Varastegan
Institute for Medical Sciences

Digestion, Absorption, Transport, and Excretion of Nutrients

(Session 1)

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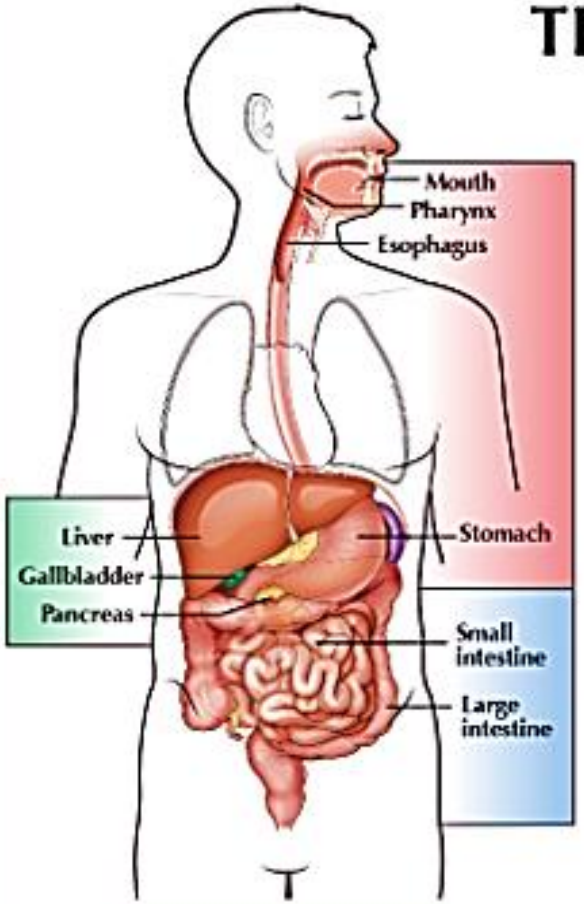
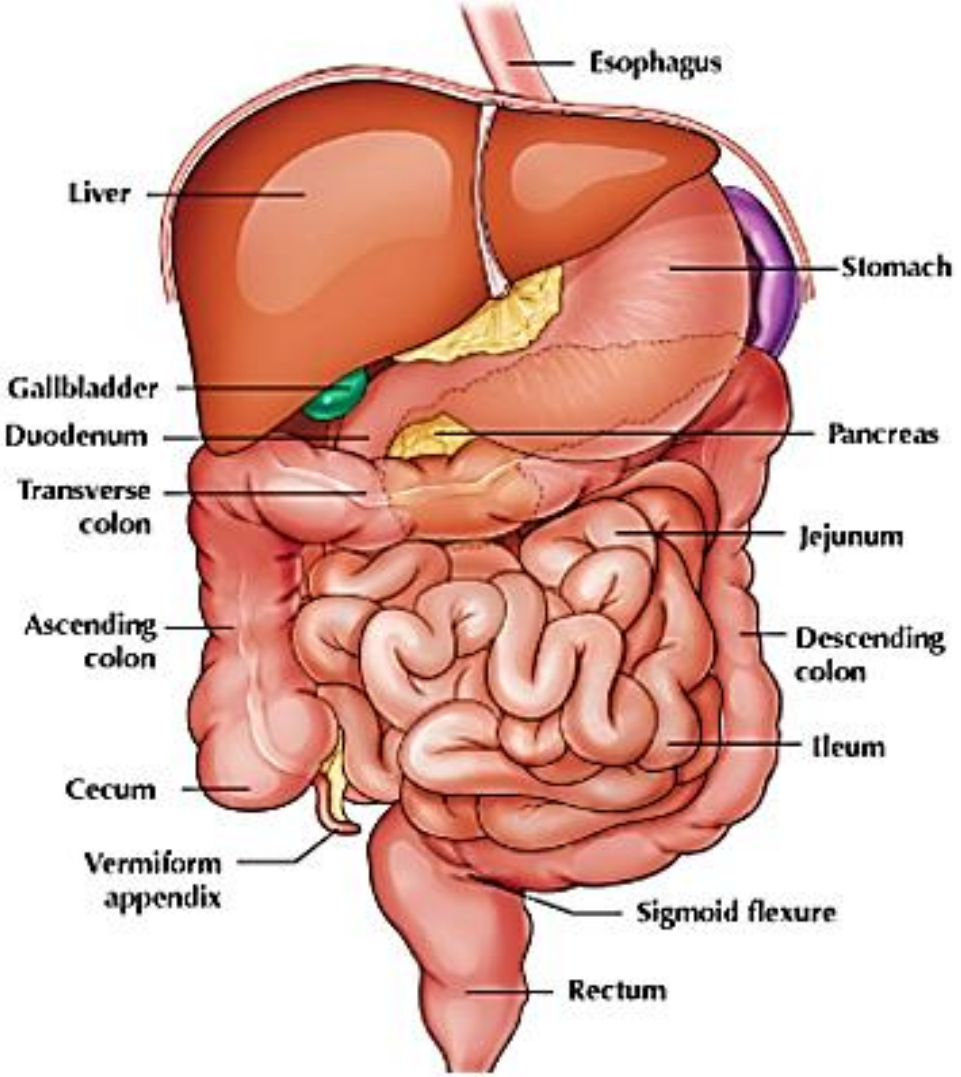
The Gastrointestinal Tract

THE GASTROINTESTINAL SYSTEM





The gastrointestinal tract (GIT):

- Digests the ingested proteins, carbohydrates, and lipids

- Absorbs the fluids and nutrients

- Provides a physical and immunologic barrier to microorganisms, foreign materials, and potential antigens

- Participates in many regulatory, metabolic, and immunologic functions

Depending on the nature of the diet consumed, 90% to 97% of food is digested and absorbed; most of the unabsorbed material is of plant origin.

Compared with ruminants, **humans** are less efficient at extracting energy from fibrous materials because we **lack the enzymes to hydrolyze the chemical bonds that link the molecules of sugars that make up plant fibers.**

However, fibrous foods are partially fermented by bacteria in the human colon, contributing to 5% to 10% of the energy needed by humans.

The GIT extends from the mouth to the anus and includes the oropharyngeal structures, esophagus, stomach, liver, gallbladder, pancreas, small intestine, and large intestine.

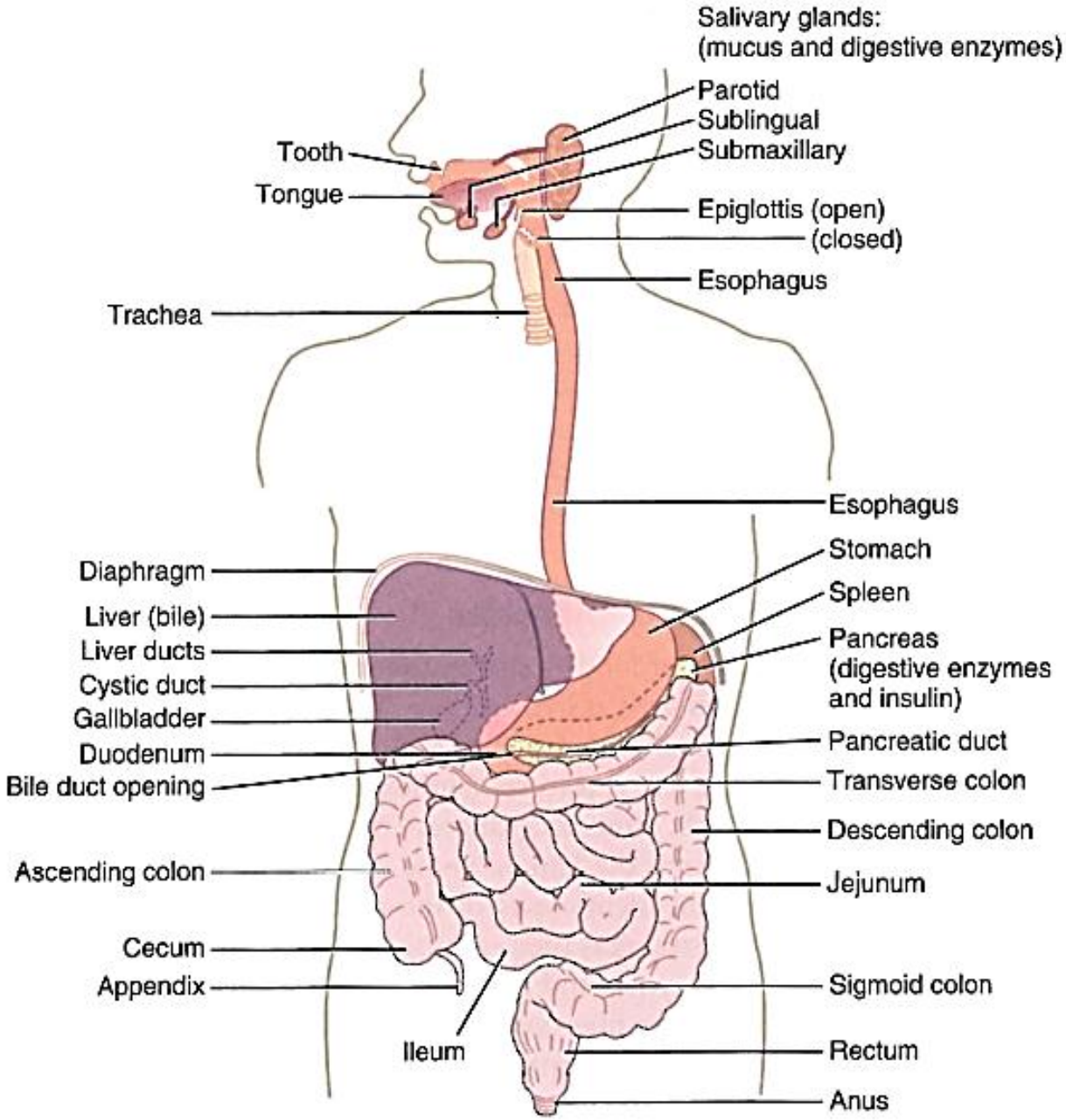


FIGURE 1-1 The digestive system.

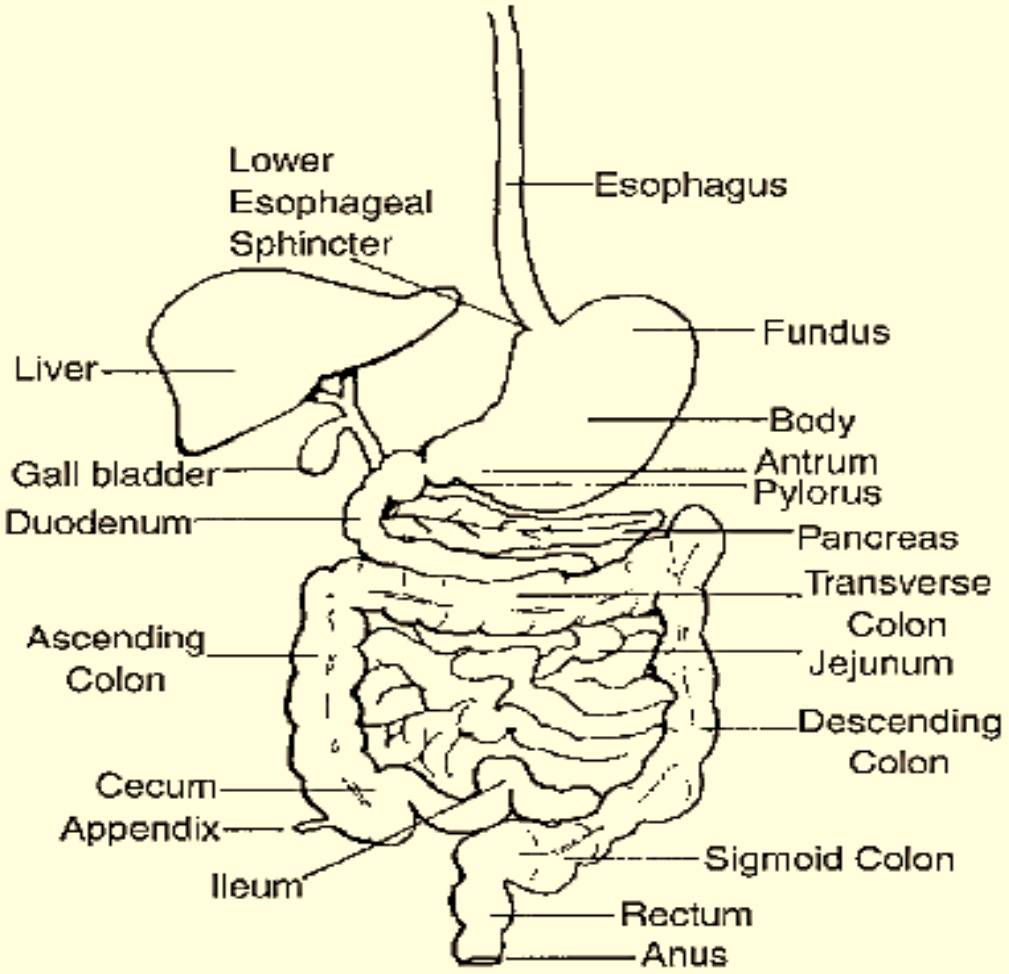


Fig. 42.1. Anatomy of the stomach, small intestine, and large intestine. The duodenum is located in the retroperitoneal space and bends around the head of the pancreas. The jejunum lies within the peritoneal cavity and begins at the ligament of Trietz. Jejunal bowel loops are predominantly located in the left and middle upper abdomen. The proximal ileum lies in the middle abdominal region. The distal ileum lies in the right lower quadrant and joins the colon at the ileal cecal valve. The *cutout* reveals the duodenum and the ligament of Trietz that lie behind the transverse colon.

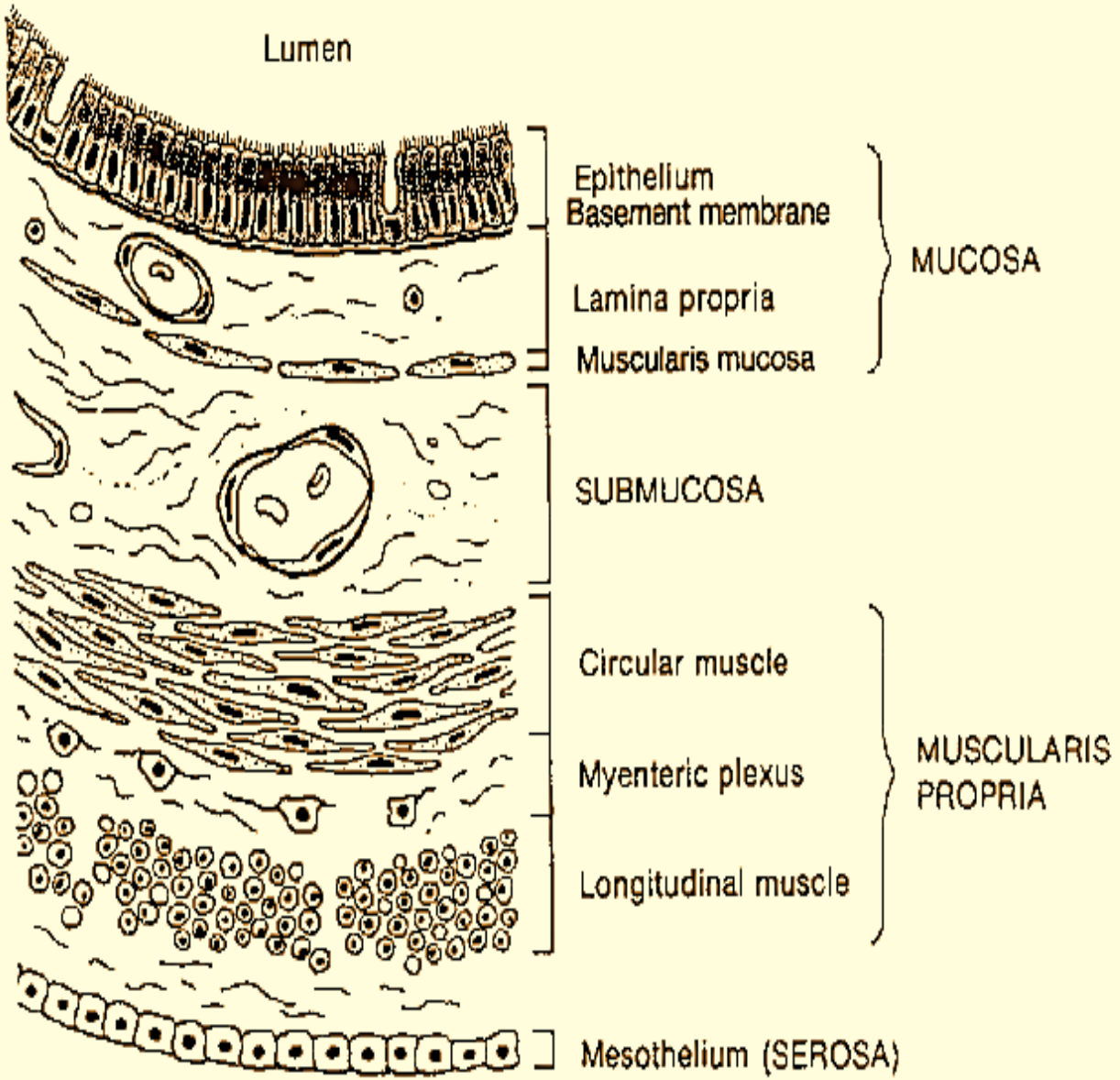


Fig. 42.2. Schematic organization of the wall of the gastrointestinal tract. (Reprinted with permission from Yamada T, Alpers DH, Owyang C et al, eds. Textbook of Gastroenterology. 2nd ed. Philadelphia: JB Lippincott, 1991:142.)

GIT:

Is one of the largest organs in the body, has the greatest surface area, has the largest number of immune cells, and is one of the most metabolically active tissues in the body.

The cells lining the GIT have a life span of 3 to 5 days, and they are fully functional only for the last 2 to 3 days.

Approximately, **45% and 75% of the energy requirements of the cells lining small intestine and colon are supplied by nutrients passing through their lumen, respectively**.

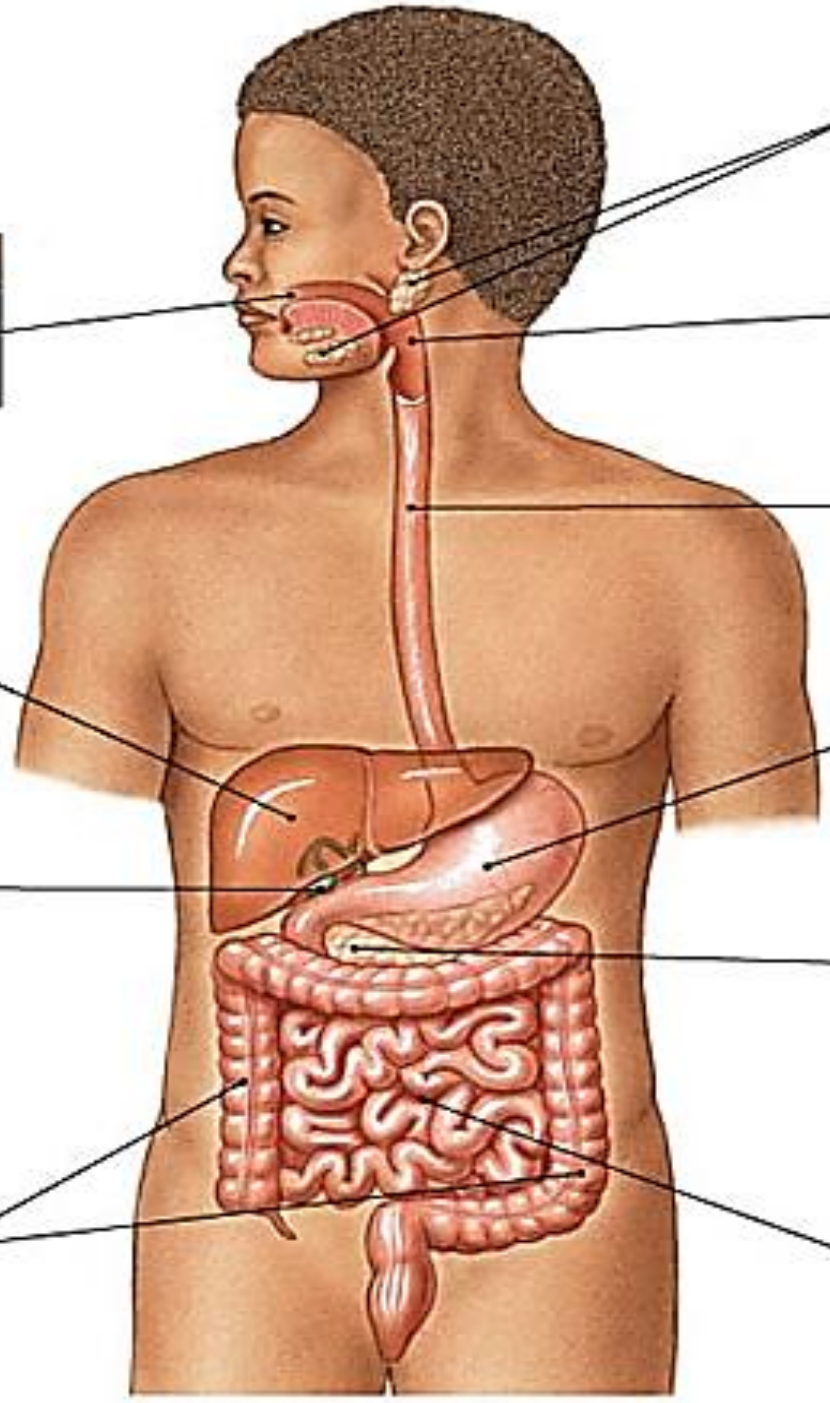
Due to this fact and because of the high metabolic activity and requirements, **the cells lining the GIT are more susceptible than most tissues to micronutrient deficiencies; protein-energy malnutrition; and damage**.

After only a few days of starvation, the GIT atrophies (i.e. the surface area decreases and secretions, synthetic functions, blood flow, and absorptive capacity are all reduced).

Resumption of food intake, even with less than adequate calories, **results in cellular proliferation and return of normal GI function** after only a few days.

Optimum function of the human GIT depends on a constant supply of foods rather than on consumption of large amounts of foods interrupted by prolonged fasts.

Brief Overview of Digestive and Absorptive Processes



SALIVARY GLANDS

Secretion of lubricating fluid containing enzymes that break down carbohydrates

ORAL CAVITY, TEETH, TONGUE

Mechanical processing, moistening, mixing with salivary secretions

PHARYNX

Pharyngeal muscles propel materials into the esophagus

ESOPHAGUS

Transport of materials to the stomach

LIVER

Secretion of bile (important for lipid digestion), storage of nutrients, many other vital functions

STOMACH

Chemical breakdown of materials via acid and enzymes; mechanical processing through muscular contractions

GALLBLADDER

Storage and concentration of bile

PANCREAS

Exocrine cells secrete buffers and digestive enzymes; endocrine cells secrete hormones

LARGE INTESTINE

Dehydration and compaction of indigestible materials in preparation for elimination

SMALL INTESTINE

Enzymatic digestion and absorption of water, organic substrates, vitamins, and ions

In the mouth, chewing reduces the size of food particles, which are mixed with salivary secretions that prepare them for swallowing.

A small amount of starch is degraded by salivary amylase, but this overall carbohydrate digestion is minimal.

The esophagus transports food and liquid from the oral cavity and pharynx to the stomach.

In the stomach, food is mixed with acidic fluid and proteolytic and lipolytic enzymes.

Small amounts of lipid digestion take place, and some proteins are changed in structure or partially digested to large peptides.

When food reaches the appropriate consistency and concentration, the stomach allows its contents to pass into the small intestine.

Alcohol, the exception, is absorbed through the stomach.

In the first 100 cm of small intestine, the presence of food stimulates the release of hormones that stimulate the production and release of powerful enzymes from the pancreas and small intestine and bile from the liver and gallbladder, resulting in the digestion and absorption of most ingested food.

In the small intestine, starches and proteins are reduced to smaller-molecular-weight carbohydrates and small to medium-size peptides.

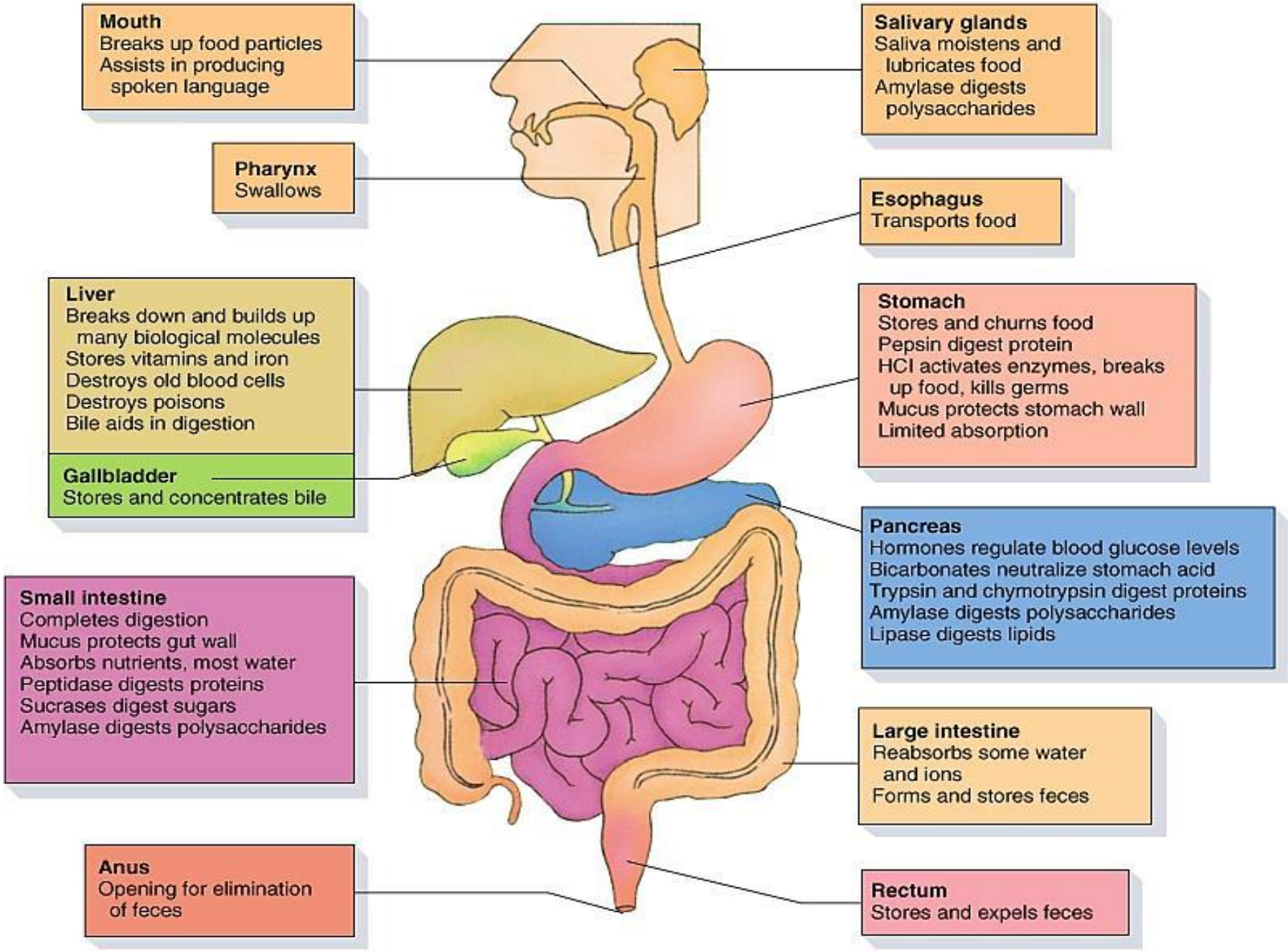
Dietary fats are reduced from visible globules of fat to microscopic droplets of triglycerides, then **to free fatty acids and monoglycerides**.

Enzymes from the brush border of the small intestine further reduce the remaining carbohydrates to monosaccharides and peptides to single amino acids, dipeptides, and tripeptides.

Along the remaining length of the small intestine, **almost all the macronutrients, minerals, vitamins, trace elements, and fluid are absorbed before reaching the colon**.

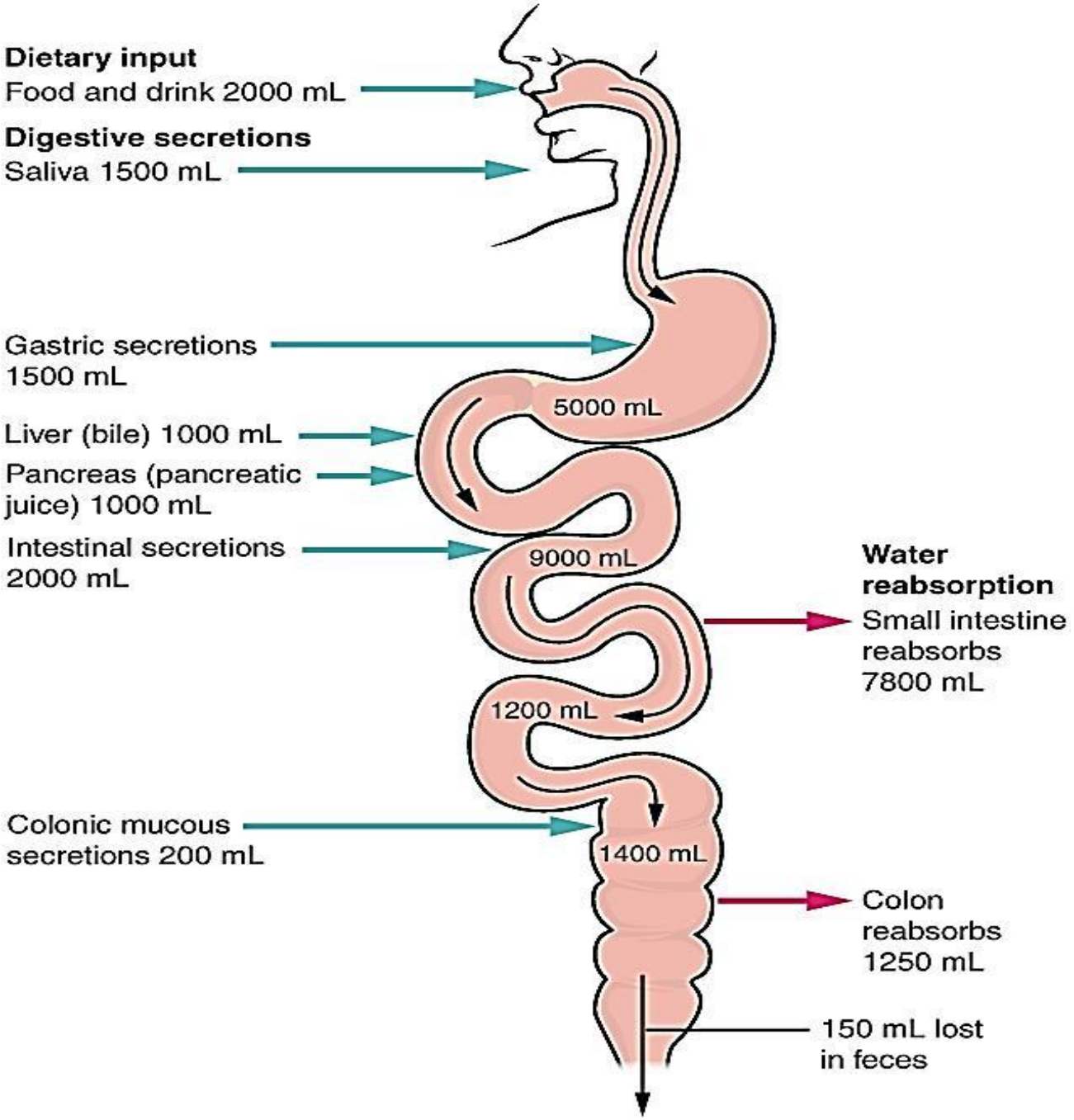
The colon and rectum absorb most of the remaining fluid delivered from the small intestine.

The colon absorbs electrolytes and only a small amount of remaining nutrients.


Mouth
Breaks up food particles
Assists in producing spoken language
Pharynx
Swallows
Liver
Breaks down and builds up many biological molecules
Stores vitamins and iron
Destroys old blood cells
Destroys poisons
Bile aids in digestion
Gallbladder
Stores and concentrates bile
Small intestine
Completes digestion
Mucus protects gut wall
Absorbs nutrients, most water
Peptidase digests proteins
Sucrases digest sugars
Amylase digests polysaccharides
Anus
Opening for elimination of feces
Salivary glands
Saliva moistens and lubricates food
Amylase digests polysaccharides
Esophagus
Transports food
Stomach
Stores and churns food
Pepsin digest protein
HCl activates enzymes, breaks up food, kills germs
Mucus protects stomach wall
Limited absorption
Pancreas
Hormones regulate blood glucose levels
Bicarbonates neutralize stomach acid
Trypsin and chymotrypsin digest proteins
Amylase digests polysaccharides
Lipase digests lipids
Large intestine
Reabsorbs some water and ions
Forms and stores feces
Rectum
Stores and expels feces

Together with salivary and gastric secretions, secretions from the pancreas, small intestine, and gallbladder contribute 7 to 9 L of fluid in a day, approximately three to four times more fluid than is normally consumed orally.

All but 100 to 150 mL of the total fluid entering the lumen is reabsorbed.


Dietary input
Food and drink 2000 mL
Digestive secretions
Saliva 1500 mL
Gastric secretions
1500 mL
5000 mL
Liver (bile) 1000 mL
Pancreas (pancreatic
juice) 1000 mL
Intestinal secretions
2000 mL
9000 mL
Water
reabsorption
Small intestine
reabsorbs
7800 mL
1200 mL
Colonic mucous
secretions 200 mL
1400 mL
Colon
reabsorbs
1250 mL
150 mL lost
in feces

Most nutrients absorbed from the GIT enter the portal vein for transport to the liver, where they may be stored, transformed into other substances, or released into circulation.

End products of most dietary fats are transported into the bloodstream via the lymphatic circulation.

Remaining fiber, resistant starch, sugar, and amino acids are fermented in the brush border of the colon, and produce short-chain fatty acids (SCFAs) and gas.

SCFAs help maintain normal mucosal function, salvage a small amount of energy from some of the residual carbohydrates and amino acids**, and facilitate the absorption of salt and water**.

Some of the carbohydrate and fiber resistant to digestion in the upper GIT serve as "prebiotic" material by producing SCFAs, decreasing the colonic pH, and increasing the mass of "helpful" bacteria.

In the large intestine, the distal colon, rectum, and anus control defecation.

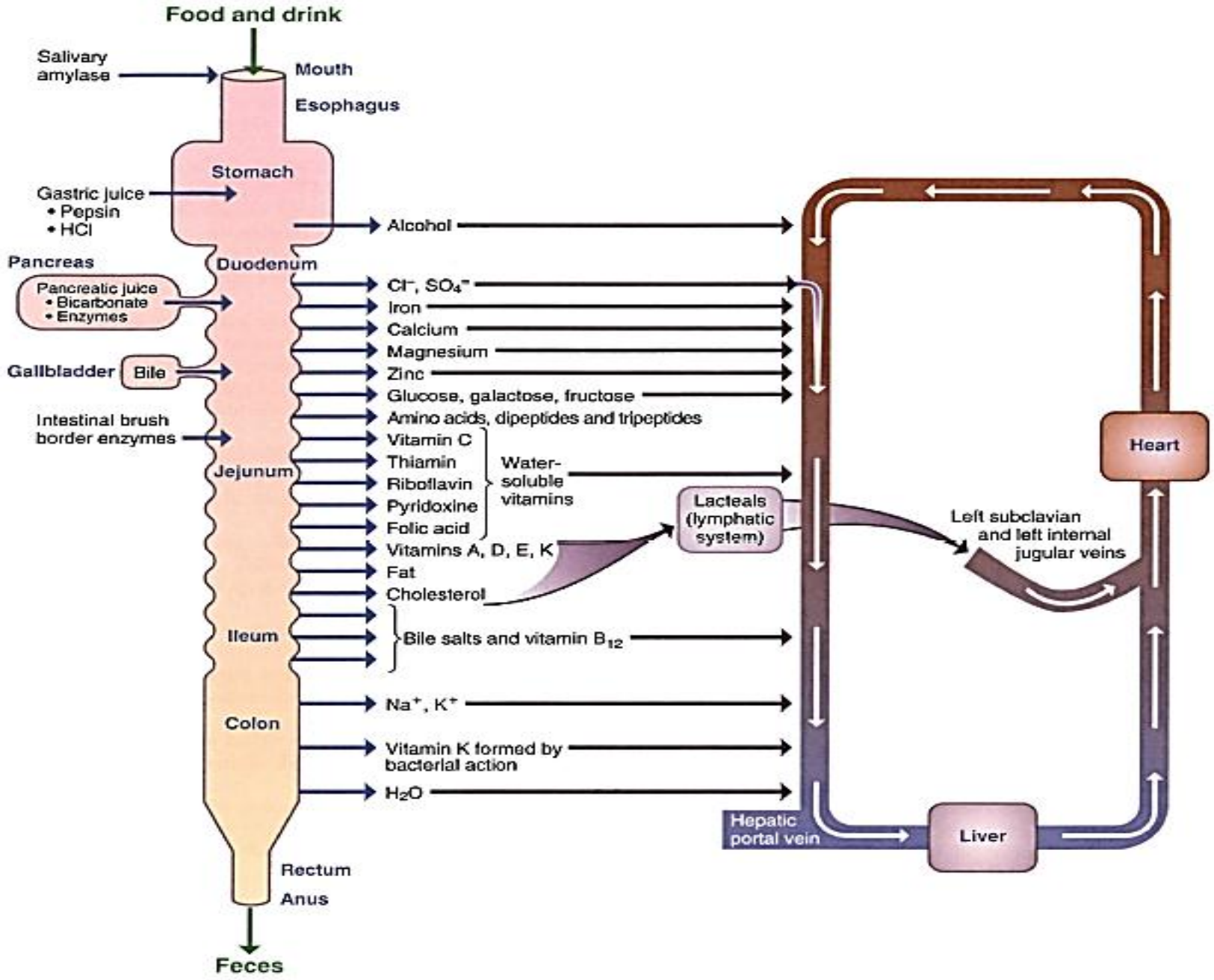


FIGURE 1-9 Sites of secretion and absorption in the gastrointestinal tract.

Table 23.2 Overview of the Functions of the Gastrointestinal Organs

ORGAN	MAJOR FUNCTIONS*	COMMENTS/ADDITIONAL FUNCTIONS
Mouth and associated accessory organs	■ Ingestion: food is voluntarily placed into oral cavity ■ Propulsion: voluntary (buccal) phase of deglutition (swallowing) initiated by tongue; propels food into pharynx ■ Mechanical breakdown: mastication (chewing) by teeth and mixing movements by tongue ■ Digestion: salivary amylase in saliva, produced by salivary glands, begins chemical breakdown of starch	Mouth serves as a receptacle; most functions performed by associated accessory organs. Mucus in saliva helps dissolve foods so they can be tasted and moistens food so that tongue can compact it into a bolus that can be swallowed. Saliva cleanses and lubricates oral cavity and teeth.
Pharynx and esophagus	■ Propulsion: peristaltic waves move food bolus to stomach, thus accomplishing involuntary (pharyngeal-esophageal) phase of deglutition	Primarily food chutes; mucus produced helps to lubricate food passageways.
Stomach	■ Mechanical breakdown and propulsion: peristaltic waves mix food with gastric juice and propel it into the duodenum ■ Digestion: pepsin begins the digestion of proteins ■ Absorption: absorbs a few fat-soluble substances (aspirin, alcohol, some drugs)	Also stores food until it can be moved into the duodenum. Hydrochloric acid produced is a bacteriostatic agent and activates protein-digesting enzymes. Mucus produced helps lubricate and protect stomach from self-digestion. Intrinsic factor produced is required for intestinal absorption of vitamin B_{12}.
Small intestine and associated accessory organs (liver, gallbladder, pancreas)	■ Mechanical breakdown and propulsion: segmentation by smooth muscle of the small intestine continually mixes contents with digestive juices and, along with short-distance peristaltic waves, moves food along tract, allowing sufficient time for digestion and absorption ■ Digestion: digestive enzymes delivered from pancreas and brush border enzymes attached to microvilli membranes complete digestion of all classes of foods ■ Absorption: breakdown products of carbohydrate, protein, fat, and nucleic acid digestion, plus vitamins, electrolytes, and water, are absorbed by active and passive mechanisms	Small intestine is highly modified for digestion and absorption (circular folds, villi, and microvilli). Alkaline mucus produced by intestinal glands and bicarbonate-rich juice ducted in from pancreas help neutralize acidic chyme and provide proper environment for enzymatic activity. Bile produced by liver emulsifies fats and enhances (1) fat digestion and (2) absorption of fatty acids, monoglycerides, cholesterol, phospholipids, and fat-soluble vitamins. Gallbladder stores and concentrates bile, releasing it to small intestine in response to hormonal signals.
Large intestine	■ Digestion: some remaining food residues are digested by enteric bacteria (which also produce vitamin K and some B vitamins) ■ Absorption: absorbs most remaining water, electrolytes (largely NaCl), and vitamins produced by bacteria ■ Propulsion: propels feces toward rectum by haustral churning and mass movements ■ Defecation: reflex triggered by rectal distension; eliminates feces from body	Temporarily stores and concentrates residues until defecation can occur. Copious mucus produced by goblet cells eases passage of feces through colon.

Enzymes in Digestion

Digestion of food is accomplished by enzymatic hydrolysis.

Digestive enzymes are synthesized in specialized cells in the mouth, stomach, pancreas, and small intestine and are released into the lumen.

Some enzymes are localized in the lipoprotein membranes of the mucosal cells and attach to their substrates as they enter the cell.

Except for fiber and some carbohydrates, digestion and absorption are essentially completed in the small intestine, because no digestive enzymes are secreted from the large intestine.

Generally, the ingested carbohydrates, lipids, and proteins must be converted to their simple constituents by digestive enzymes before they are absorbed.

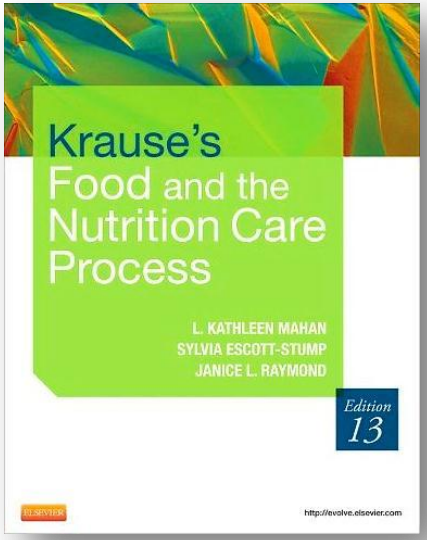
TABLE 1-1

Summary of Enzymatic Digestion and Absorption

Secretion and Source	Enzymes	Substrate	Action and Resulting Products	Final Products Absorbed
Saliva from salivary glands in mouth	Ptyalin (salivary amylase)	Starch	Hydrolysis to form dextrins and branched oligosaccharides	—
Gastric juice from gastric glands in stomach mucosa	Pepsin	Protein (in the presence of hydrochloric acid)	Hydrolysis of peptide bonds to form polypeptides and amino acids	—
	Gastric lipase	Fat, especially shorter chain	Hydrolysis to form free fatty acids	—
Exocrine secretions from pancreas	Lipase	Fat (in the presence of bile salts)	Hydrolysis to form monoglycerides and fatty acids; incorporated into micelles	Fatty acids into mucosal cells; reesterified as triglycerides
	Cholesterol esterase	Cholesterol	Hydrolysis to form esters of cholesterol and fatty acids; incorporated into micelles	Cholesterol into mucosal cells; transferred to chylomicrons
	α-Amylase	Starch and dextrins	Hydrolysis to form dextrins and maltose	—
	Trypsin (activated trypsinogen)	Proteins and polypeptides	Hydrolysis of interior peptide bonds to form polypeptides	—
	Chymotrypsin (activated chymotrypsinogen)	Proteins and peptides	Hydrolysis of interior peptide bonds to form polypeptides	—
	Carboxypeptidase	Polypeptides	Hydrolysis of terminal peptide bonds (carboxyl end) to form amino acids	Amino acids
	Ribonuclease and deoxyribonuclease	Ribonucleic acids and (RNA) deoxyribonucleic acids (DNA)	Hydrolysis to form mononucleotides	Mononucleotides
	Elastase	Fibrous protein	Hydrolysis to form peptides and amino acids	—
Small intestine enzymes (primarily in brush border)	Carboxypeptidase, aminopeptidase, and dipeptidase	Polypeptides	Hydrolysis of carboxyl terminus, amino terminus, or internal peptide bonds	Amino acids
	Enterokinase	Trypsinogen	Activates trypsin	Dipeptides and tripeptides
	Sucrase	Sucrose	Hydrolysis to form glucose and fructose	Glucose and fructose
	α-Dextrinase (isomaltase)	Dextrin (isomaltose)	Hydrolysis to form glucose	Glucose
	Maltase	Maltose	Hydrolysis to form glucose	Glucose
	Lactase	Lactose	Hydrolysis to from glucose and galactose	Glucose and galactose
	Nucleotidases	Nucleic acids	Hydrolysis to form nucleotides and phosphates	Nucleotides
	Nucleosidase and phosphorylase	Nucleosides	Hydrolysis to form purines, pyrimidines, and pentose phosphate	Purine and pyrimidine bases

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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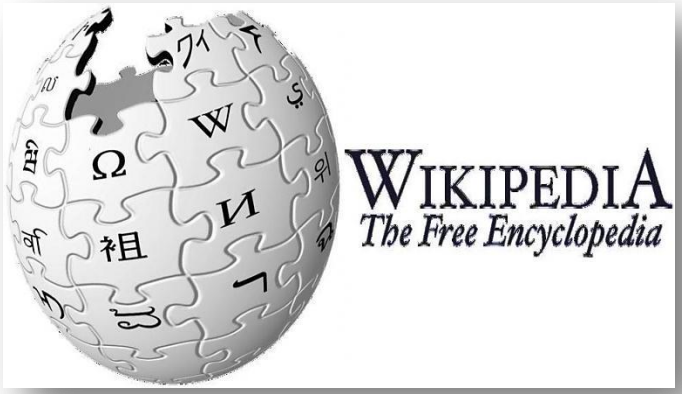
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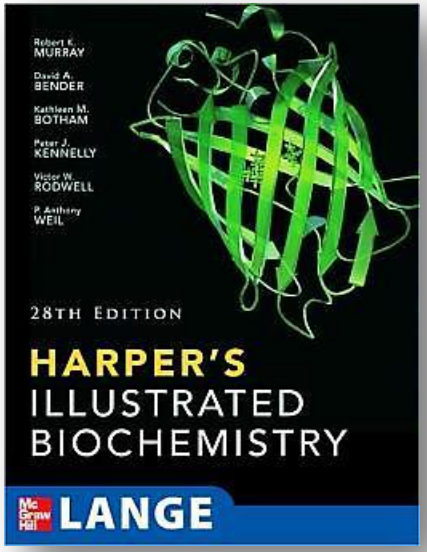
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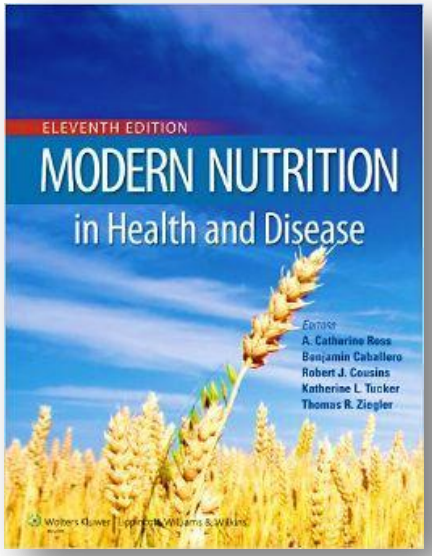
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