Varastegan
Institute for Medical Sciences

Digestion, Absorption, Transport, and Excretion of Nutrients

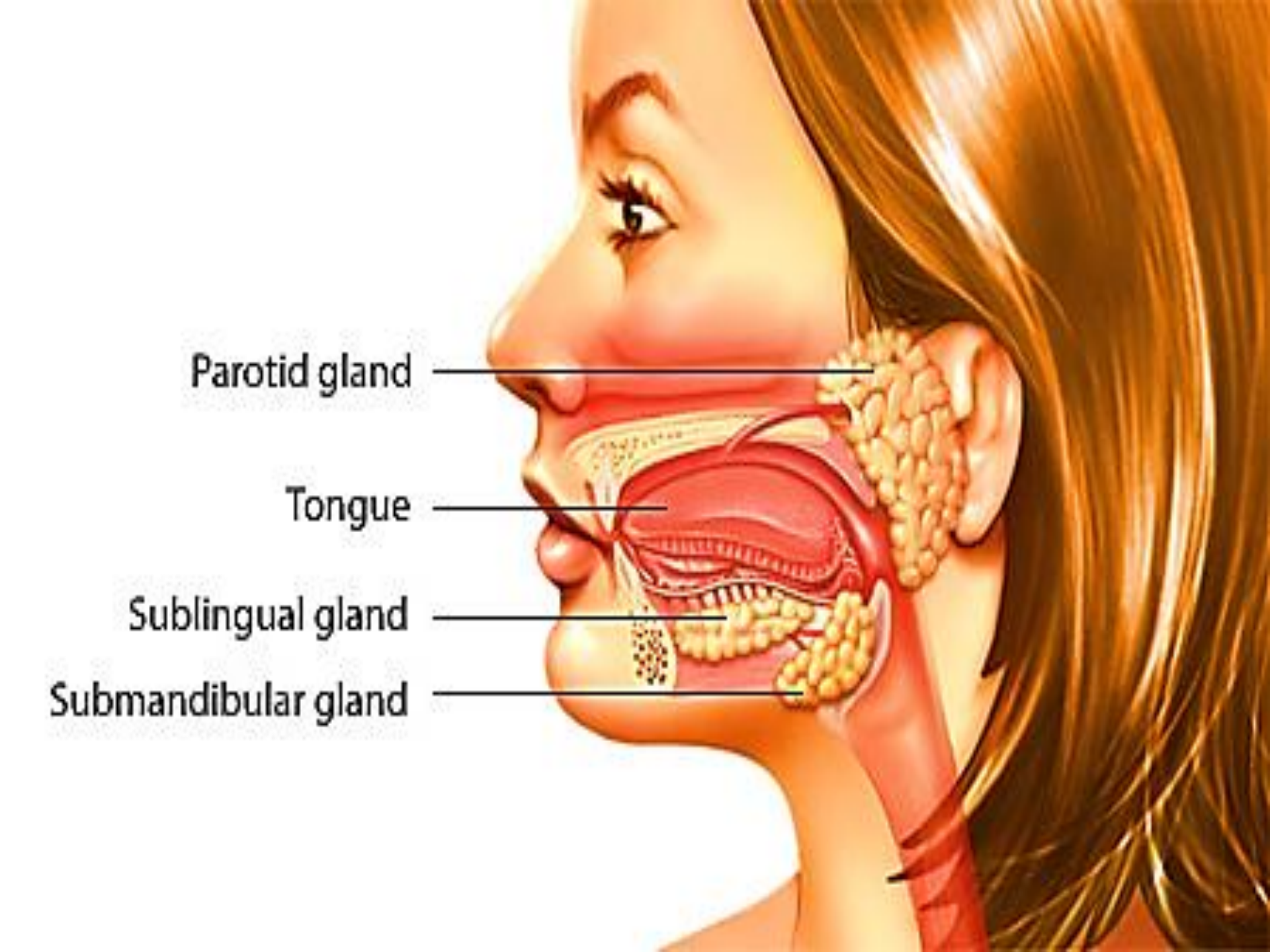
(Session 3)

Mohsen Karamati
Department of Nutrition Sciences, Varastegan Institute for Medical Sciences, Mashhad, Iran
E-mail: karamatim@varastegan.ac.ir

Digestion in the Mouth

In the mouth, the teeth grind and crush food into small particles, while the food mass is simultaneously moistened and lubricated by saliva.

Three pairs of salivary glands; the parotid, submaxillary, and sublingual glands; produce approximately 1.5 L of saliva daily.

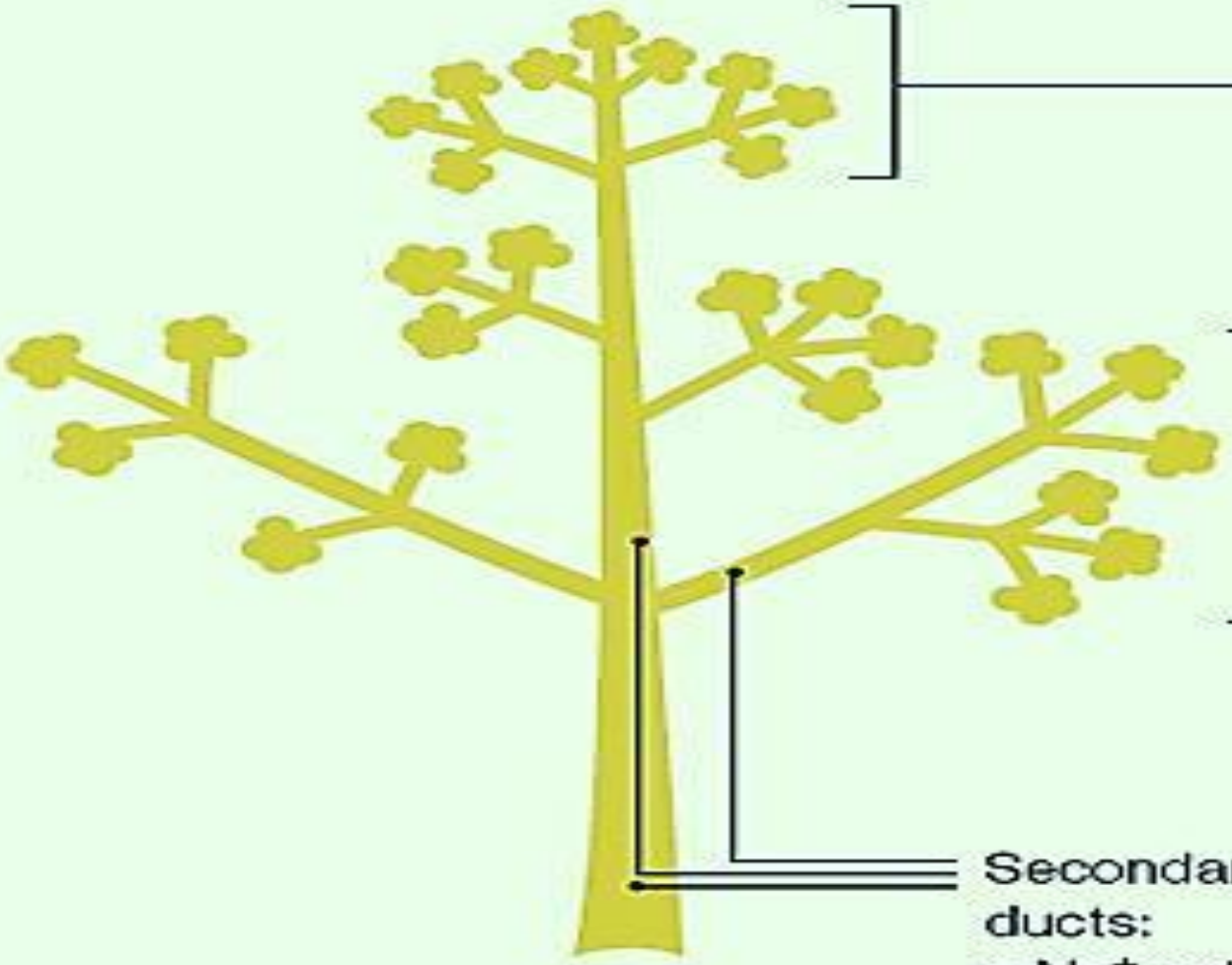

Parotid gland
Tongue
Sublingual gland
Submandibular gland

Serous saliva, contain salivary amylase (ptyalin) and lipase, which minimally digest starch and fat, respectively.

The salivary amylase becomes inactive when it reaches the acidic contents of the stomach.

Mucosal saliva contains mucus, a protein that causes particles of food to stick together and lubricates the mass for swallowing.

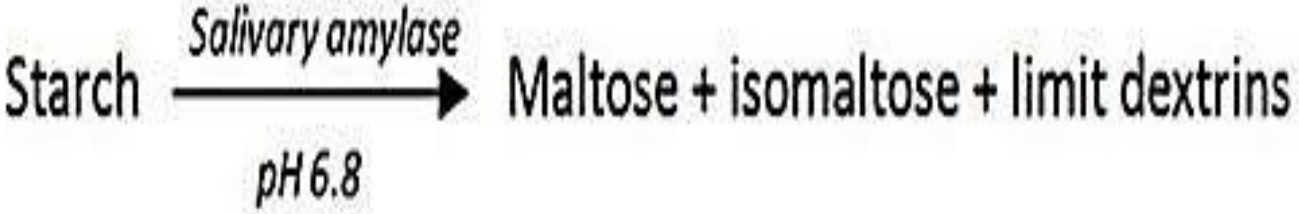
Salivary gland



Primary secretion in acini contains:
- ptyalin
- mucus
- extracellular fluid

Secondary modification in ducts:
- Na^+ actively reabsorbed
- K^+ actively secreted
- Cl^- passively absorbed
- HCO_3^- secreted

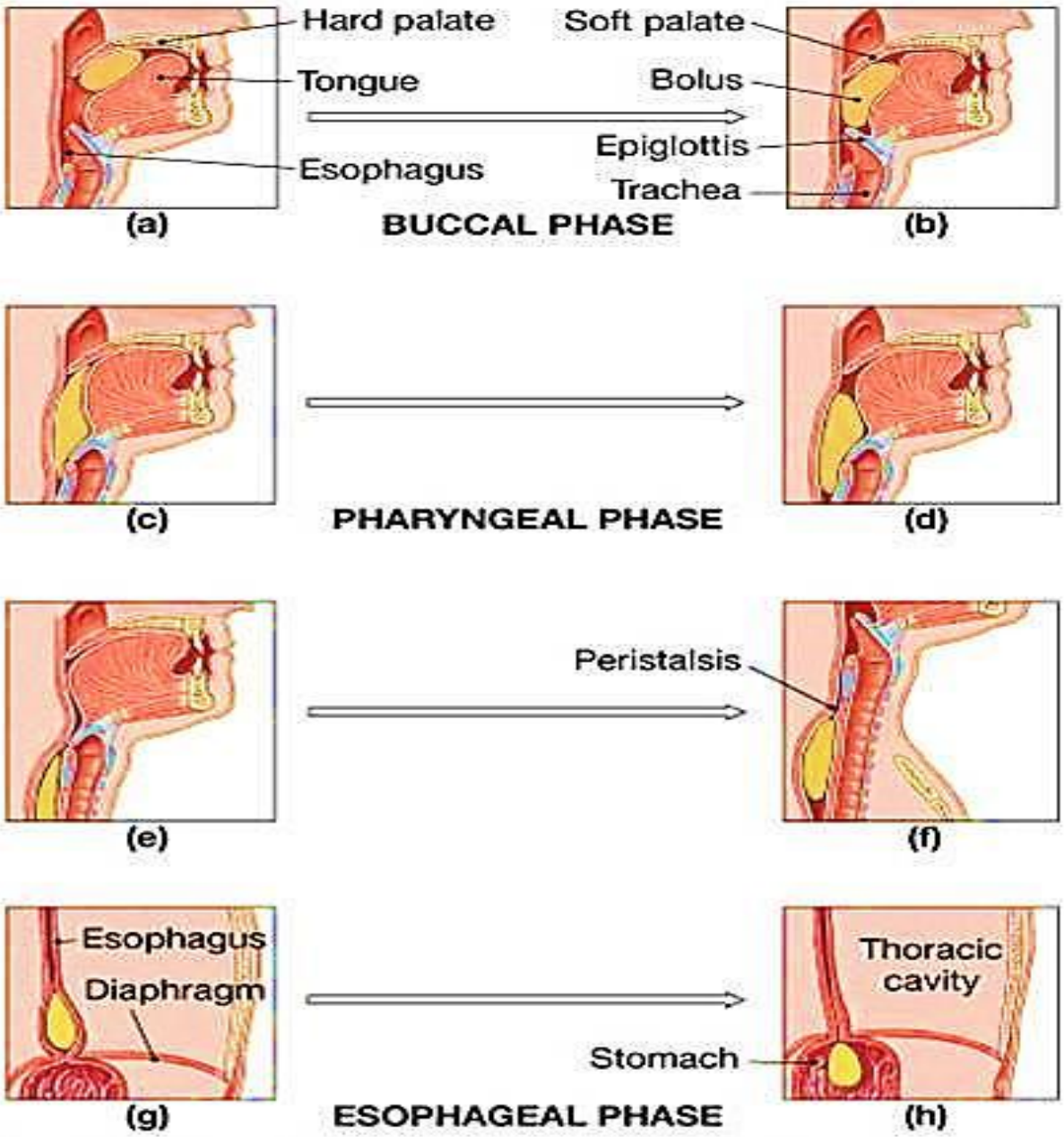
Saliva


Starch
Salivary amylase
pH 6.8
Maltose + isomaltose + limit dextrins


Milk Fat
(infants)
Lingual lipase
from Ebner's Glands
Medium Sized
Fatty Acids

The masticated food mass, or bolus, is passed back to the pharynx under voluntary control, but throughout the esophagus the process of swallowing (deglutition) is involuntary; peristalsis then moves the food rapidly into the stomach.

The process of deglutition, or swallowing



Digestion in the Stomach

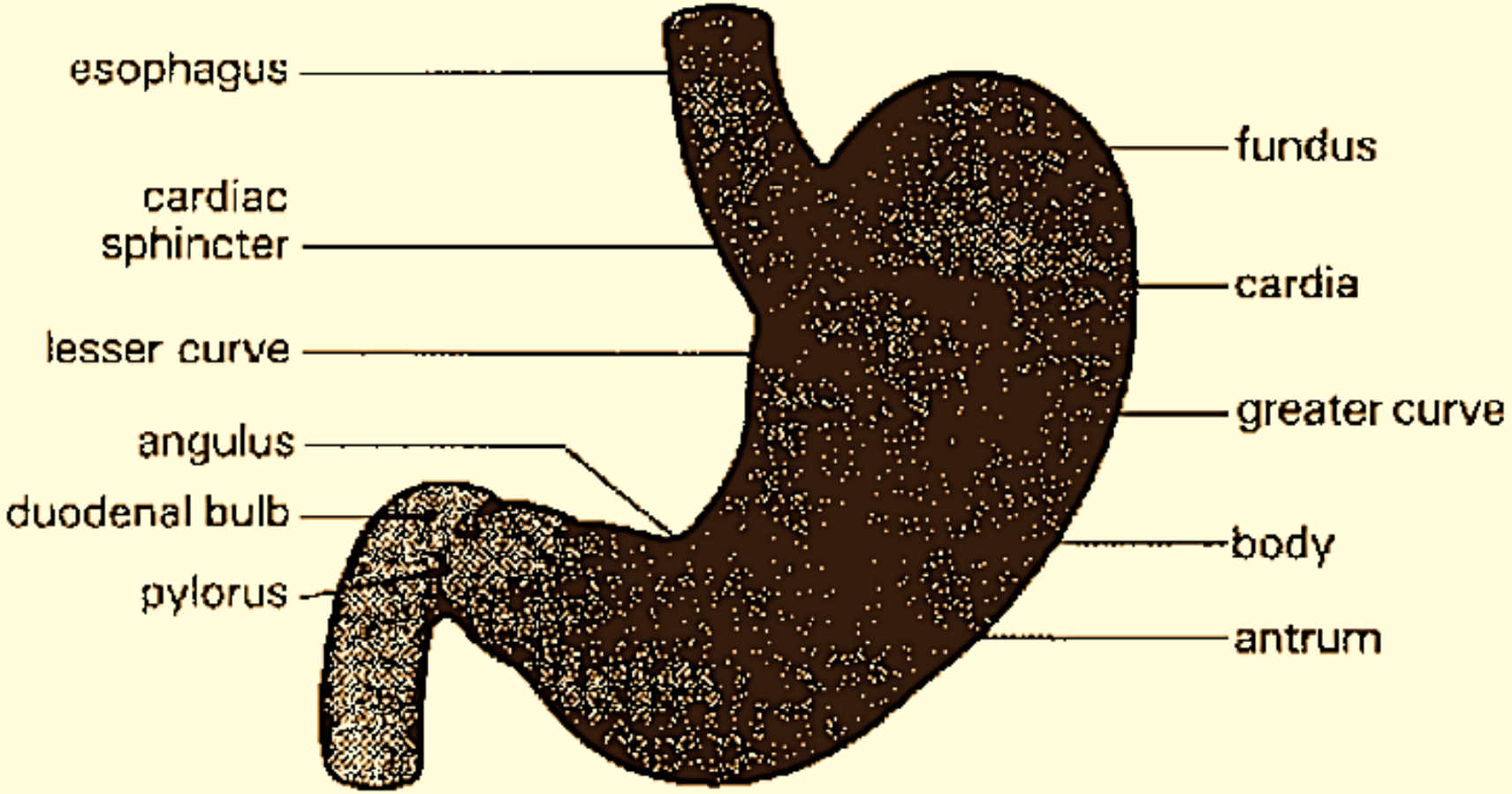


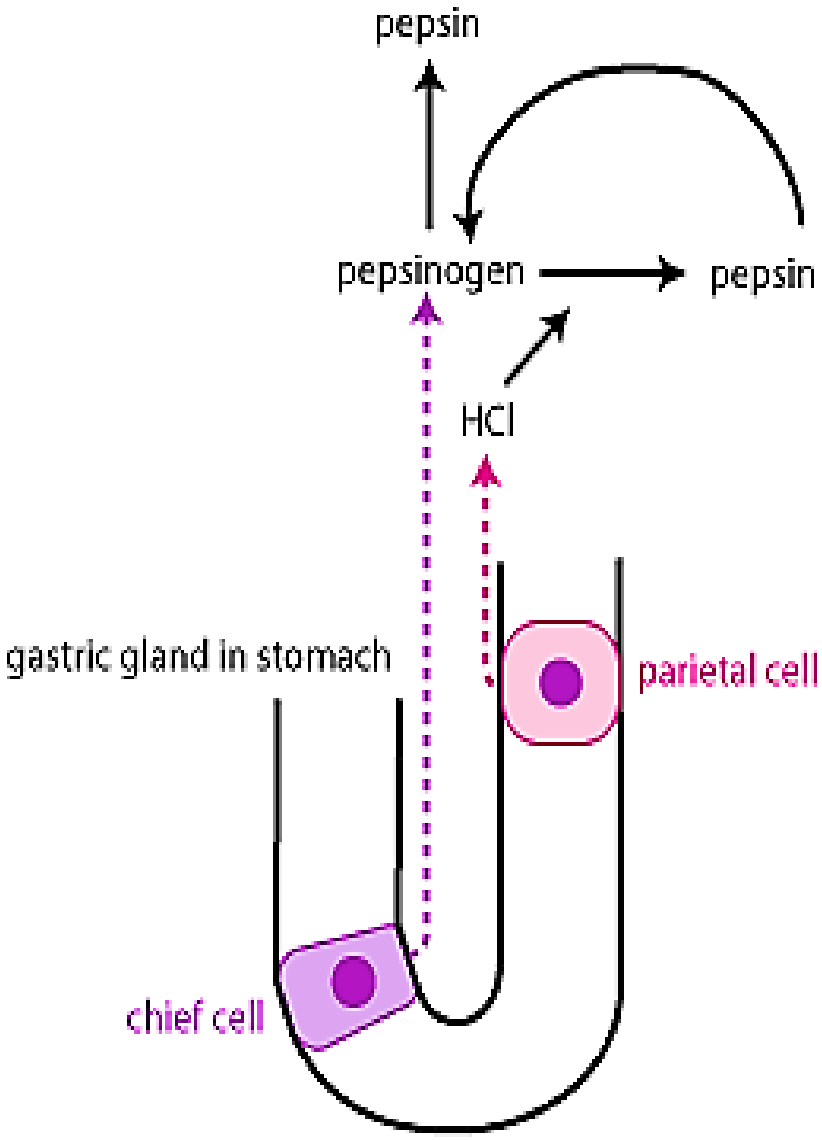
Fig. 42.3. Regional organization of the stomach and proximal duodenum. (Reprinted with permission from Yamada T, Alpers DH, Owyang C et al, eds. Textbook of Gastroenterology. 2nd ed. Philadelphia: JB Lippincott, 1991:1304.)

Food particles are propelled forward and mixed with gastric secretions by wavelike contractions.

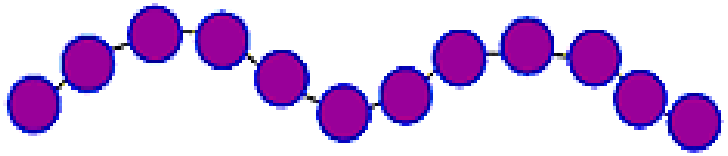
On average, **2000 to 2500 mL of gastric juice is secreted daily, which contains hydrochloric acid (secreted by the parietal cells in the walls of the fundus and corpus), a protease, gastric lipase, mucus, intrinsic factor (a glycoprotein that facilitates vitamin B_{12} absorption in the ileum), and the GI hormone gastrin**.

The gastric protease is pepsin and is secreted from chief cells of gastric glands in the fundus and corpus in an inactive form, pepsinogen, which is converted by hydrochloric acid to its active form (i.e. pepsin).

Pepsin is active only in the acid environment of the stomach and changes the shape and size of some of the proteins in a normal meal.

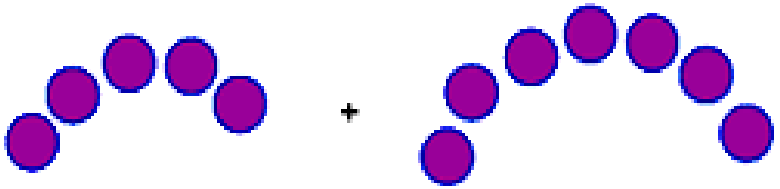


Digestion of protein / polypeptide



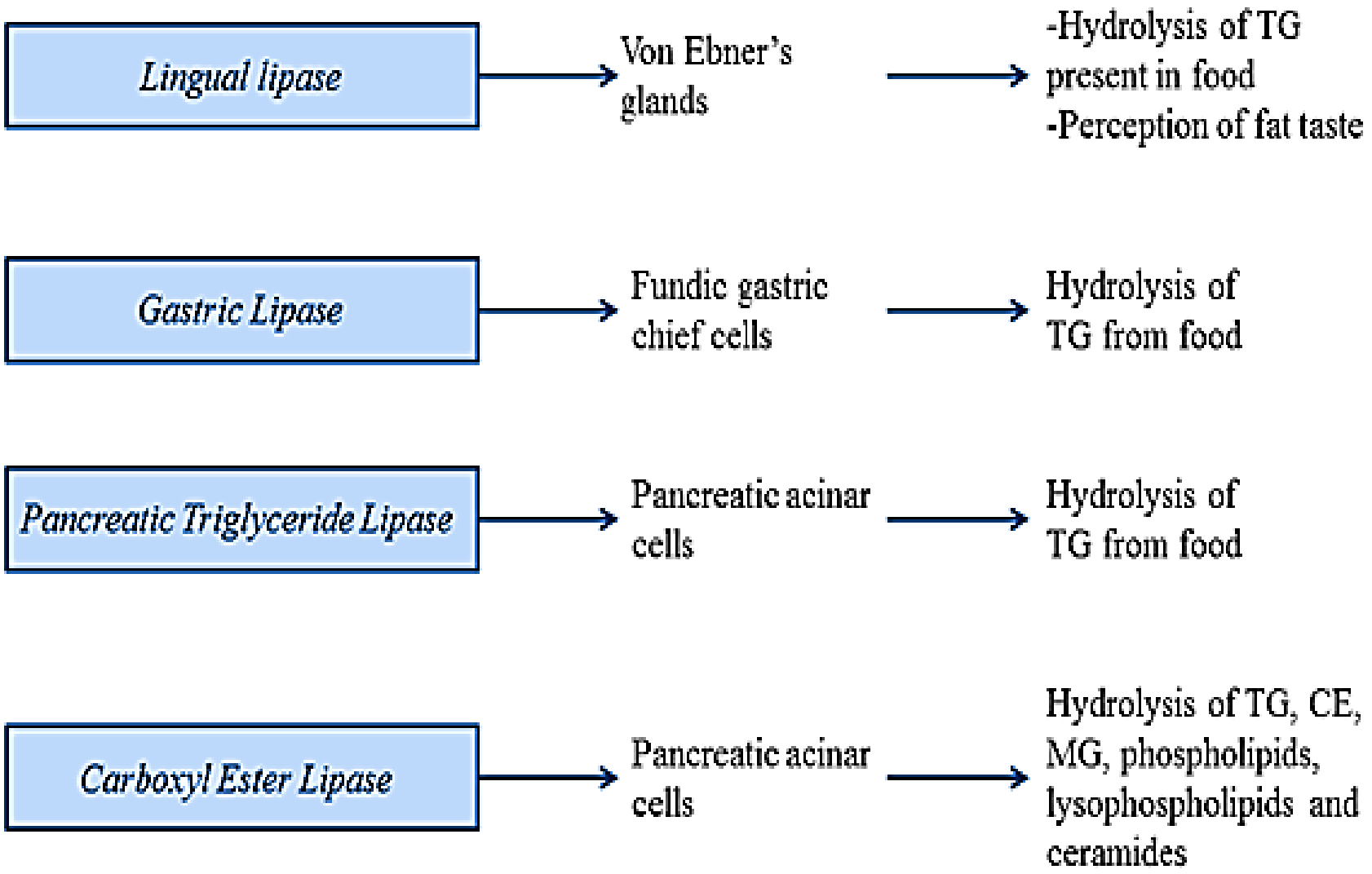
The peptide bonds between the amino acids are hydrolysed

Pepsin is a protease that hydrolyses the protein into smaller polypeptides



Gastric lipase, which is an acid-stable enzyme secreted by chief cells, is more specific for triglycerides composed of medium- and SCFAs and, like lingual lipase, is considerably less active than pancreatic lipase.

In general, lingual and gastric lipases may have a relatively important role in the liquid diet of infants; but, when pancreatic insufficiency occurs, it becomes apparent that they are not sufficient to prevent lipid malabsorption.


Lingual lipase
Von Ebner's glands
-Hydrolysis of TG present in food
-Perception of fat taste
Gastric Lipase
Fundic gastric chief cells
Hydrolysis of TG from food
Pancreatic Triglyceride Lipase
Pancreatic acinar cells
Hydrolysis of TG from food
Carboxyl Ester Lipase
Pancreatic acinar cells
Hydrolysis of TG, CE, MG, phospholipids, lysophospholipids and ceramides

In the process of gastric digestion, most of the food becomes semiliquid chyme, which is 50% water.

Gastric secretions are also important in increasing the availability and downstream absorption of vitamin Bl2, calcium, iron, and zinc.

TABLE 42.3 GASTRIC CELL SECRETORY PRODUCTS AND FUNCTION

CELL TYPE	PRODUCT	FUNCTION
Surface cells	Mucus	Lubrication
Neck cells	Bicarbonate	Protection
	Trefoil peptides	
Parietal cells	Hydrogen ion	Protein digestion
	Intrinsic factor	Binding of cobalamin (vitamin B_{12})
Chief cells	Pepsinogen	Protein digestion when activated
	Gastric lipase	Triglyceride digestion, not requiring bile salt, MCT > LCT
Endocrine cells	Gastrin	Release of histamine
	Histamine	Stimulation of acid secretion
	Somatostatin	Inhibition of acid secretion

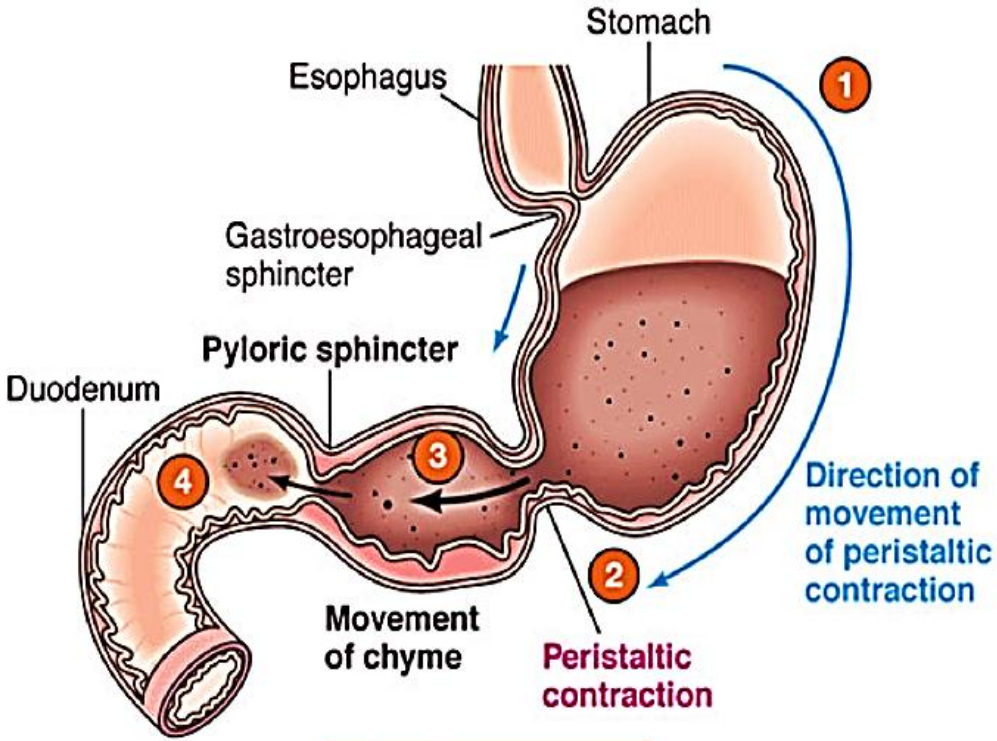
LCT, long-chain triglyceride; MCT, medium-chain triglyceride.

Normally, **the combined actions of very low pH (ranging from 1 to 4) of stomach and its proteolytic enzymes result in a significant reduction in the concentration of microorganisms ingested with food**.

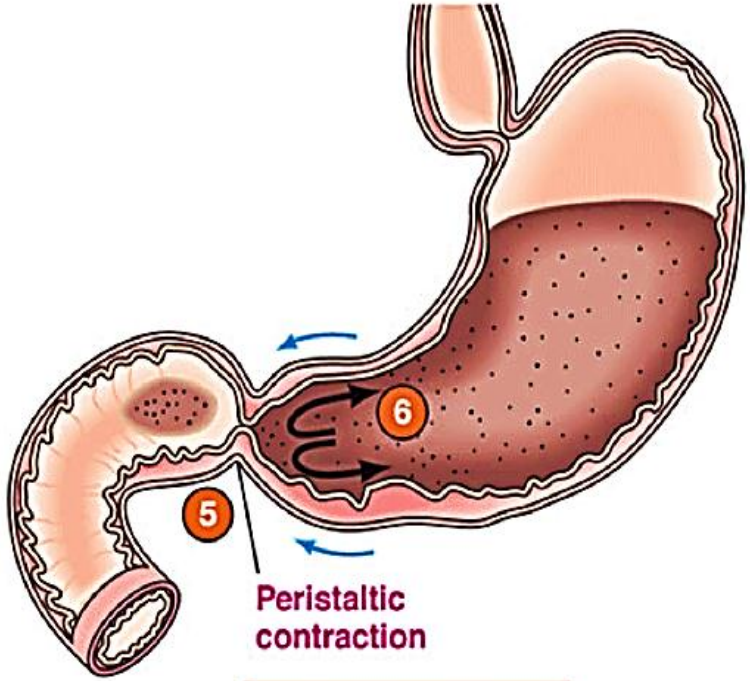
Yet, some microbes may escape and enter the intestine if consumed in sufficient concentrations or if achlorhydria, gastrectomy, GI dysfunction or disease, poor nutrition, or drugs that suppress acid secretions are present; leading to increased risk of bacterial overgrowth in the intestine.

The stomach continuously mixes and churns food and normally releases the food mixture in small quantities into the small intestine.

The presence of food in the intestine and regulatory hormones provide feedback to slow gastric emptying.



Gastric emptying



Gastric mixing

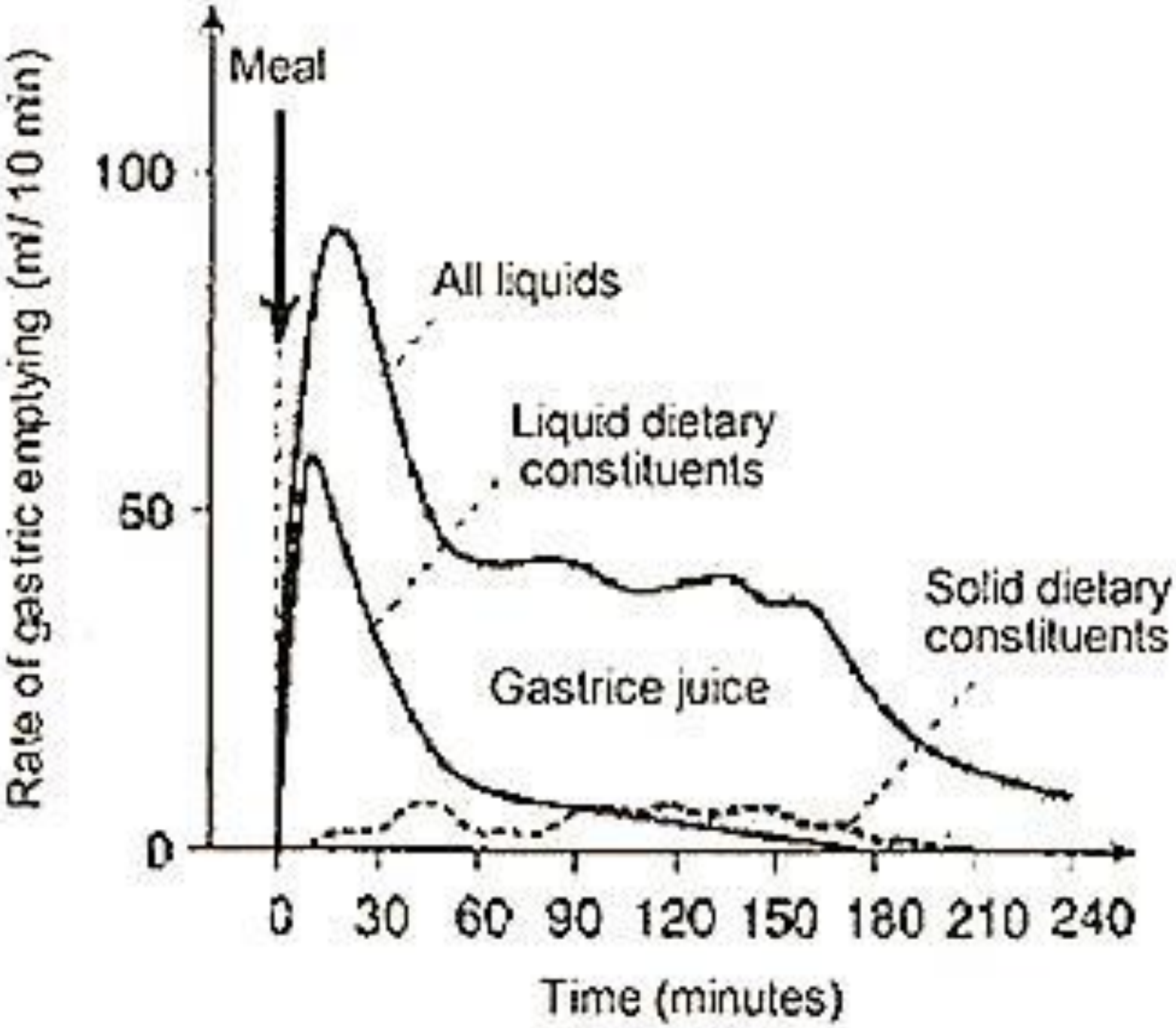
1. A peristalic contraction originates in the upper fundus and sweeps down toward the pyloric sphincter.
2. The contraction becomes more vigorous as it reaches the thick-muscled antrum.
3. The strong antral peristalic contraction propels the chyme forward.
4. A small portion of chyme is pushed through 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.

In the stomach, most of a liquid meal empties within 1 to 2 hours, and most of a solid meal empties within 2 to 3 hours.

When eaten alone, carbohydrates leave the stomach the most rapidly, followed by protein, fat, and fibrous food.

In general, large particles leave the stomach more slowly than small particles, and concentrated foods tend to empty more slowly than low-calorie meals.

In a meal with mixed types of foods, emptying of the stomach depends on the overall volume and characteristics of the foods.


Meal
100
50
0
All liquids
Liquid dietary constituents
Solid dietary constituents
Gastrice juice
0 30 60 90 120 150 180 210 240
Time (minutes)
Rate of gastric emptying (ml/10 min)

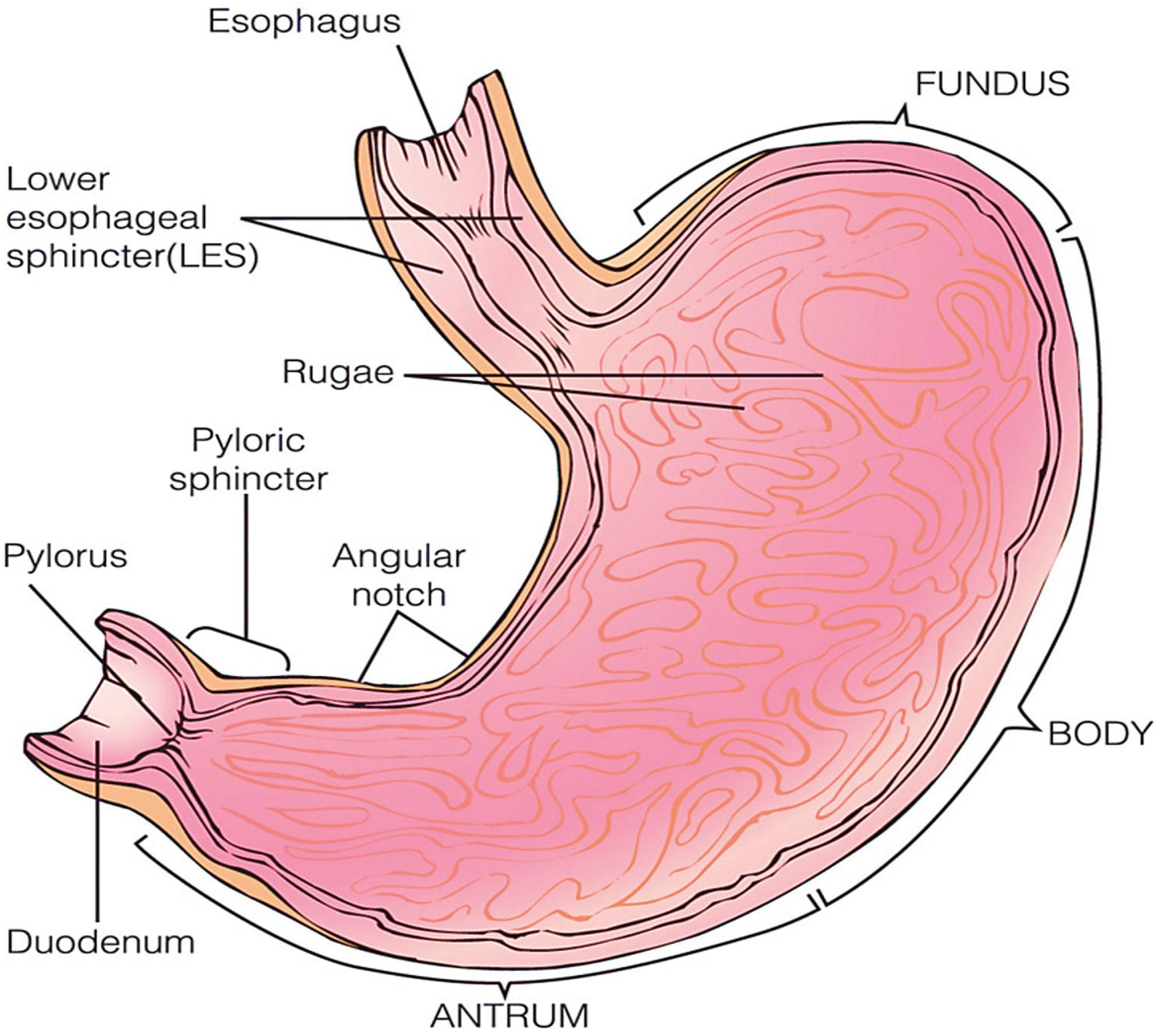
Factors Influencing Gastric Emptying Rate

	Increased	Decreased
Physiologic Factors		
Liquids	+	
Solids, fat, amino acids		+
Posture (prone, right side)	+	
Pathologic Factors		
Trauma, pain, labor		+
Myocardial infarction, diabetes mellitus		+
Migraine		+
Increased intracranial pressure		+
GI obstruction		+
Pharmacologic Factors		
Anticholinergics, narcotics, alcohol		+
Metoclopramide	+	
Sodium bicarbonate	+	
Aluminum, magnesium hydroxide		+

The lower esophageal sphincter (LES) prevents reflux of gastric contents into the esophagus.

The pyloric sphincter helps regulate the exit of gastric contents, preventing backflow of chyme from the duodenum into the stomach.

Emotional changes, food, GI regulators, and irritation from nearby ulcers may alter the performance of these strictures (e.g. certain foods and beverages may lower LES pressure, permitting reflux of stomach contents back into the esophagus).

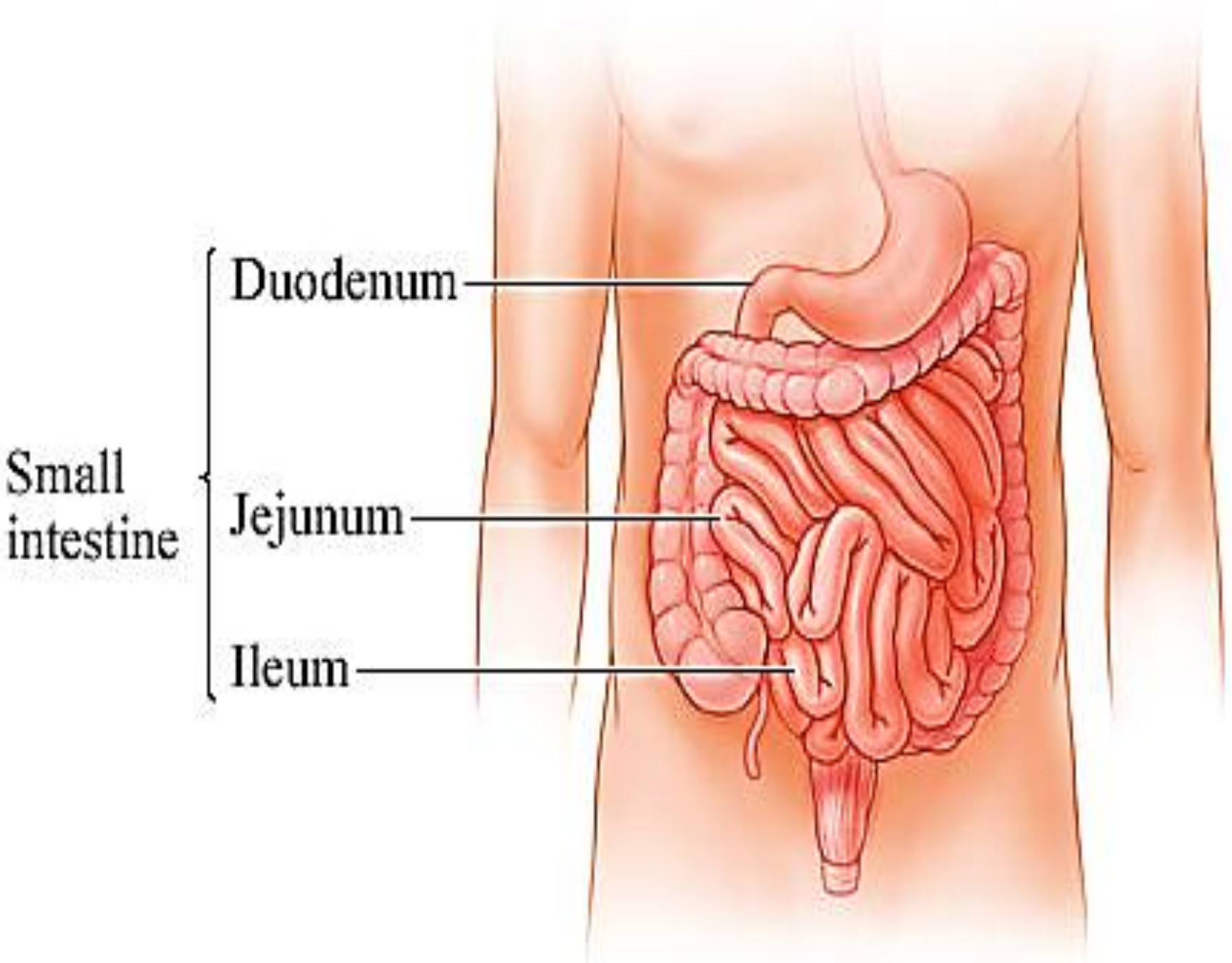

Esophagus
FUNDUS
Lower
esophageal
sphincter(LES)
Rugae
Pyloric
sphincter
Pylorus
Angular
notch
BODY
Duodenum
ANTRUM

Digestion in the Small Intestine

The small intestine is a 7 m long organ divided into the duodenum, the jejunum, and the ileum.

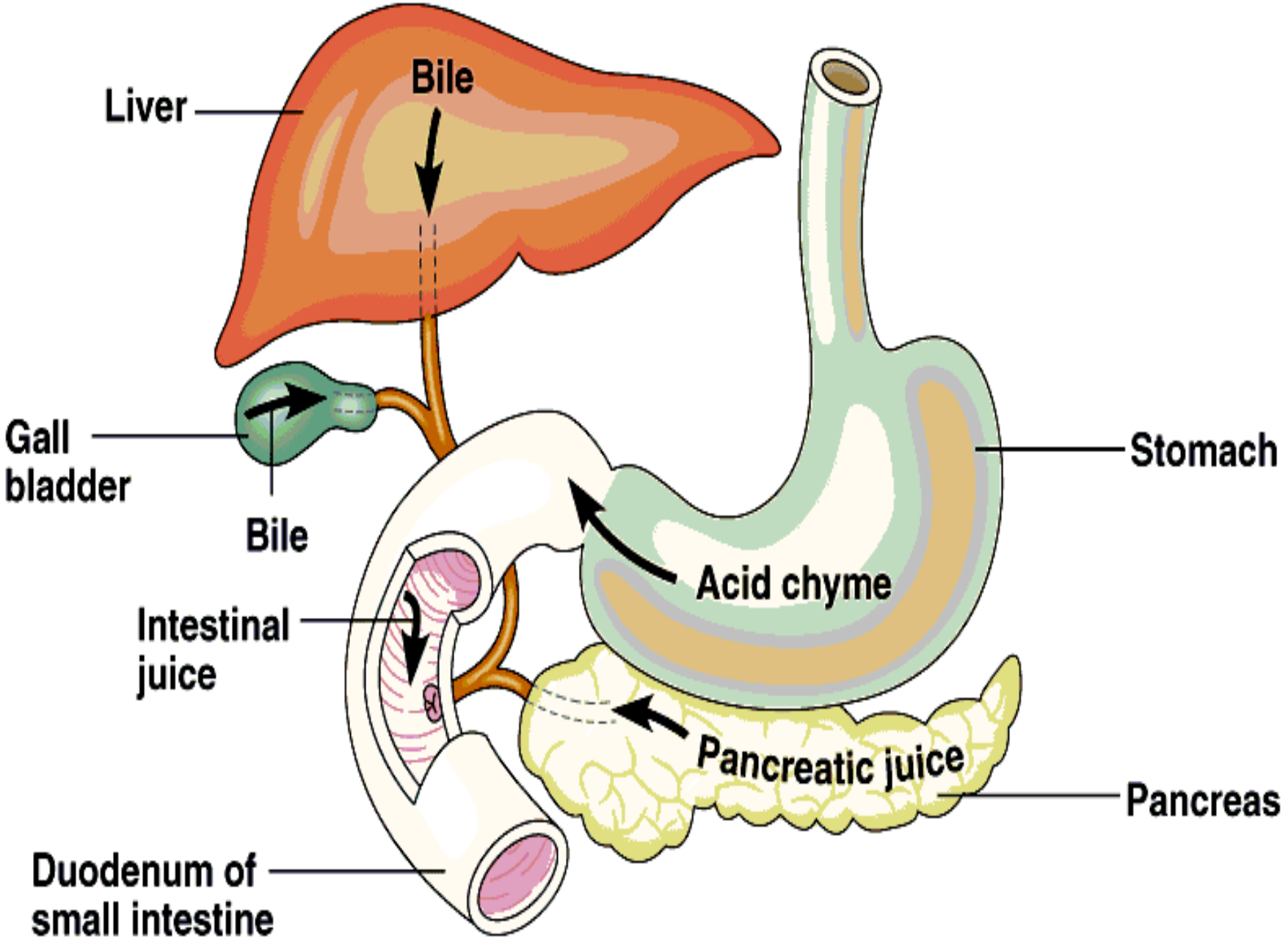
The duodenum is approximately 0.5 m long, the jejunum is 2 to 3 m, and the ileum is 3 to 4 m.

Most of the digestion is completed in the duodenum and upper jejunum, and the absorption of most nutrients is completed by the time the material reaches the middle of the jejunum.


Small intestine
Duodenum
Jejunum
Ileum

The acidic chyme from the stomach enters the duodenum, where it is neutralized by duodenal juices and the bicarbonate-containing secretions from the pancreas and biliary tract.

This is extremely necessary for the function of the enzymes of the small intestine and pancreas, because they operate more effectively in a more neutral pH.

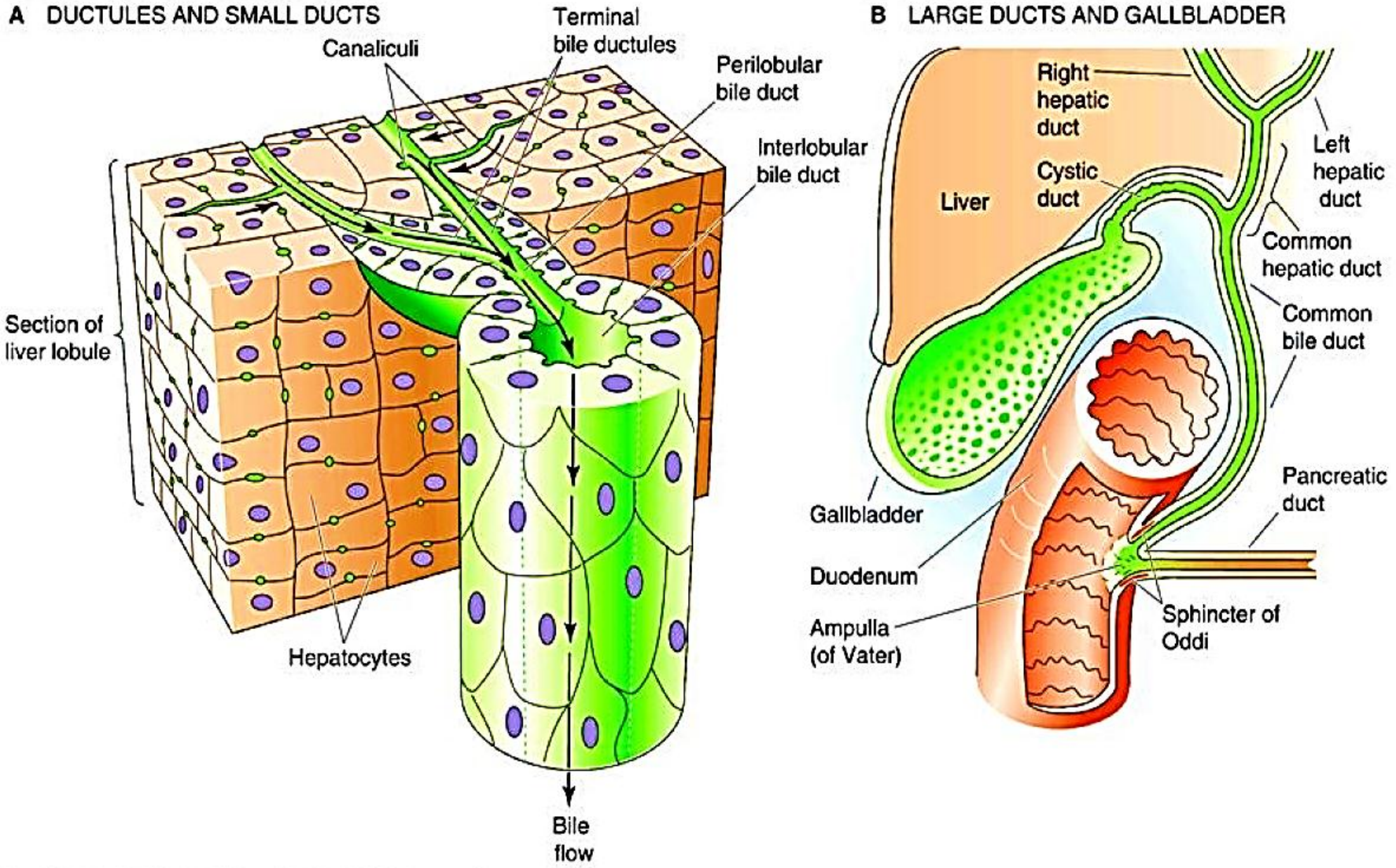

Liver
Bile
Gall bladder
Bile
Stomach
Acid chyme
Intestinal juice
Pancreatic juice
Pancreas
Duodenum of small intestine

The entry of partially digested foods also stimulates the release of several hormones that in turn stimulate the secretion of enzymes and fluids (e.g. bile) and affect GI motility and satiety.

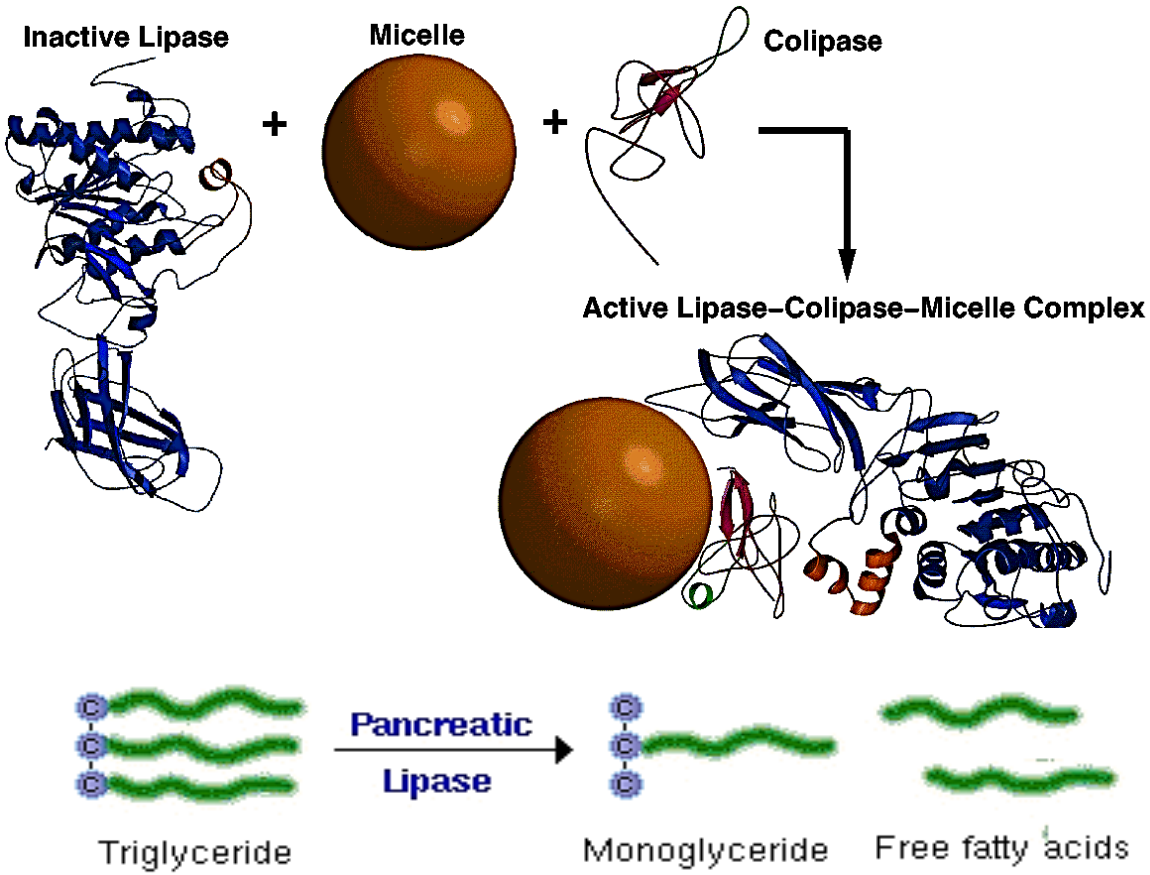
Bile, which is predominantly a mixture of water, bile salts, pigments, and cholesterol, is secreted from the liver, stored in the gallbladder, and released into the duodenum.

Through their surfactant properties, the bile salts facilitate the digestion and absorption of lipids, cholesterol, and fat-soluble vitamins.

Bile is secreted by the liver, stored in the gall bladder and ejected into the small intestine



The major pancreatic lipid-digesting enzymes are lipase and colipase.



The major pancreatic proteolytic enzymes are trypsin, chymotrypsin, carboxypeptidase, aminopeptidase, ribonuclease, and deoxyribonuclease.

TABLE 42.7 PANCREATIC PROTEASES

PROTEASE	FUNCTION
Endopeptidases	
Trypsin	Cleaves internal bonds at lysine or arginine residues and cleaves other pancreatic proenzymes
Chymotrypsin	Cleaves bonds at aromatic or neutral amino acid residues
Elastase	Cleaves bonds at aliphatic amino acid residues
Exopeptidases	
Carboxypeptidase A	Cleaves aromatic amino acids from carboxy terminal end of protein and peptides
Carboxypeptidase B	Cleaves arginine or lysine from carboxy terminal end of proteins and peptides

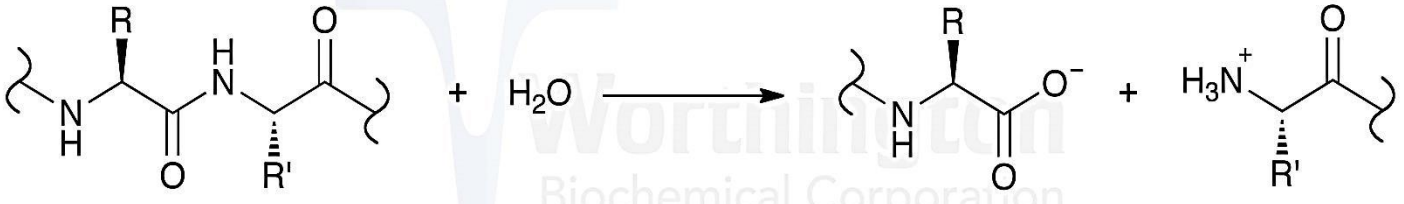
Trypsin

Polypeptide

Polypeptide fragments

R = Arg and Lys

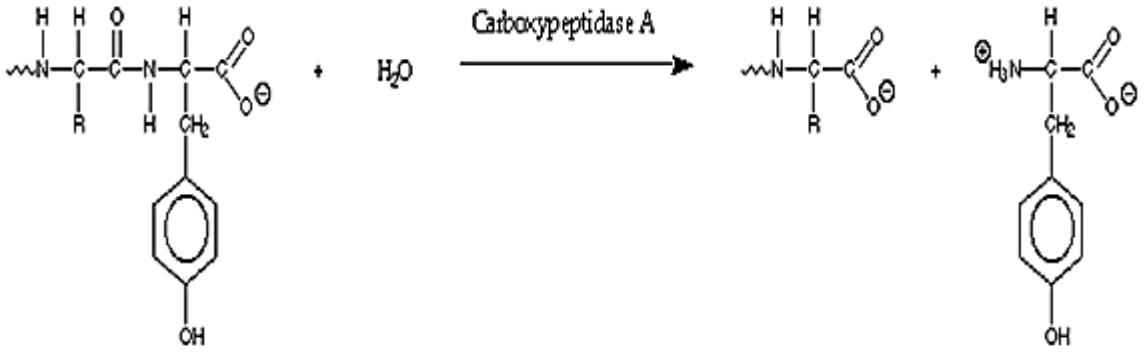
Chymotrypsin



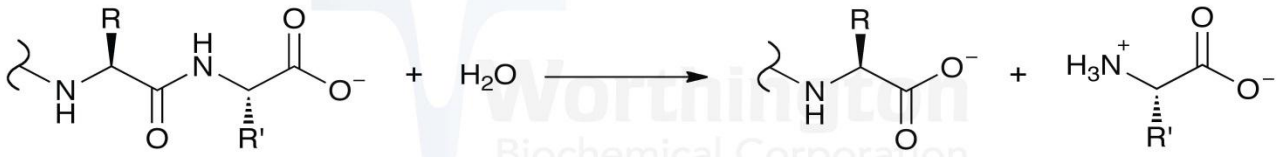
Polypeptide

Polypeptide fragments

R = Phe, Trp, and Tyr; R' ≠ Pro

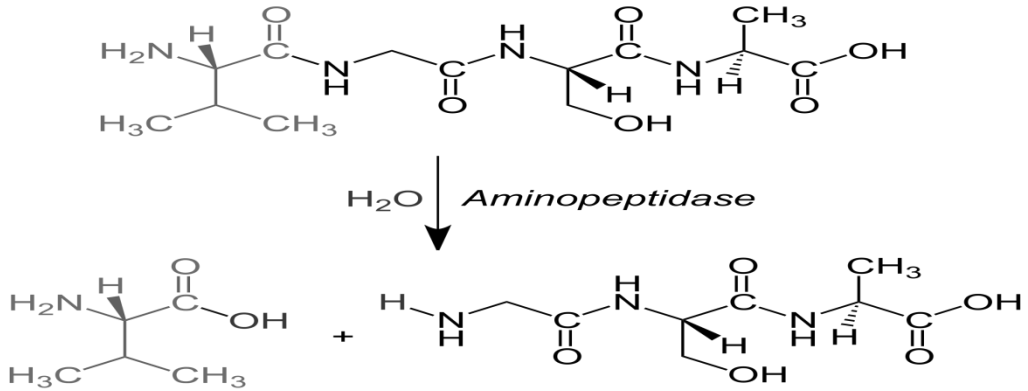


Carboxypeptidase B

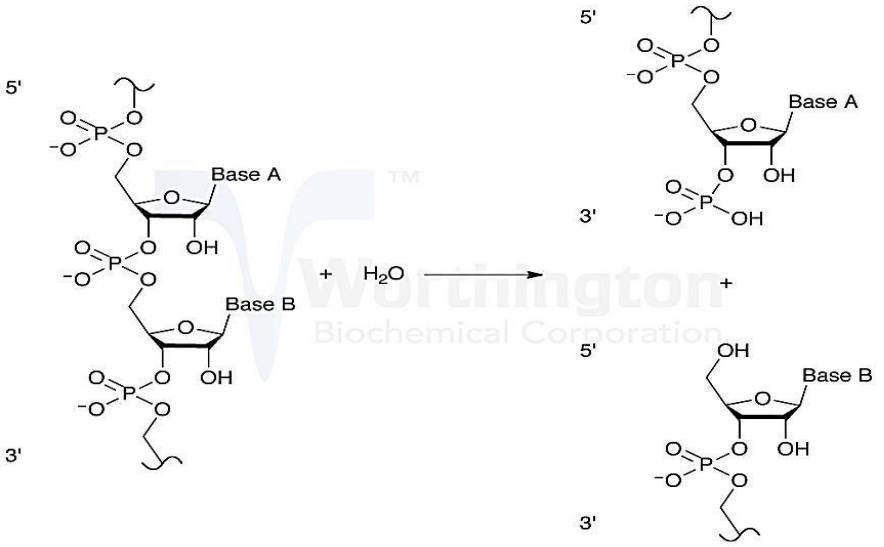


Polypeptide (**n** residues) Polypeptide (**n-1** residues) Amino Acid

R' = Arg, Lys, and ornithine



Ribonuclease A

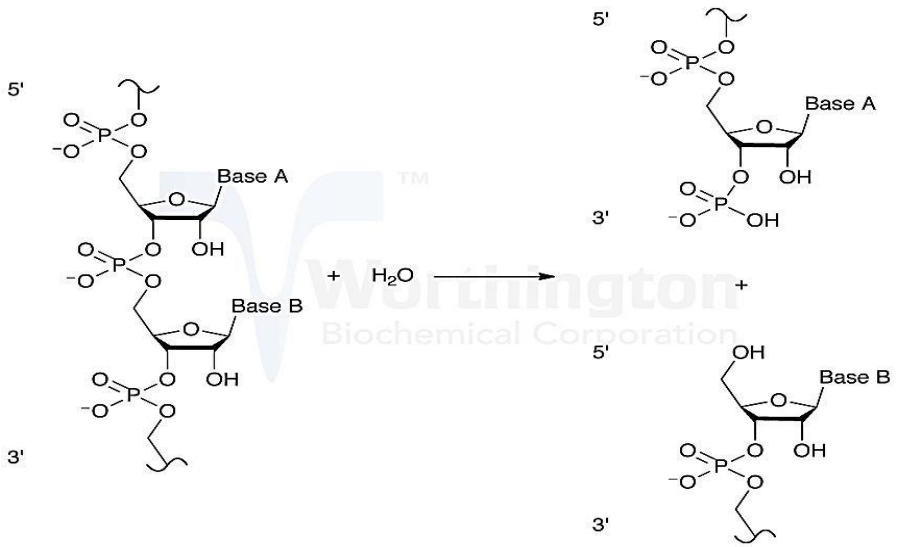


Ribonucleic Acid

Base A = Cytosine or Uracil

3'-Phosphate nucleotides

Ribonuclease T1

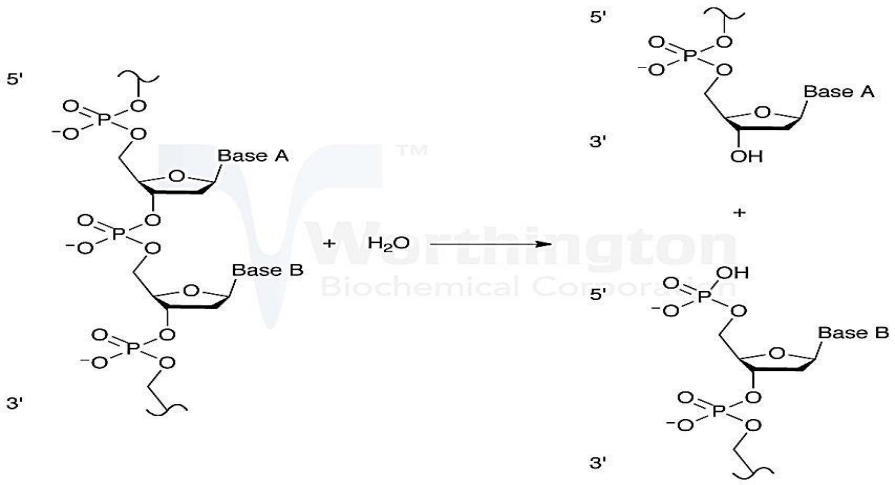


Ribonucleic Acid

Base A = Guanine

3'-Phosphate nucleotides

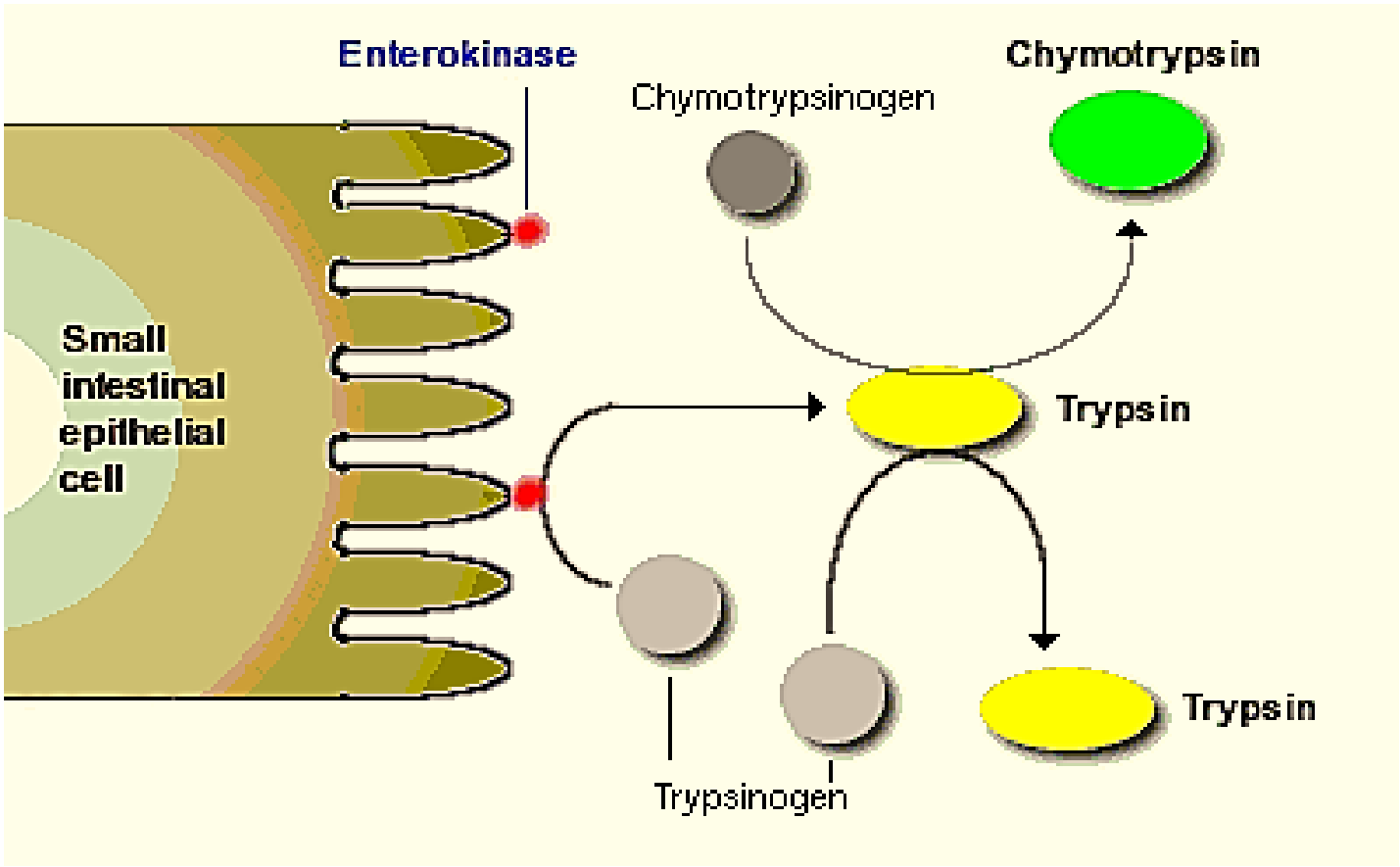
Deoxyribonuclease I

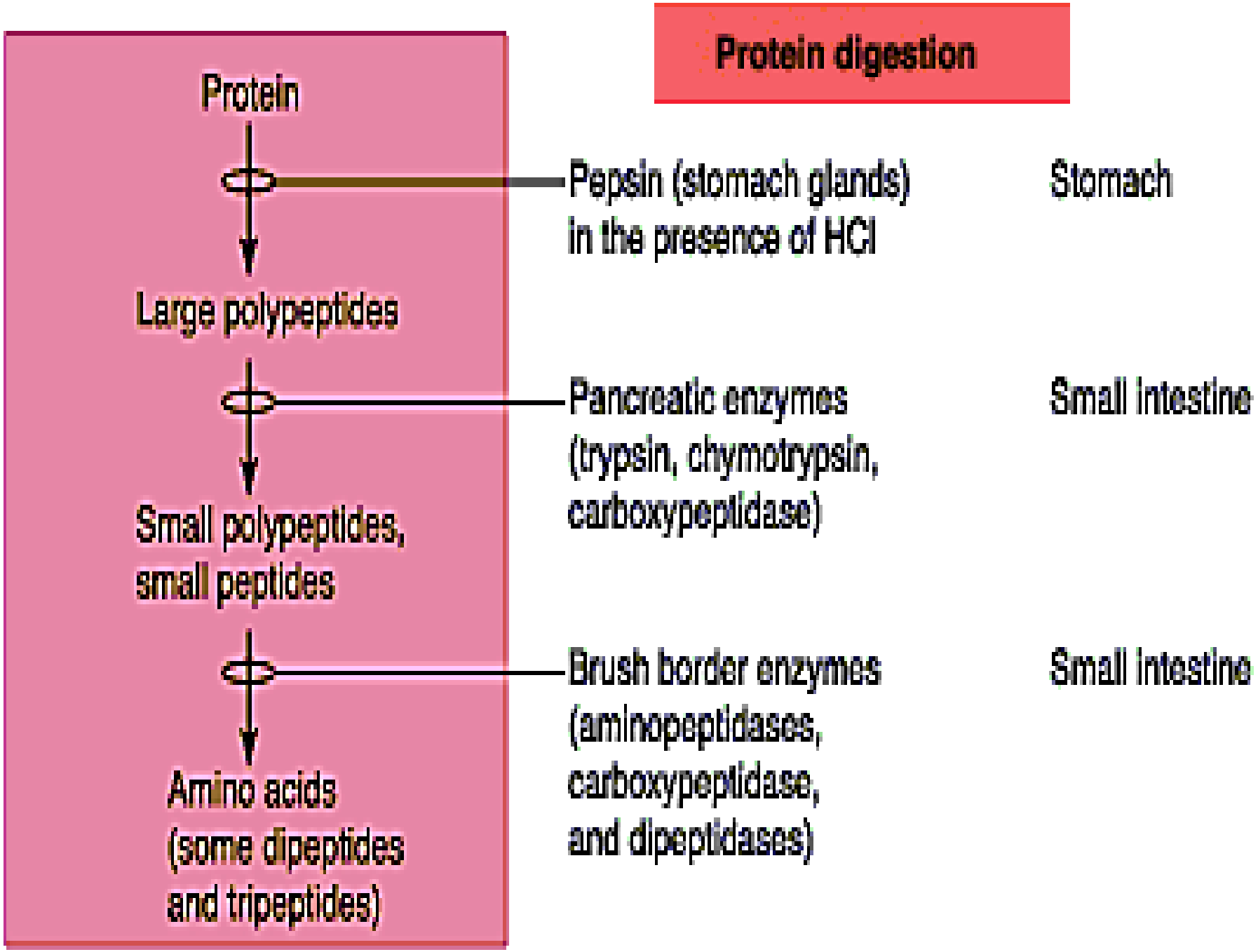


Deoxyribonucleic Acid

5'-Phosphate nucleotides

Trypsin and chymotrypsin are secreted in their inactive forms and are activated by enterokinase (also known as enteropeptidase), which is secreted when chyme contacts the intestinal mucosa.




Protein digestion
Protein
Pepsin (stomach glands) in the presence of HCl
Stomach
Large polypeptides
Pancreatic enzymes (trypsin, chymotrypsin, carboxypeptidase)
Small intestine
Small polypeptides, small peptides
Brush border enzymes (aminopeptidases, carboxypeptidase, and dipeptidases)
Small intestine
Amino acids (some dipeptides and tripeptides)

Pancreatic amylase hydrolyzes large starch molecules into units of approximately two to six sugars.

Enzymes lining the brush border of the villi further break down the carbohydrate molecules into monosaccharides before absorption.

Resistant starches and most ingested dietary fiber escape digestion in the small intestine and add to fibrous material available for fermentation by colonic microbes.

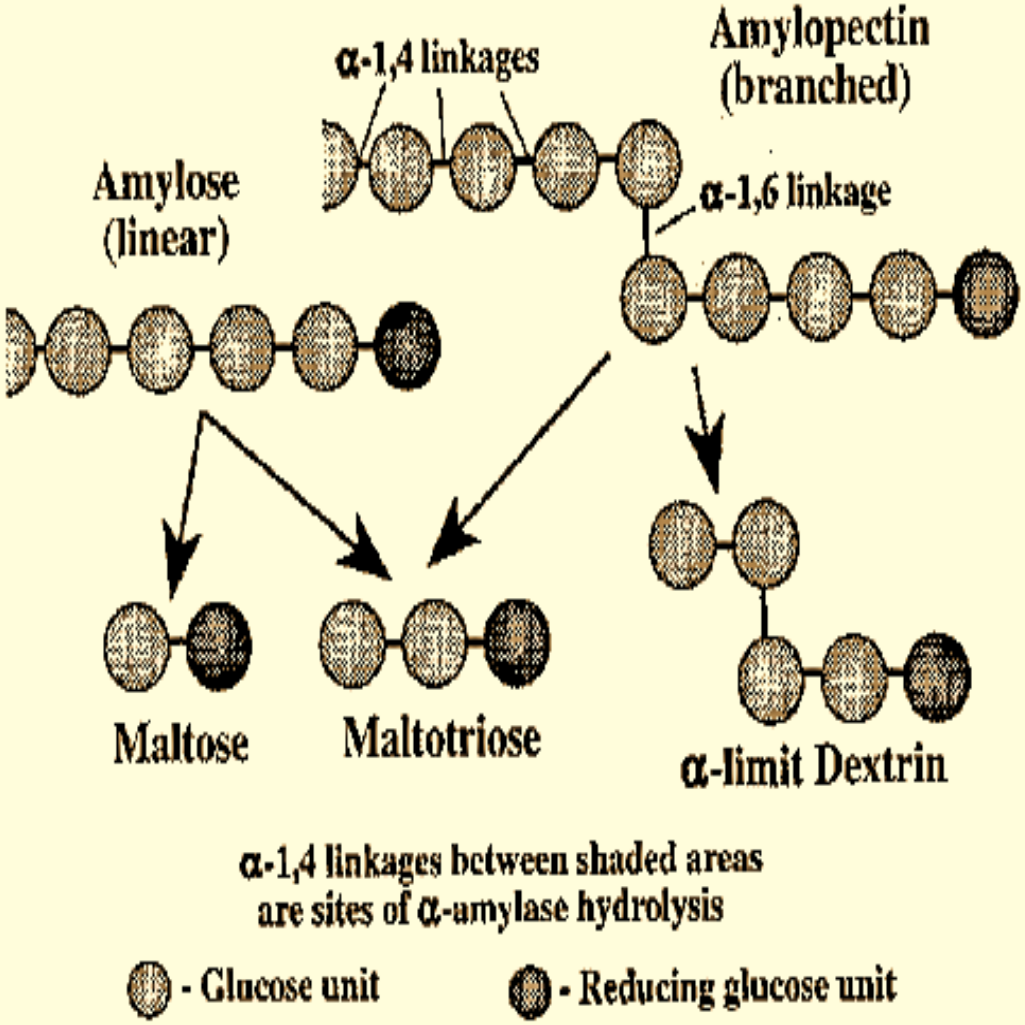
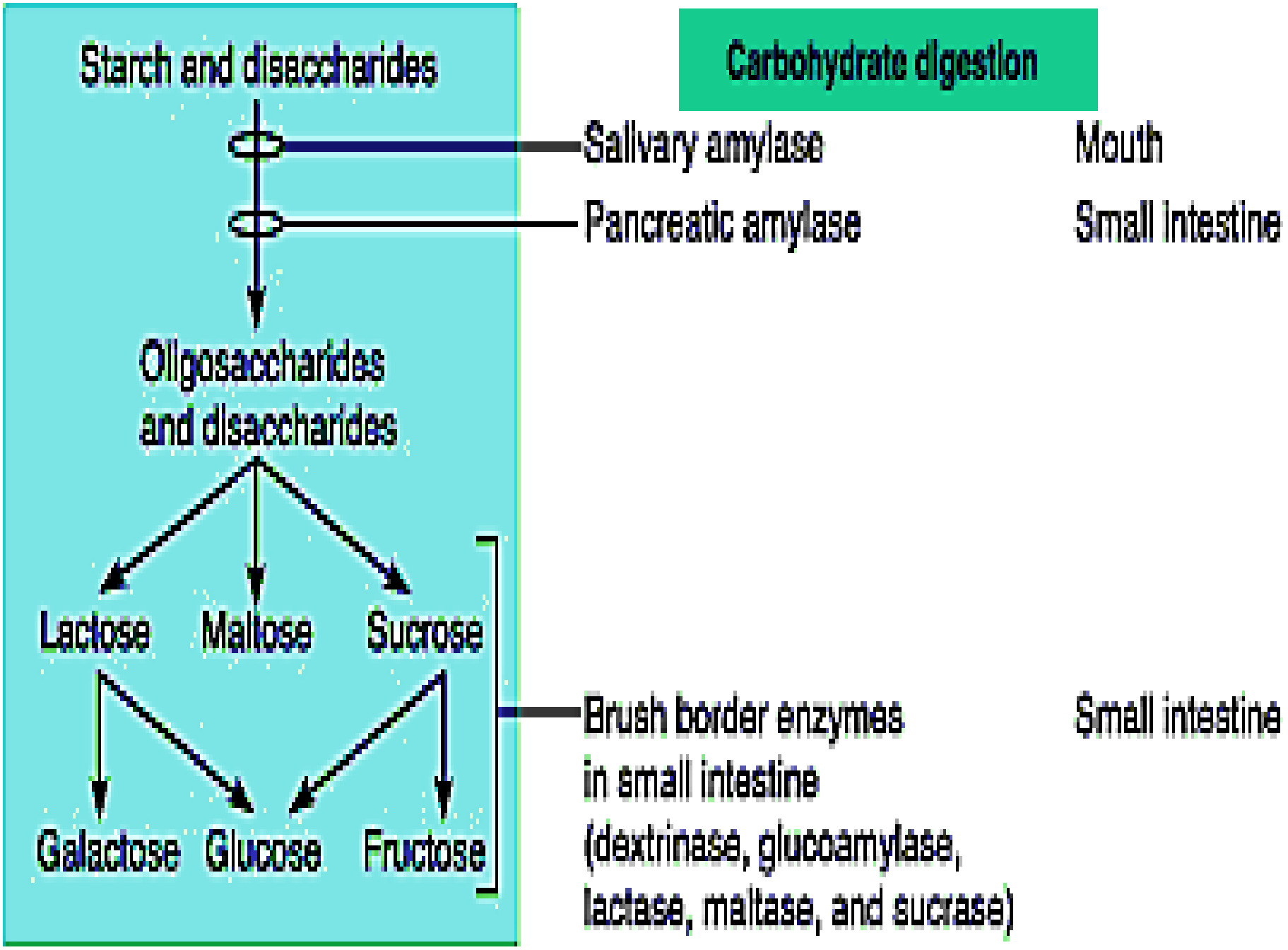


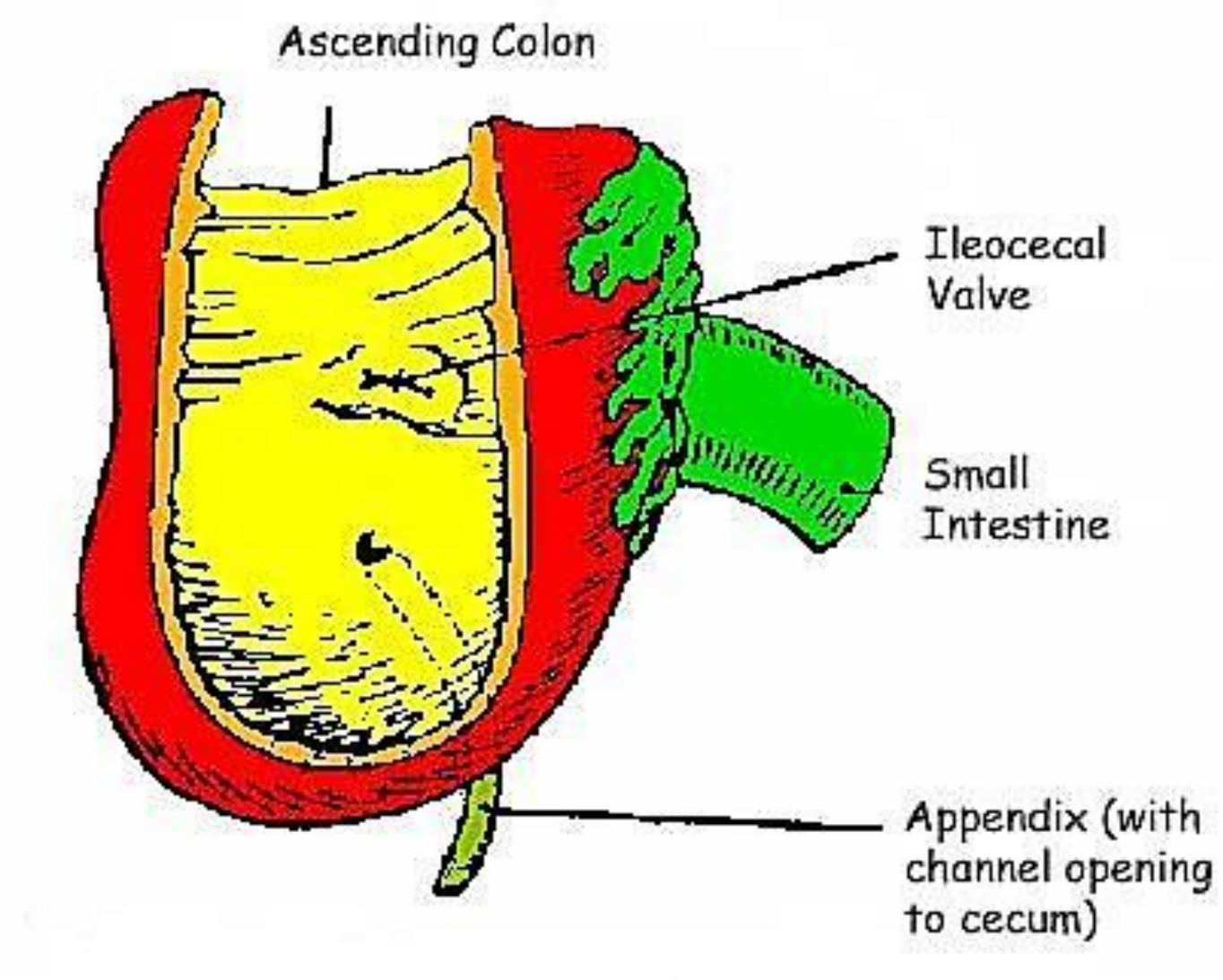
FIg. 42.14. Starch (amylose and amylopectin) digestion by pancreatic amylase produces maltose, maltotriose, and α-limit dextrans. (Reprinted with permission from Chang EB, Sitrin MD, Black DD, eds. Gastrointestinal, Hepatobiliary, and Nutritional Physiology. Philadelphia: Lippincott-Raven, 1996:122.)


Carbohydrate digestion
Starch and disaccharides
Salivary amylase
Mouth
Pancreatic amylase
Small intestine
Oligosaccharides
and disaccharides
Lactose
Maltose
Sucrose
Galactose
Glucose
Fructose
Brush border enzymes
in small intestine
(dextrinase, glucoamylase,
lactase, maltase, and sucrase)
Small intestine

Intestinal contents move along the small intestine at a rate of 1 cm per minute, taking from 3 to 8 hours to travel through the entire intestine to the ileocecal valve.

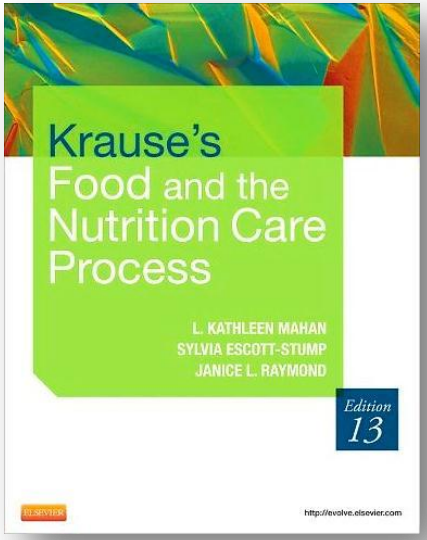
The ileocecal valve, **limits the amount of intestinal material passed back and forth from the small intestine to the colon**.

A damaged or nonfunctional ileocecal valve results in the entry of significant amounts of fluid and substrate into the colon and increased chance for microbial overgrowth.


Ascending Colon
Ileocecal Valve
Small Intestine
Appendix (with channel opening to cecum)

References:

1- Beyer PL. Intake: Digestion, Absorbtion, Transport, and Excretion of Nutrients. In: Mahan LK, Escott-Stump S, Raymond JL, editors. Krause's food & the nutrition care process. 13th ed. USA: Elsevier; 2012: 2-18.
2- Murray RK, Bender DA, Botham KM, Kennelly PJ, Rodwell VW, Weil PA, editors. Harper's Illustrated Biochemistry. 28th ed. USA: McGraw-Hill; 2009.
3- Ross AC, Caballero B, Cousins RJ, Tucker KL, Ziegler TR, editors. Modern Nutrition in Health and Disease. 11th ed. USA: Lippincott Williams & Wilkins; 2014.
4- Wikipedia, the free encyclopedia. Available from: URL: http://en.wikipedia.org


Krause's
Food and the
Nutrition Care
Process
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SYLVIA ESCOTT-STUMP
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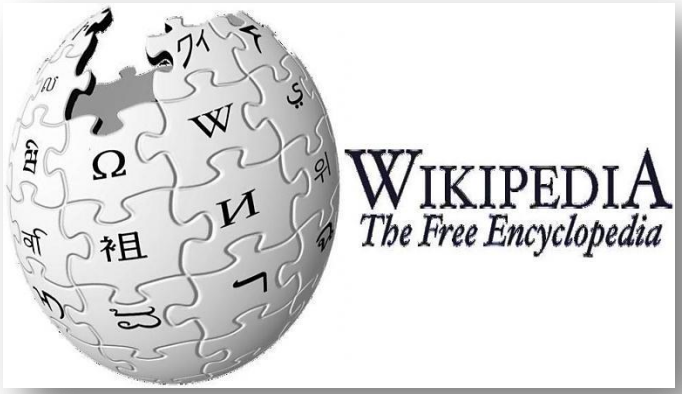
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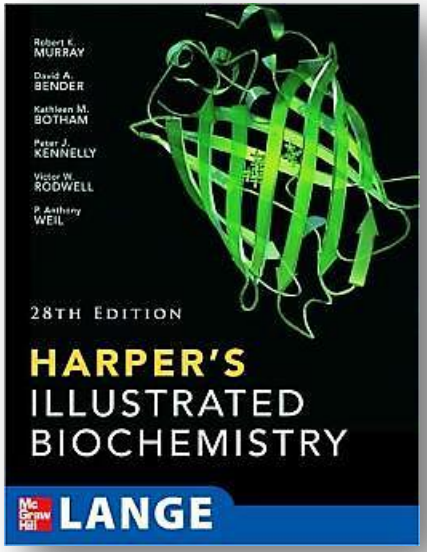
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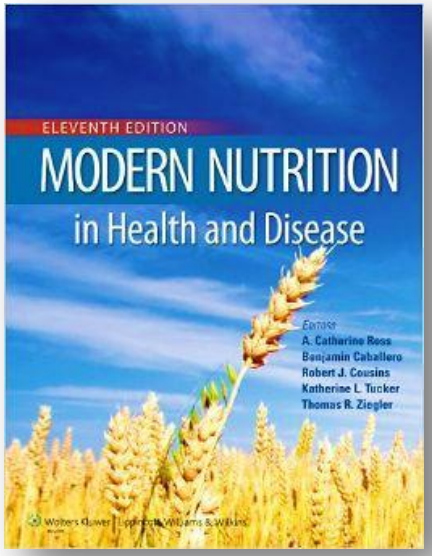
Victor W. RODWELL
P. Anthony WEIL
28TH EDITION
HARPER'S
ILLUSTRATED
BIOCHEMISTRY
LANGE


ELEVENTH EDITION
MODERN NUTRITION
in Health and Disease
A. Catharine Ross
Benjamin Caballero
Robert J. Cousins
Katherine L. Tucker
Thomas R. Ziegler