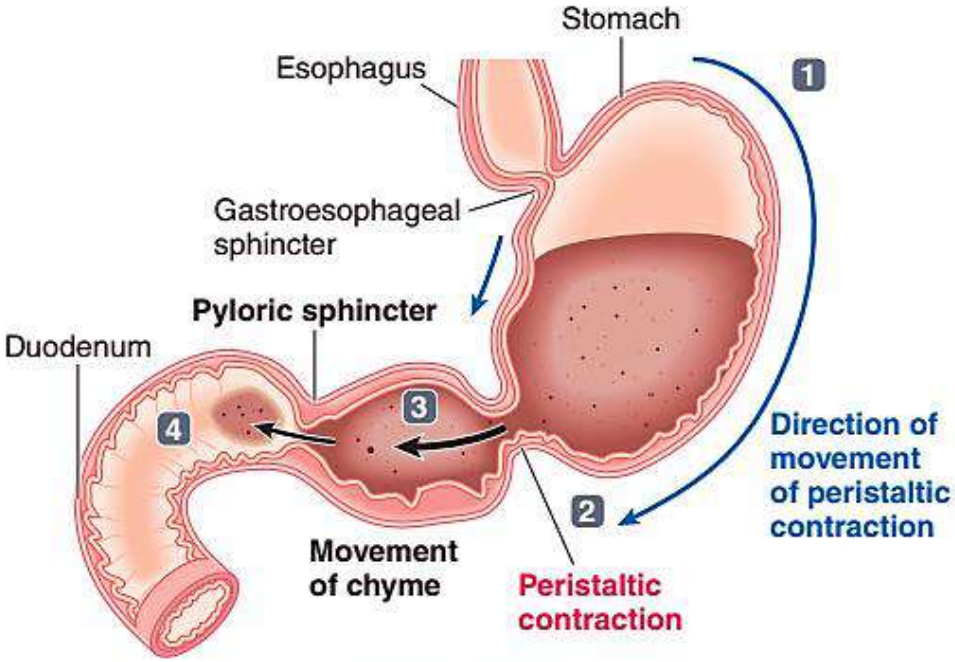
Figure 16-6 Anatomy of the stomach. The stomach is divided into three sections based on structural and functional distinctions—the fundus, body, and antrum. The mucosal lining of the stomach is divided into the oxyntic mucosa and the pyloric gland area based on differences in glandular secretion.

- **Gastric filling involves receptive relaxation**

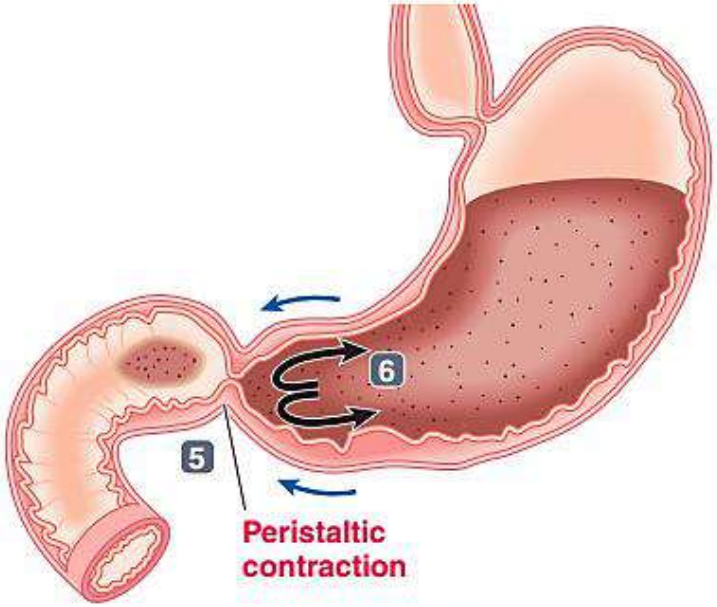
- When empty, the stomach has a volume 50ml and about 1 liter during a meal. It is able to accommodate such a 20-fold change in volume with little change in tension in its walls and little rise in intragastric pressure.
- During a meal, the folds get smaller and flatten out as the stomach relaxes slightly with each mouthful, much like the gradual expansion of a collapsed ice bag as it is being filled. This reflex relaxation of the stomach as it is receiving food is called **receptive relaxation**.

- **Gastric storage takes place in the body of the stomach**

- A group of pacesetter cells located in the upper fundus region generate rhythmic pattern of spontaneous depolarizations “a rate of three per minute”; **basic electrical rhythm (BER)**, occurs continuously and may or may not be accompanied by contraction of the stomach’s circular smooth muscle layer.
- Once initiated, the peristaltic wave spreads over the fundus and body to the antrum and pyloric sphincter. Because the muscle layers are thin in the fundus and body, the peristaltic contractions in this region are weak. When the waves reach the antrum, they become much stronger and more vigorous, because the muscle there is much thicker (fig.16-9).



Gastric emptying



Gastric mixing

1 A peristaltic contraction originates in the upper fundus and sweeps down toward the pyloric sphincter.

2 The contraction becomes more vigorous as it reaches the thick-muscled antrum.

3 The strong antral peristaltic contraction propels the chyme forward.

4 A small portion of chyme is pushed through the partially open sphincter into the duodenum. The stronger the antral contraction, the more chyme is emptied with each contractile wave.

5 When the peristaltic contraction reaches the pyloric sphincter, the sphincter is tightly closed and no further emptying takes place.

6 When chyme that was being propelled forward hits the closed sphincter, it is tossed back into the antrum. Mixing of chyme is accomplished as chyme is propelled forward and tossed back into the antrum with each peristaltic contraction, a process called retropulsion.

› Figure 16-7 **Gastric emptying and mixing as a result of antral peristaltic contractions.**

VIP: Gastric emptying is largely controlled by factors in the duodenum

- The amount of chyme that escape into the duodenum with each peristaltic wave before the pyloric sphincter closes tightly depends largely on the strength of peristalsis. The intensity of natural peristalsis can vary markedly under the influence of different gastric and duodenal factors (table 16-2).
- These factors influence the stomach's excitability by slightly depolarizing of hyperpolarizing the gastric smooth muscle.
- The greater the excitability, the more frequently the BER, the greater the degree of peristaltic activity, and the faster the rate of gastric emptying.

TABLE 16-2 Factors Regulating Gastric Motility and Emptying

Factors	Mode of Regulation	Effects on Gastric Motility and Emptying
Within the Stomach		
Volume of chyme	Distension has a direct effect on gastric smooth muscle excitability, and also acts through the intrinsic plexuses, the vagus nerve, and gastrin	Increased volume stimulates motility and emptying
Degree of fluidity	Direct effect; contents must be in a fluid form to be evacuated	Increased fluidity allows more rapid emptying
Within the Duodenum		
Presence of fat, acid, hypertonicity, or distension	Initiates the enterogastric reflex or triggers the release of enterogastrones (secretin, cholecystokinin)	These factors in the duodenum inhibit further gastric motility and emptying until the duodenum has coped with factors already present
Outside the Digestive System		
Emotion	Alters autonomic balance	Stimulates or inhibits motility and emptying
Intense pain	Increases sympathetic activity	Inhibits motility and emptying

VIP

- **Factors in the stomach that influence the rate of gastric emptying**
- *Volume of chyme and degree of fluidity* **(table 16-2)**.

- **Factors in the duodenum that influence the rate of gastric emptying**
- The four most important duodenal factors that influence gastric emptying are ***fate***, ***acid***, ***hypertonicity***, and ***distension***.

- ***N.B.*** The subsequent reduction in antral peristaltic activity slows down the rate of gastric emptying;
- The *neural response* is mediated through both the intrinsic nerve plexuses (short reflex) and the autonomic nerves (long reflex). Collectively, these reflexes are called the **enterogstric reflex**.
- The *hormonal response* involves the release from the duodenal mucosa of several hormones collectively known as **enterogastrons** ; the most important enterogastrons are ***secretin*** *and* ***cholecysotikinin (CCK)***.

- ***Emotions can influence gastric motility***

The stomach does not actively participate in vomiting

- The stomach, the esophagus, and associated sphincters are all relaxed during vomiting. The major force for expulsion comes, surprisingly, from contraction of the respiratory muscles, the **diaphragm** and the **abdominal muscles**.
- The complex act of vomiting begins with a deep inspiration and closure of the glottis. The contracting diaphragm descends downward on the stomach while simultaneous contraction of the abdominal muscles compresses the abdominal cavity, increasing the intra-abdominal pressure and forcing the abdominal viscera upward.
- The gastric contents are forced upward through the relaxed sphincters and esophagus and out through the mouth. Also, the uvula is elevated to close off the nasal cavity.

➢ **Causes of vomiting;** the causes of vomiting include the following:

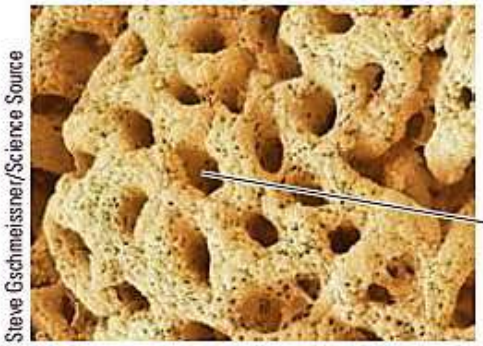
- Tactile (touch) stimulation of the back of the throat, which is one of the most potent stimuli.
- Irritation or distension of the stomach and duodenum.
- Elevated intracranial pressure, such as that caused by cerebral hemorrhage.
- Rotation or acceleration of the head producing dizziness, such as occurs in motion sickness.
- Chemical agents, including drugs or noxious substances that initiate vomiting (called **emetics**) either by acting in the upper portions of the gastrointestinal tract or by stimulating chemoreceptors in a specialized **chemoreceptor trigger zone** adjacent to the vomiting center in the brain.
- Psychogenic vomiting induced by emotional factors.

- **Effect of vomiting**

- The body experiences large losses of secreted fluids and acids that normally would be reabsorbed. It can lead to dehydration and circulatory problems, and the loss of acid from the stomach can lead to metabolic alkalosis.
- Vomiting is not always detrimental, however, it can provide a useful service in removing noxious material from the stomach rather than allowing it to be retained and absorbed.

Gastric digestive juice is secreted by glands located at the base of gastric pits

- Each day the stomach secretes about 2 liters of gastric juice. The gastric mucosa is divided into (1) the **oxyntic mucosa**, which lines the body and fundus, (2)the **pyloric gland area (PGA)**, which lines the antrum. The luminal surface of the stomach is pitted. The first portion of these invaginations are called **gastric pits**, at the base of which the **gastric glands** are located. A variety of secretory cells line these invaginations, some exocrine and some endocrine or paracrine (table 16-4).
- A sparse number of **stem cells** are also found in the gastric pits. These cells rapidly divide and serve as the parent cells of all new cells of the gastric mucosa, to become surface epithelial cells or they differentiate into chief or parietal cells. Through this activity, the entire stomach mucosa is replaced about every three days.



Steve Gschmeissner/Science Source

Scanning electron micrograph of stomach lining showing gastric pits (indents)

Gastric pit

Oxyntic mucosa

Stomach lumen

Pyloric gland area

Gastric gland

Mucosa

Submucosa

In oxyntic mucosa

Surface epithelial cells

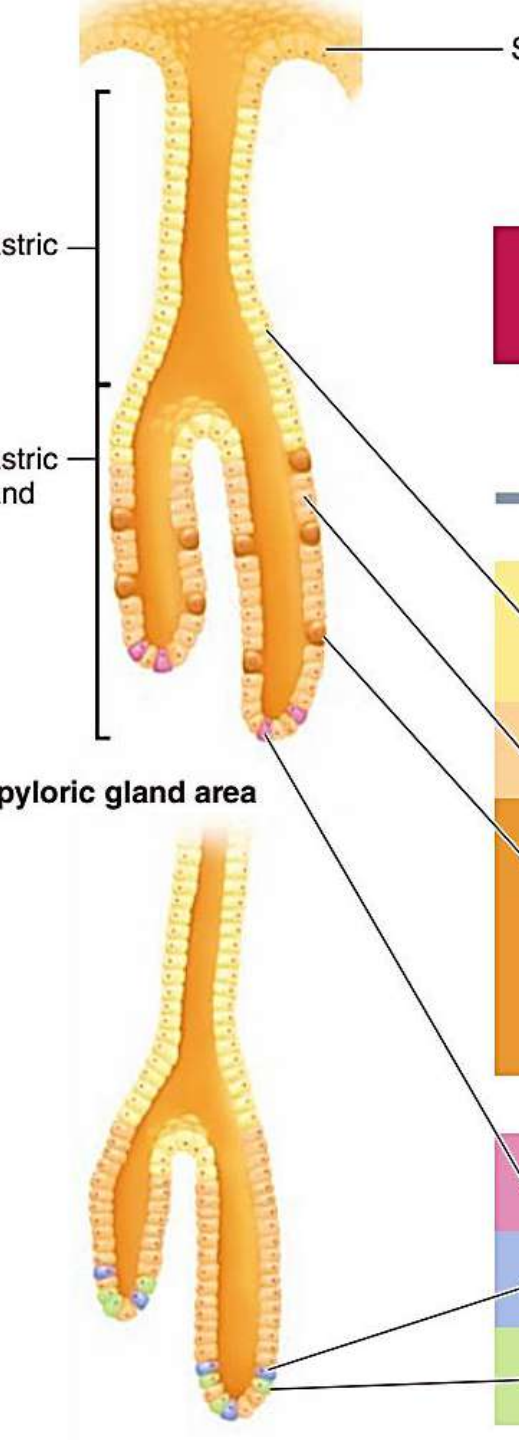


TABLE 16-3 The Stomach Mucosa and the Gastric Glands

Type of Secretory Cell	Product Secreted	Stimuli for Secretion	Function(s) of Secretory Product
Exocrine Cells			
Mucous cells	Alkaline mucus	Mechanical stimulation by contents	Protects mucosa against mechanical, pepsin, and acid injury
Chief cells	Pepsinogen	ACh, gastrin	When activated, begins protein digestion
Parietal cells	Hydrochloric acid	ACh, gastrin, histamine	Activates pepsinogen, breaks down connective tissue, denatures proteins, kills microorganisms
	Intrinsic factor		Facilitates absorption of vitamin B_{12}
Endocrine/Paracrine Cells			
Enterochromaffin-like (ECL) cells	Histamine	ACh, gastrin	Stimulates parietal cells
G cells	Gastrin	Protein products, ACh	Stimulates parietal, chief, and ECL cells
D cells	Somatostatin	Acid	Inhibits parietal, G, and ECL cells

Hydrochloric acid activates pepsinogen

Gastric endocrine and paracrine secretory cells

These are as follows:

Enterochormaffin-like (ECL), secrete histamine.

The gastric glands of the PGA, primarily secrete mucus and pepsinogen, **G cells**, endocrine cells secrete *gastrin* hormone.

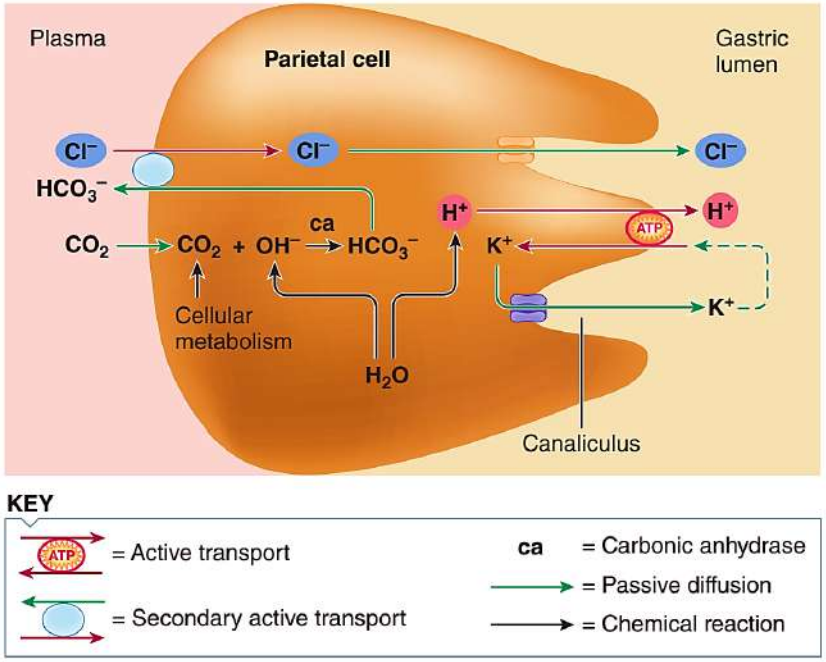
D cells, secrete the paracrine *somatostatin*.

HCl activates pepsinogen

As a result of this HCl secretion, the pH of the luminal contents falls as low as 2. H^+ and Cl^- are actively transported by separate pumps in the parietal cell's plasma membrane, with the H^+ concentration being as much as 3 million times greater in the lumen than in the blood. Chloride is also actively secreted but against a much smaller concentration gradient of only ½ times.

Mechanism of H^+ and Cl^- secretion

The secreted H^+ is not transported from the plasma but is derived instead from metabolic processes within the parietal cell (fig.16-10).



› **Figure 16-8 Mechanism of HCl secretion.** The stomach's parietal cells actively secrete H^+ and Cl^- by the actions of two separate pumps. H^+ is secreted into the lumen by a primary H^+–K^+ ATPase active-transport pump at the parietal cell's luminal border. The K^+ transported into the cell by the pump promptly exits through a luminal K^+ channel, thus being recycled between the cell and lumen. The secreted H^+ is derived from the breakdown of H_2O into H^+ and OH^-. Catalyzed by carbonic anhydrase, the OH^- combines with CO_2 (that is either metabolically produced in the cell or diffuses in from the plasma) to form HCO_3^-. Cl^- is secreted by secondary active transport. Driven by the HCO_3^- concentration gradient, a Cl^-–HCO_3^- antiporter in the basolateral membrane transports HCO_3^- down its concentration gradient into the plasma and simultaneously transports Cl^- into the parietal cell against its concentration gradient. Cl^- secretion is completed as the Cl^- that entered from the plasma diffuses out of the cell down its electrochemical gradient through a luminal Cl^- channel into the lumen.

Pepsinogen, once activated, begins protein digestion

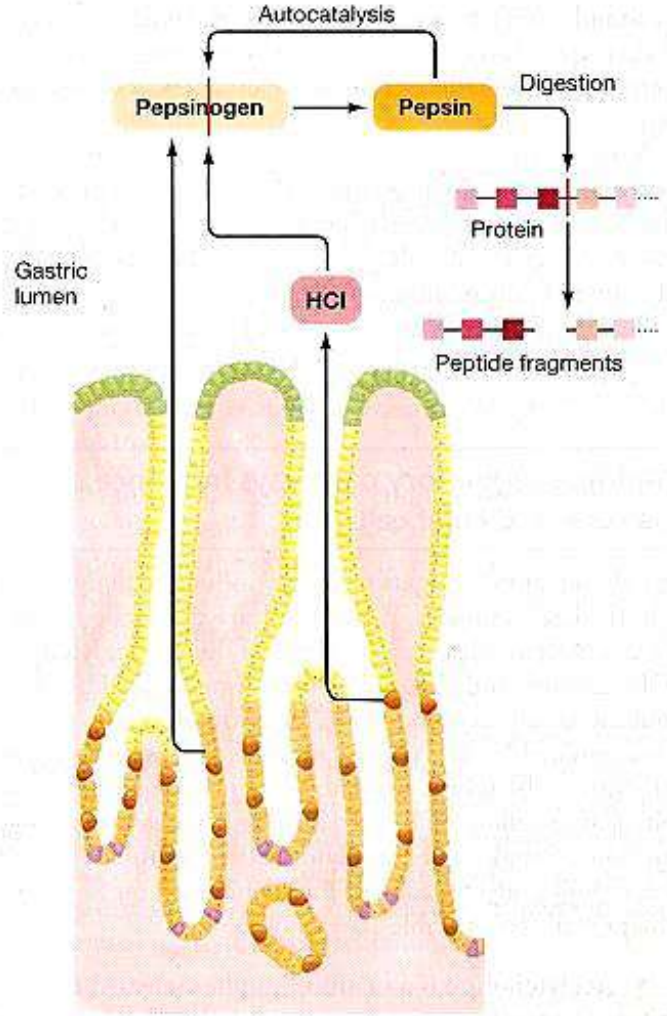
- **Functions of HCl**

- Although HCl does not actually digest anything, it performs several functions that assist digestion;

1. Activates the enzyme precursor pepsinogen to an active enzyme, pepsin.
2. Aids in the breakdown of connective tissue and muscle fibers, thereby reducing large food particles into smaller particles.
3. Denatures protein; that is, it uncoils proteins from their tertiary structure, thus exposing more of the peptide bonds for enzymatic attack.

Along with salivary lysozyme, kills most of the microorganisms ingested with the food.

- The major digestive constituent of gastric secretion is **pepsinogen**, an inactive enzymatic molecule synthesized and packaged by the endoplasmic reticulum and Golgi complex of chief cells. It is stored in the chief cell's cytoplasm within secretory vesicles, **zymogen granules** (fig.16-11).



● FIGURE 16-11

Pepsinogen activation in the stomach lumen

In the lumen, hydrochloric acid (HCl) activates pepsinogen to its active form, pepsin, by cleaving off a small fragment. Once activated, pepsin autocatalytically activates more pepsinogen and begins protein digestion. Secretion of pepsinogen in the inactive form prevents it from digesting the protein structures of the cells in which it is produced.

Intrinsic factor is essential for absorption of vitamin B_{12}

- Intrinsic factor, another secretory product of the parietal cell, is important in the absorption of vitamin B_{12}. binding of he intrinsic factor-vitamin B_{12} complex with a special receptor located only in the terminal ileum, triggers the receptor-mediated endocytosis of the complex at this location.
- In the absence of intrinsic factor, vitamin B_{12} fails to be absorbed, so erythrocyte production is defective, and *pernicious anemia* results, caused by an autoimmune attack against the parietal cells , treated by regular injections of vitamin B_{12}.

➢ **Multiple regulatory pathways influence the parietal and chief cells**

- Four chemical messengers primarily influence the secretion of gastric digestive juices. Parietal cells have separate receptors for each of these messengers. Three of them –acetylcholine (Ach), gastrin, and histamine-are stimulatory.
- The fourth regulatory agent-somatostatin-inhibits acid secretion. Ach and gastrin also increase pepsinogen secretion through their stimulatory effect on the chief cells, (table 16-4).

Control of gastric secretion involves three phases

The rate of gastric secretion can be influenced by three phases (table 16-4 and 16-5): VIP

- Cephalic phase; refers to the increases secretion of HCl and pepsinogen occurs in feed-forward fashion stimulation act in the head even before the presence of food in the stomach.
- Gastric phase; occurs when food actually reaches the stomach.
- Intestinal phase; the *intestinal phase of gastric secretion* encompasses the factors originating in the small intestine that influence gastric secretion, this phase is inhibitory.

TABLE 16-4 Stimulation of Gastric Secretion

Phase	Stimuli	Excitatory Mechanism for Enhancing Gastric Secretion
Cephalic phase of gastric secretion	Stimuli in the head—seeing, smelling, tasting, chewing, swallowing food	+ Vagus → + Intrinsic nerves → ↑ACh → + Chief and parietal cells → ↑Gastric secretion; + Vagus → + G cells → ↑Gastrin → + Chief and parietal cells; ↑Gastrin → + ECL cells → ↑Histamine → + Chief and parietal cells
Gastric phase of gastric secretion	Stimuli in the stomach—protein, (peptide fragments), distension, caffeine, alcohol	+ Vagus → + Intrinsic nerves → ↑ACh → + Chief and parietal cells → ↑Gastric secretion; + Vagus → + G cells → ↑Gastrin → + Chief and parietal cells; ↑Gastrin → + ECL cells → ↑Histamine → + Chief and parietal cells

Gastric secretion gradually decreases as food empties from the stomach into the intestine

- How the flow of gastric juices shut off when they are no longer needed?
- Gastric secretion is gradually reduced by three different means as the stomach empties (fig. 16-5).

VIP

TABLE 16-5 Inhibition of Gastric Secretion

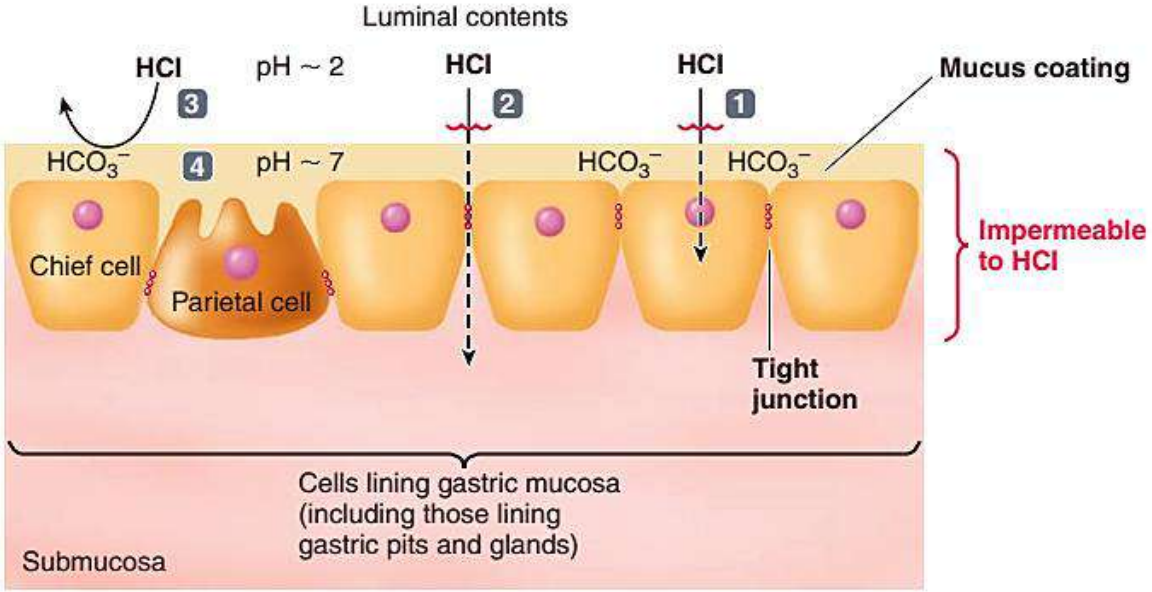
Region	Stimuli	Inhibitory Mechanism for Gastric Secretion
Body and antrum	Removal of protein and distension as the stomach empties	(−) Intrinsic nerves; (−) Vagus; (−) G cells → ↓Gastrin → ↓Histamine → ↓Gastric secretion
Antrum and duodenum	Accumulation of acid	(+) D cells → ↑Somatostatin → (−) Parietal cells, (−) G cells, (−) ECL cells → ↓Gastric secretion
Duodenum (intestinal phase of gastric secretion)	Fat Acid Hypertonicity Distension	(+) Enterogastric reflex; (+) ↑Enterogastrones (cholecystokinin and secretin) → (−) Parietal cells, (−) Chief cells, (−) Smooth muscle cells → ↓Gastric secretion and motility

The stomach lining is protected from gastric secretions by the gastric mucosal barrier

- How can the stomach contain strong acid contents and proteolytic enzymes without destroying itself? (fig. 16-12)

Mucus provides a protective coating, in addition, other barriers to mucosal acid damage are provided by the mucosal lining itself; (1) the luminal membranes of the gasteric mucosal cells are almost impermeable to H^+, so acid cannot penetrate *into* the cells and cause cellular damage. (2) the lateral edges of these cells are joined together by tight junctions, so acid cannot diffuse *between* the lumen cells into the underlying submucosa.

These protective mechanisms are further enhanced by the fact that the entire stomach lining is replaced every three days.



The components of the gastric mucosal barrier enable the stomach to contain acid without injuring itself:

1 The luminal membranes of the gastric mucosal cells are impermeable to H^+ so that HCl cannot penetrate into the cells.

2 The cells are joined by tight junctions that prevent HCl from penetrating between them.

3 A mucus coating over the gastric mucosa serves as a physical barrier to acid penetration.

4 The HCO_3^--rich mucus also serves as a chemical barrier that neutralizes acid in the vicinity of the mucosa. Even when luminal pH is 2, the mucus pH is 7.

- **Carbohydrate digestion continues in the body of the stomach; protein digestion begins in the antrum**

- In the body of the stomach, food remains in a semisolid mass, because peristaltic contractions in this region are too weak for mixing to occur, so very little protein digestion occurs here.
- Even though acid inactivates salivary amylase, the unmixed interior of the food mass is free of acid
- Digestion by the gastric juice itself is accomplished in the antrum of the stomach, where the food is thoroughly mixed with HCl and pepsin, thereby initiating protein digestion.

- **The stomach absorbs alcohol and aspirin but no food**

- No food or water is absorbed into the blood through the stomach mucosa. However, two noteworthy non-nutrient substances are absorbed directly by the stomach – ***ethyl alcohol*** which is lipid soluble and ***aspirin***.
- In the highly acidic environment of the stomach lumen, weak acids are almost totally un-ionized. Weak acids are lipid soluble, so they can be absorbed quickly by crossing the plasma membranes of the epithelial cells that line the stomach.

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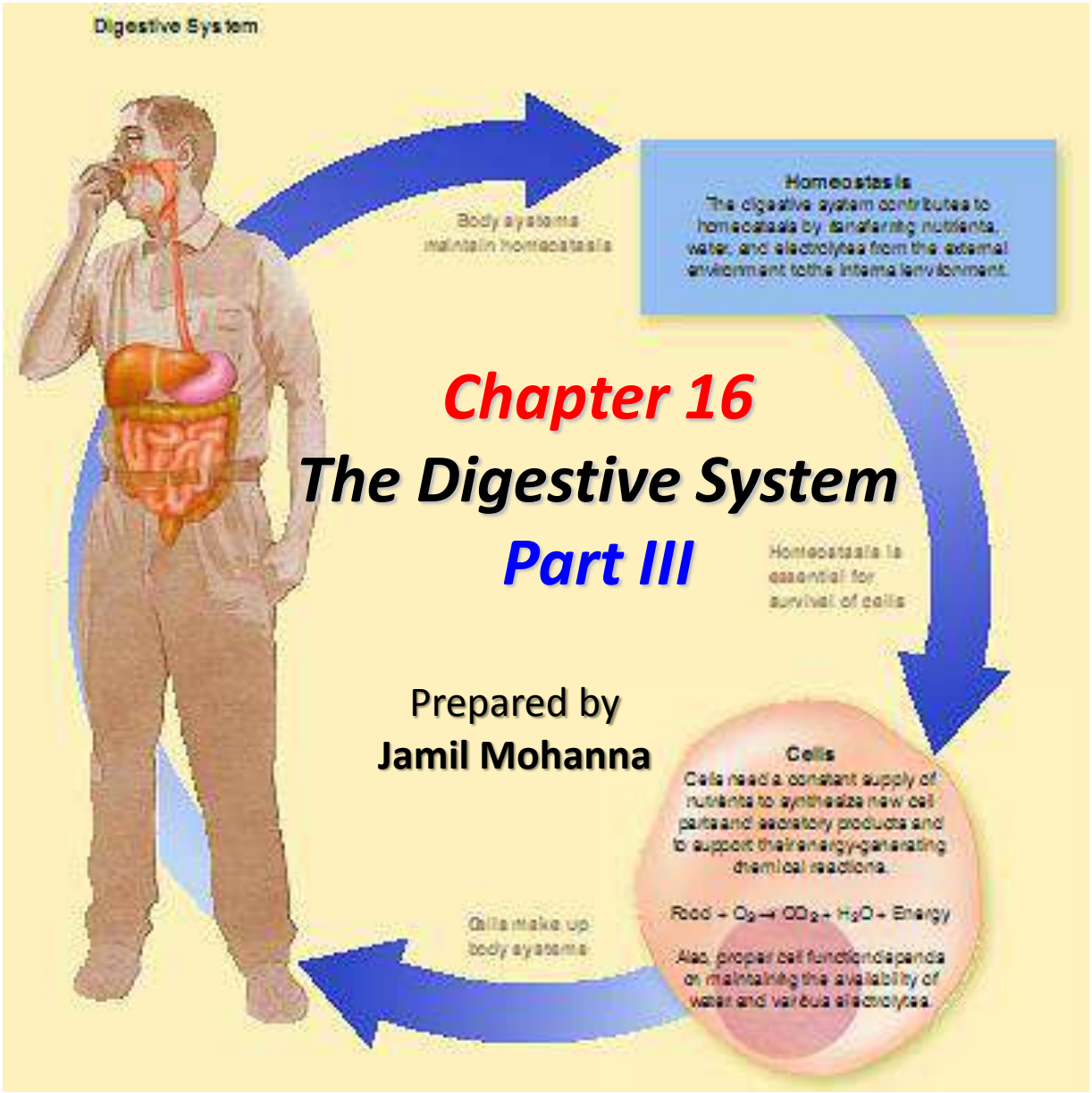


Chapter 16

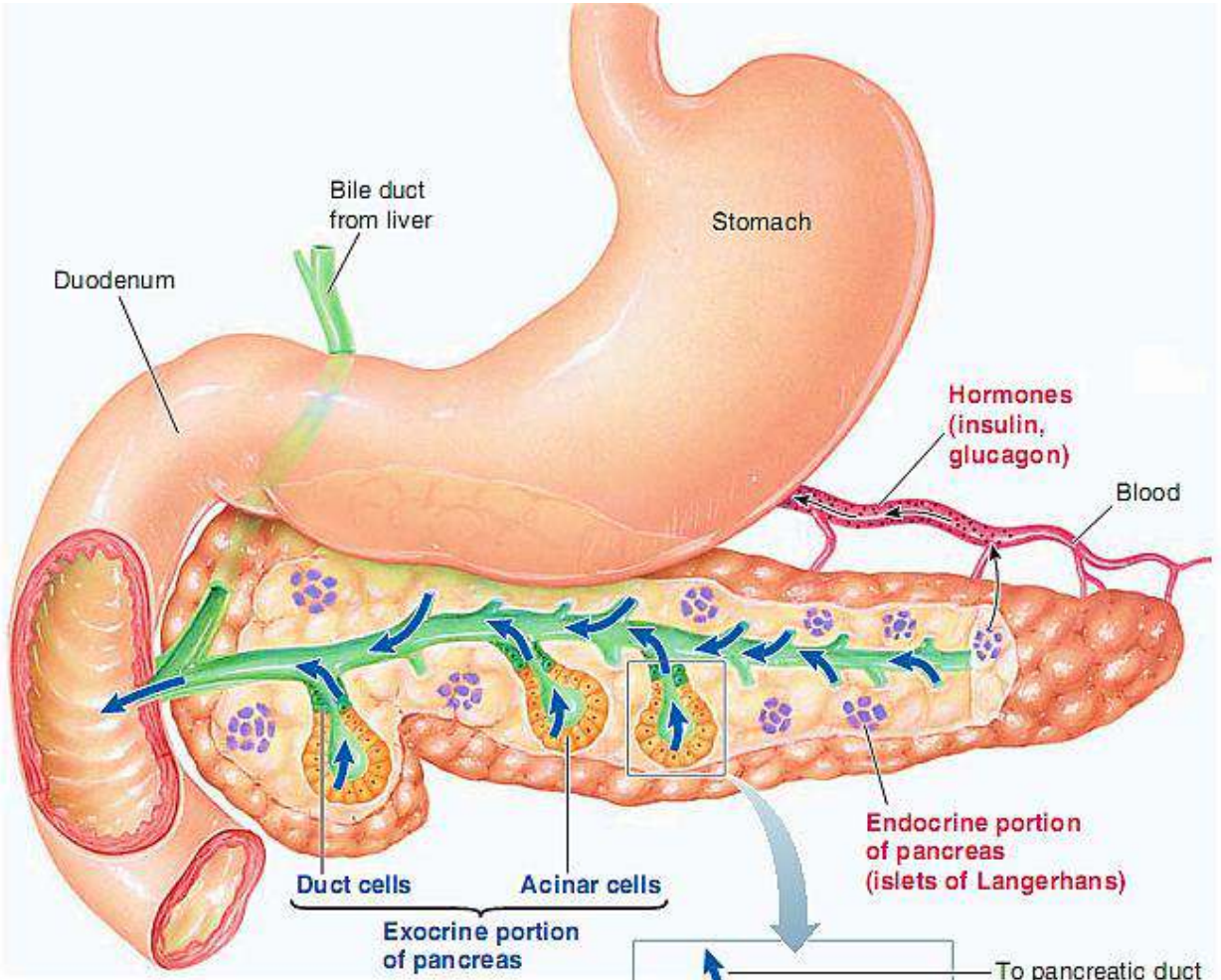
The Digestive System

Part III

Prepared by
Jamil Mohanna

The pancreas contains exocrine and endocrine cells.

- Endocrine cells of the islets of Langerhans secrete hormones.
- The exocrine pancreas secretes digestive enzymes and an aqueous alkaline fluid. The alkaline fluid has sodium bicarbonate.
- The enzymes are proteolytic enzymes, pancreatic amylase, and pancreatic lipase.
- Trypsin, formed from trypsinogen, is a proteolytic enzyme. Chymotrypsin and carboxypeptidase are other proteolytic enzymes.
- Pancreatic amylase converts starch to disaccharides.
- Pancreatic lipase hydrolyzes dietary lipids.
- Pancreatic exocrine secretion is regulated by secretin and CCK, enzymes secreted by the small intestine. **Secretin** signals the secretion of **sodium bicarbonate** from the pancreas. **CCK** regulates the secretion of pancreas **digestive enzymes**.



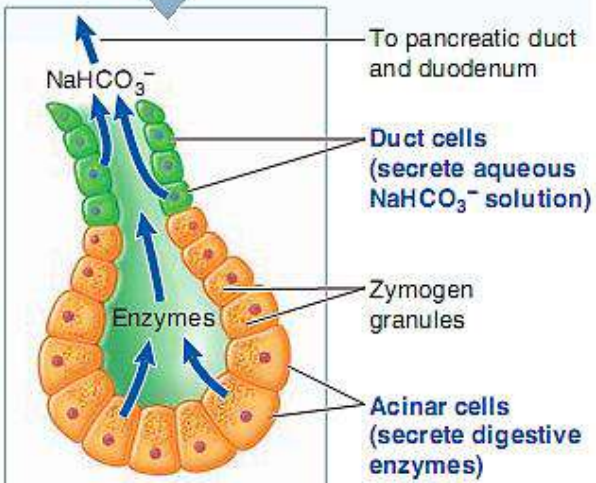
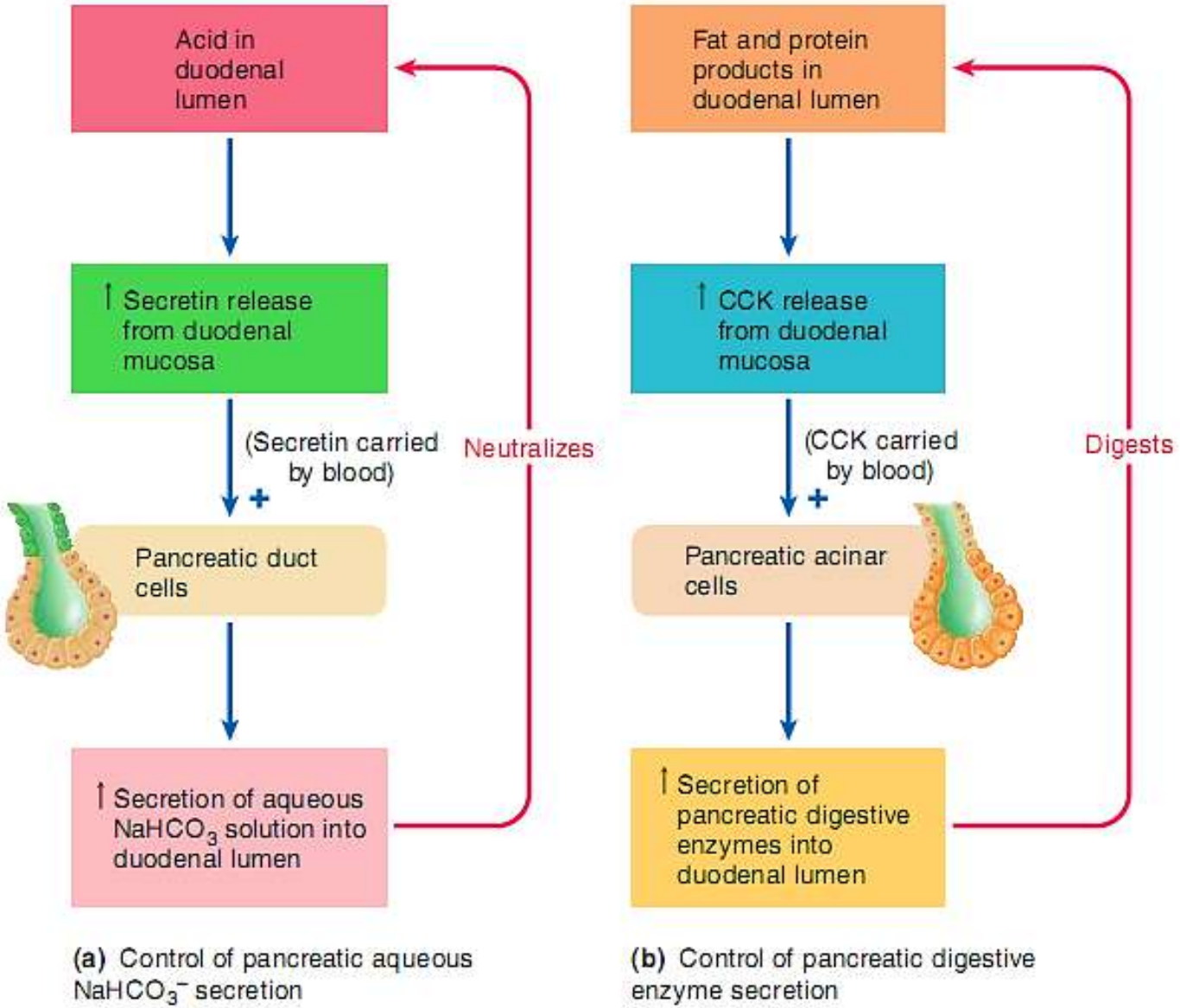


FIGURE 16-12 Exocrine and endocrine portions of the pancreas. The exocrine pancreas secretes into the duodenal lumen a digestive juice composed of digestive enzymes secreted by the acinar cells and an aqueous $NaHCO_3$ solution secreted by the duct cells. The endocrine pancreas secretes the hormones insulin and glucagon into the blood.



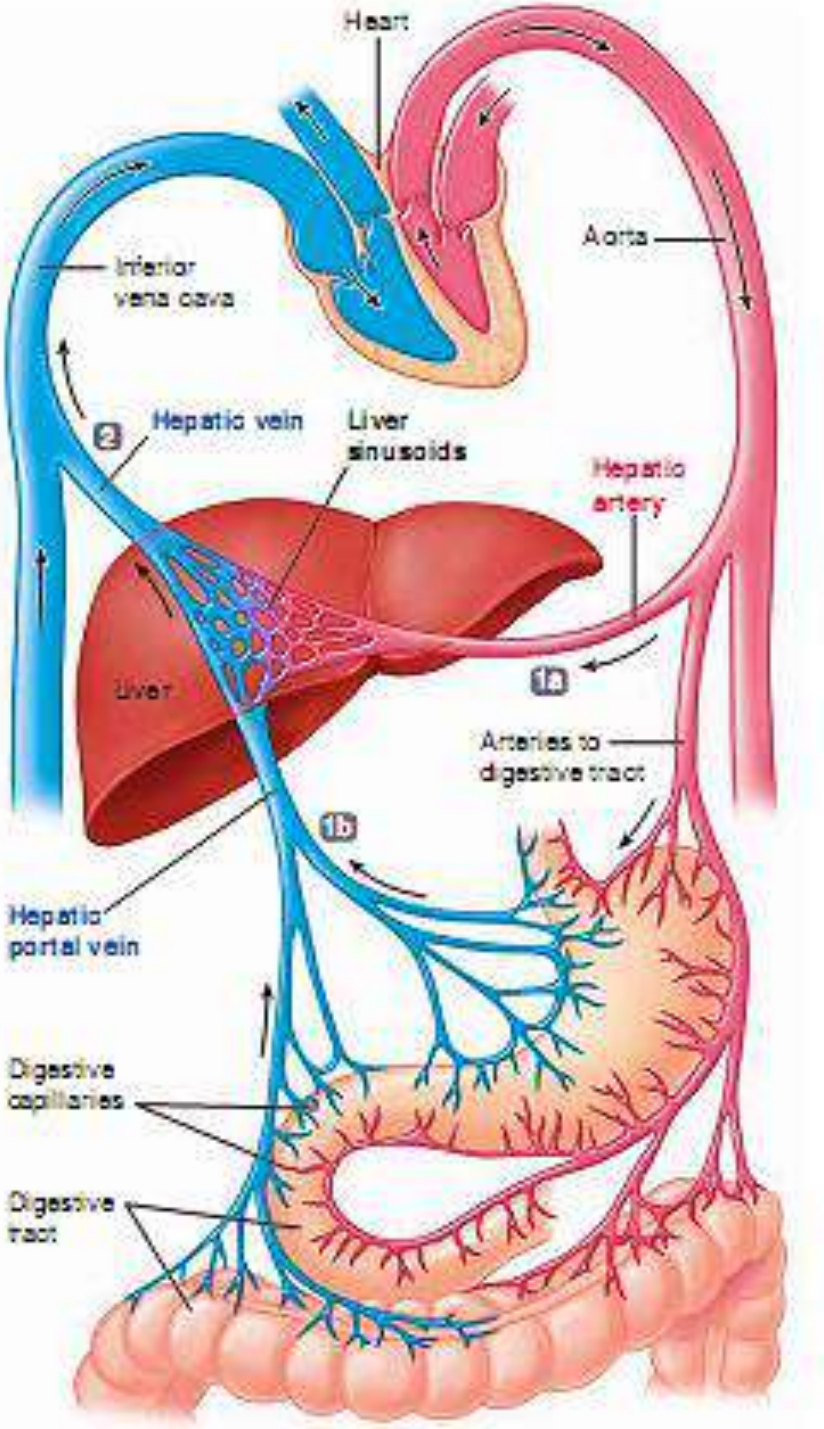
● **FIGURE 16-13 Hormonal control of pancreatic exocrine secretion.**

The liver performs various important functions, including bile production

1. It carries out the metabolic processing of nutrients.
2. It detoxifies or degrades body wastes.
3. It synthesizes plasma proteins, needed for blood clotting , hormones transport , Angiotensinogen.
4. It stores substances such as glycogen and fats.
5. It activates vitamin D.
6. It removes bacteria and worn-out RBCs.
7. Secreting the hormones like; thrombopoietin, hepcidin, and insulin-like growth factor-I .
8. Producing acute phase proteins important in inflammation.
9. It excretes cholesterol and bilirubin.

Liver Blood Flow

- **Blood enters the liver from the digestive tract by the hepatic portal system. The portal vein of this system breaks into a capillary network, the liver sinusoids.**



The liver receives blood from two sources:

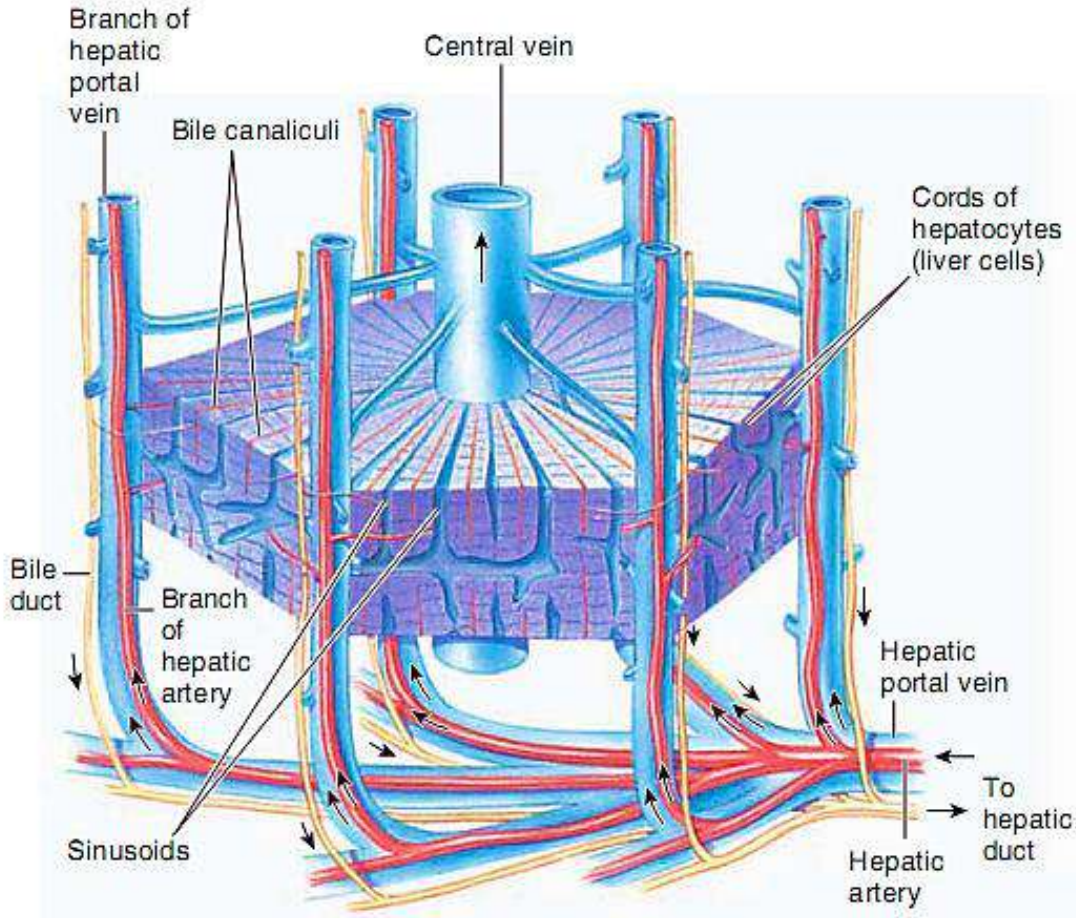
1a Arterial blood, which provides the liver's O_2 supply and carries blood-borne metabolites for hepatic processing, is delivered by the **hepatic artery**.

1b Venous blood draining the digestive tract is carried by the **hepatic portal vein** to the liver for processing and storage of newly absorbed nutrients.

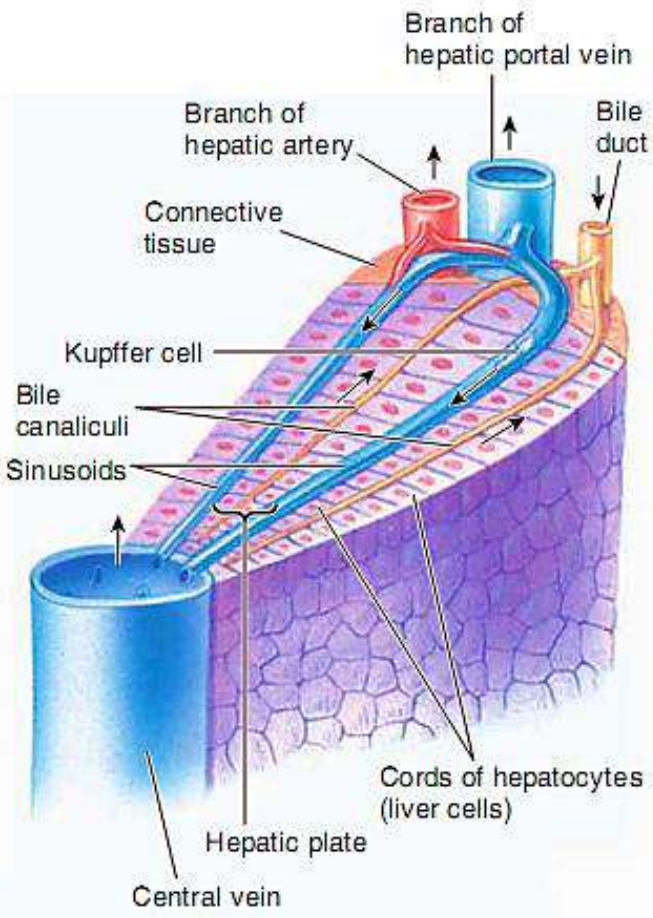
2 Blood leaves the liver via the **hepatic vein**.

FIGURE 16-14 Schematic representation of liver blood flow.

The liver lobules are delineated by vascular and bile channels.



(a) Hepatic lobule



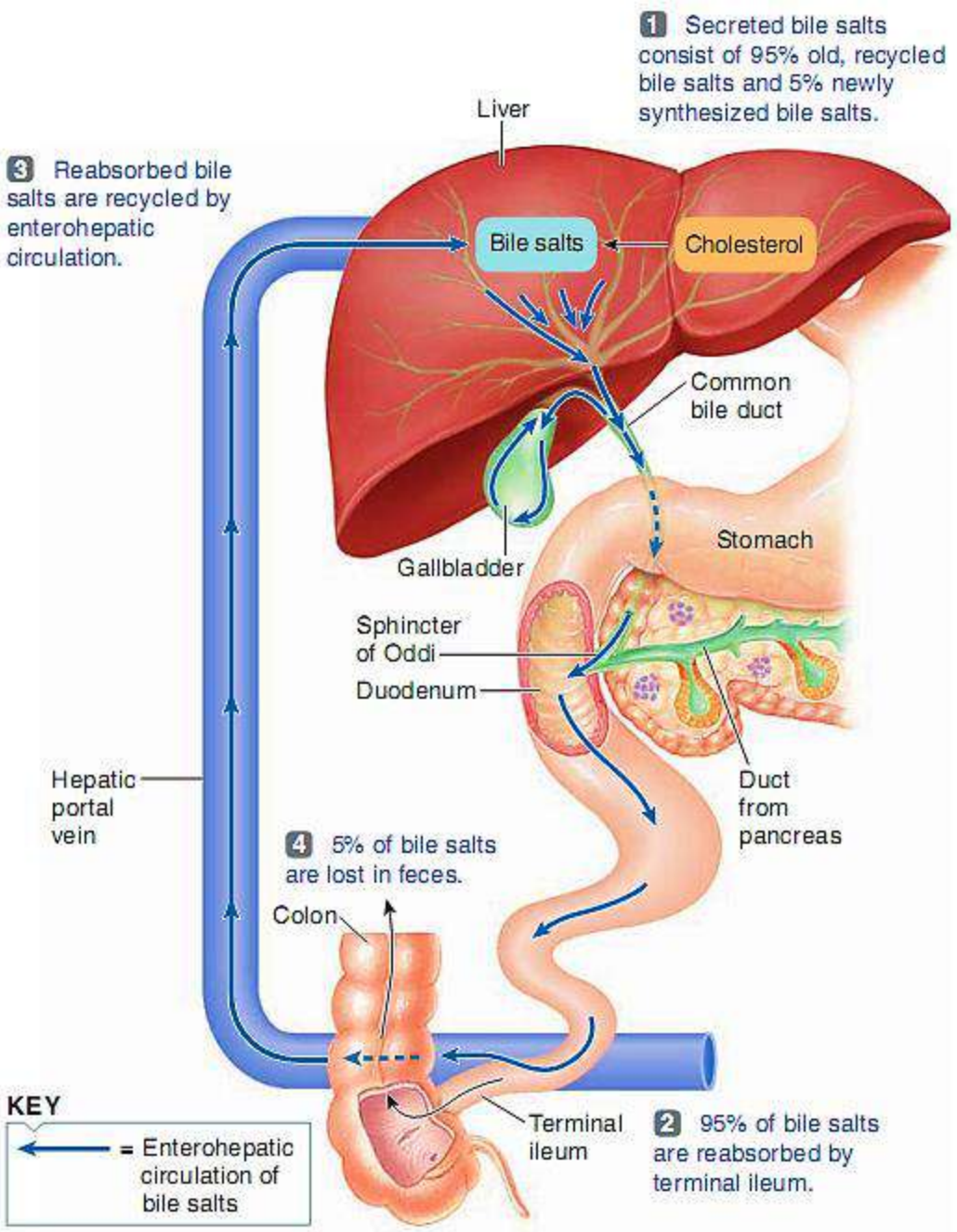
(b) Wedge of a hepatic lobule

● **FIGURE 16-15 Anatomy of the liver.**

- **The liver lobules are delineated by vascular and bile channels. Hepatocytes continuously secrete bile into these channels.**

- **Bile ducts from the lobules in the liver converge to form the common bile duct. This duct transports bile from the liver to the duodenum.**

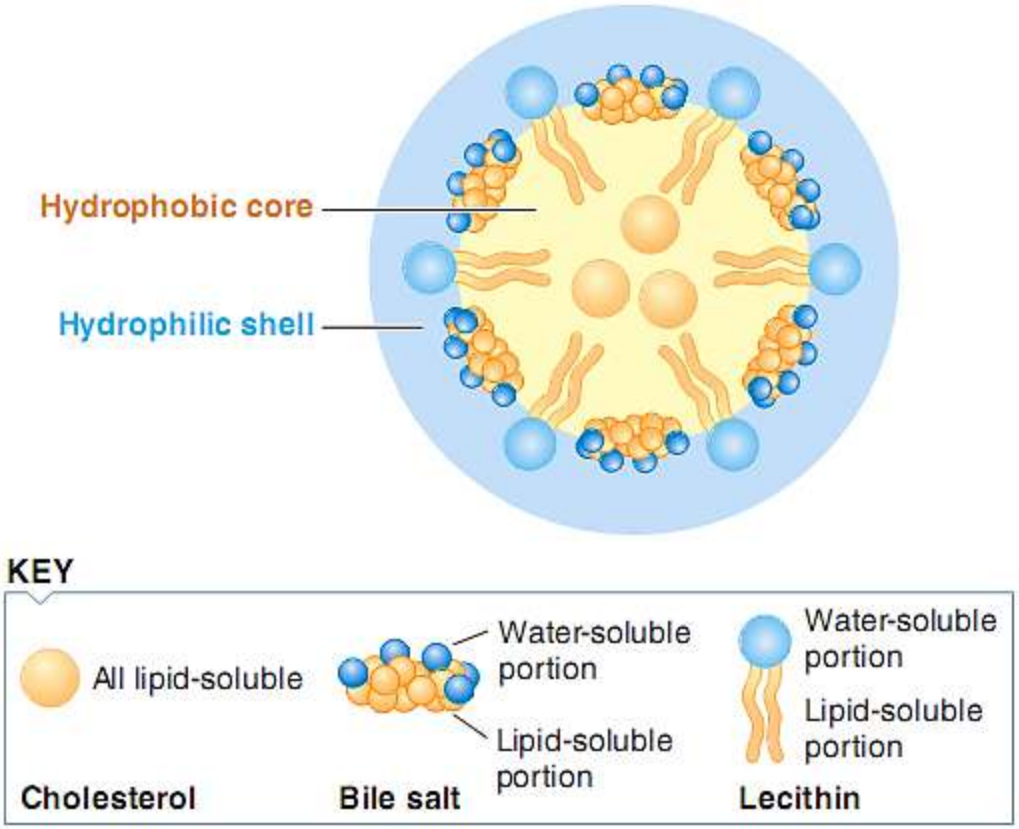
- **Bile is stored in the gallbladder between meals. After a meal the liver and gallbladder secrete bile into the small intestine for fat digestion.**



● **FIGURE 16-16 Enterohepatic circulation of bile salts.** The majority of bile salts are recycled between the liver and small intestine through the enterohepatic

Bile salts aid fat digestion and absorption.

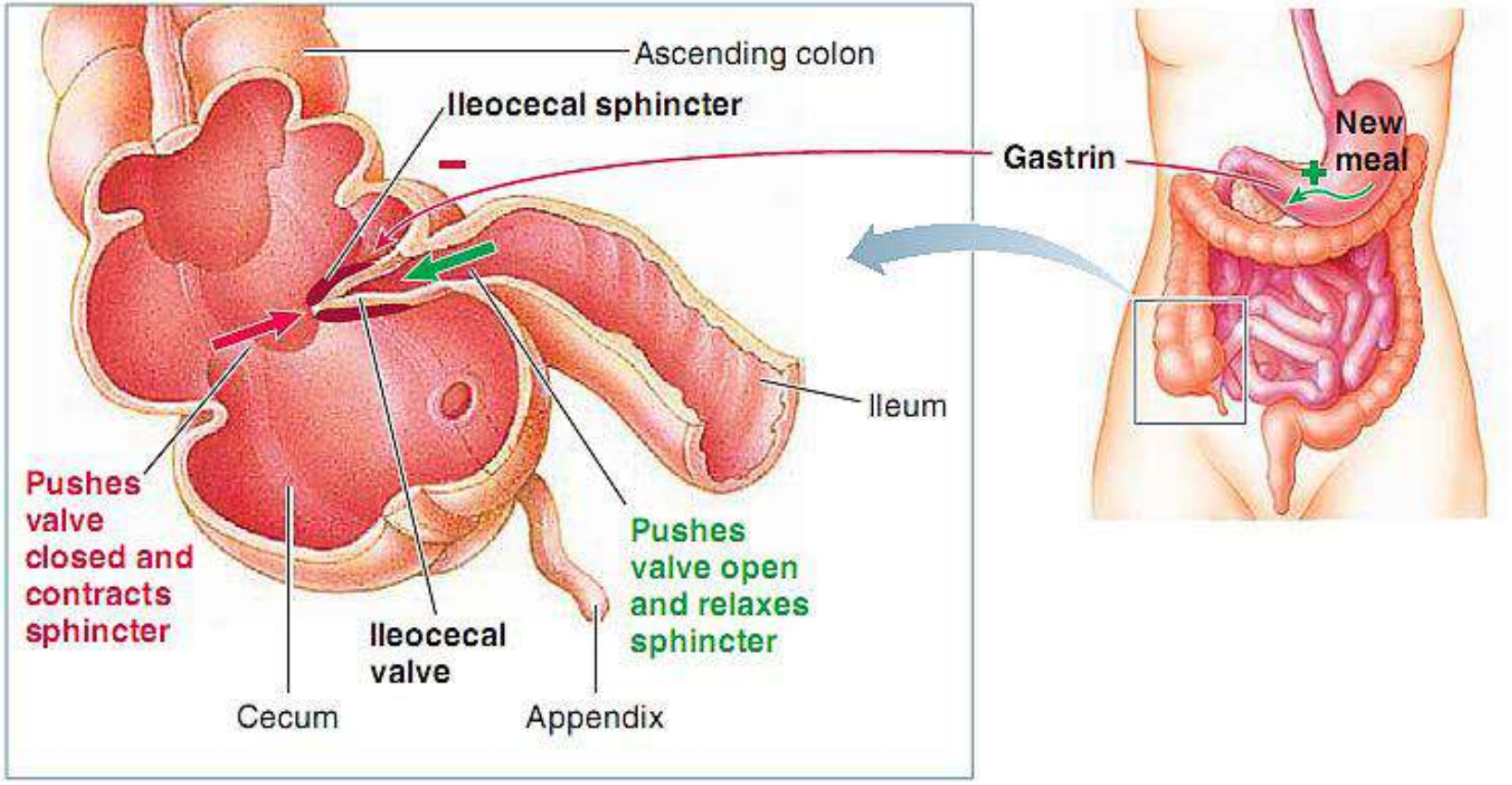
- The detergent action of bile emulsifies fats. Fat globules are broken into smaller droplets, increasing surface area to facilitate enzymatic attack (pancreatic lipase).
- Pancreatic lipase is anchored to a fat droplet by the polypeptide colipase.
- Bile salts adsorb on the surface of small fat droplets, preventing the droplets for recoalescing. This also helps enzymatic attack.
- **Bilirubin** is a waste product excreted in the bile, its accumulation causes **jaundice**.
- Bile salts are the most potent stimulus for increased bile secretion. Its secretion occurs by a chemical mechanism, hormonal mechanism (↑secretin), and a neural mechanism.
- The gallbladder stores and concentrates bile between meals and empties during meals.
- Hepatitis and cirrhosis are the most common liver disorders.



● **FIGURE 16-18 A micelle.** Bile constituents (bile salts, lecithin, and cholesterol) aggregate to form micelles that consist of a hydrophilic (water-soluble) shell and a hydrophobic (lipid-soluble) core. Because the outer shell of a micelle is water soluble, the products of fat digestion, which are not water soluble, can be carried through the watery luminal contents to the absorptive surface of the small intestine by dissolving in the micelle's lipid-soluble core. This figure is not drawn to scale compared to the lipid emulsion droplets in ● Figure 16-17b. An emulsified fat droplet ranges in diameter from 200 to 5000 nm (average 1000 nm) compared to a micelle, which is 3 to 10 nm in diameter.

The small intestine is where most digestion and absorption occur.

- Its three segments are the duodenum, jejunum, and ileum.
- The process of segmentation mixes and slowly propels the food.
- Segmentation contractions are initiated by BER cells.
- The circular smooth muscle responsiveness is influenced by the distension of the intestine, gastrin, and extrinsic nerve activity.
- Segmentation mixes chyme with secretions and slowly moves the contents through the tract.
- The migrating motility complex is an internal housekeeper. It sweeps the intestine clean between meals.
- The ileocecal juncture, between the small and large intestine, prevents contamination of the small intestine by colonic bacteria.



● **FIGURE 16-20 Control of the ileocecal valve/sphincter.** The juncture between the ileum and large intestine is the ileocecal valve, which is surrounded by thickened smooth muscle, the ileocecal sphincter. Pressure on the cecal side pushes the valve closed and contracts the sphincter, preventing the bacteria-laden colonic contents from contaminating the nutrient-rich small intestine. The valve/sphincter opens and allows ileal contents to enter the large intestine in response to pressure on the ileal side of the valve and to the hormone gastrin secreted as a new meal enters the stomach.

Other facts about the small intestine include:

- It does not secrete digestive enzymes. The pancreas secretes enzymes into the tract.
- The small intestine enzymes complete digestion intracellularly. These include the disaccharidases and aminopeptidases.
- Fat digestion is completed within the small-intestine lumen, but carbohydrate and protein digestion are completed within the confines of the brush border.
- The brush-border plasma membrane contains three categories of membrane-bound enzymes:

1. **Enterokinase,** which activates the pancreatic enzyme trypsinogen.
2. **The Disaccharidases (maltase, sucrase,** and **lactase),** which hydrolyze disaccharides into their constituent monosaccharides.
3. **The aminopeptidases,** which hydrolyze the small peptide fragments into their amino acid components.

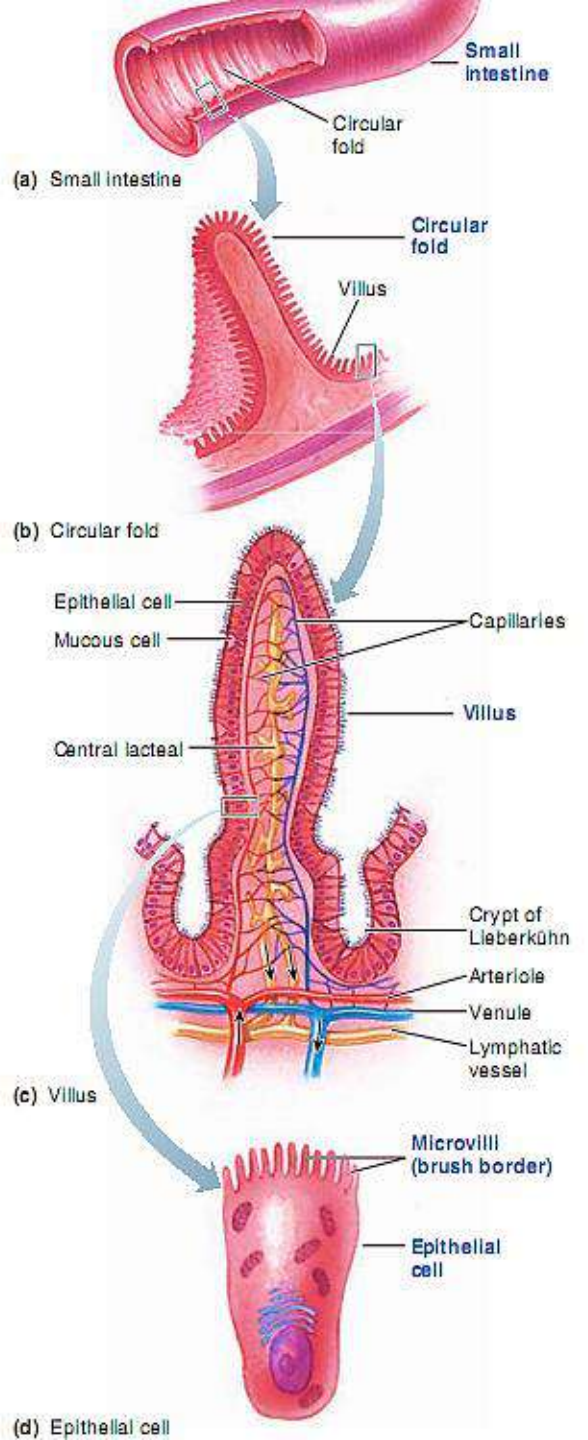
- A ***lactose intolerance*** is due to a deficiency of lactase.
- Table16 – 6

TABLE 16-6 Digestive Processes for the Three Major Categories of Nutrients

Nutrients	Enzymes for Digesting Nutrient	Source of Enzymes	Site of Action of Enzymes	Action of Enzymes	Absorbable Units of Nutrients
Carbohydrate	Amylase	Salivary glands	Mouth and (mostly) body of stomach	Hydrolyzes polysaccharides to disaccharides	
		Exocrine pancreas	Small-intestine lumen		
	Disaccharidases (maltase, sucrase, lactase)	Small-intestine epithelial cells	Small-intestine brush border	Hydrolyze disaccharides to monosaccharides	Monosaccharides, especially glucose
Protein	Pepsin	Stomach chief cells	Stomach antrum	Hydrolyzes protein to peptide fragments	
	Trypsin, chymotrypsin carboxypeptidase	Exocrine pancreas	Small-intestine lumen	Attack different peptide fragments	
	Aminopeptidases	Small-intestine epithelial cells	Small-intestine brush border	Hydrolyze peptide fragments to amino acids	Amino acids and a few small peptides
Fat	Lipase	Exocrine pancreas	Small-intestine lumen	Hydrolyzes triglycerides to fatty acids and monoglycerides	Fatty acids and monoglycerides
	Bile salts (not an enzyme)	Liver	Small-intestine lumen	Emulsify large fat globules for attack by pancreatic lipase	

The small intestine has adaptations to maximize absorption. The mucosal lining has a large surface area due to its circular folds and fingerlike projections called villi. The epithelial cells also have microvilli.

- A villus has a cover of epithelial cells, a connective tissue core, a capillary network, and the terminal lymphatic vessel.
- During absorption molecules produced by digestive enter the capillary or lymphatic vessel.
- The mucosal lining has a rapid turnover. The crypts of Liberkuhn have stem cells for cell regeneration.
- See next Figures and the Flash.



The epithelial cells in the inner lining of the small intestine have a variety of transport mechanisms.

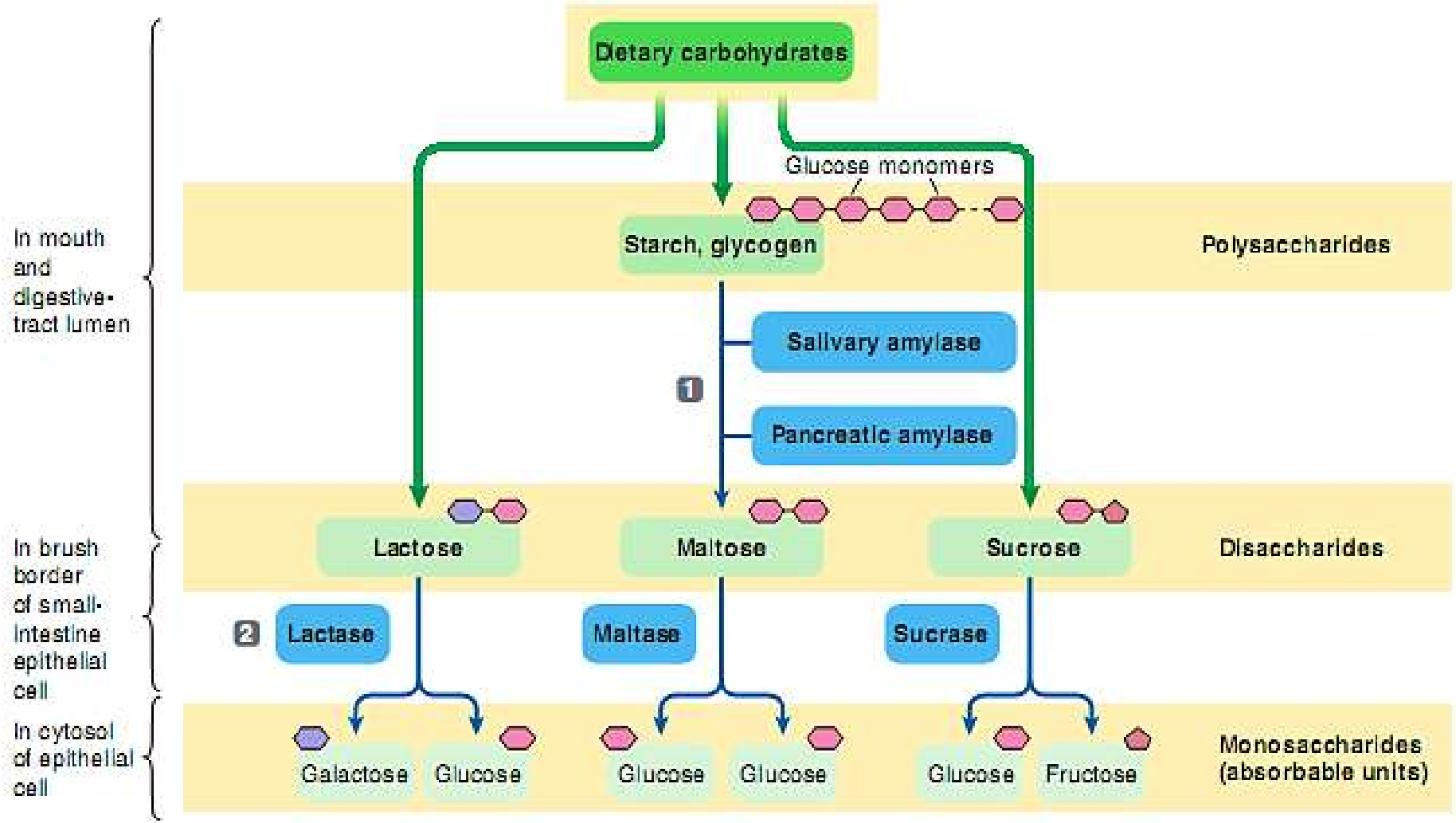
- Energy-dependent sodium transport absorption drives passive water absorption.
- Sodium is pumped from the tract lumen into the interstitial fluid. From their, it enters capillaries by diffusion.
- The transport of sodium creates an osmotic pressure. Water follow the sodium as it is absorbed.
- Glucose and galactose are moved by secondary active transport. They are cotransported with sodium.
- Fructose is absorbed by passive facilitated diffusion.
- Amino and small peptides are absorbed across intestinal cells by secondary active transport.

Digested fat is absorbed passively and enters the lymph. It undergoes a series of transformations for absorption.

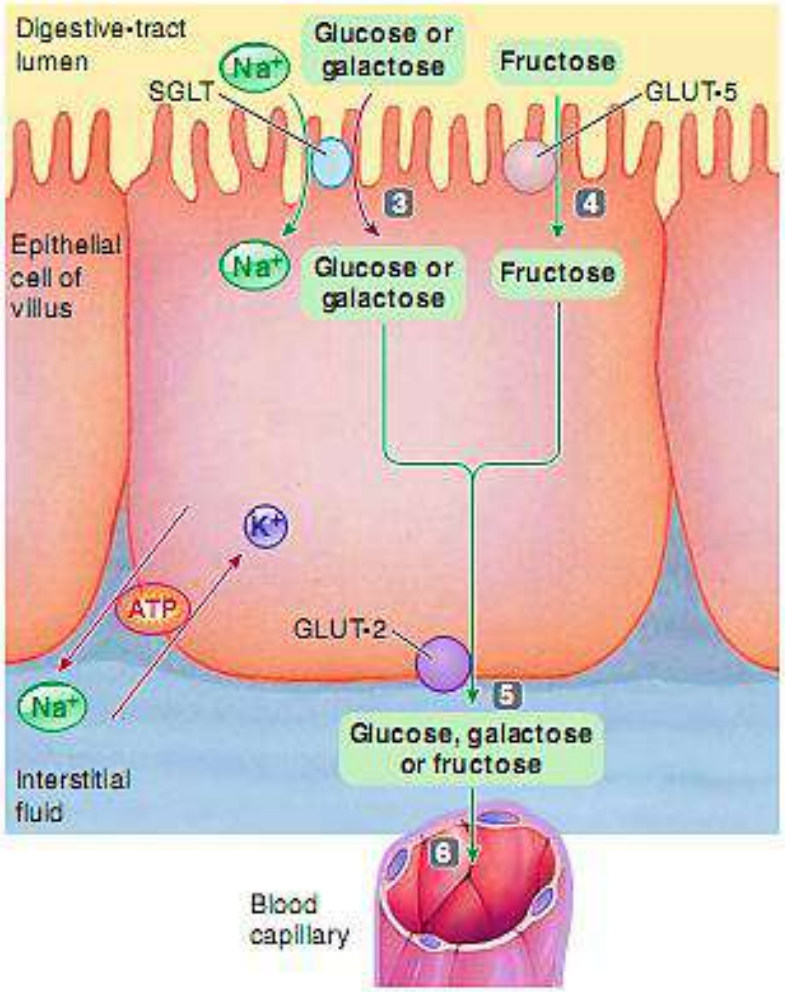
- Monoglycerides and free fatty acids are produced by hydrolysis.
- These water-insoluble products are carried to the inside of water-soluble micelles.
- On the mucosal surface these molecules leave the micelle and passively diffuse through the lipid bi-layer of the luminal membrane. They are resynthesized into triglycerides inside the epithelial cells.
- There they form water-soluble chylomicrons which leave the cells by exocytosis.
- They enter the central lacteals, lymphatic vessels.

Other facts on adsorption include:

- Vitamin adsorption is mainly passive. Water-soluble vitamins are absorbed with water. Fat-soluble vitamins are absorbed in micelles.
- Iron and calcium absorption is regulated. Only a part of ingested iron can be absorbed.
- Some absorbed iron is immediately transported to the blood. Transferrin carries some iron to the bone marrow. Excess iron is stored in the ferritin pool. Unused iron is lost in the feces.
- Most calcium is absorbed by active transport. About two-thirds of ingested calcium is absorbed. The remaining one-thirds is eliminated.
- Most absorbed nutrients immediately pass through the liver for processing. The liver monitors nutrient molecules and controls their concentration in the blood or lymph leaving the liver.
- Extensive absorption by the small intestine keeps pace with secretion. A biochemical balance exists among the stomach, pancreas, and small intestine.
- Diarrhea results in the loss of fluid and electrolytes.



(a) Carbohydrate digestion



(b) Carbohydrate absorption

1 The dietary polysaccharides starch and glycogen are converted into the disaccharide maltose through the action of salivary and pancreatic amylase.

2 Maltose and the dietary disaccharides lactose and sucrose are converted to their respective monosaccharides by the disaccharidases (maltase, lactase, and sucrase) located in the brush borders of the small-intestine epithelial cells.

3 The monosaccharides glucose and galactose are absorbed into the epithelial cells by Na^+- and energy-dependent secondary active transport (via the symporter SGLT) located at the luminal membrane.

4 The monosaccharide fructose enters the cell by passive facilitated diffusion via GLUT-5.

5 Glucose, galactose, and fructose exit the cell at the basal membrane by passive facilitated diffusion via GLUT-2.

6 These monosaccharides enter the blood by simple diffusion.

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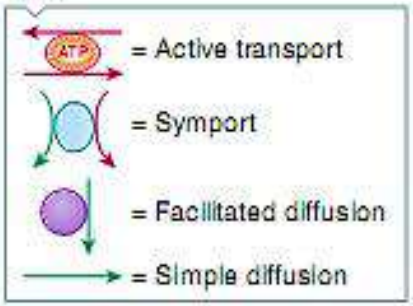
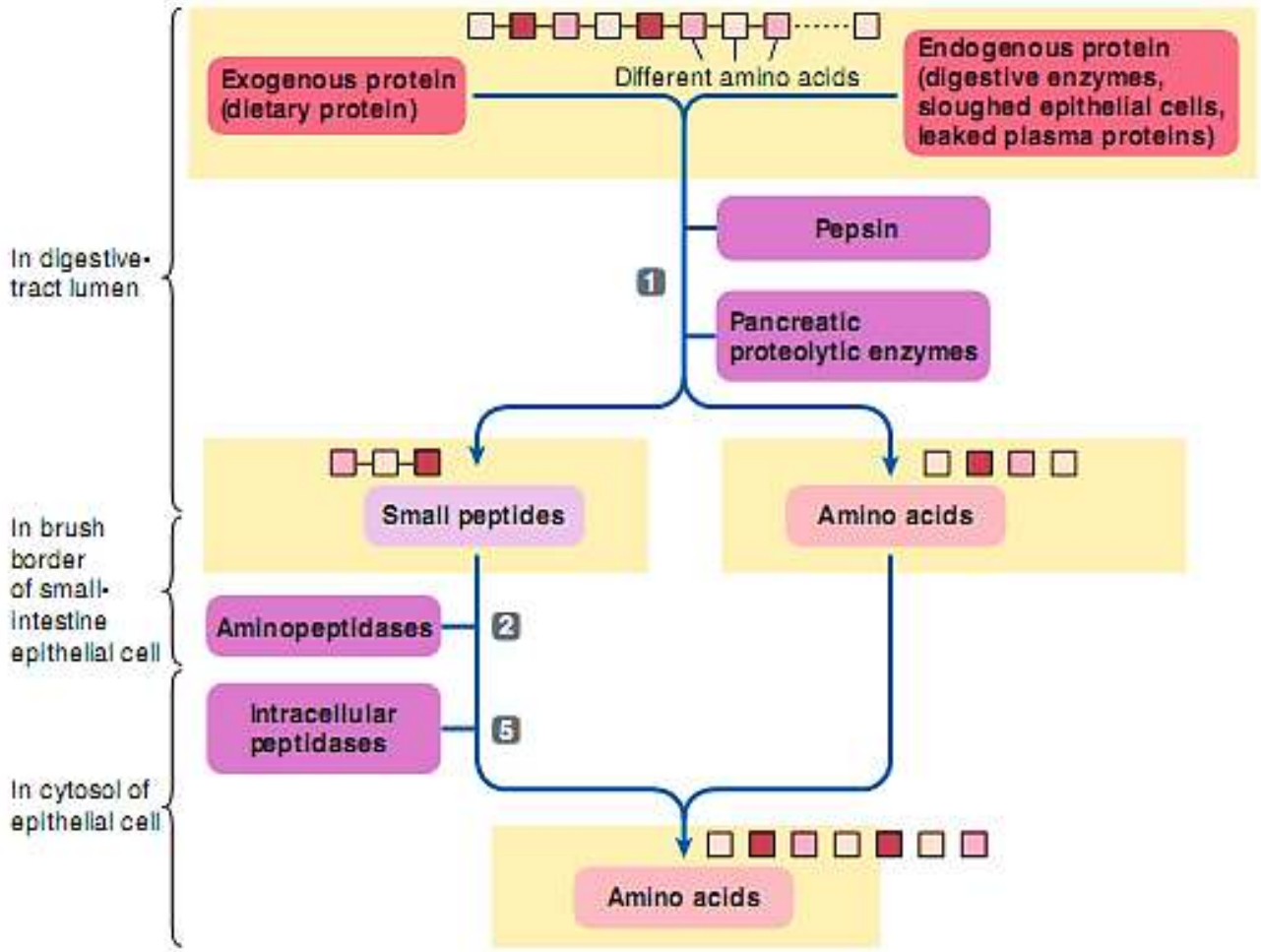
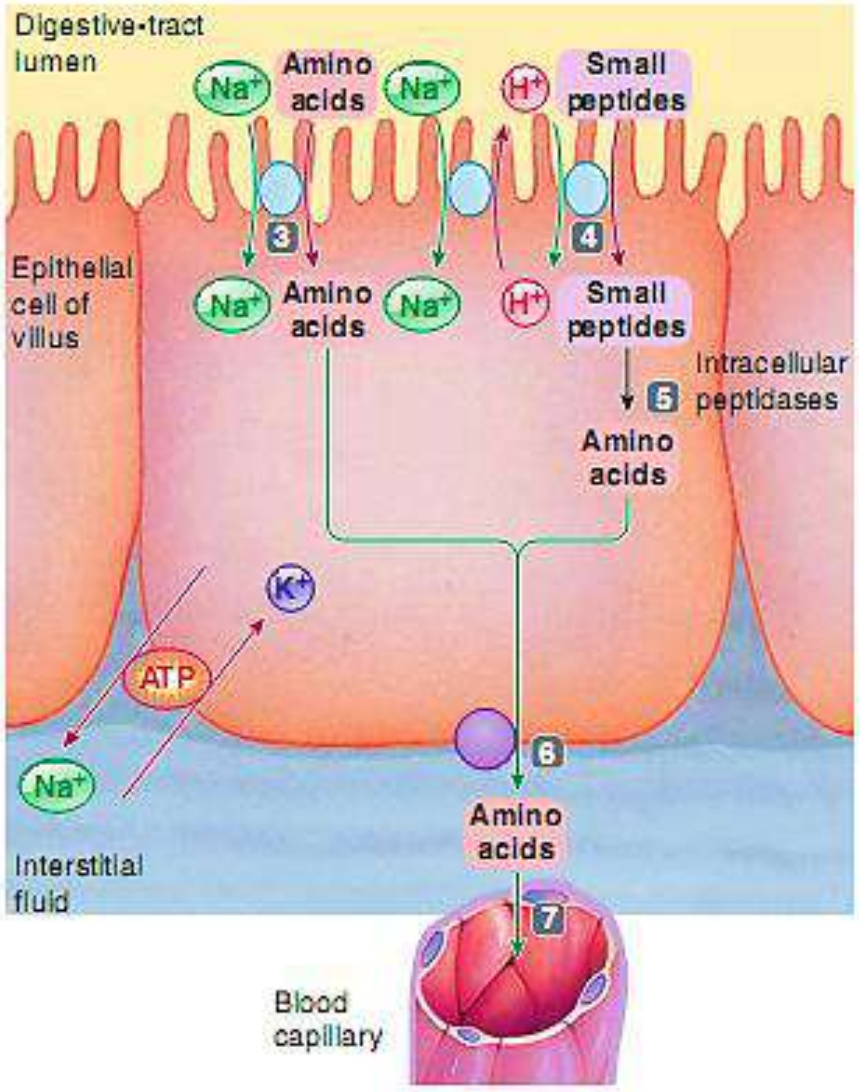


● **FIGURE 16-24 Carbohydrate digestion and absorption.**



(a) Protein digestion



(b) Protein absorption

● FIGURE 16-25 Protein digestion and absorption.

1 Dietary and endogenous proteins are hydrolyzed into their constituent amino acids and a few small peptide fragments by gastric pepsin and the pancreatic proteolytic enzymes.

2 Many small peptides are converted into their respective amino acids by the aminopeptidases located in the brush borders of the small-intestine epithelial cells.

3 Amino acids are absorbed into the epithelial cells by means of Na^+- and energy-dependent secondary active transport via a symporter. Various amino acids are transported by carriers specific for them.

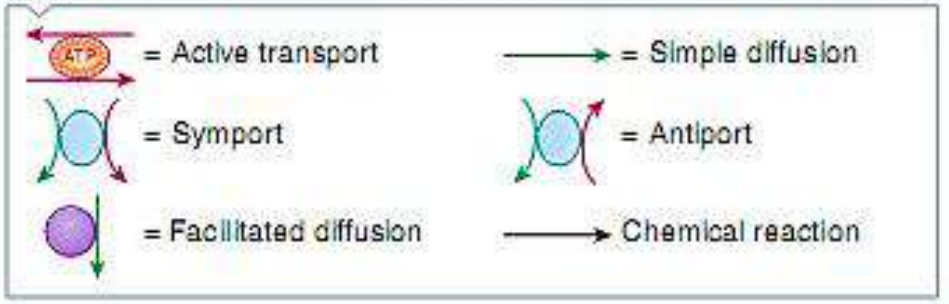
4 Some small peptides are absorbed by a different type of symporter driven by H^+, Na^+-, and energy-dependent tertiary active transport.

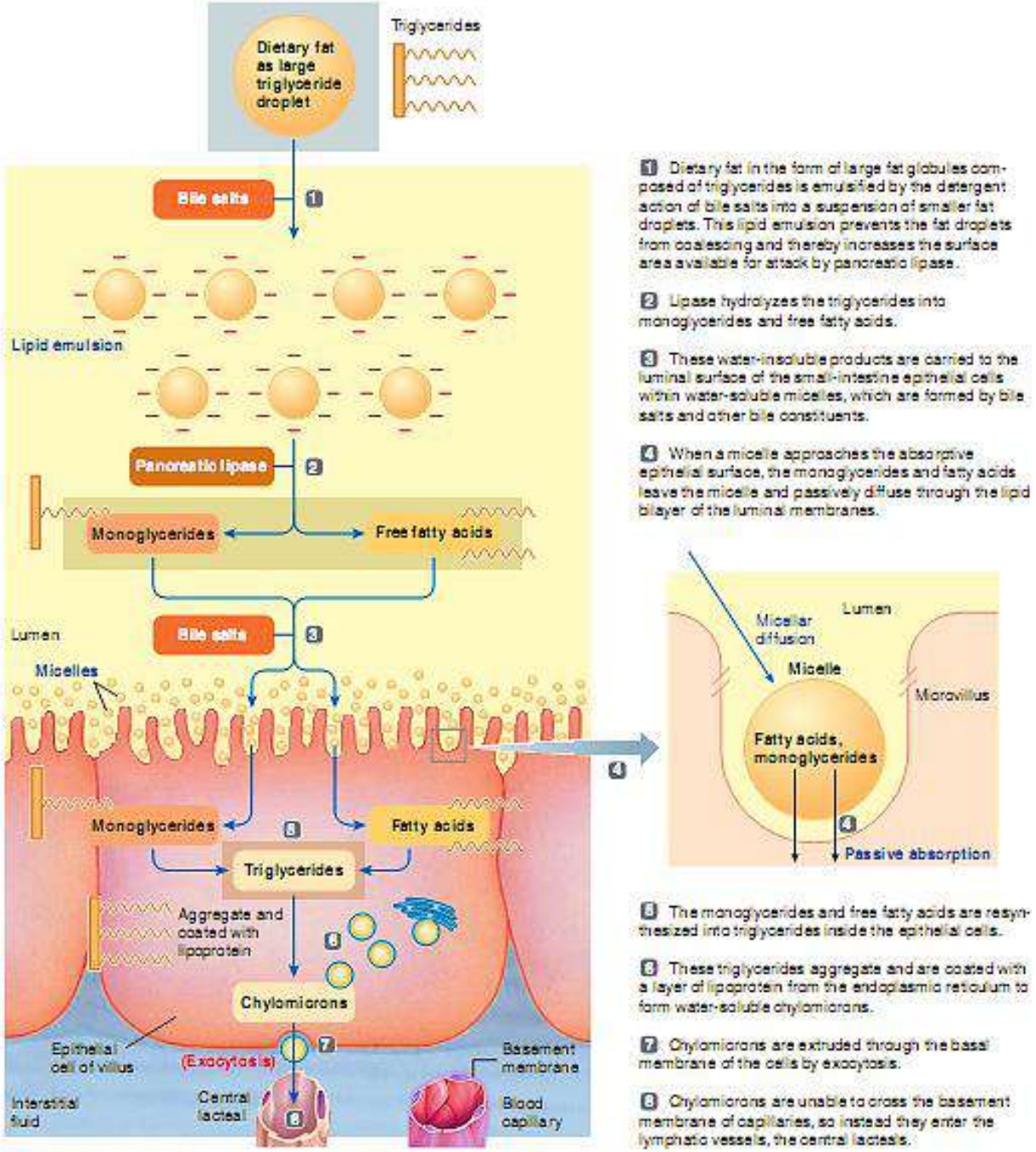
5 Most absorbed small peptides are broken down into their amino acids by intracellular peptidases.

6 Amino acids exit the cell at the basal membrane via various passive carriers.

7 Amino acids enter the blood by simple diffusion. (A small percentage of di- and tripeptides also enter the blood intact.)

KEY





1 Dietary fat in the form of large fat globules composed of triglycerides is emulsified by the detergent action of bile salts into a suspension of smaller fat droplets. This lipid emulsion prevents the fat droplets from coalescing and thereby increases the surface area available for attack by pancreatic lipase.

2 Lipase hydrolyzes the triglycerides into monoglycerides and free fatty acids.

3 These water-insoluble products are carried to the luminal surface of the small-intestine epithelial cells within water-soluble micelles, which are formed by bile salts and other bile constituents.

4 When a micelle approaches the absorptive epithelial surface, the monoglycerides and fatty acids leave the micelle and passively diffuse through the lipid bilayer of the luminal membranes.

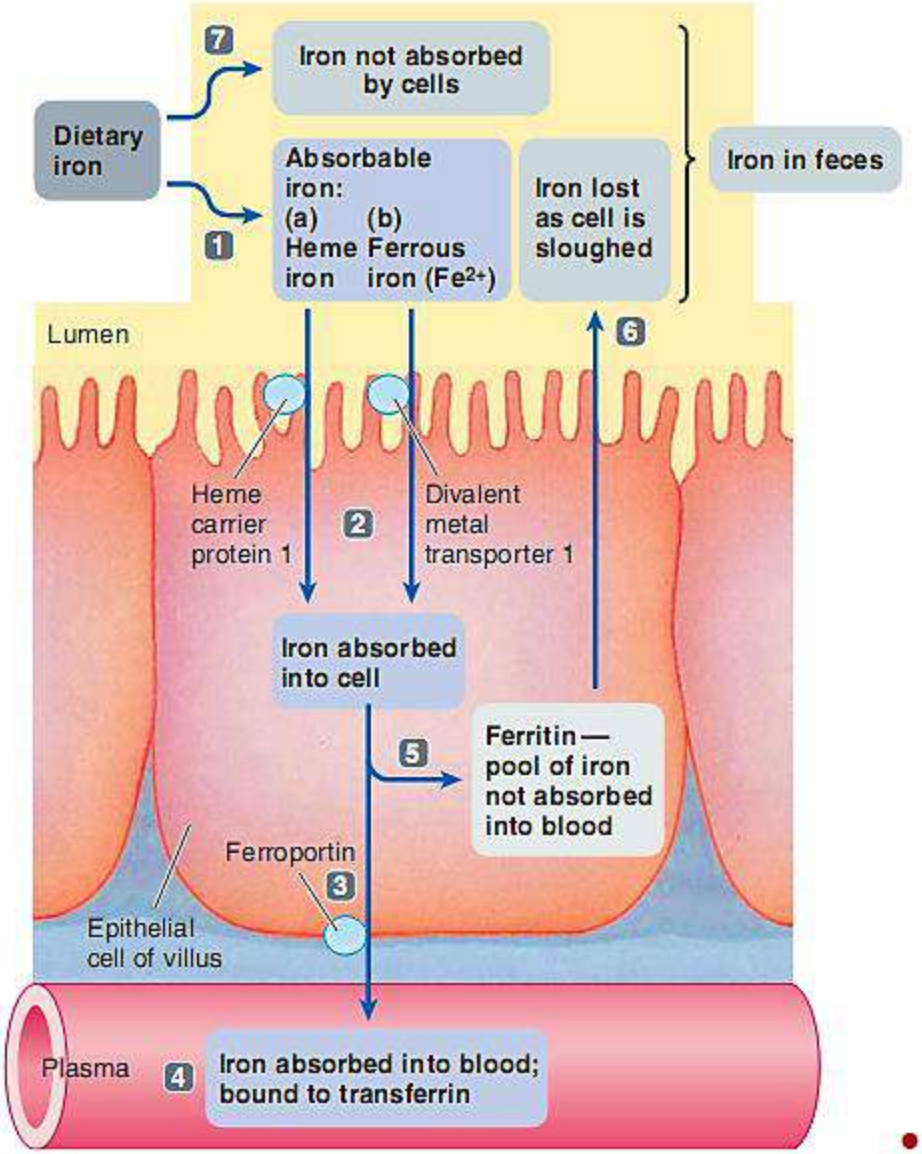
5 The monoglycerides and free fatty acids are resynthesized into triglycerides inside the epithelial cells.

6 These triglycerides aggregate and are coated with a layer of lipoprotein from the endoplasmic reticulum to form water-soluble chylomicrons.

7 Chylomicrons are extruded through the basal membrane of the cells by exocytosis.

8 Chylomicrons are unable to cross the basement membrane of capillaries, so instead they enter the lymphatic vessels, the central lacteals.

● **FIGURE 16-26 Fat digestion and absorption.** Because fat is not soluble in water, it must undergo a series of transformations in order to be digested and absorbed.



1 Only a portion of ingested iron is in a form that can be absorbed, either heme iron or ferrous iron (Fe^{2+}).

2 Iron is absorbed across the luminal membrane of small-intestine epithelial cells by different energy-dependent carriers for heme and Fe^{2+}.

3 Dietary iron that is absorbed into the small-intestine epithelial cells and is immediately needed for red blood cell production is transferred into the blood by the membrane iron transporter ferroportin.

4 In the blood, the absorbed iron is carried to the bone marrow bound to transferrin, a plasma protein carrier.

5 Absorbed dietary iron that is not immediately needed is stored in the epithelial cells as ferritin, which cannot be transferred into the blood.

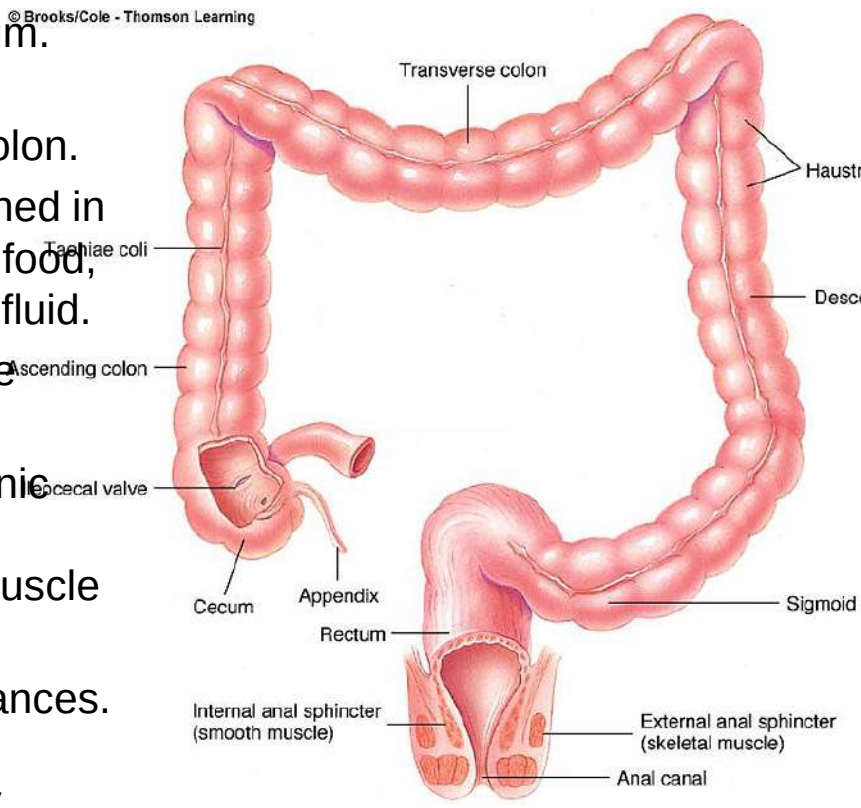
6 This unused iron is lost in the feces as the ferritin-containing epithelial cells are sloughed.

7 Dietary iron that was not absorbed is also lost in the feces.

● **FIGURE 16-27 Iron absorption.**

The large intestine is mainly a drying and storage organ.

- It consists of the colon, cecum, appendix, and rectum.
- The colon consists of the cecum, ascending colon, transverse colon, descending colon, and sigmoid colon.
- Most digestion and absorption has been accomplished in the small intestine. The colon receives indigestible food, unabsorbed biliary components, and the remaining fluid.
- The colon extracts water and salt and eliminates the feces.
- Contractions of the haustrae slowly shuffle the colonic contents back and forth. They are initiated by the autonomous rhythmic contractions of the smooth muscle in the wall of the large intestine.
- Mass movements propel colonic contents long distances. They drive the feces into the distal part of the large intestine. Material is stored here until eliminated by defecation.



The feces are eliminated by the defecation reflex.

- Muscle contractions and the relaxation of two sphincter muscles eliminate the feces.
- Constipation occurs when the feces become too dry. There is prolonged distention of the large intestine.
- The large-intestine secretion is entirely protective. It consists of an alkaline mucus solution which protects the intestinal mucosa.
- The colon contains many beneficial bacteria. Their functions include making vitamin K and enhancing intestinal motility.
- Intestinal gases are absorbed or expelled.

Overview of the gastrointestinal hormones
Gastrin, Secretin, CCK and GIP

- Gastrin increases the secretion of hydrochloric acid and pepsinogen and enhances gastric motility.
- Secretin inhibits gastric emptying and gastric secretion, stimulate the pancreas to produce sodium bicarbonate, and stimulates the liver to produce bile.
- CCK inhibits gastric motility and secretion, stimulates pancreatic enzymes and signals the gallbladder to secrete bile.
- **GIP** promotes metabolic processing of nutrients once they are absorbed.

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