Gastrointestinal Physiology
Lecture 5

Physiology of the Small Intestine: Motility and Secretion

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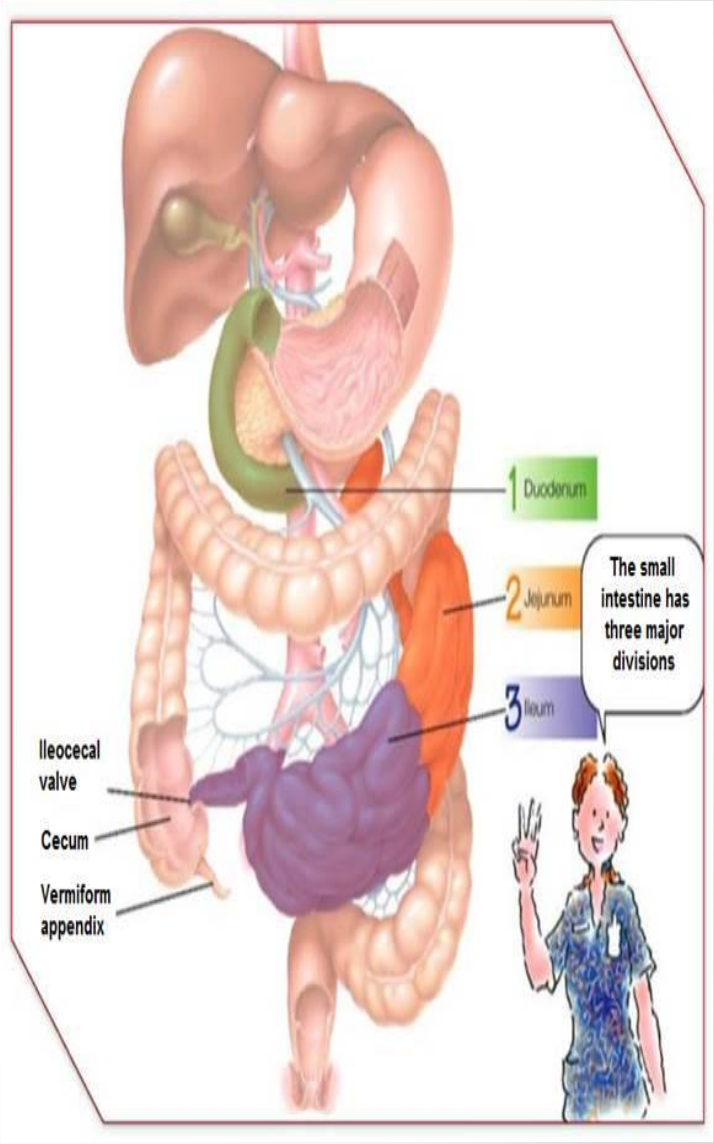
Learning Objectives

- Motility in the small intestine.
- Control of intestinal motility.
- Secretions of the small intestine
- Digestion of carbohydrates, proteins and fats.
- Basic principles of gastrointestinal absorption.
  - ✓ Absorption of carbohydrates
  - ✓ Absorption of proteins
  - ✓ Absorption of fats
  - ✓ Absorption of vitamins
  - ✓ Absorption and secretion of electrolytes and water

Motility in the Small Intestine

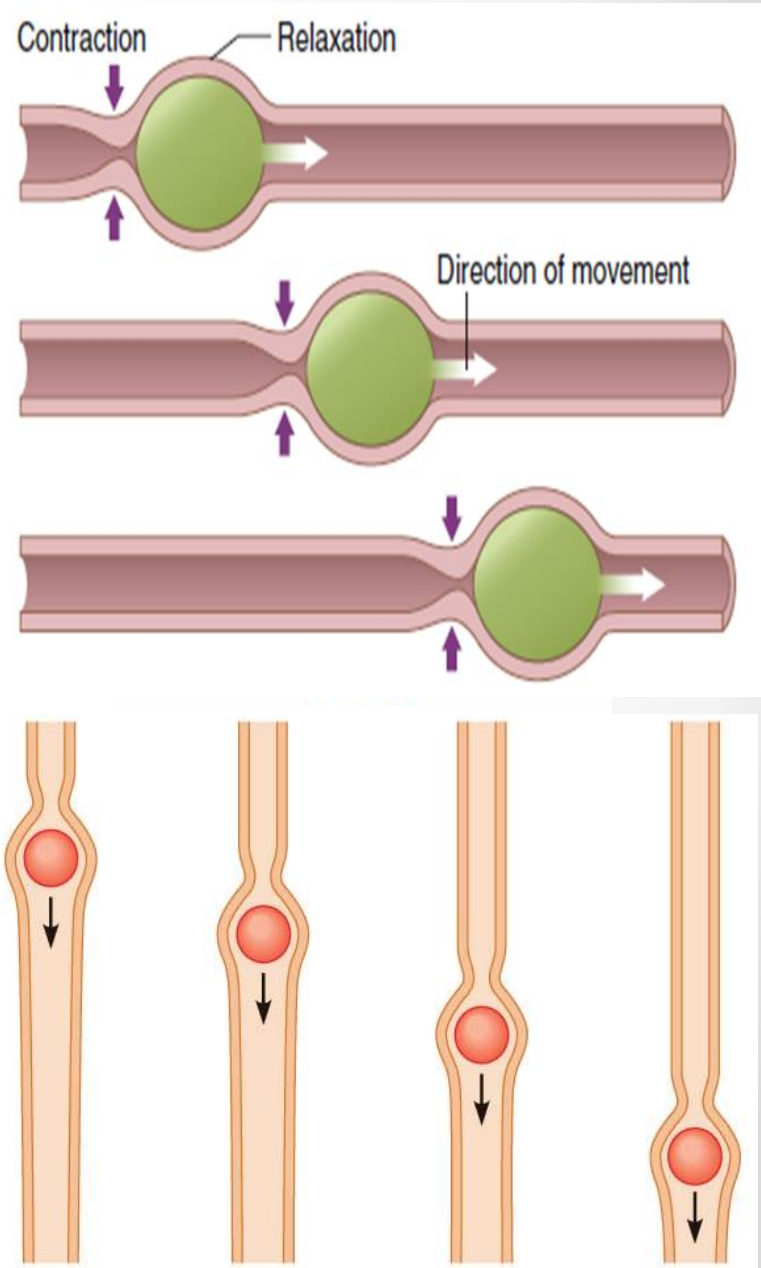
The movements of the small intestine can be divided into:

- *Propulsive contractions (Peristalsis)*
- *Segmenting (Mixing) contractions*
- *Migrating motor complex*
- *Antiperistalsis*
- *Peristaltic rush*



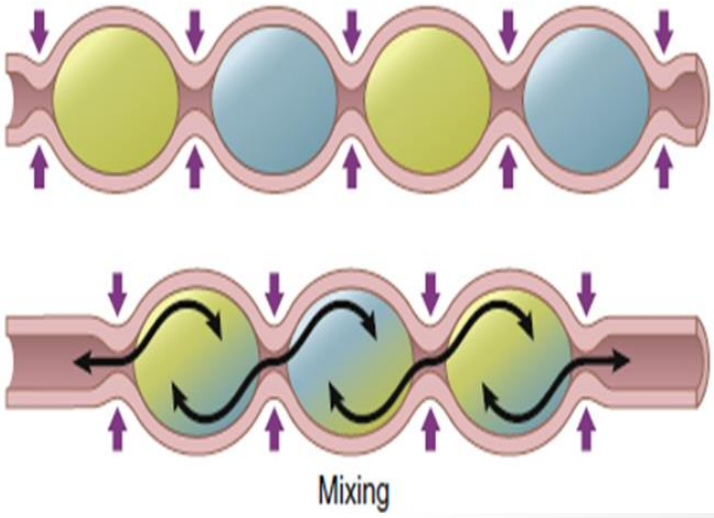
1. Propulsive Movement (Peristalsis)

- A contraction ring appears around gut, then moves forward.
- Usual stimulus is distention.
- It organizes propulsion of material over variable distances.
- It is faster in the proximal intestine and slower in the terminal intestine (velocity 0.5 to 2.0 cm/sec), (3 to 5 hours are required for passage of chyme from the pylorus to the ileocecal valve).
- Myenteric plexus is important.
- They can be blocked by atropine.



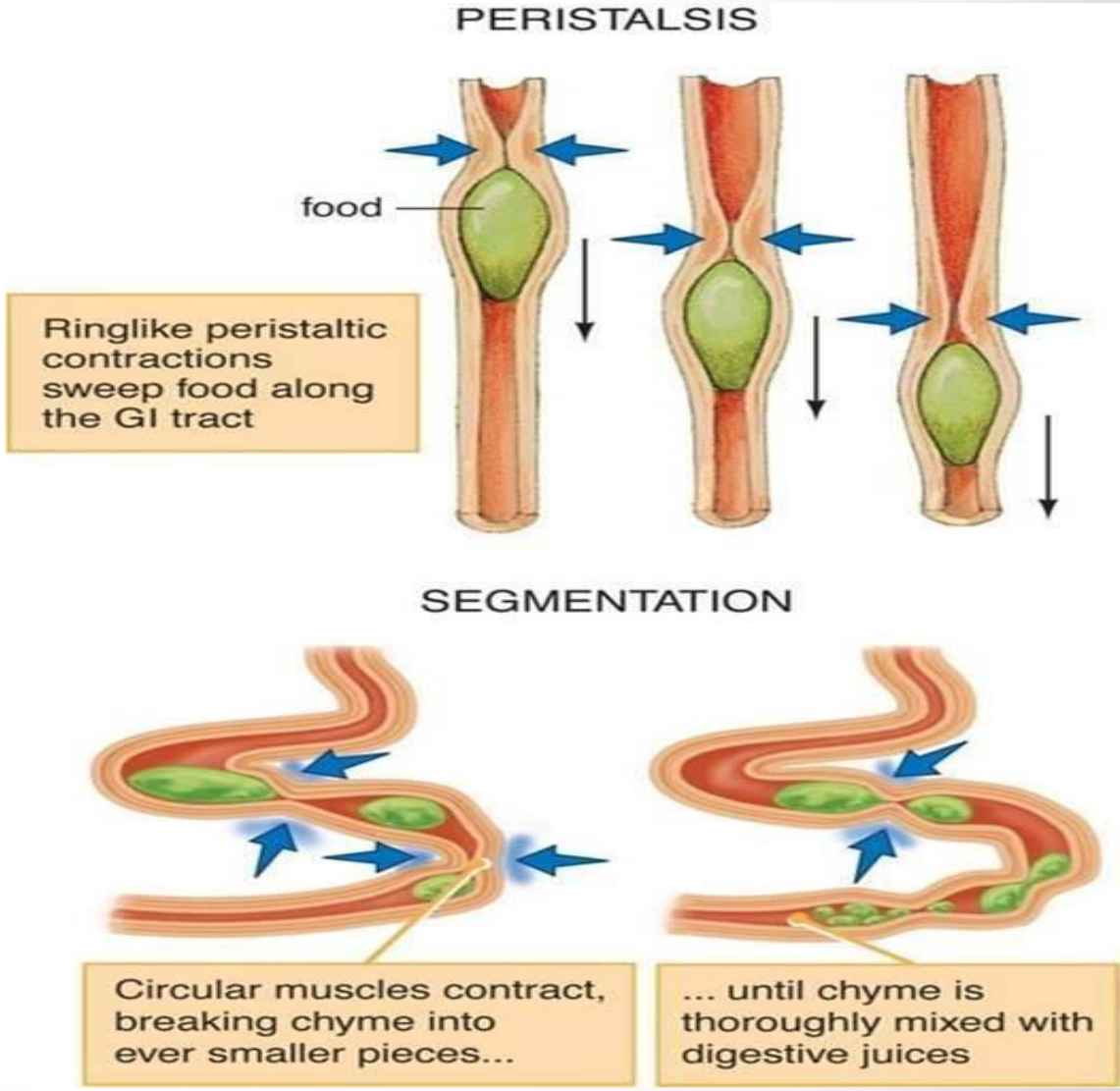
2. Mixing (Segmentation) Contractions

- A localized contraction of circular smooth muscles that constricts the intestine into spaced segments, last for fraction of min.
- As one set of segmentation contractions relaxes, a new set often begins at points between the previous ones.

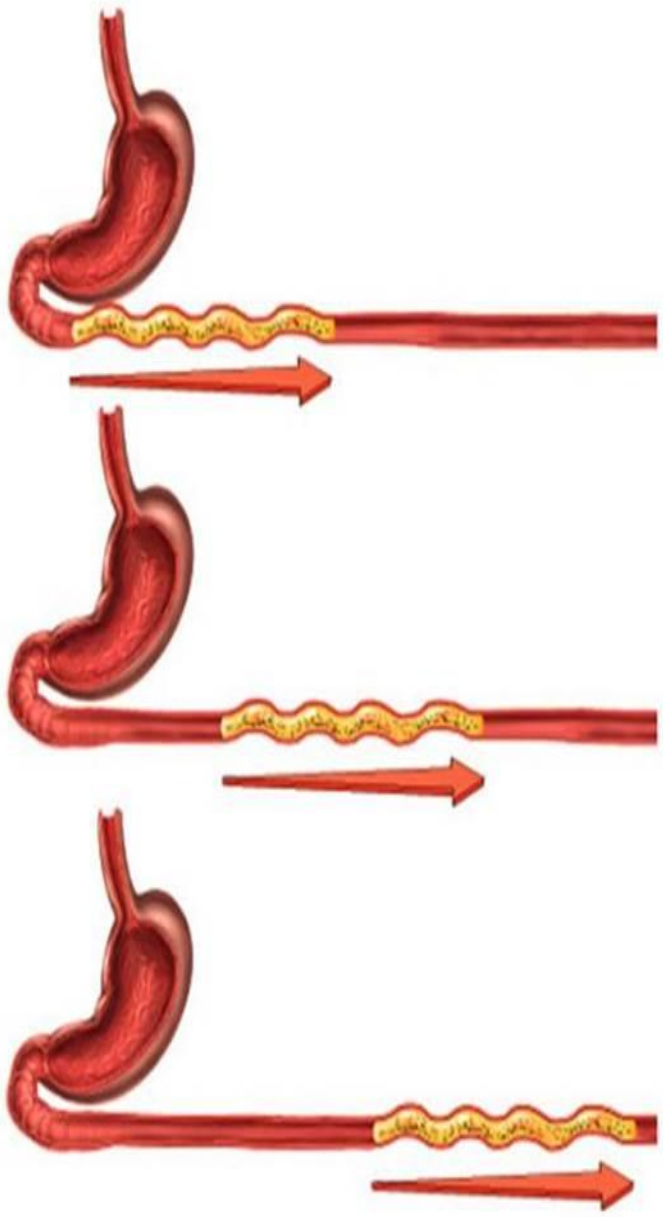


- Usual stimulus is distention.
- It is activated by enteric nervous system.
- They can be blocked by atropine.
- <u>The significance:</u>
  - Blend different juices with the chyme
  - Bring products of digestion in contact with absorptive surfaces

Peristalsis versus segmentation



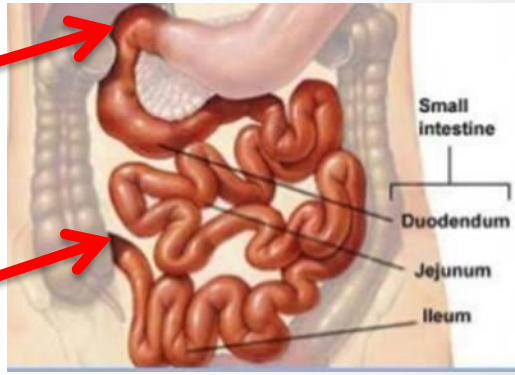
3- Migrating Motor Complex (MMC)



- Bursts of depolarization accompanied by peristaltic contraction that begins in empty stomach during interdigestive period (after absorption occurs)
- Travels a long whole length of small intestine to reach ileocaecal valve after 1.5-2 h. where it disappears. A new wave of MMC starts.
- Activity of MMC terminates as soon as food is ingested.
- Function of MMC is to sweep material (undigested food residues, dead mucosal cells and bacteria) into colon and keeping the small intestine clean.
- Regulated by autonomic nerves and by release of hormone motilin.

4- Antiperistalsis

- A wave of contraction in the alimentary canal that passes in an oral (i.e. upward, backwards) direction and force the contents in the opposite direction.
- Occurs between:-
  - Stomach and duodenum to allow more time for neutralization of chyme.
  - Ileum and caecum to allow time for absorption.

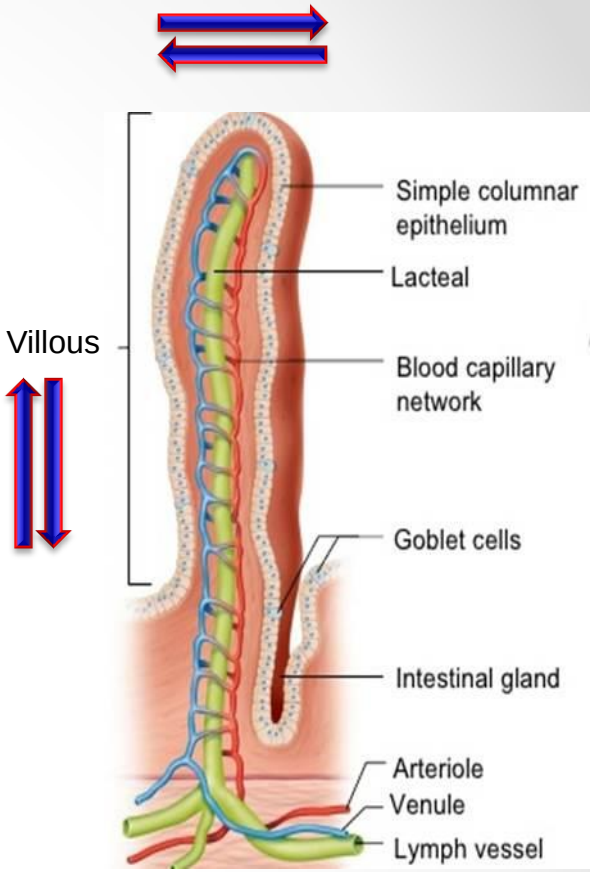


5- Peristaltic rush

- Powerful rapid peristalsis due to intense irritation of intestinal mucosa (as in infectious diarrhea).
- Initiated mainly by extrinsic nervous reflexes to brain stem and back to gut.
- Sweeps the contents of intestine into the colon without much absorption leading to diarrhea and thereby relieving the small intestine of irritative chyme or excessive distension.

Movement of the Villi

- Initiated by local nervous reflexes in response to chyme in small intestine.
- Consists of fast shortening and slow lengthening as well as side to side movements.
- Stimulated by villikinin hormone released by intestinal mucosa when it comes in contact with digestive products.
- Facilitate absorption and lymph flow from central lacteals into lymphatic system.



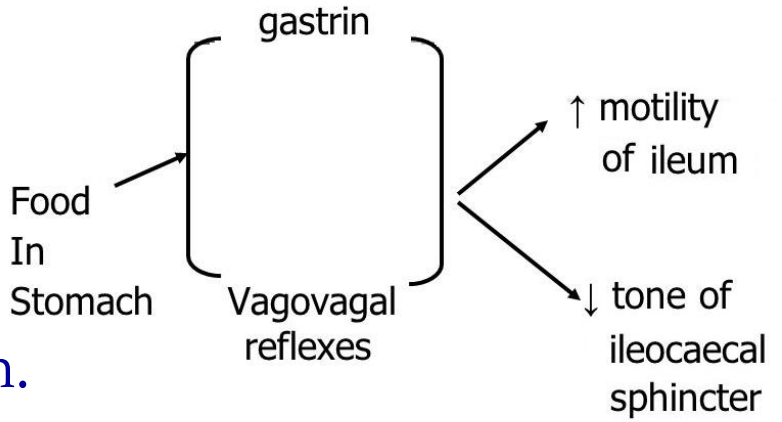
Control of Intestinal Motility

1- Neural factors

- Vagal excitation increases intestinal and villous movements.
- Sympathetic excitation decreases intestinal and villous movements.

Gastroileal reflex

- Initiated by gastric distension.
- Impulses are conducted through myenteric plexus to initiate a fast peristaltic wave passing to the ileum.
- The ileocaecal valve relaxes allowing chyme to pass into cecum.
- This reflex is mediated by vagus nerve.



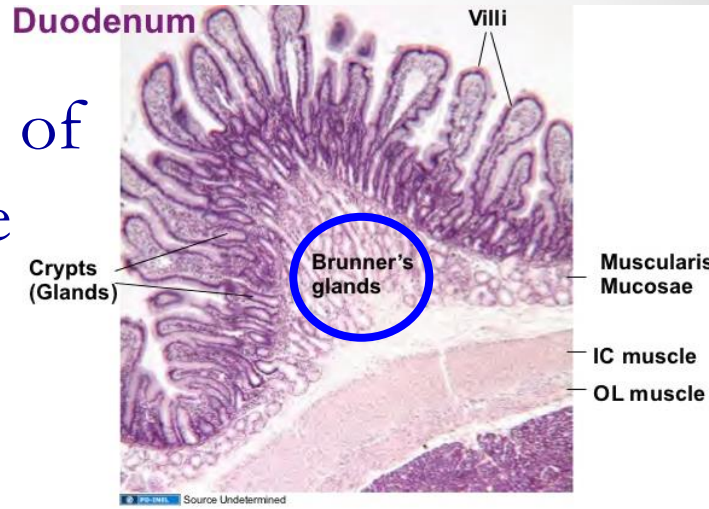
2- ***Hormonal factors***

- Gastrin, CCK, insulin and serotonin stimulate intestinal motility.
- Gastrin and CCK relax ileocecal sphincter.
- Motilin secreted from duodenum stimulates intestinal motility and regulate MMC.
- Villikinin stimulates movement of the villi.
- Secretin and glucagon inhibits intestinal motility and contract ileocecal sphincter.

Secretions of the Small Intestine

Secretion of Mucus by Brunner's Glands in the Duodenum

- *Brunner's glands* secrete large amounts of alkaline mucus, which contains a large amount of bicarbonate ions.
- Mucus protects the mucosa
- Brunner's glands are stimulated by (1) irritating stimuli on the duodenal mucosa; (2) vagal stimulation, (3) secretin.
- Brunner's glands are inhibited by sympathetic stimulation



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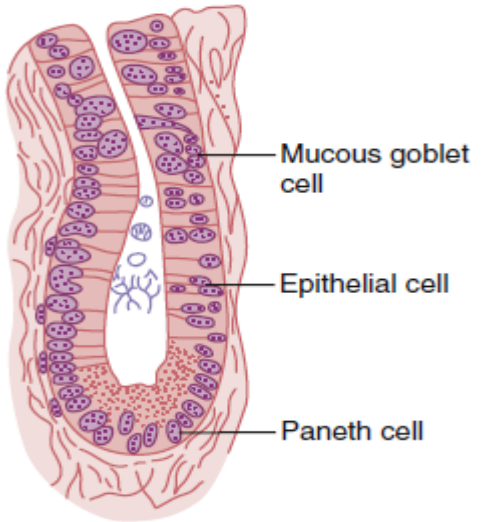
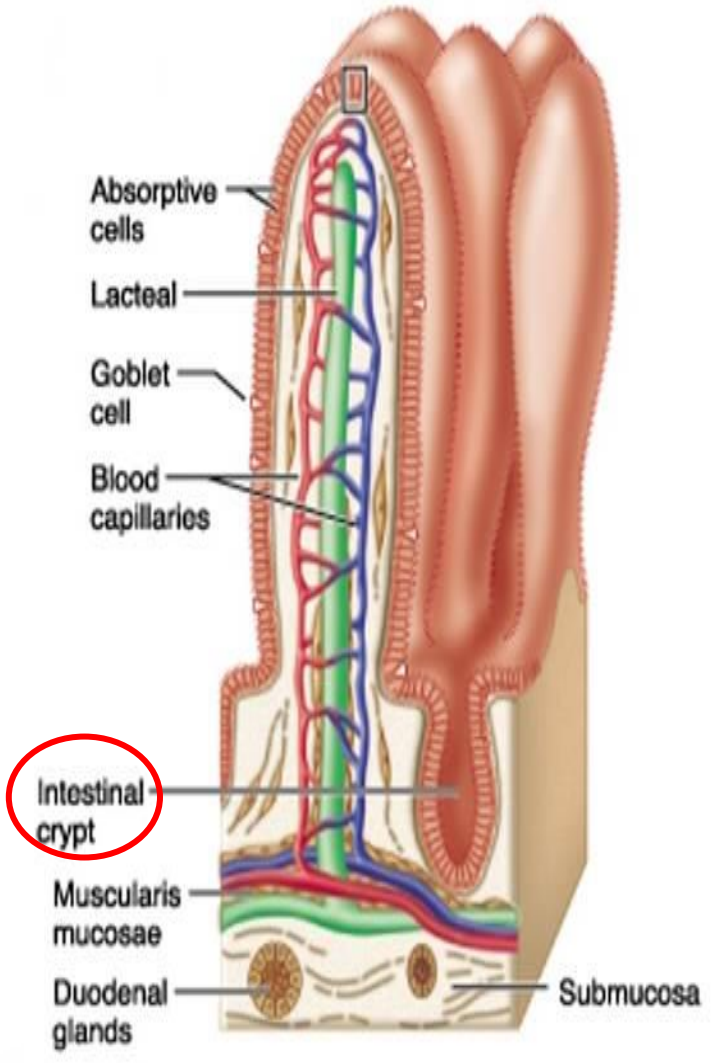


Intestinal Juice (Succus Entericus)

- It is secreted from intestinal crypts (small pits which lie between intestinal villi).
- Volume: 1800 ml/day.
- pH: 7.5-8. It participates in the neutralization of acid chyme delivered from stomach.
- Composition: 0.6 % organic, 1 % inorganic substance.
- Most of the enzymes are found either in the brush border or in the cytoplasm of the enterocytes.
- The enzymes that are actually secreted into the lumen are enteropeptidase and amylase



Control of Intestinal Secretion

Intestinal juice secretion is stimulated by:

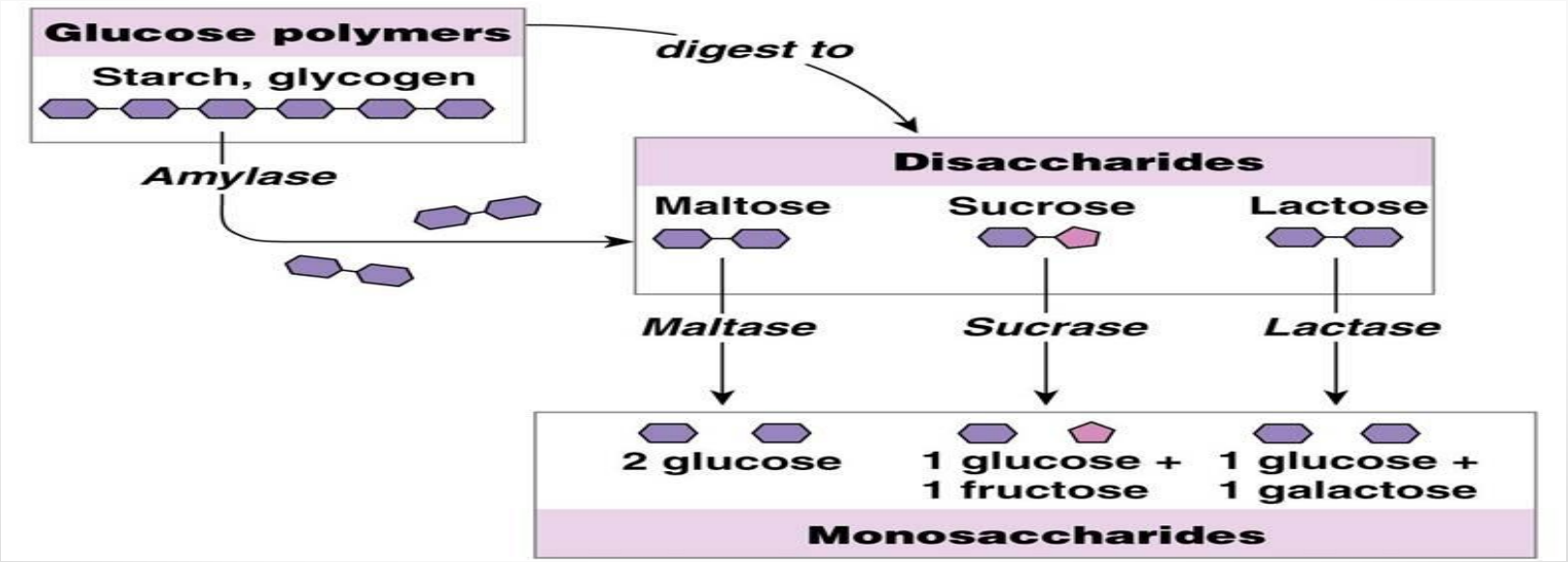
a. Distension, tactile and vagal stimulation.

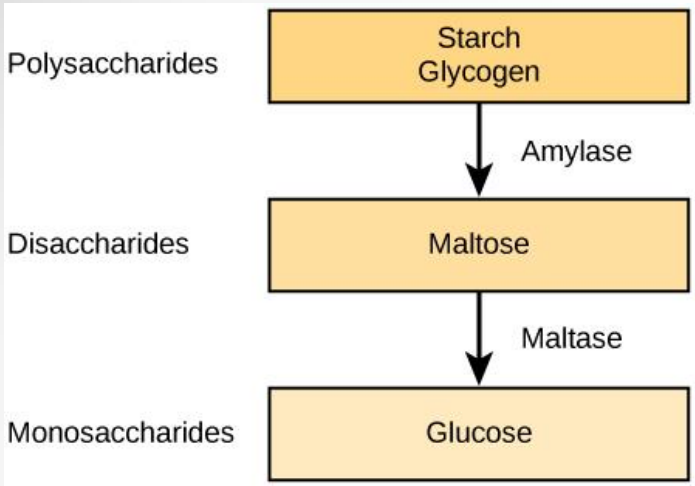
b. Hormones as gastrin, secretin, CCK, glucagons, enterocrinin.

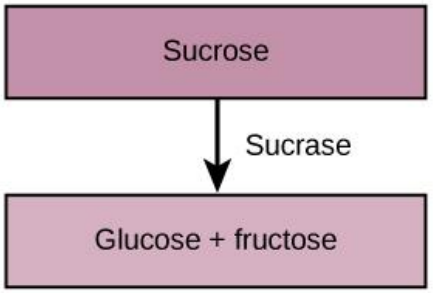
In contrast, sympathetic stimulation exerts an inhibitory effect.

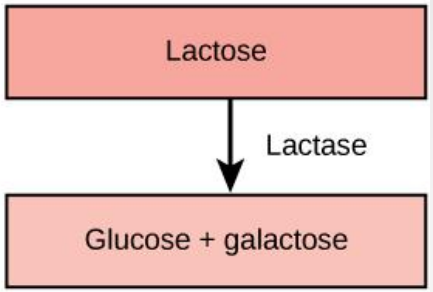
Digestion of Carbohydrates

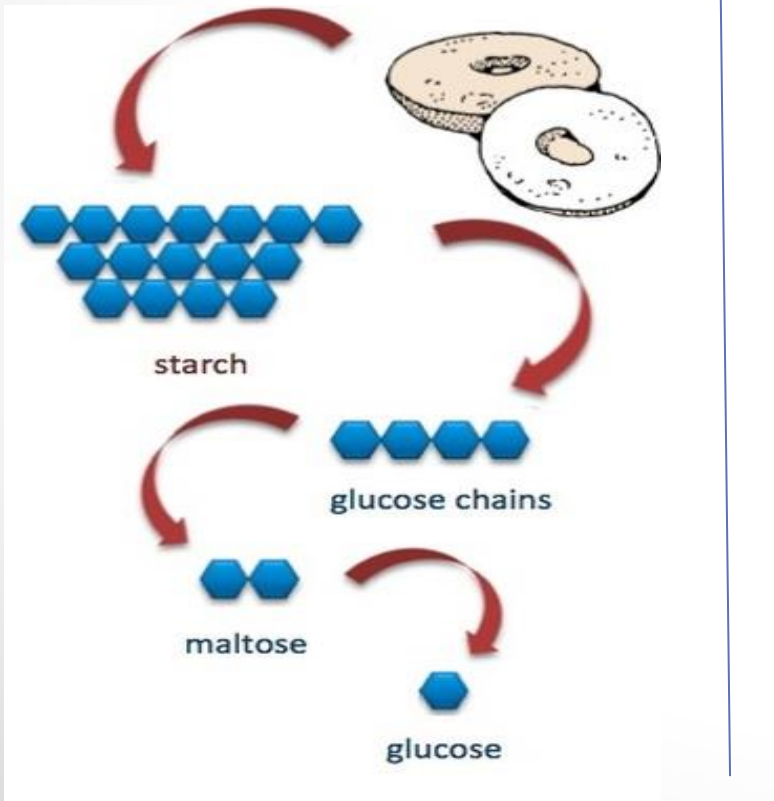
- The enterocytes contain four enzymes (lactase, sucrase, maltase, and a-dextrinase), which are capable of splitting the disaccharides lactose, sucrose, and maltose, plus other small glucose polymers, into their constituent monosaccharides.
- These enzymes are located in the enterocytes covering the intestinal microvilli brush border, so that the disaccharides are digested as they come in contact with these enterocytes.

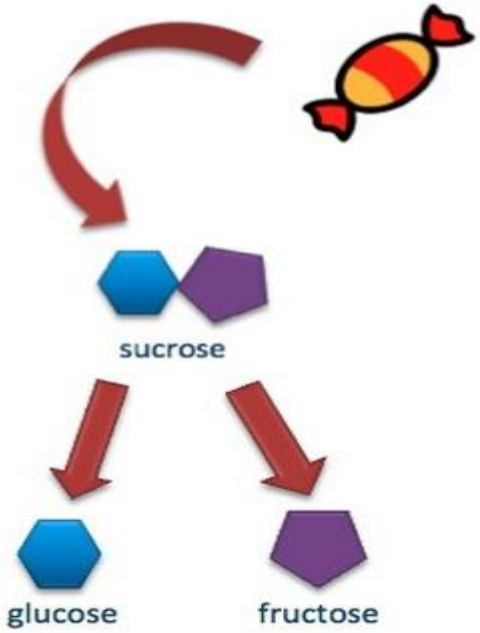


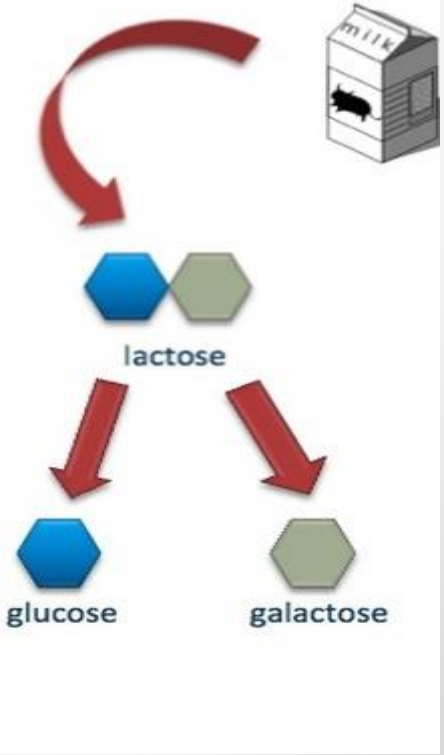

Polysaccharides
Starch
Glycogen
Amylase
Disaccharides
Maltose
Maltase
Monosaccharides
Glucose


Sucrose
Sucrase
Glucose + fructose

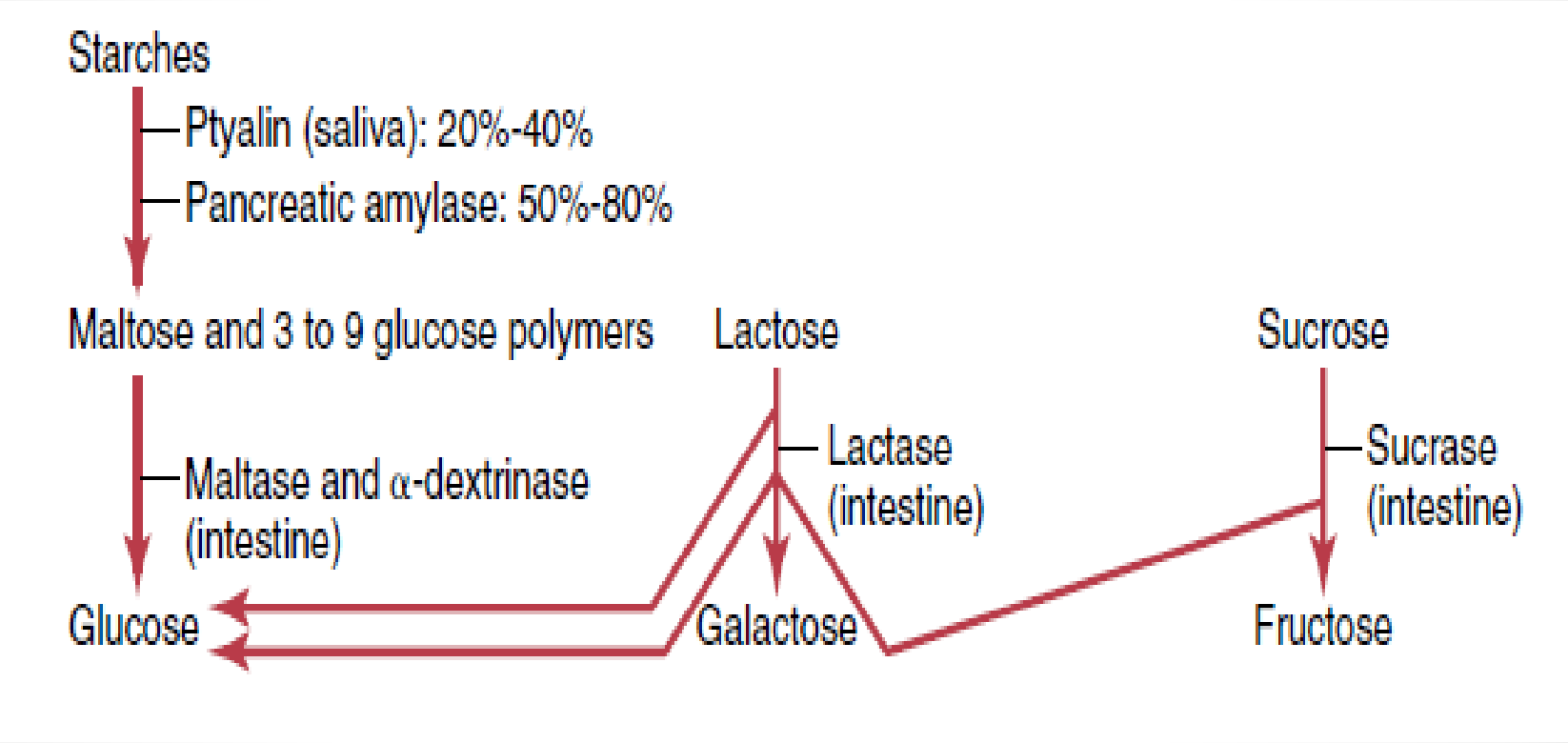

Lactose
Lactase
Glucose + galactose


starch
glucose chains
maltose
glucose


sucrose
glucose
fructose

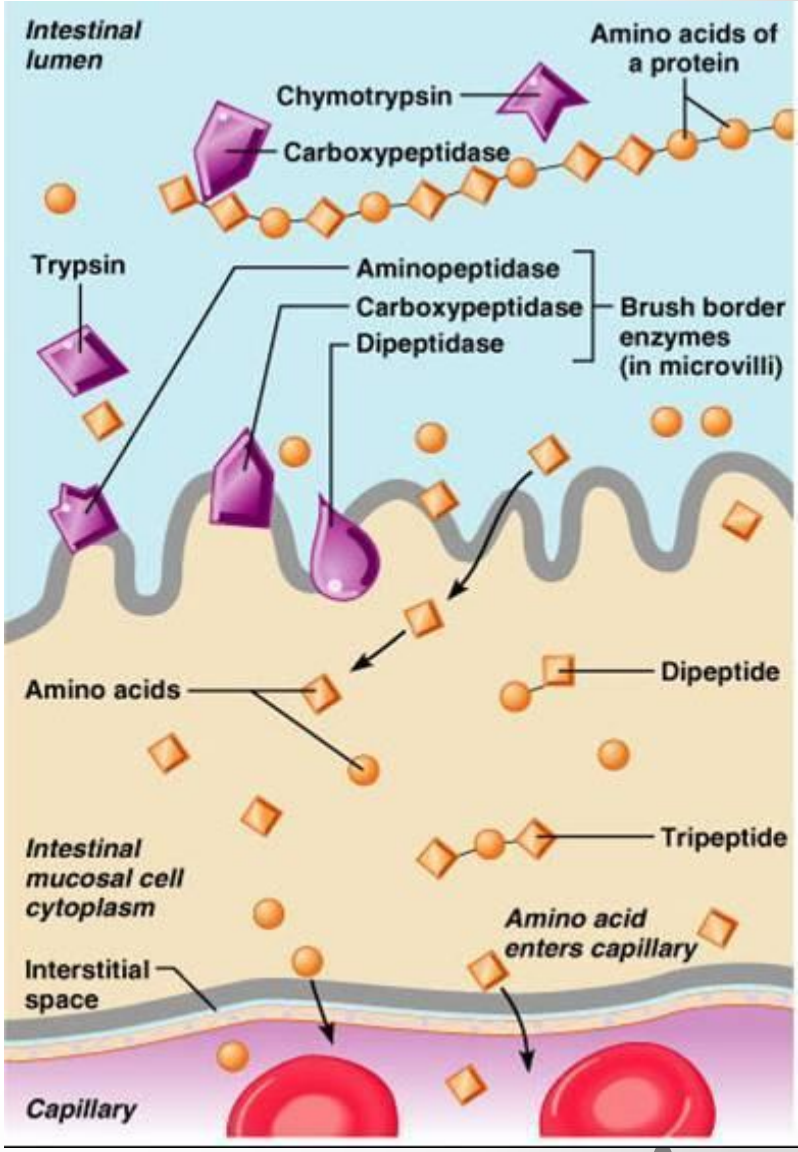

lactose
glucose
galactose

Digestion of Carbohydrates

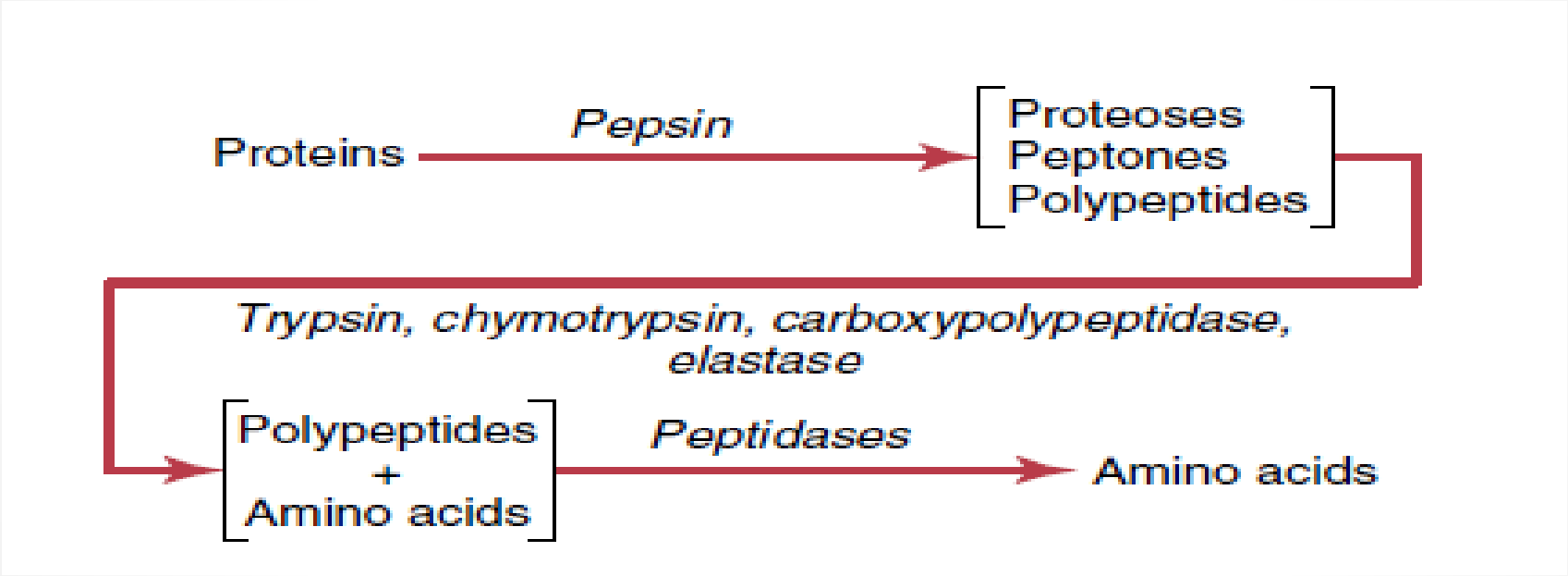


Digestion of Proteins

- A small percentage of proteins are digested to AA by the pancreatic juices.
- Most proteins remain as dipeptides and tripeptides
- Most protein digestion occurs in the duodenum and jejunum by aminopeptidases, oligopeptidases, intracellular di and tripeptidases.

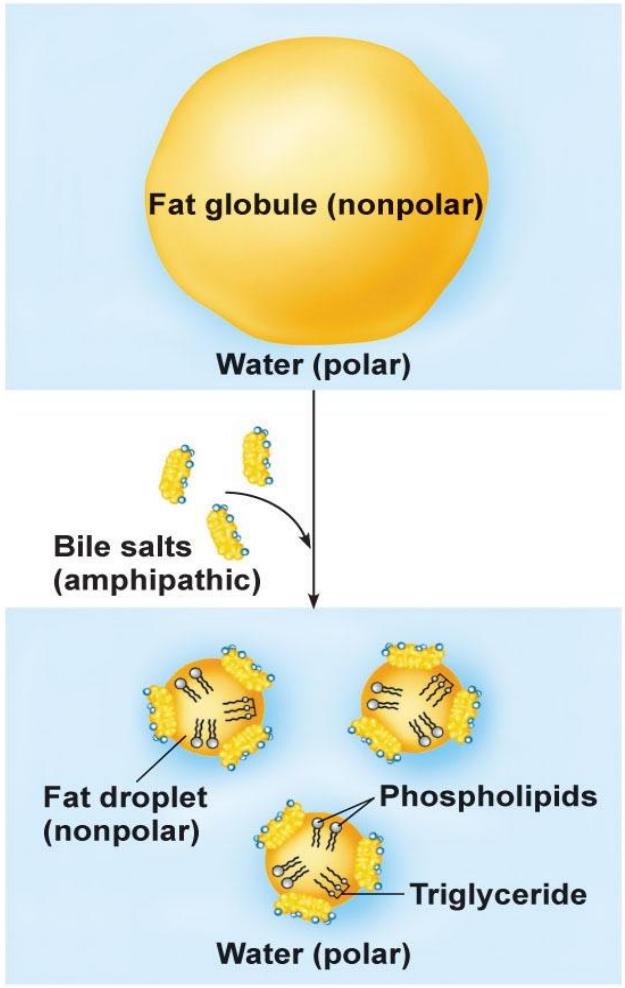


Digestion of Proteins



Digestion of Fats

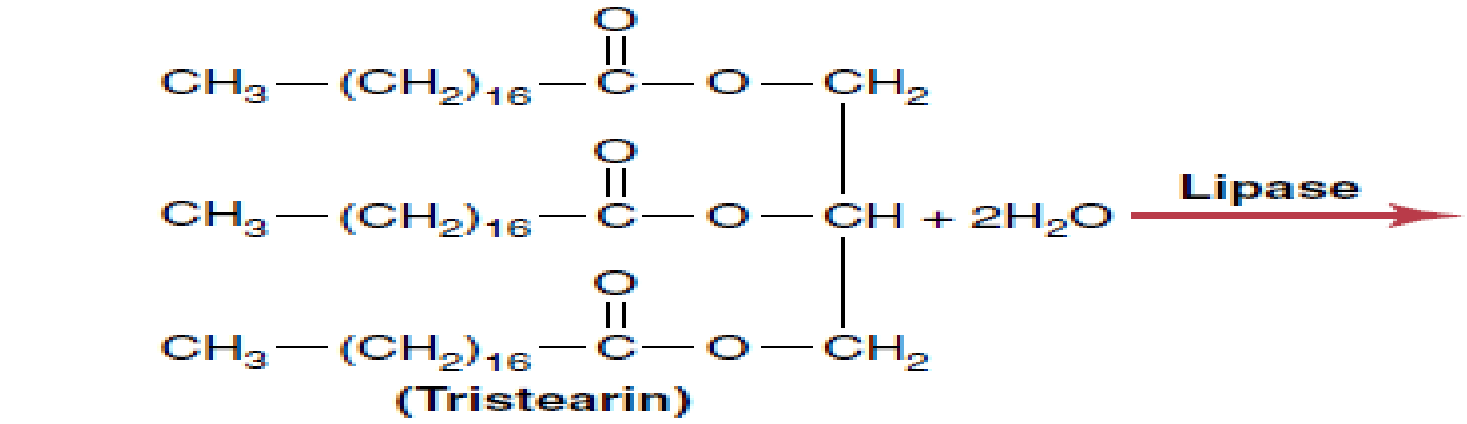
- Bile salts and lecithin in the bile help fat digestion by make the fat globules readily fragmentable with the water in the small intestine (emulsification of fat).
- Bile salts break the fat globules into very small sizes, so that the water-soluble digestive enzymes can act on the globule surfaces.



Digestion of Fats

Fat —(*Bile + agitation*)→ Emulsified fat

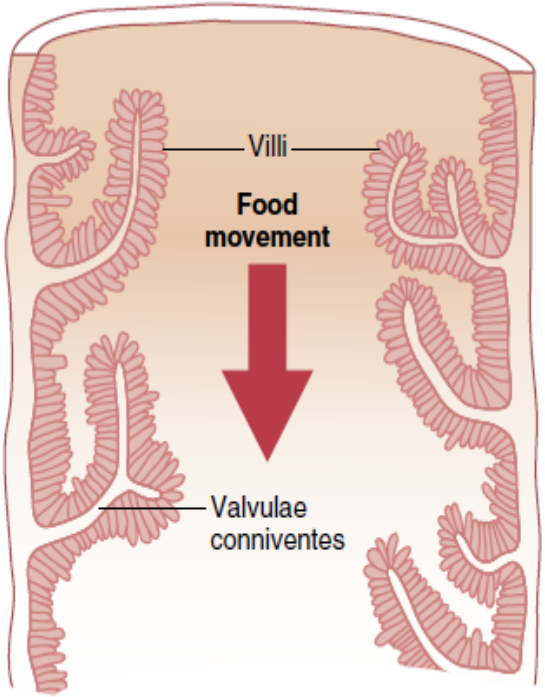
Emulsified fat —*Pancreatic lipase*→ Fatty acids and 2-monoglycerides

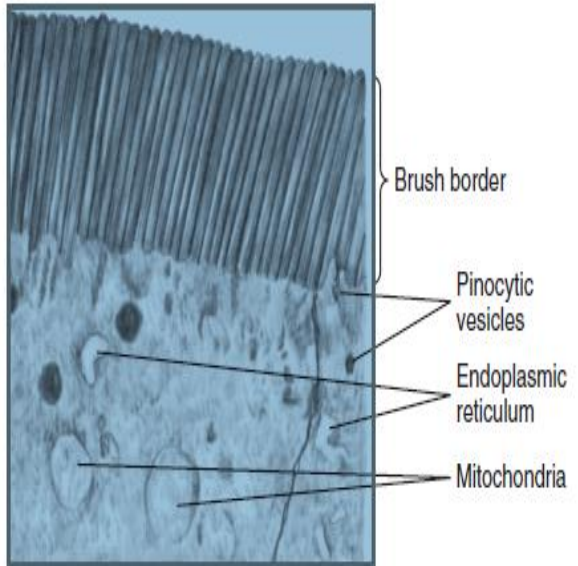


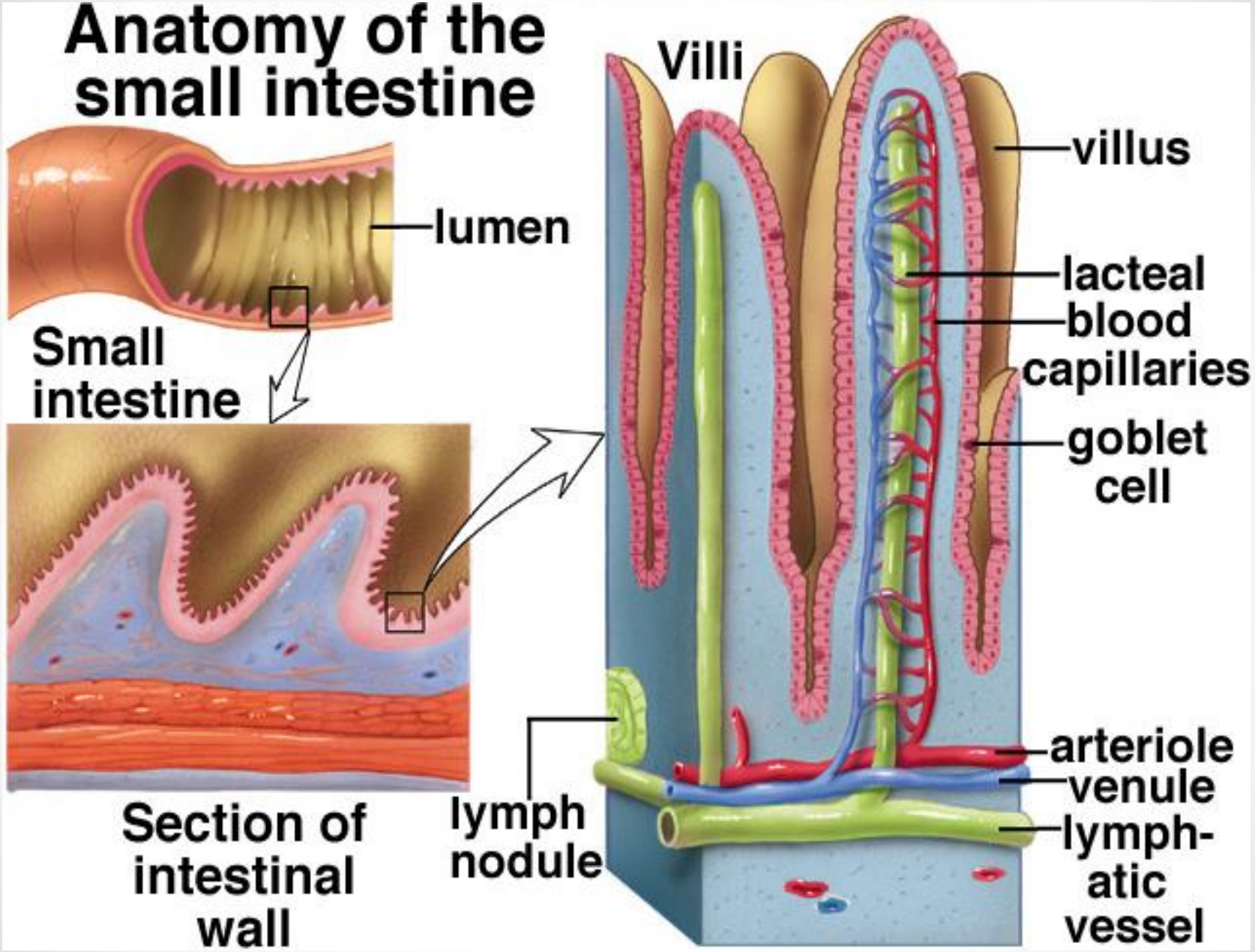
Basic Principles of Gastrointestinal Absorption

Absorptive Surface of the Small Intestinal

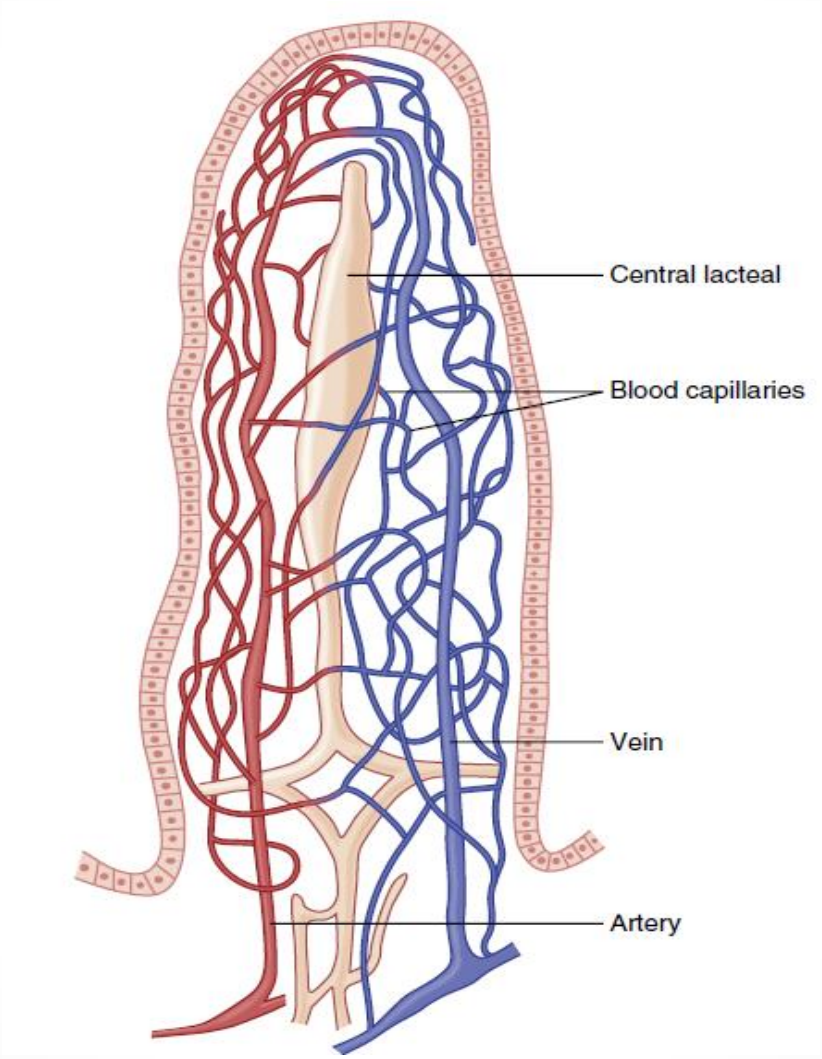
- The absorptive surface of the small intestinal mucosa, showing many folds called *valvulae conniventes*, well developed in the duodenum and jejunum. They increase the surface area of the absorptive mucosa about ***3-fold***.
- The presence of villi on the mucosal surface enhances the total absorptive area another ***10-fold***.
- The epithelial cell on each villus is characterized by a brush border, consisting of as many as 1000 microvilli (increases the surface area another ***20-fold***).
- All these increase the intestinal surface **600x** (Provides the surface area equivalent to a tennis court)





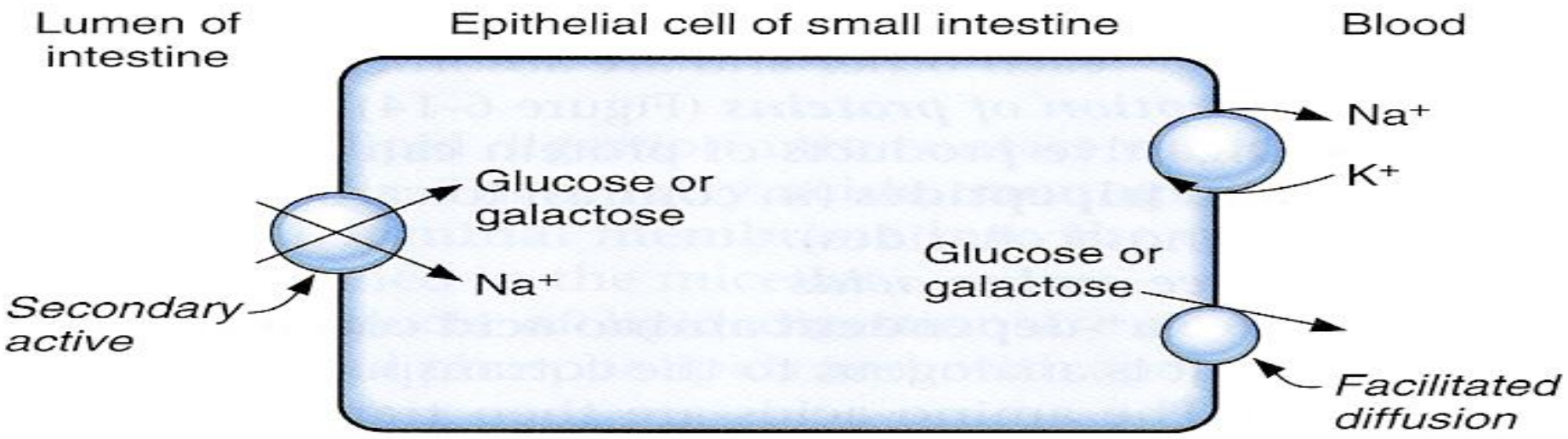

Anatomy of the small intestine
lumen
Small intestine
Section of intestinal wall
Villi
villus
lacteal
blood capillaries
goblet cell
lymph nodule
arteriole
venule
lymph-atic vessel

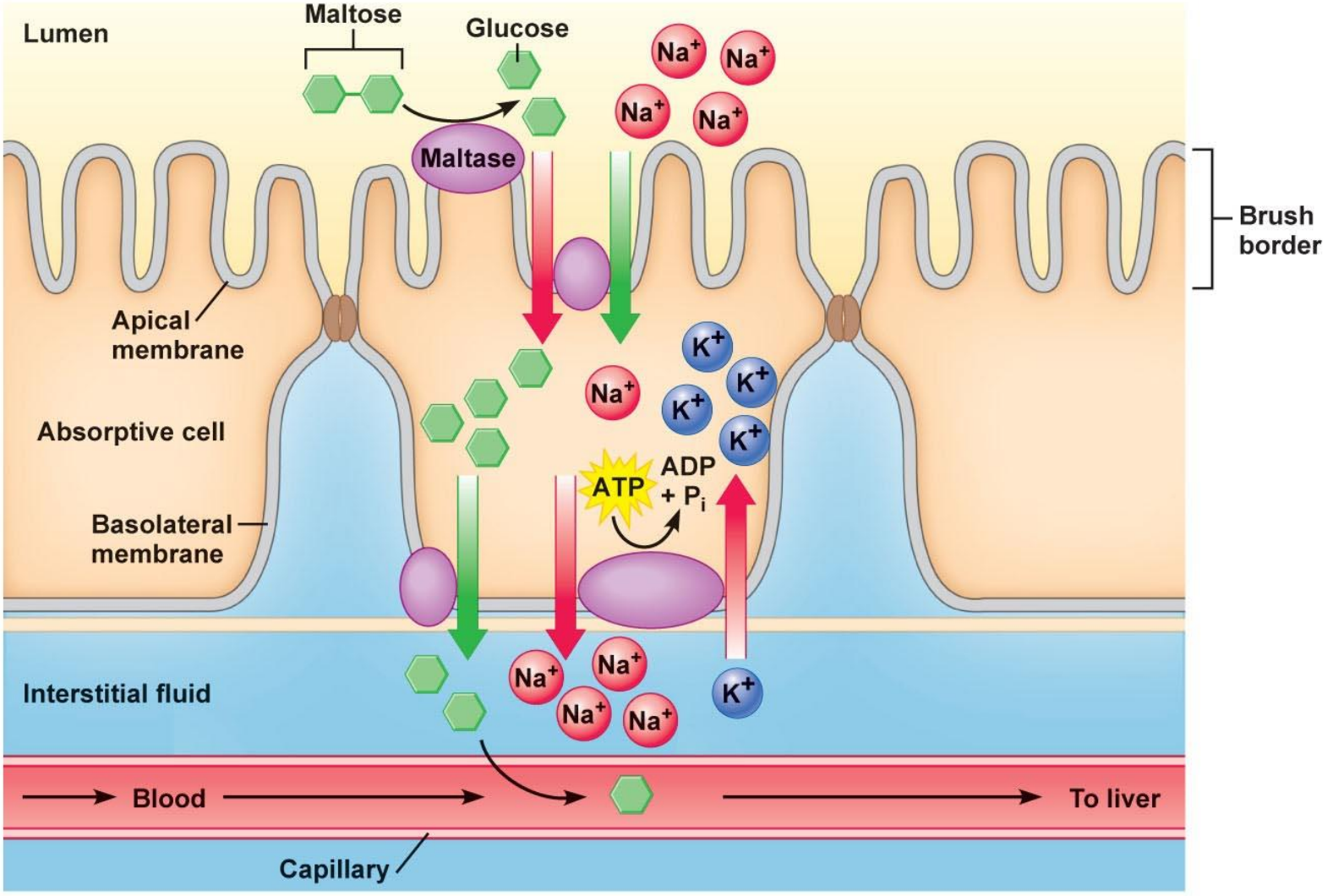
Microvasculature of the villus



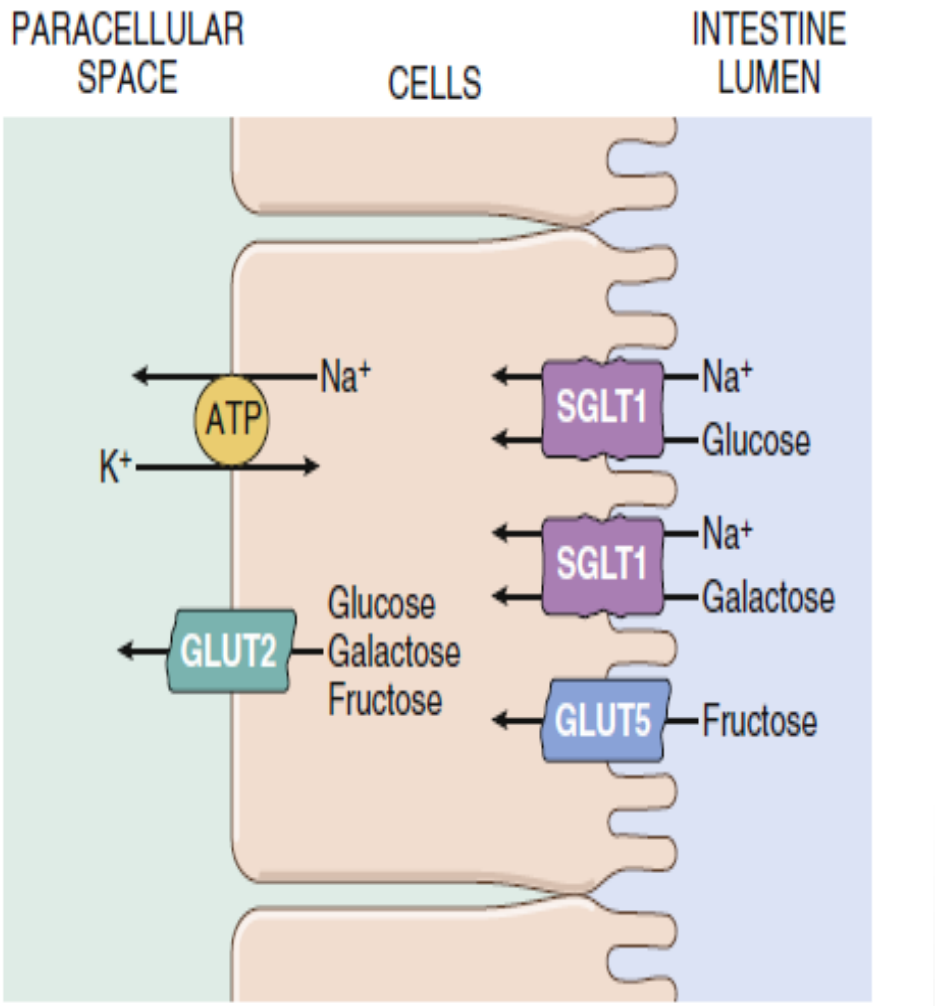
Absorption of Carbohydrates

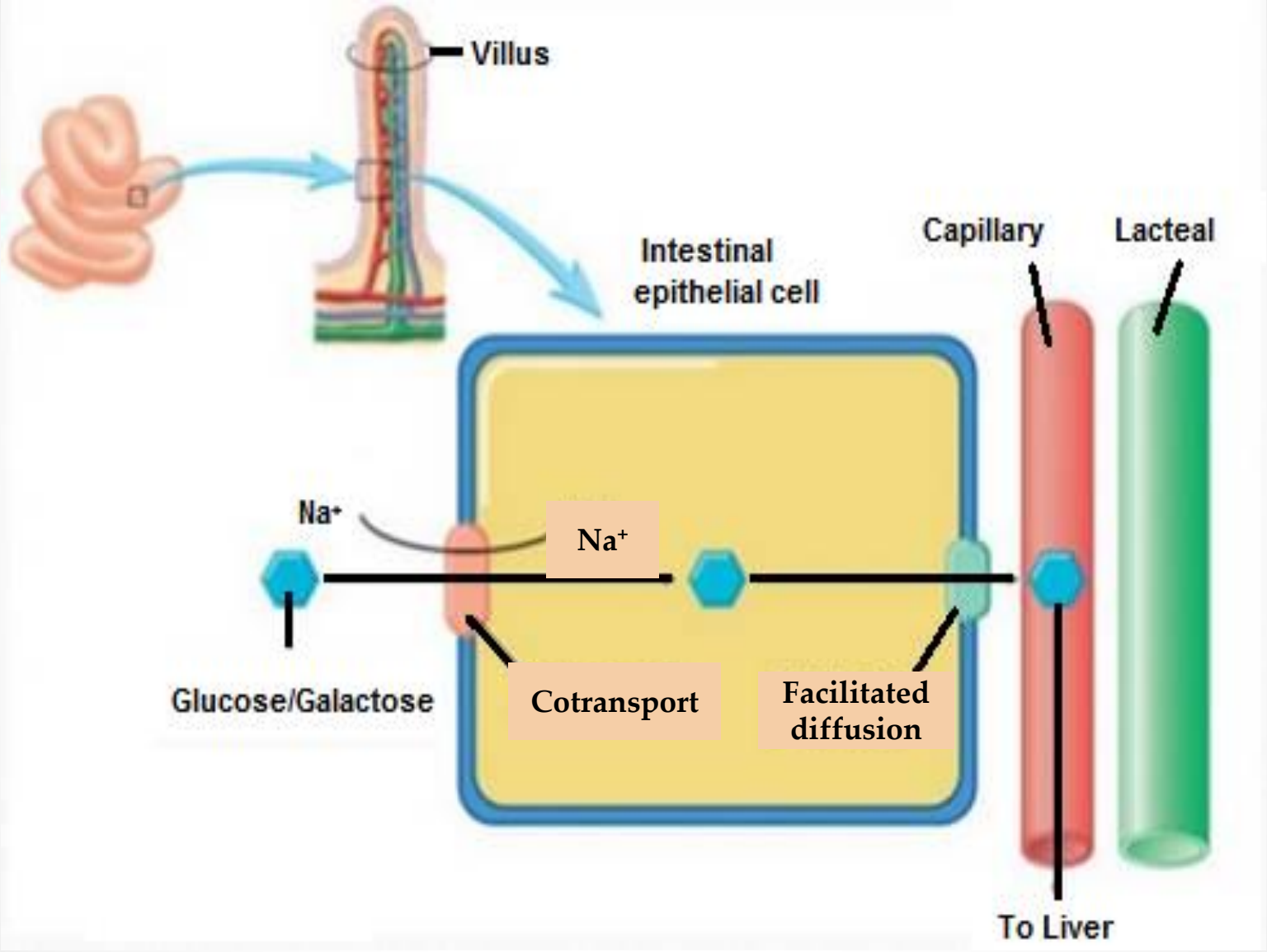
- All the carbohydrates in the food are absorbed in the form of monosaccharides; only a small fraction are absorbed as disaccharides.
- Glucose and galactose absorption occurs in a cotransport mode with active transport of Na^+ (2ry active transport) .
- Fructose is independent on Na^+ but it transports in lumenal membrane via facilitated diffusion.
- Pentose is transported by passive diffusion





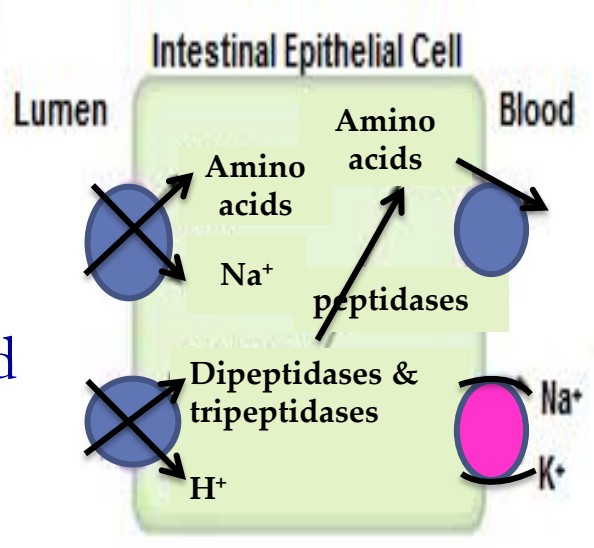
Absorption of Glucose, Galactose and Fructose

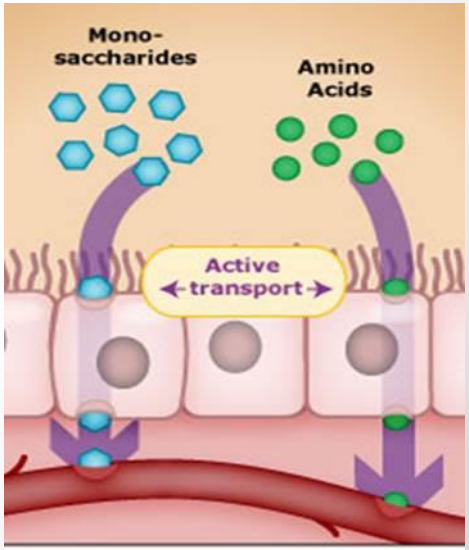



Villus
Intestinal epithelial cell
Capillary
Lacteal
Na+
Na+
Glucose/Galactose
Cotransport
Facilitated diffusion
To Liver

Absorption of Proteins

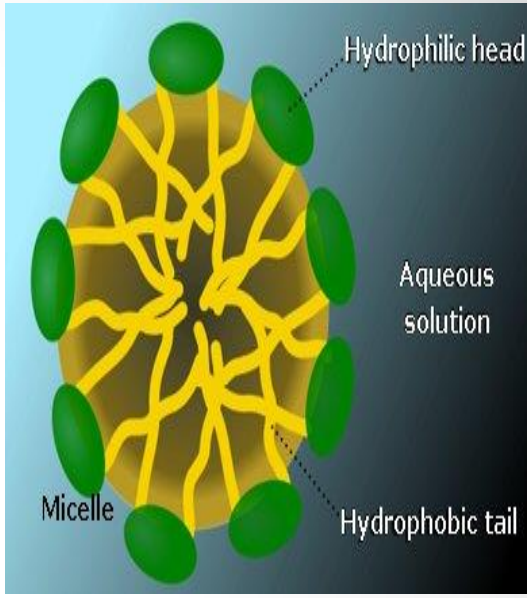
- Proteins are absorbed in the form of dipeptides, tripeptides, and a few free amino acids.
- The energy for most of this transport is supplied by Na^+ co-transport mechanism (secondary active transport) .
- That is, most peptide or amino acid molecules bind in the cell's microvillus membrane with a specific transport protein that requires Na^+ binding before transport can occur.
- After binding, Na^+ then moves down its electrochemical gradient to the interior of the cell and pulls the amino acid or peptide along with it.
- Di and tripeptides are hydrolyzed by brush border and cytoplasmic oligopeptidases.
- AA leaves the cell at the basolateral membrane by facilitated transport.





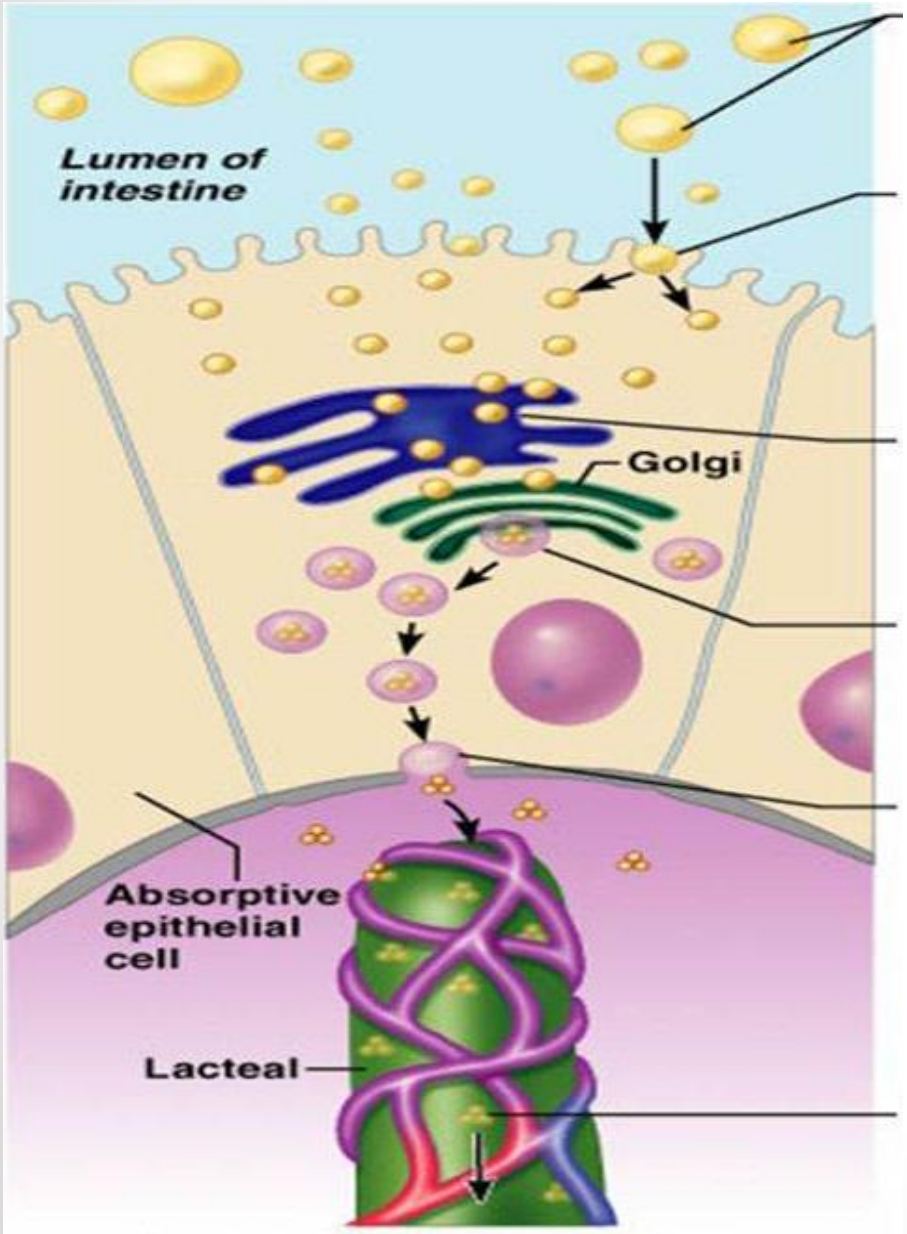
Role of Micelles in Fats Absorption

- *B*ile salt are amphipathic molecules, each composed of a sterol nucleus (fat-soluble) and a polar group (water-soluble).
- The polar parts are (-) charged, they allow the entire micelle globule to dissolve in the water of the digestive fluids.
- *Micelles are* small spherical, cylindrical globules composed of 20 to 40 molecules of bile salts.



- Long chain FA, MG, cholesterol and fat soluble vitamins are incorporated into the interior of the micelle.
- Thus, the micelles perform a "ferrying" function that is highly important for fat absorption.
- In the presence of micelles, about 97 % of the fat is absorbed in the small intestine.
- The micelles carry FA & MG to the luminal borders of the intestinal epithelial cells.

Steps of Fat Absorption



Fatty acids (FA) & monoglycerides (MG) associated with the micelles in lumen of intestine.

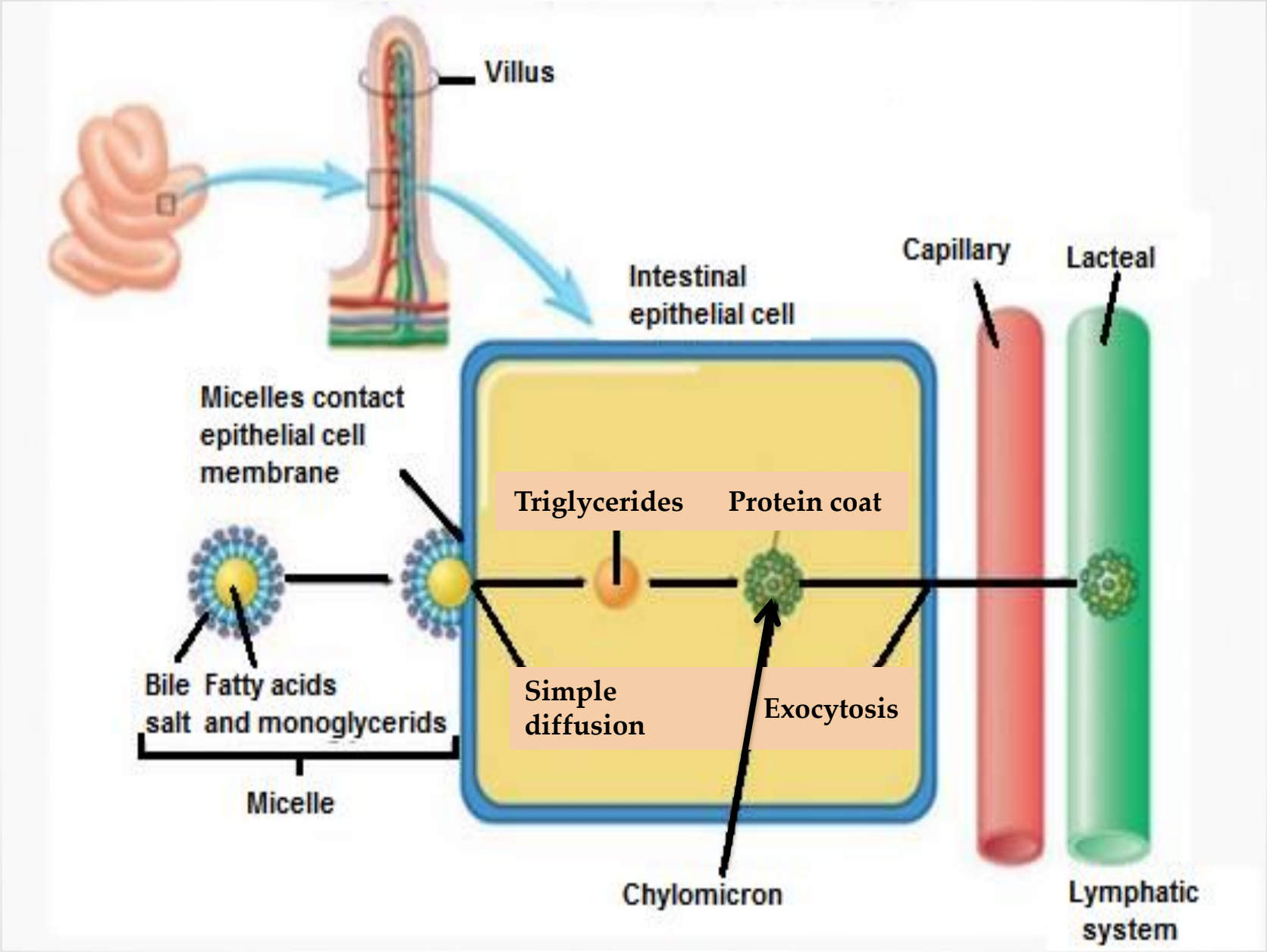
1) FA & MG leave micelles and enter epithelial cell by ***diffusion.***

2) FA are used to synthesis triglycerides in agranular endoplasmic reticulum.

3) Fatty globules are combined with proteins to form ***chylomicrons*** within Golgi apparatus.

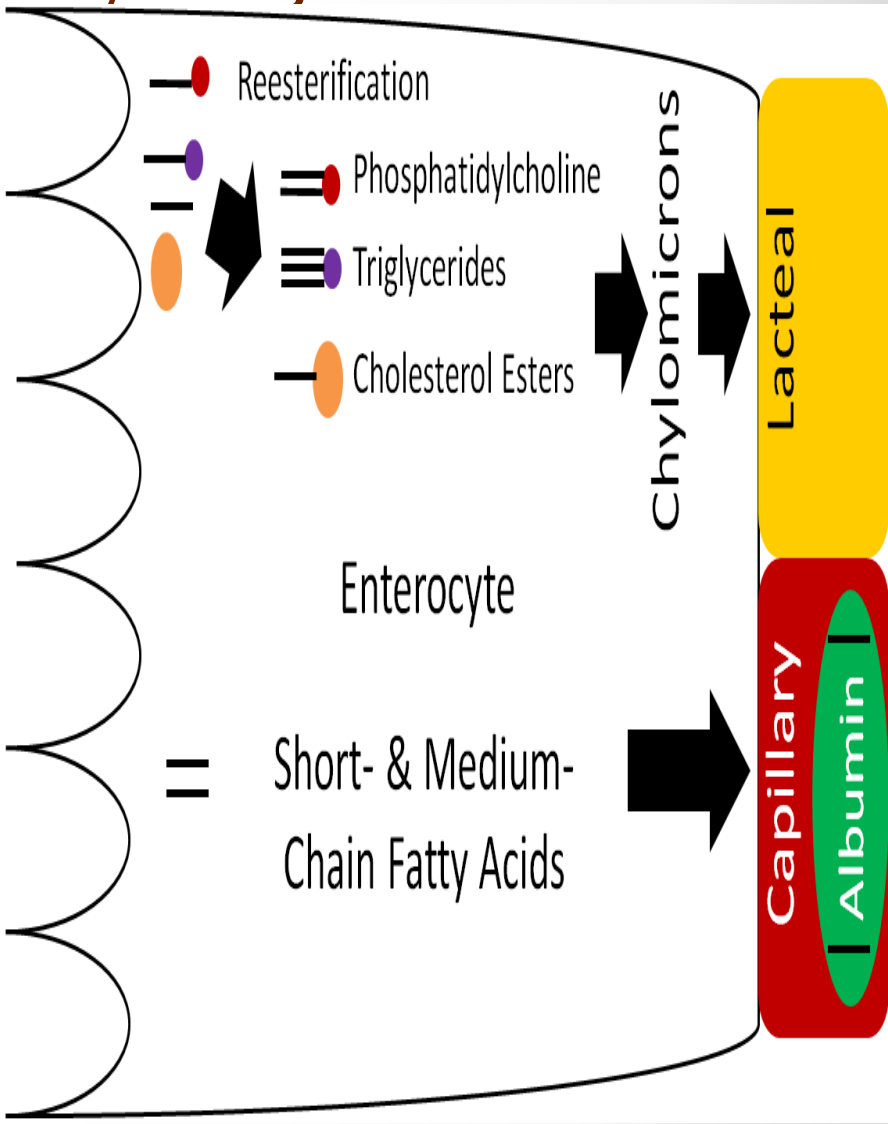
4) Vesicles containing chylomicrons leave epithelial cells by ***exocytosis*** and enter ***a lacteal*** (lymph capillary).

5) Lymph in the lacteal transport chylomicrons away from the intestine.

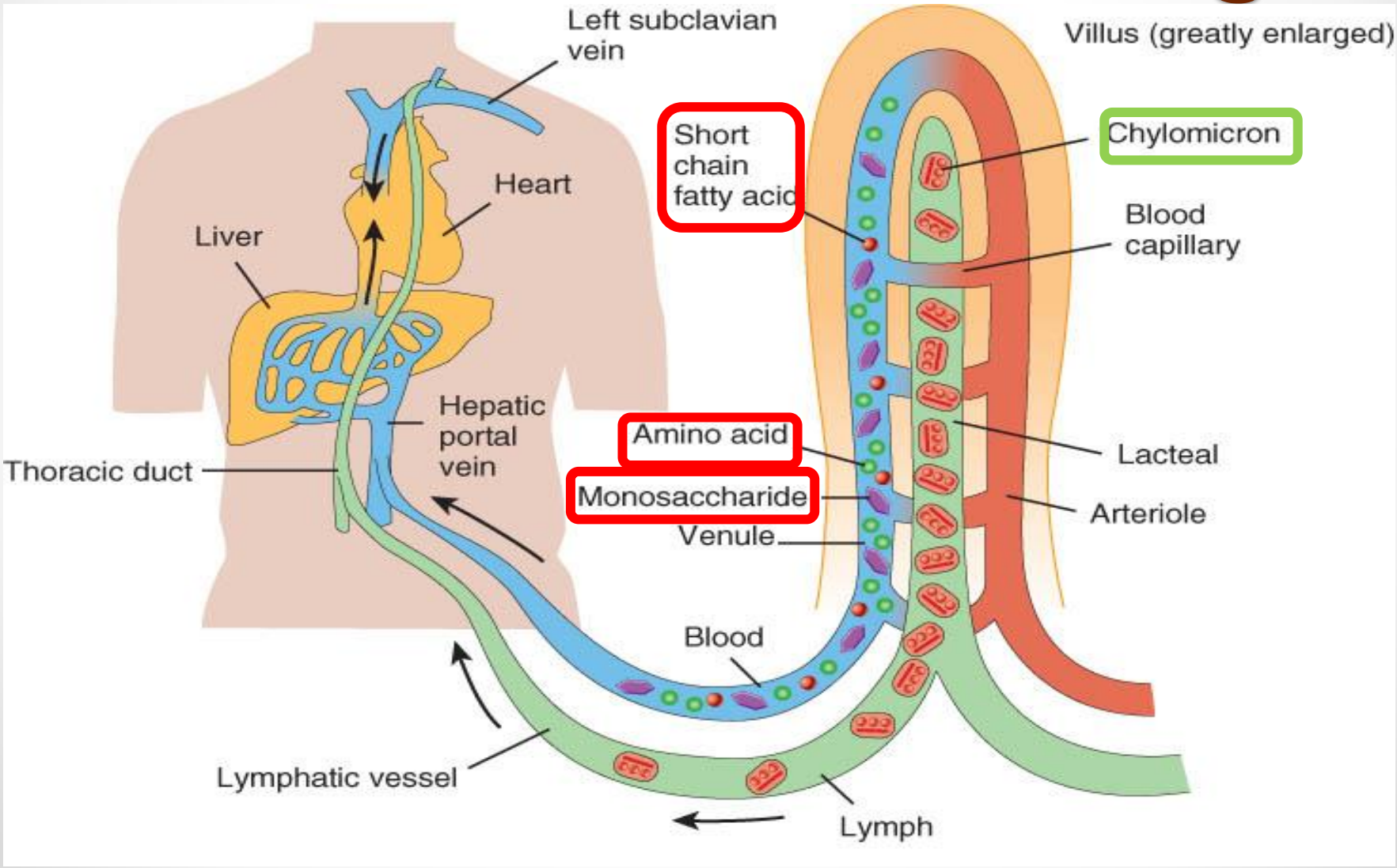

Villus
Intestinal epithelial cell
Capillary
Lacteal
Micelles contact epithelial cell membrane
Triglycerides
Protein coat
Bile salt
Fatty acids and monoglycerids
Micelle
Simple diffusion
Exocytosis
Chylomicron
Lymphatic system

Absorption of small quantities of short-and medium-chain fatty acids,

- Small quantities of short-and medium-chain fatty acids, such as those from butterfat, are absorbed directly into the capillary blood of the intestinal villi (portal blood), bound to albumin.
- The cause of this difference between short-and long-chain fatty acid absorption is that the short-chain fatty acids are more water soluble and mostly are not reconverted into triglycerides by the endoplasmic reticulum.



Where will the absorbed nutrients go?

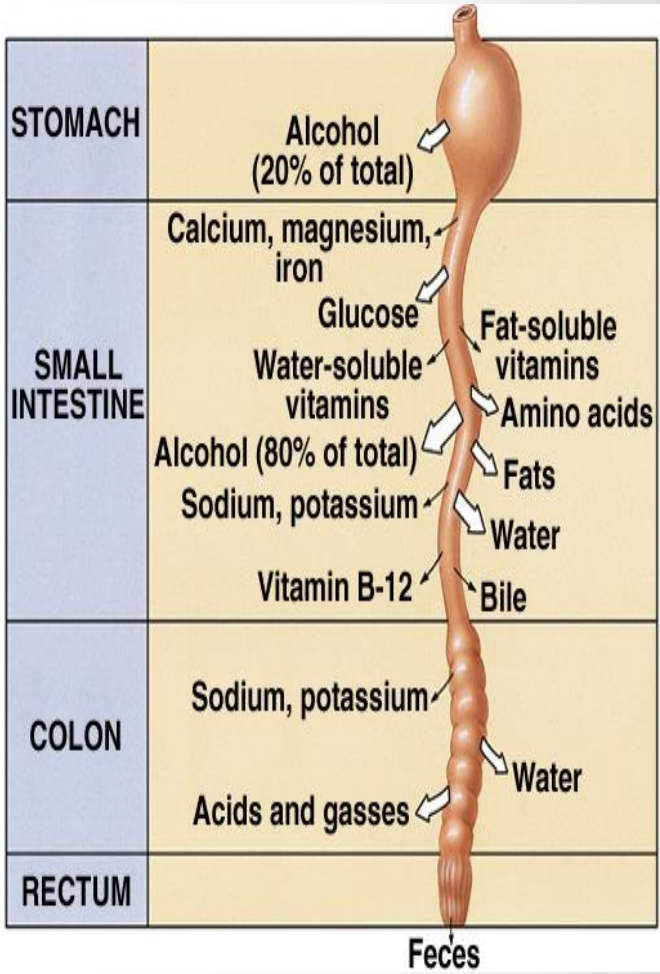


Absorption of Vitamins

a. Fat-soluble vitamins (A, D, E, & K) are incorporated into micelles and absorbed along with other lipids

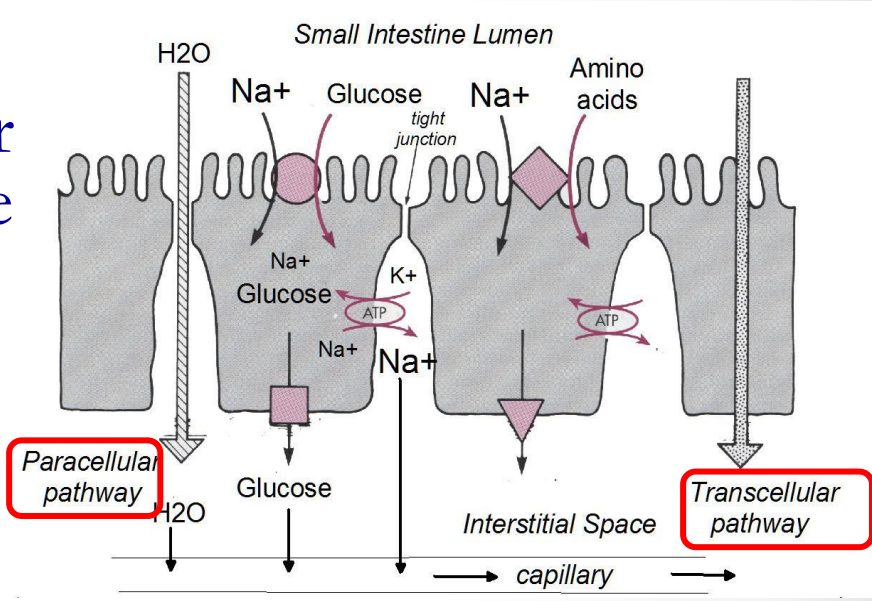
b. Most water-soluble vitamins (C, B_1, B_2, B_6, and folic acid) are absorbed by Na^+-dependent cotransport mechanisms

c. Vitamin B_{12} is absorbed in the terminal part of ileum and requires intrinsic factor
   - Ileal resection can cause vitamin B_{12} deficiency.
   - Gastrectomy results in the loss of parietal cells and loss of intrinsic factor
     ⟹ pernicious anemia

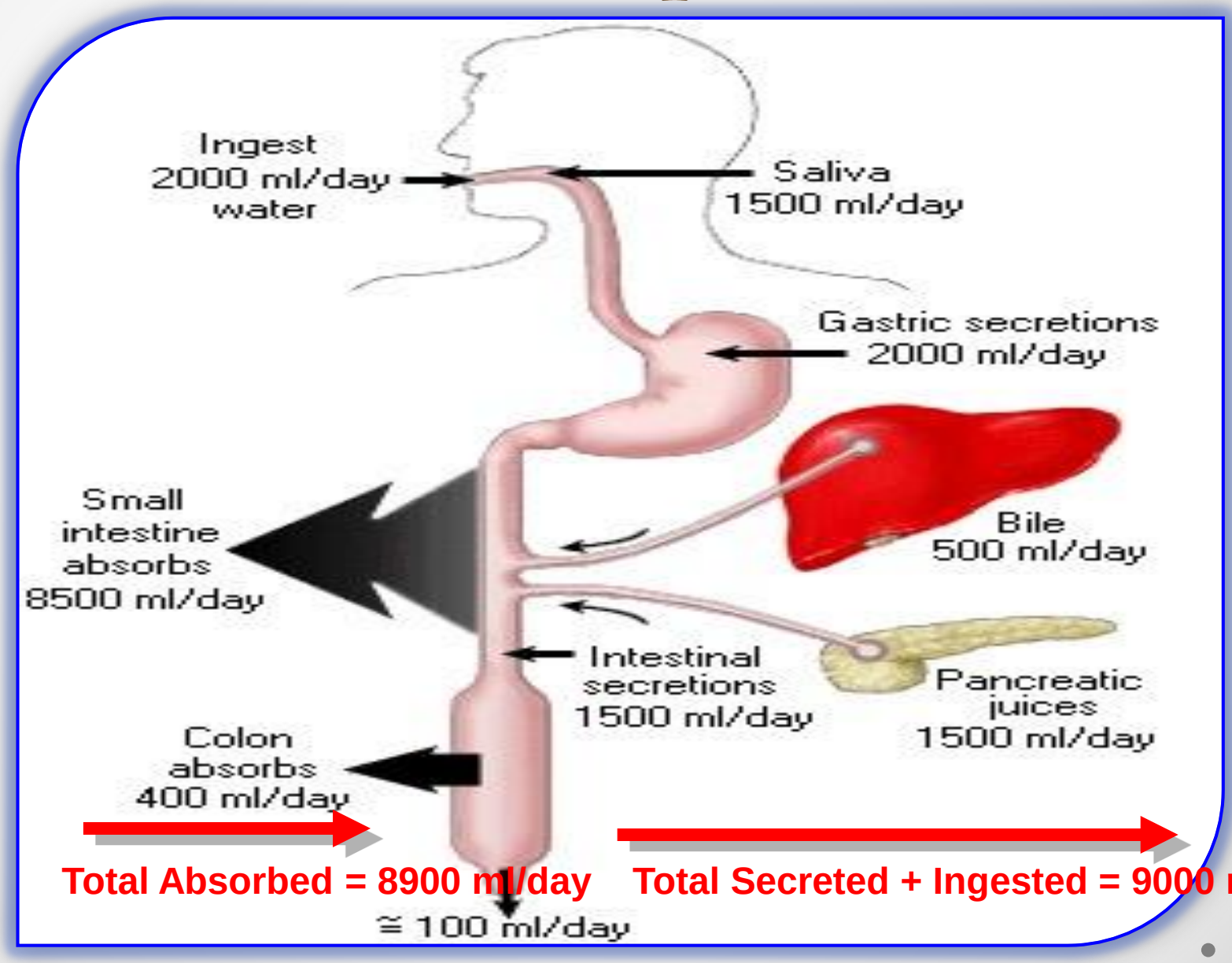


Absorption and secretion of electrolytes and water

- Electrolytes and H_2O cross intestinal epithelial cells by either transcellular or paracellular route
- The permeability of the tight junctions varies with the type of epithelium
  - Leaky epithelia are in the small intestine and gallbladder
  - A tight epithelium is in the colon



Water Absorption

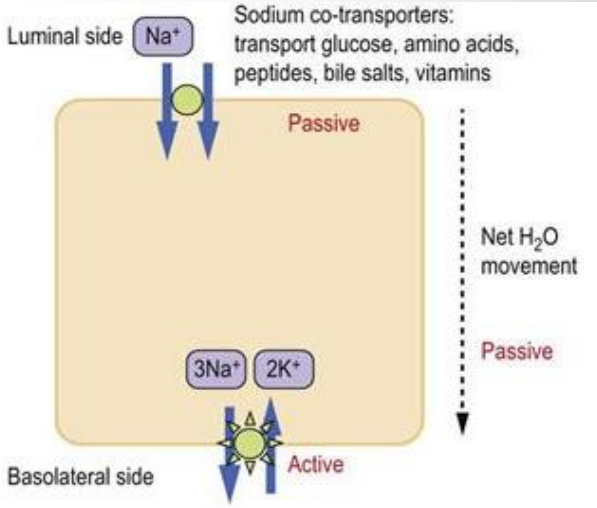


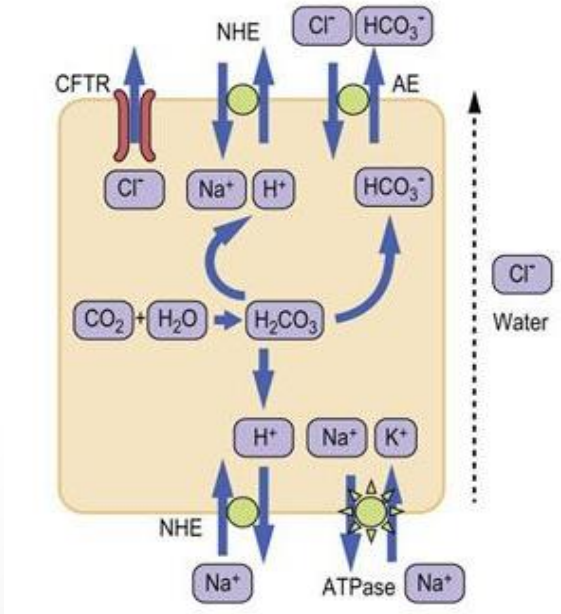
Absorption of Na^+

Na^+ moves into the intestinal cells by the following mechanisms:

1) Passive diffusion.
2) Na^+-glucose or Na^+-amino acid co-transport.
3) Na^+-Cl^- cotransport
4) Na^+-H^+ exchange.

- The next step is osmosis of water into the paracellular spaces.
- **Aldosterone Greatly Enhances Na^+ Absorption.** This effect is especially important in the colon because it allows virtually no loss of NaCl and water.





Absorption of Cl^-

Cl^- absorption accompanies Na^+ absorption by the following mechanisms:

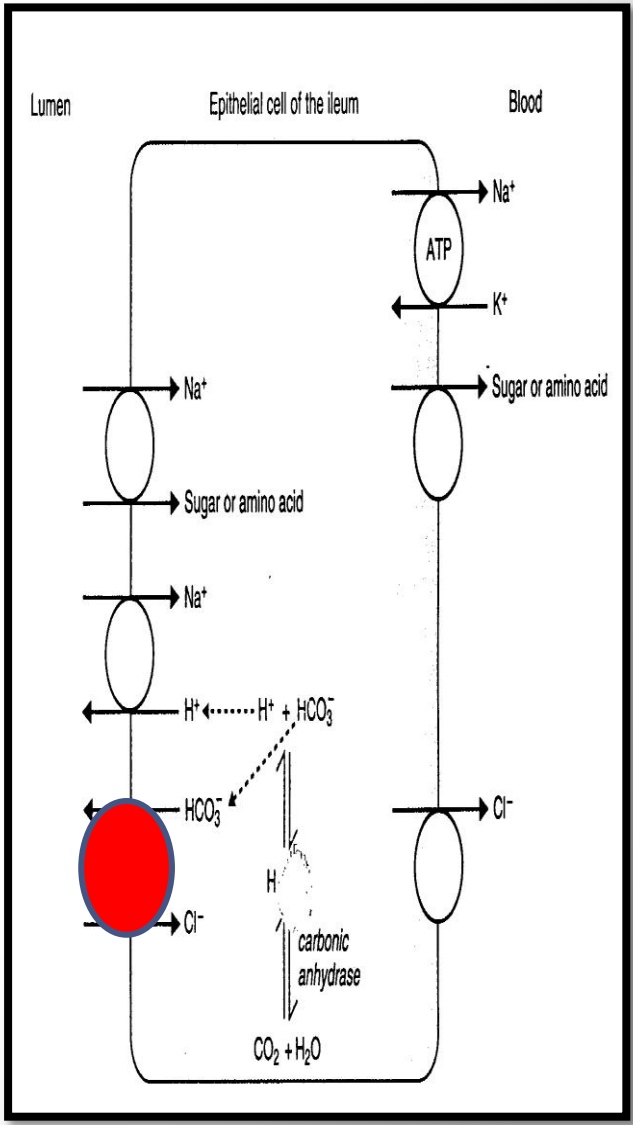
1) Passive diffusion
2) Na^+-Cl^- cotransport
3) Cl^--HCO_3^- exchange

Absorption and secretion of K^+

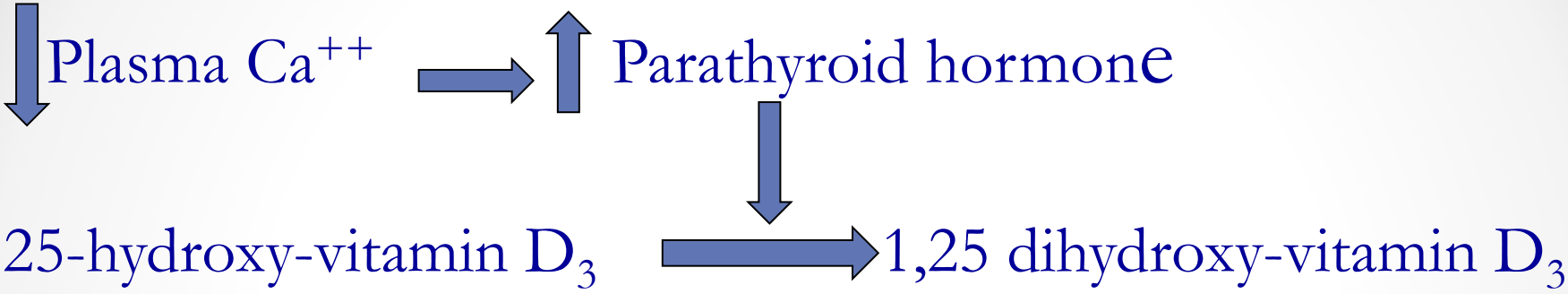
- ✓ K^+ is absorbed in the small intestine by passive diffusion
- ✓ K^+ secretion in the colon is stimulated by aldosterone
- ✓ Excessive loss of K^+ in diarrheal fluids causes hypokalemia

Secretion of Bicarbonate Ions in the Ileum

- The epithelial cells on the surfaces of the villi in the ileum and large intestine have a special capability of secreting HCO_3^- in exchange for absorption of Cl^-.
- This provides alkaline HCO_3^- that neutralize acid products formed by bacteria in the large intestine.



Ca^{++} Absorption by Enterocytes



1,25 dihydroxy-vitamin D_3 stimulates synthesis of Ca^{++}-binding protein and Ca^{++}-ATPase in enterocytes

Nutrient Absorption in The Small Intestine

Site	Absorbed Nutrients
Duodenum and upper jejunum	Most minerals
Jejunum and upper ileum	Carbohydrates, amino acids, water-soluble vitamins
Jejunum	Lipids and fat-soluble vitamins
Terminal ileum	Vitamin B_{12}

Hormonal control of absorption & secretion

- Glucocorticoid = ⇧ absorption of H_2O & ions
  (small & large intestine)
- Somatostatin = ⇧ H_2O & ions absorption
  (ileum & colon)
- Epinephrine = ⇧ NaCl absorption
  (ileum)
- Aldosterone = ⇧ synthesis of Na^+ channels
  (colon)

بسم الله الرحمن الرحيم