# Gastrointestinal Physiology
# Lecture 5

## *Physiology of the Small Intestine: Motility and Secretion*

*Dr. Hayam Gad*

*Associate Professor of Physiology,*
*College of Medicine, KSU*

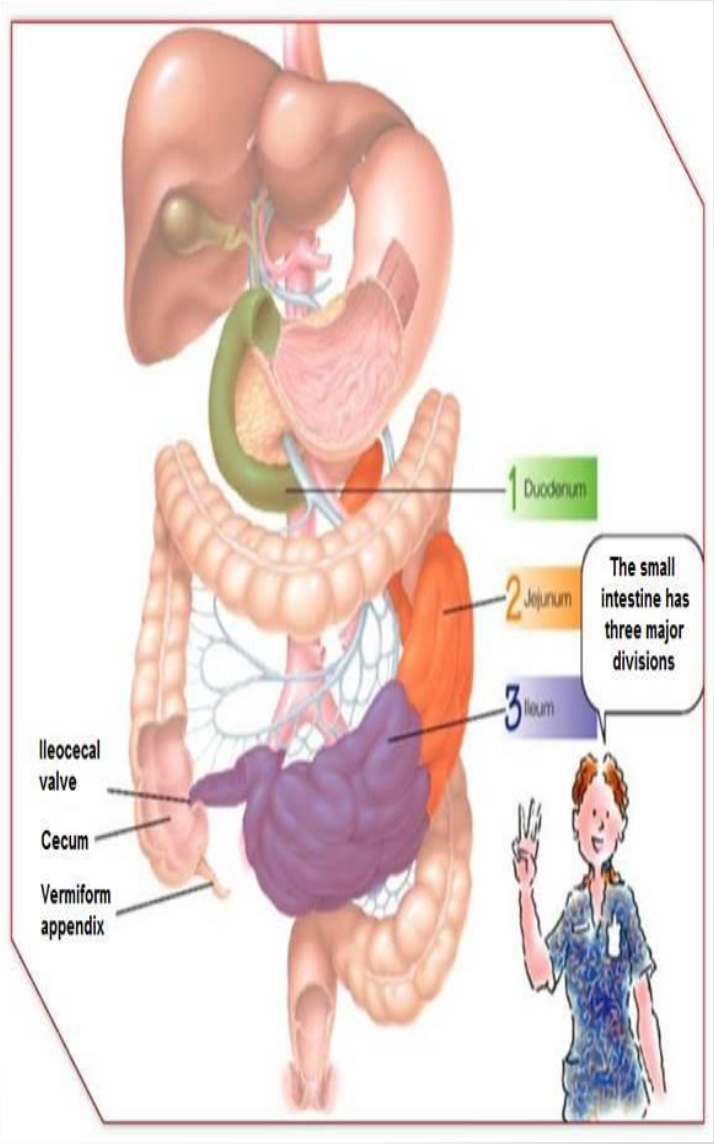
# Learning Objectives

- 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

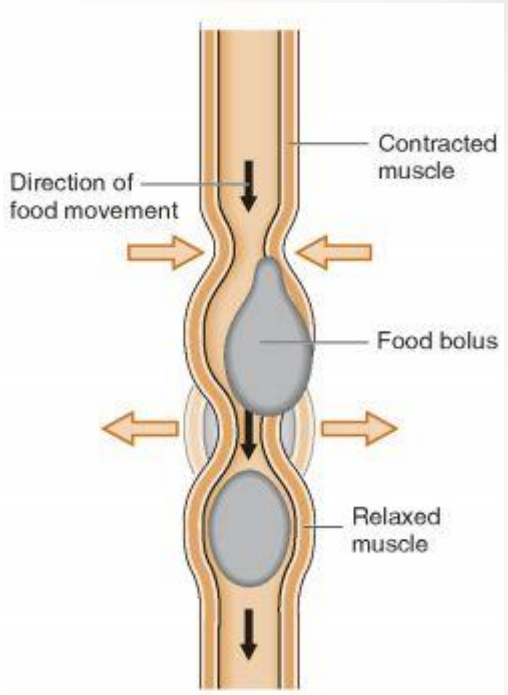
The movements of the small intestine can be divided into:

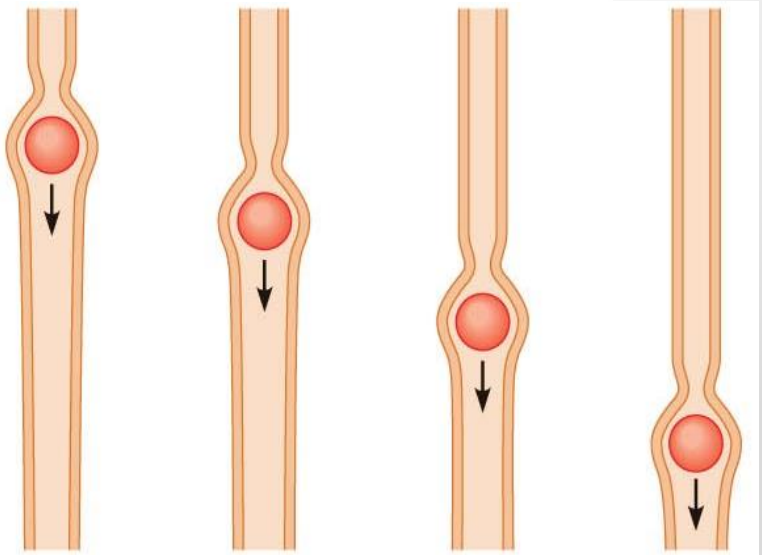
- *Propulsive contractions (Peristalsis)*
- *Segmenting (Mixing) contractions*
- *Migrating motor complex*
- *Antiperistalsis*
- *Peristaltic rush*



# 1. Propulsive Movements (Peristalsis)

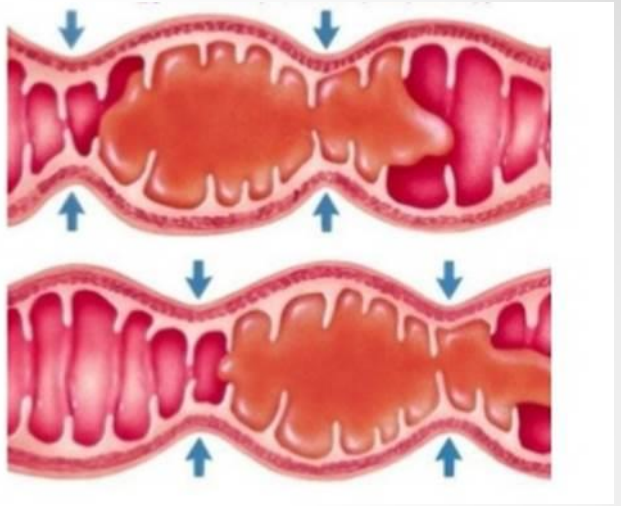
- A contraction ring appears around gut, then moves forward.
- Usual stimulus is distention.
- Organizes propulsion of material over variable distances.
- They are faster in the proximal intestine and slower in the terminal intestine (velocity 0.5 to 2.0 cm/sec), (3 to 5 hours are required for passage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



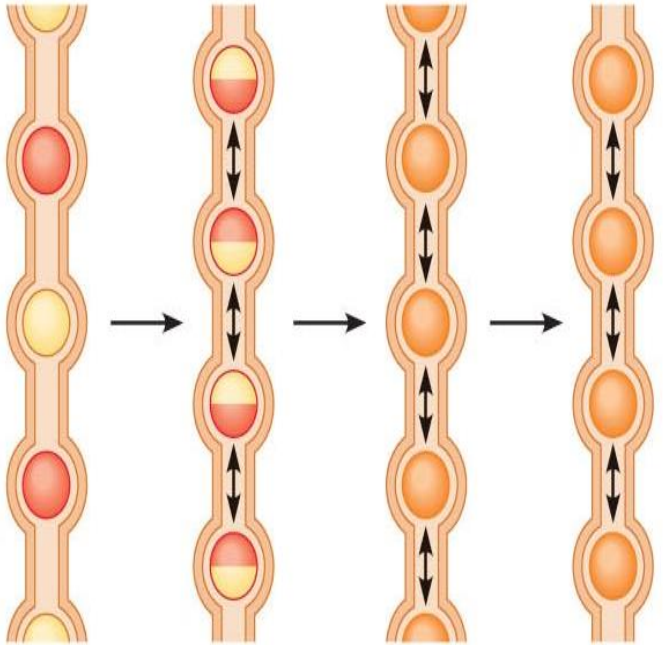



# 2. Mixing (Segmentation) Contractions

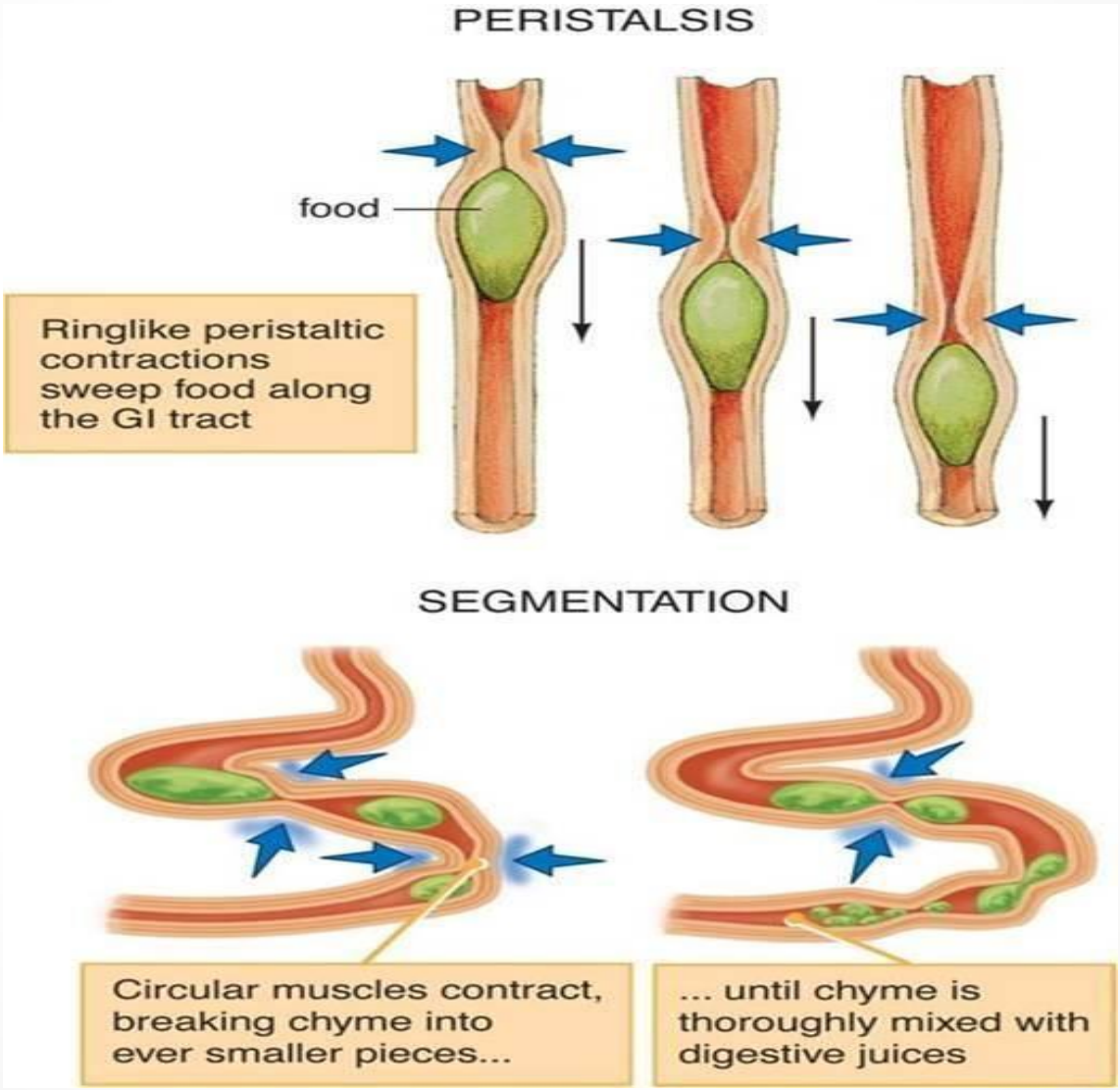
- A localized contraction of circular smooth muscles that constricts the intestine into spaced segments, last for fraction of min.



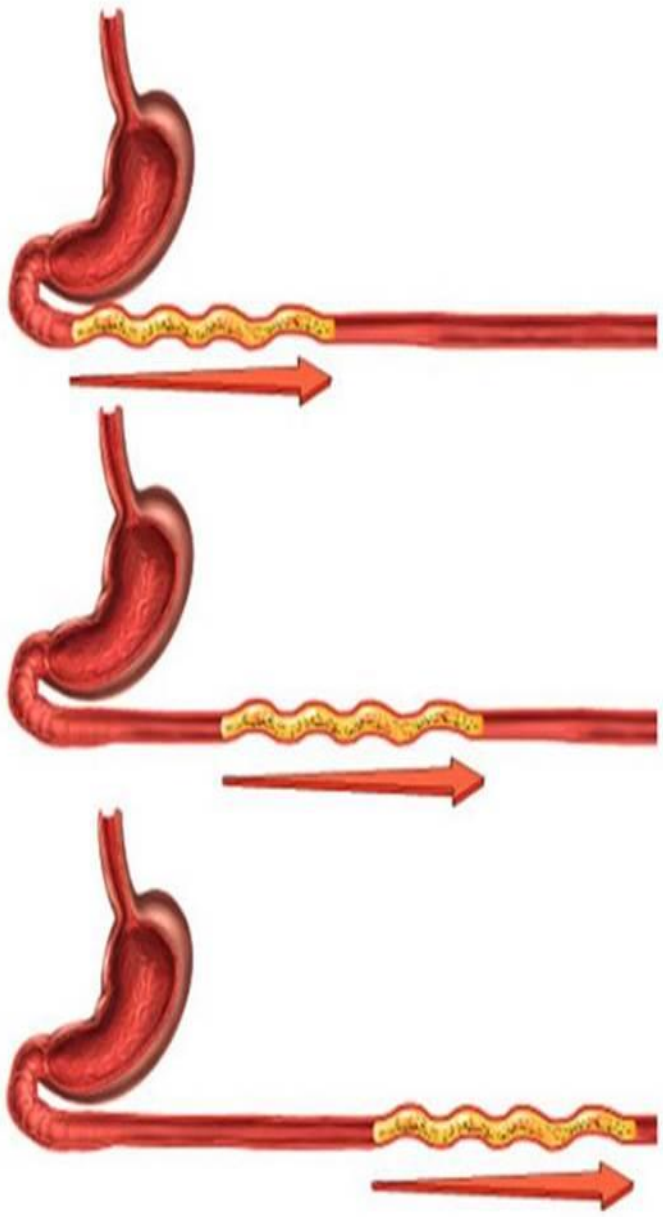
- As one set of segmentation contractions relaxes, a new set often begins at points between the previous ones.
- Usual stimulus is distention.
- It is activated by enteric nervous system.
- They can be blocked by atropine.
- <u>The significance:</u>
  - Blend different juices with the chyme
  - Bring products of digestion in contact
  - with absorptive surfaces



# Peristalsis versus segmentation



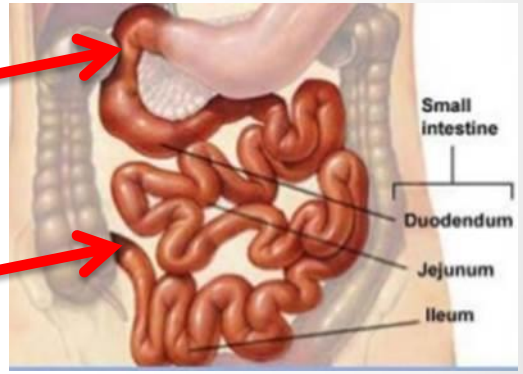
# 3- Migrating motor complex (MMC)



- 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 motilin.

# 4- Antiperistalsis

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

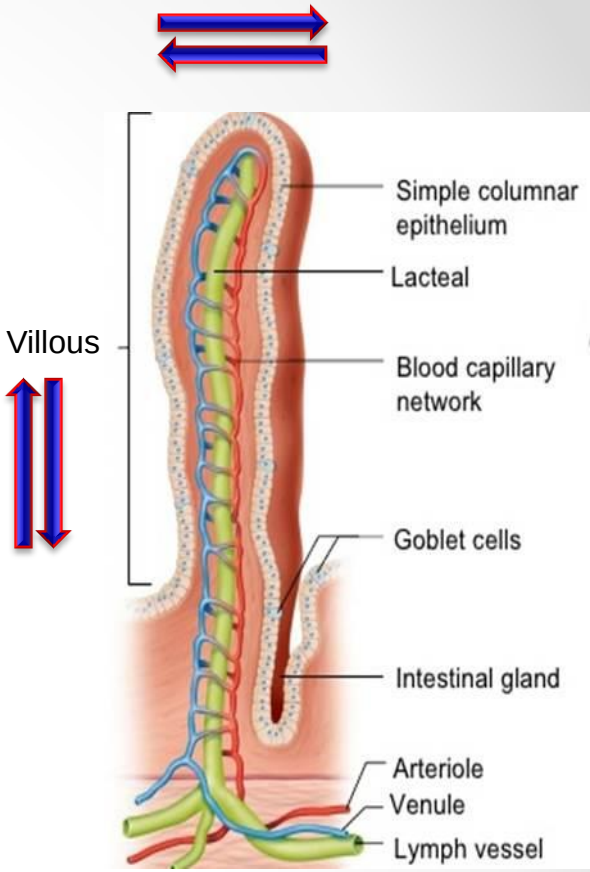


# 5- Peristaltic rush

- 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*** is 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 ileocaecal sphincter.
- Motilin secreted from duodenum stimulates intestinal motility and regulate MMC.
- Secretin and glucagons inhibits intestinal motility and contract ileocaecal sphincter.
- Villikinin stimulates movement of the villi.

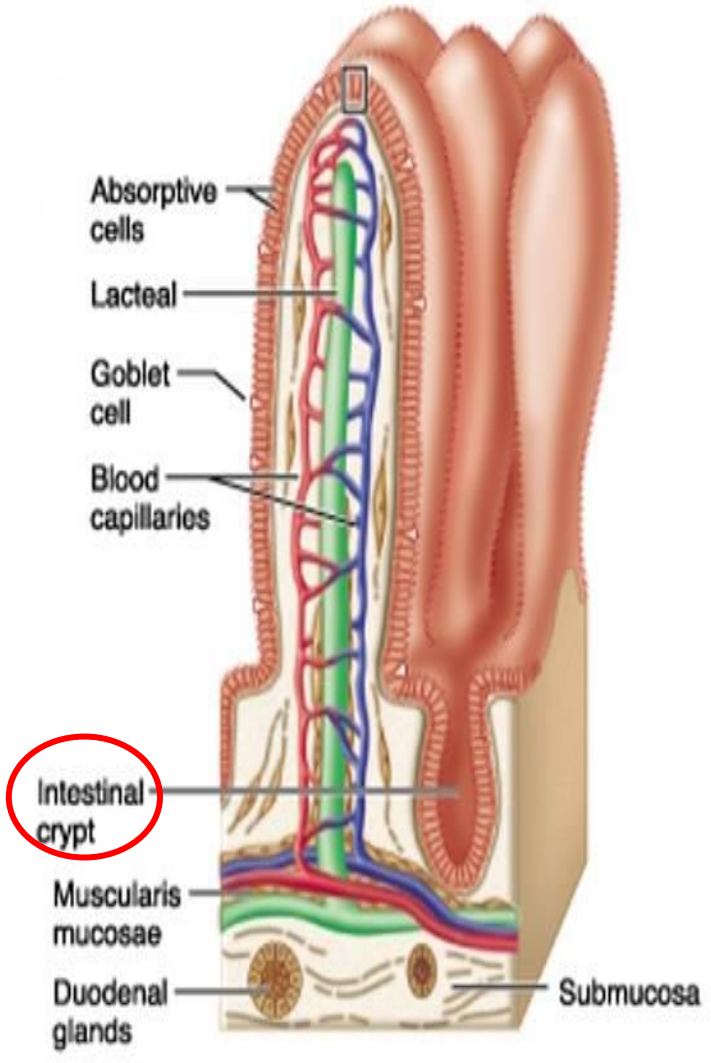
# *Secretions of The Small Intestine*

## 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

# *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*

1. **Brunner's gland secretion** is stimulated by secretin, tactile and vagal stimulation.
2. **Intestinal juice secretion** is stimulated by:

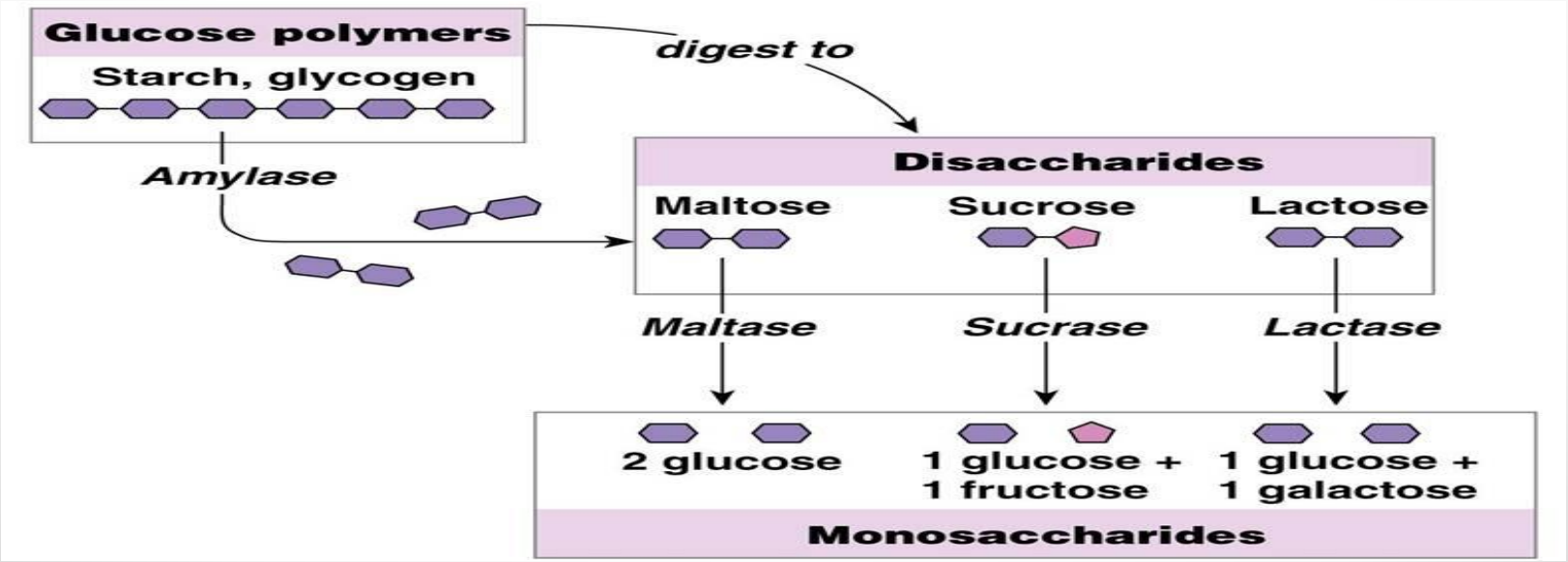
   a. Distension, tactile and vagal stimulation.

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

   Sympathetic stimulation exerts an inhibitory effect.

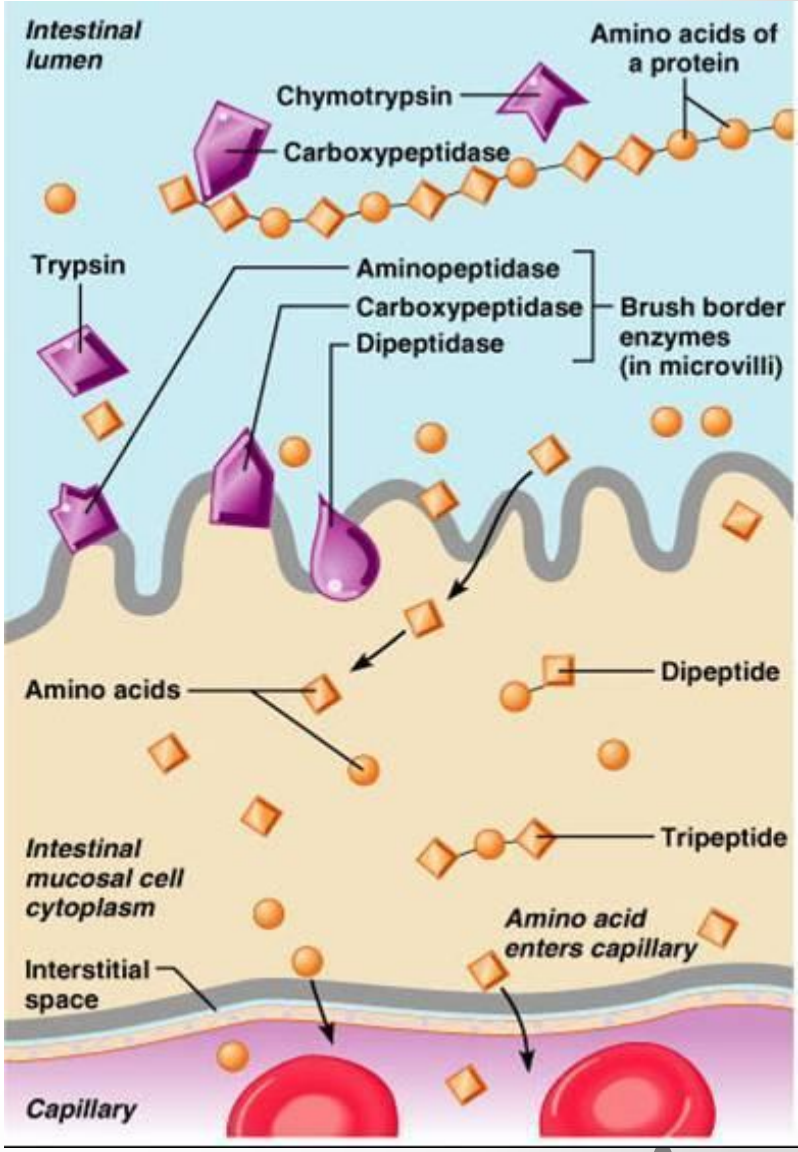
# Digestion of Carbohydrates

- 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.



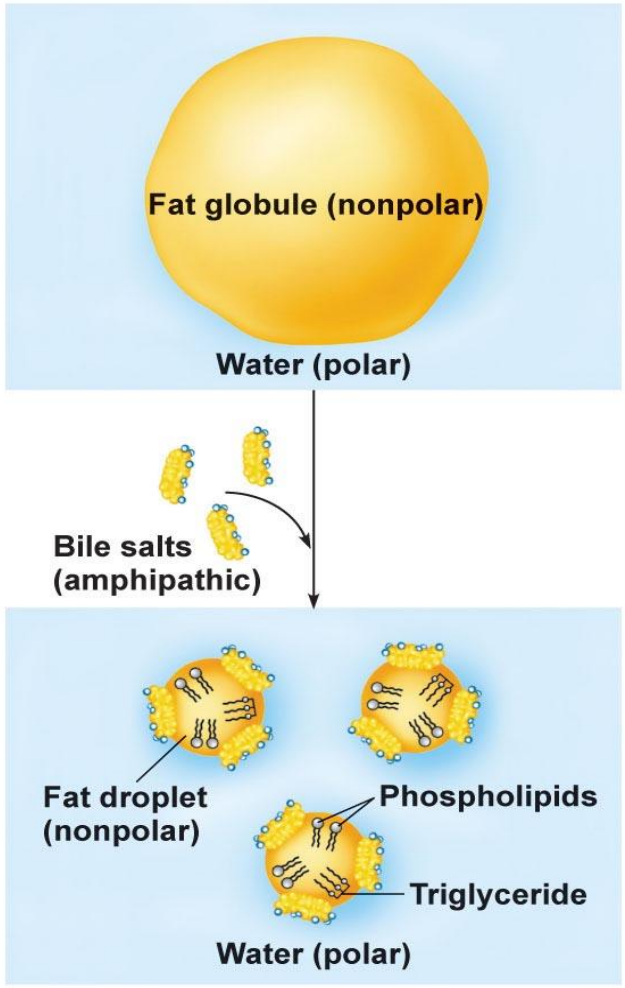
# Digestion of Proteins

- 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 Fats

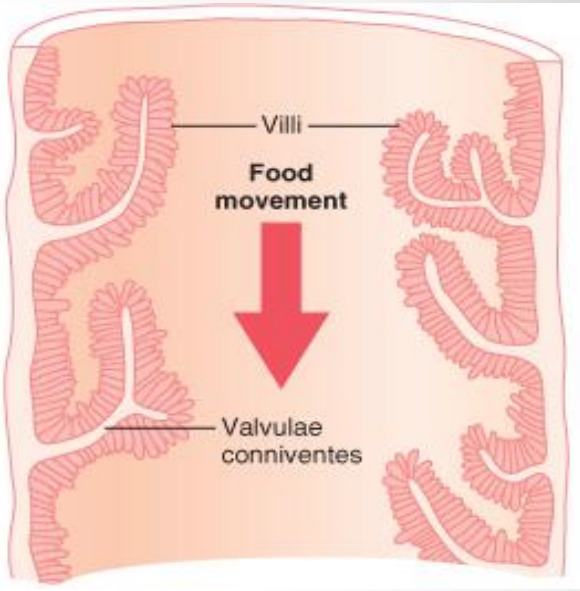
- Bile salts and lecithin in the bile help fat digestion by make the fat globules readily fragmentable with the water in the small intestine (emulsification of fat).
- Bile salts break the fat globules into very small sizes, so that the water-soluble digestive enzymes can act on the globule surfaces.

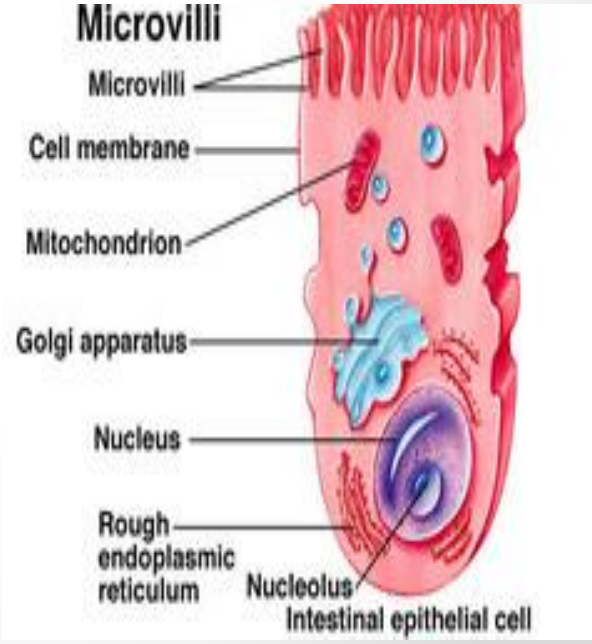


# Basic Principles of Gastrointestinal Absorption

# Absorptive Surface of the Small Intestinal

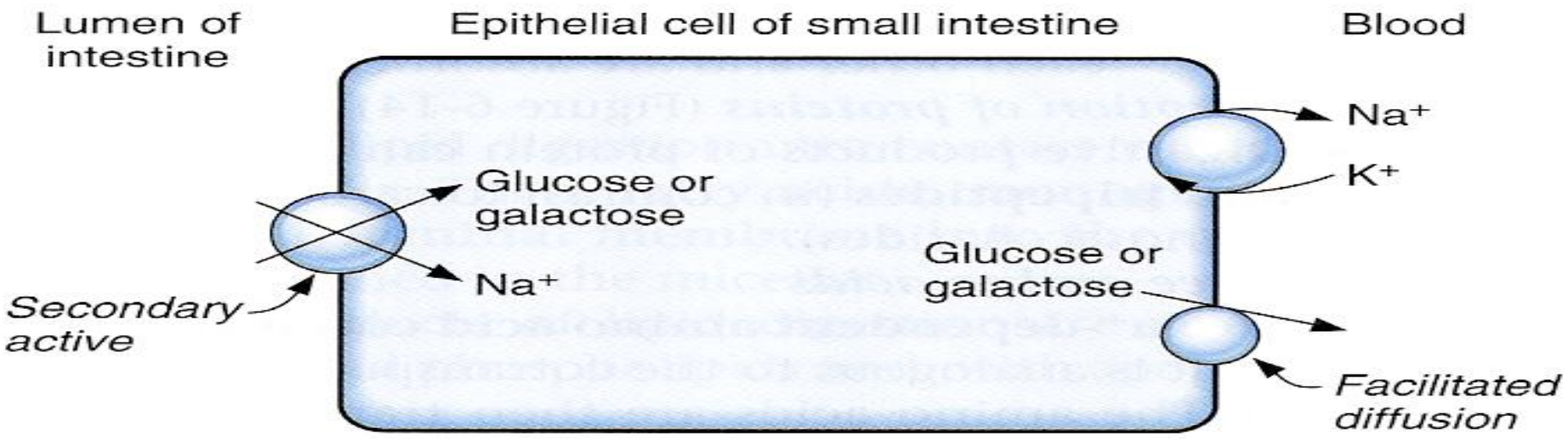
- The absorptive surface of the small intestinal mucosa, showing many folds called *valvulae conniventes*, well developed in the duodenum and jejunum. They increase the surface area of the absorptive mucosa about ***3-fold***.
- The presence of villi on the mucosal surface enhances the total absorptive 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***).

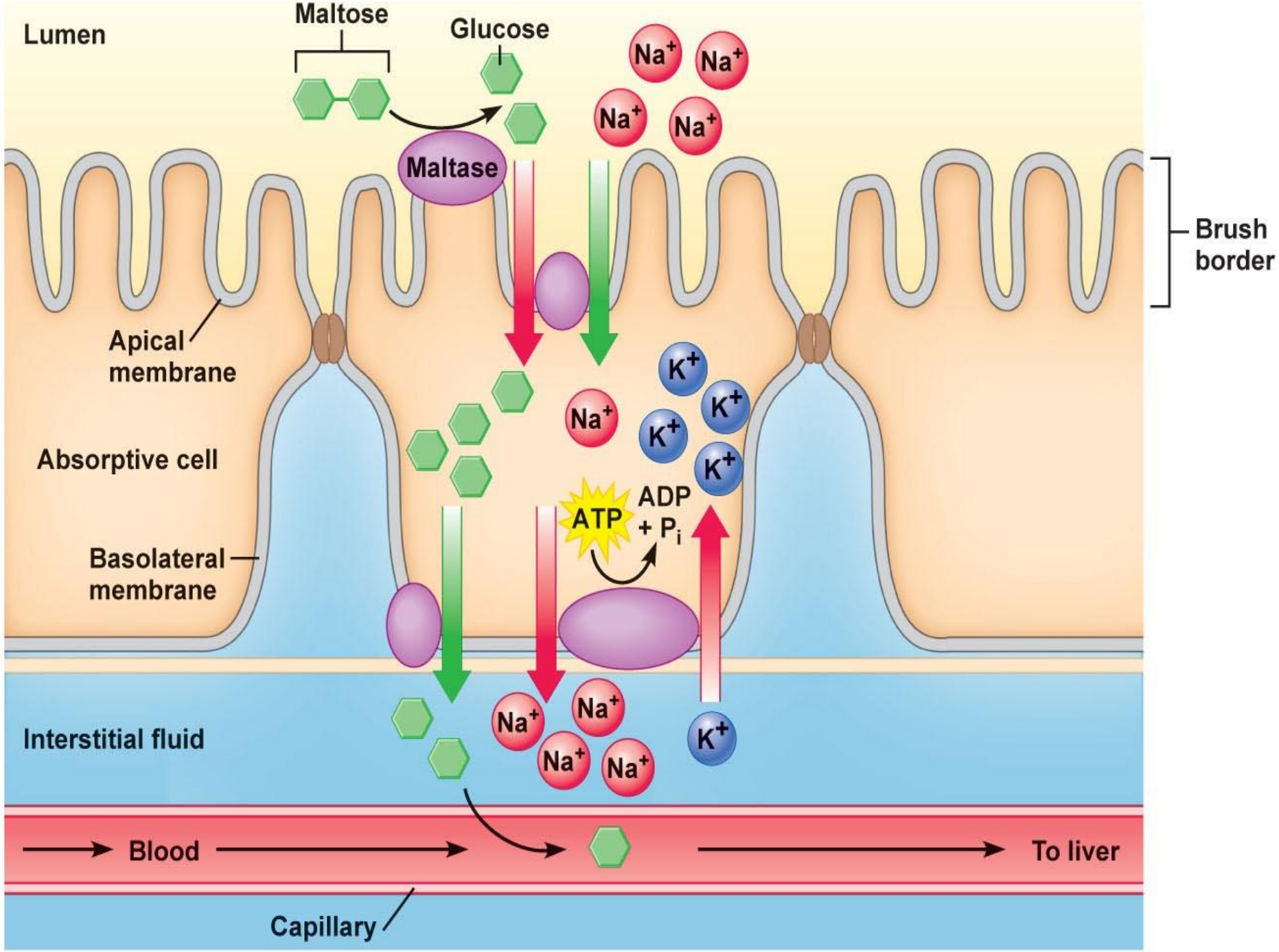


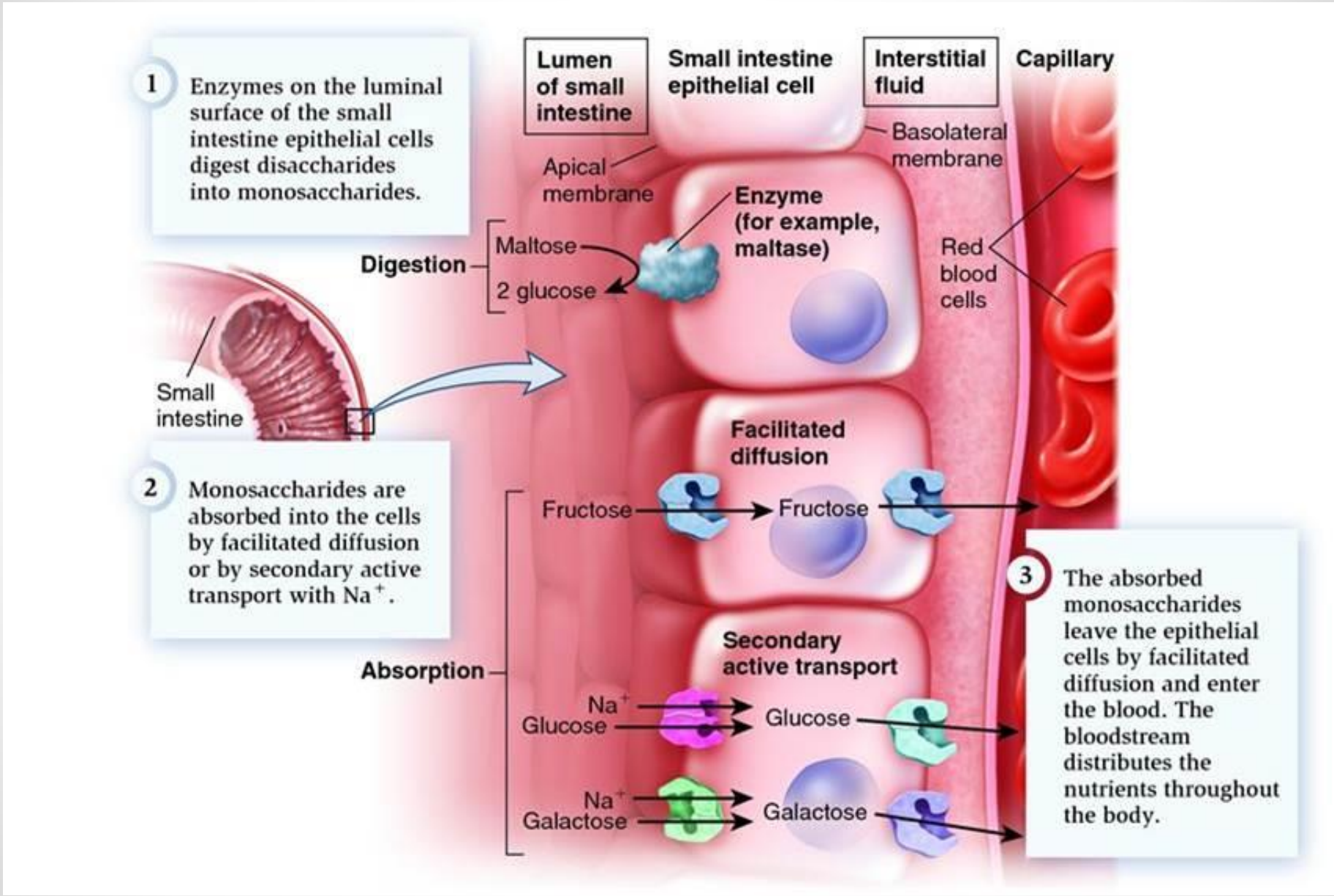



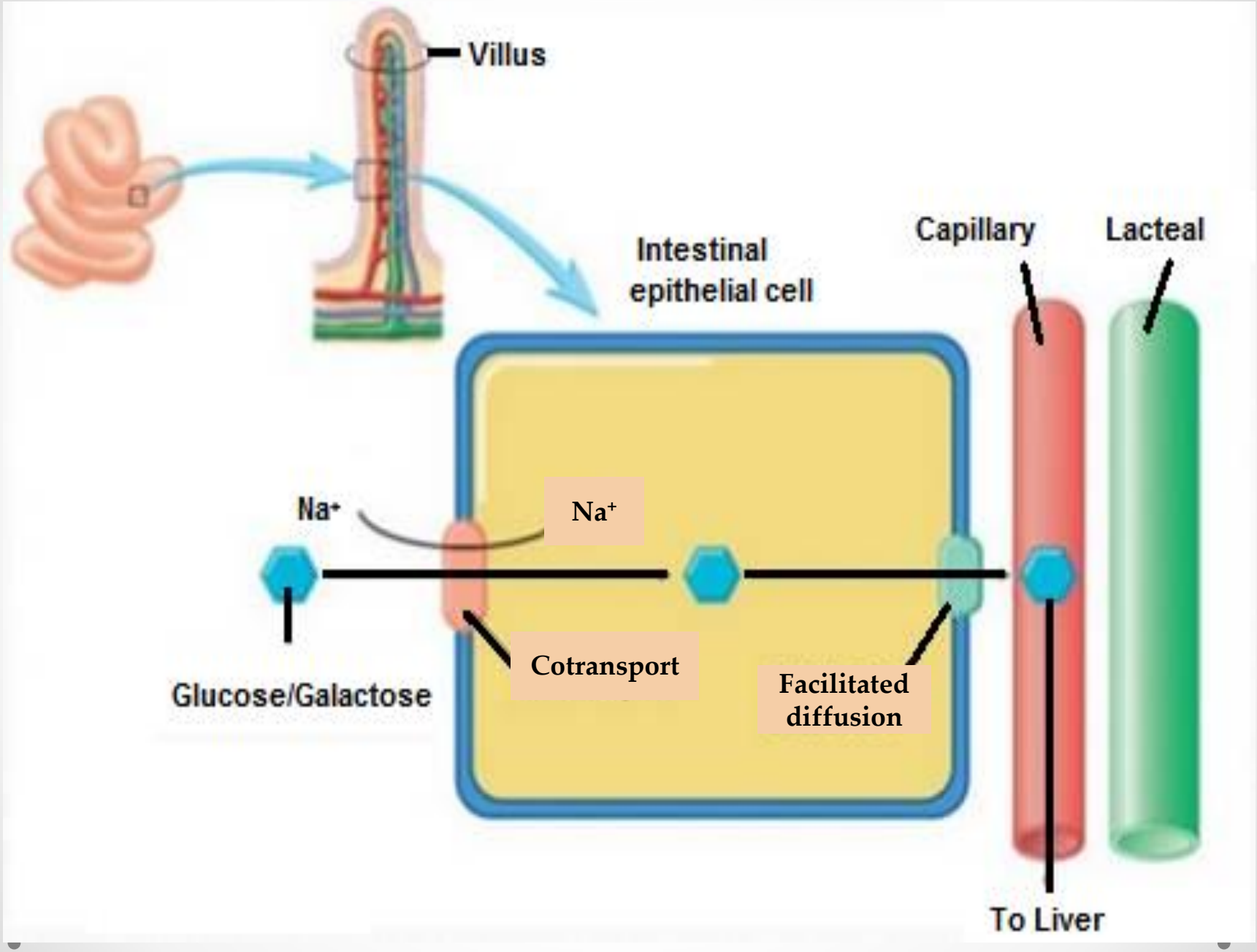
# Absorption of Carbohydrates

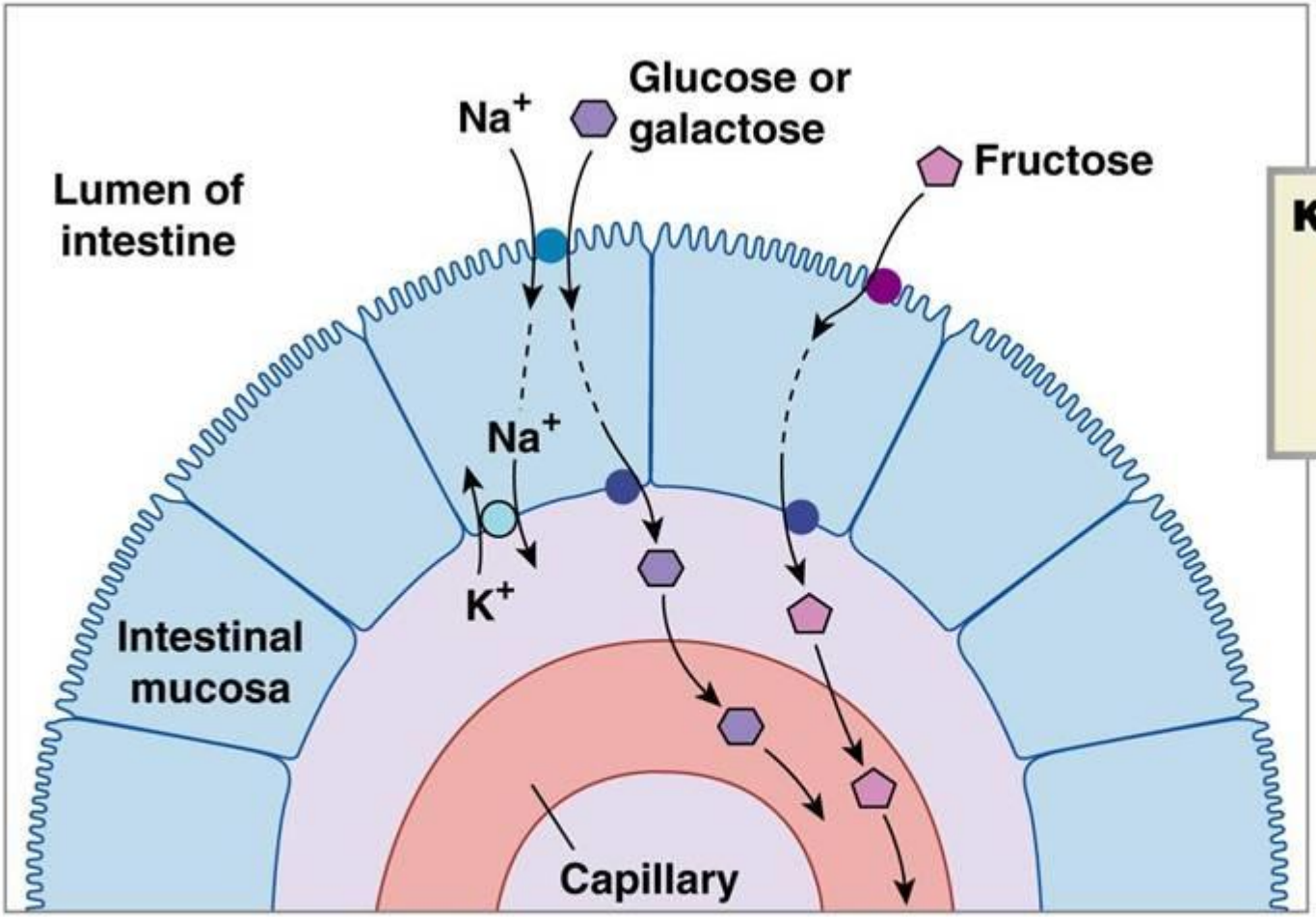
- All the carbohydrates in the food are absorbed in the form of monosaccharides; only a small fraction are absorbed as disaccharides.
- Glucose and galactose absorption occurs in a cotransport mode with active transport of $Na^+$ (2ry active transport) .
- Fructose is independent on $Na^+$ but it transports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




Lumen
Maltose
Glucose
Maltase
Na+
Na+
Na+
Na+
Brush border
Apical membrane
Absorptive cell
K+
K+
K+
K+
Na+
ATP
ADP + Pi
Basolateral membrane
Interstitial fluid
Na+
Na+
Na+
Na+
K+
Blood
To liver
Capillary


1 Enzymes on the luminal surface of the small intestine epithelial cells digest disaccharides into monosaccharides.
Lumen of small intestine
Small intestine epithelial cell
Interstitial fluid
Capillary
Basolateral membrane
Apical membrane
Enzyme (for example, maltase)
Digestion
Maltose
2 glucose
Red blood cells
Small intestine
Facilitated diffusion
Fructose
Fructose
2 Monosaccharides are absorbed into the cells by facilitated diffusion or by secondary active transport with Na+.
Absorption
Secondary active transport
Na+
Glucose
Glucose
Na+
Galactose
Galactose
3 The absorbed monosaccharides leave the epithelial cells by facilitated diffusion and enter the blood. The bloodstream distributes the nutrients throughout the body.


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

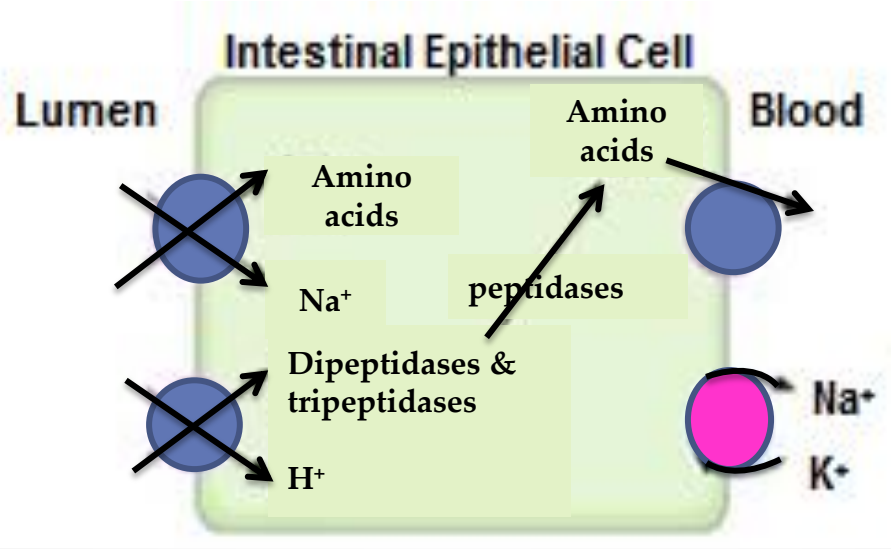


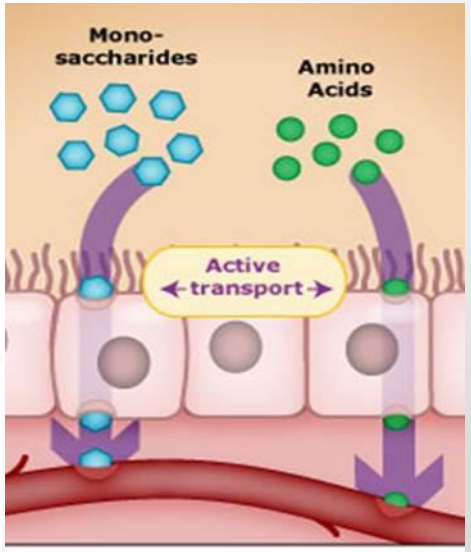

Glucose enters the cell with $Na^+$ on the SGLT symporter and exits on GLUT2. Fructose enters on GLUT5 and exits on GLUT 2.

# Absorption of Proteins

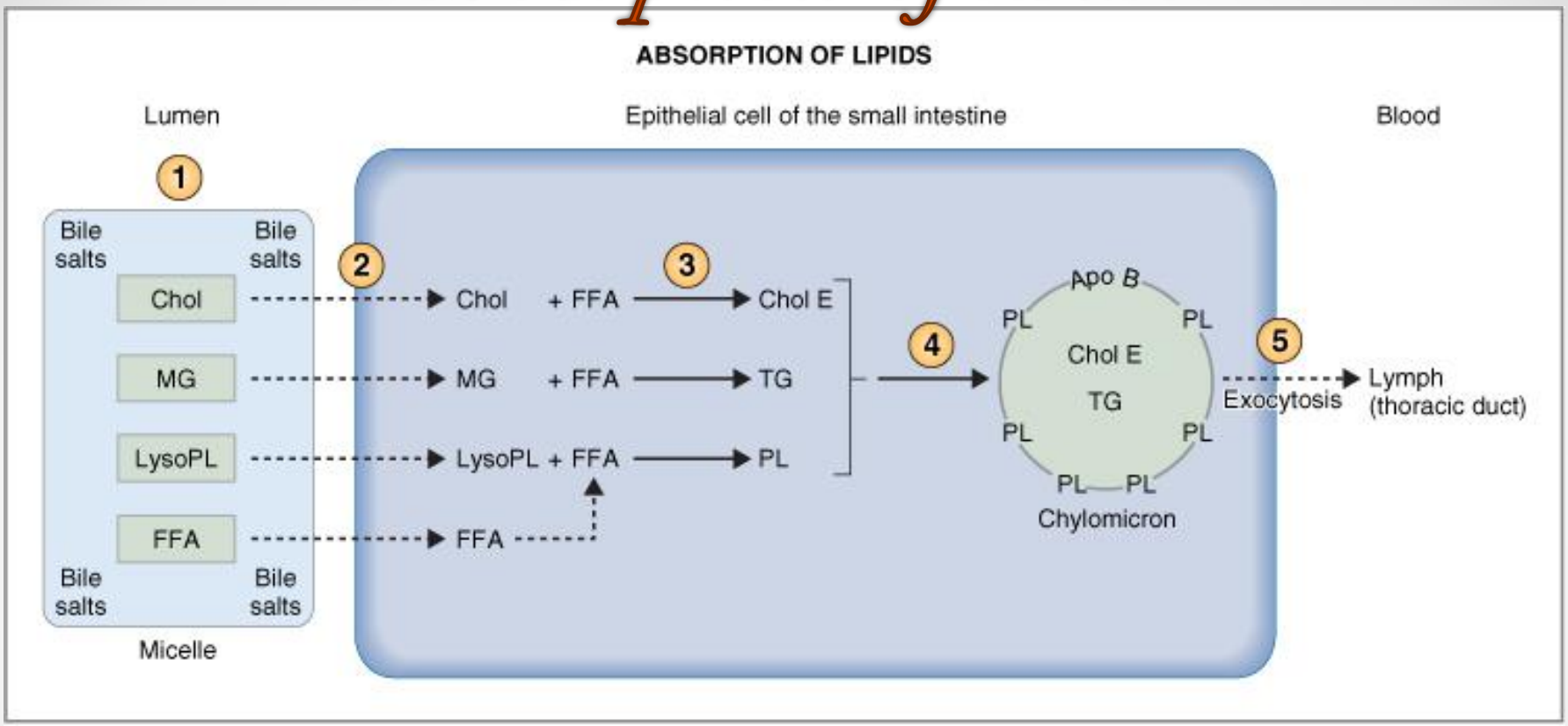
Proteins are absorbed in the form of dipeptides, tripeptides, and a few free amino acids.

- D- AA are transported by passive diffusion.
- L- AA are transported by 2ry active transport.
- Di and tripeptides cross the brush border by active transport protein carrier. They are hydrolyzed by brush border and cytoplasmic oligopeptidases.
- AA leaves the cell at the basolateral membrane by facilitated transport.



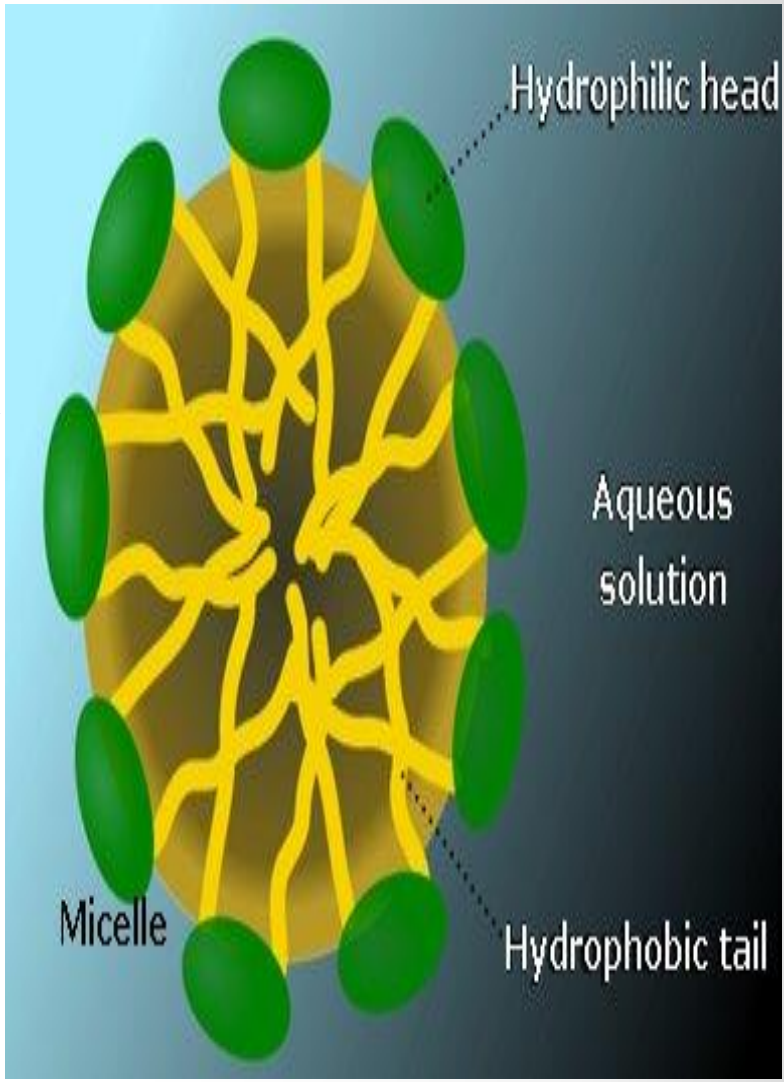
# Absorption of Fats

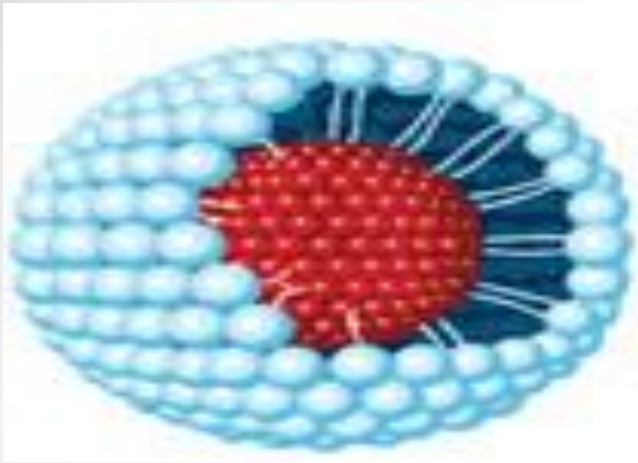


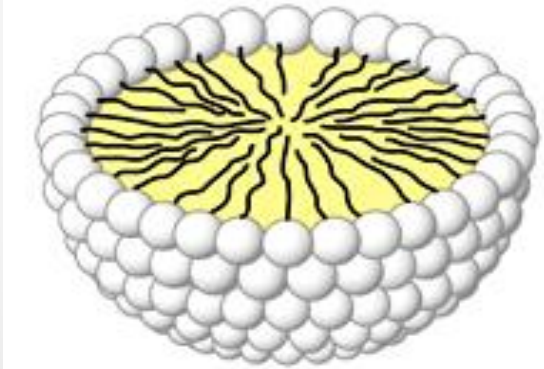

- In the presence of an abundance of bile micelles, about **97 %** of the fat is absorbed.
- In the absence of the bile micelles, only **40 to 50 %** can be absorbed.

# *Formation of Micelles*

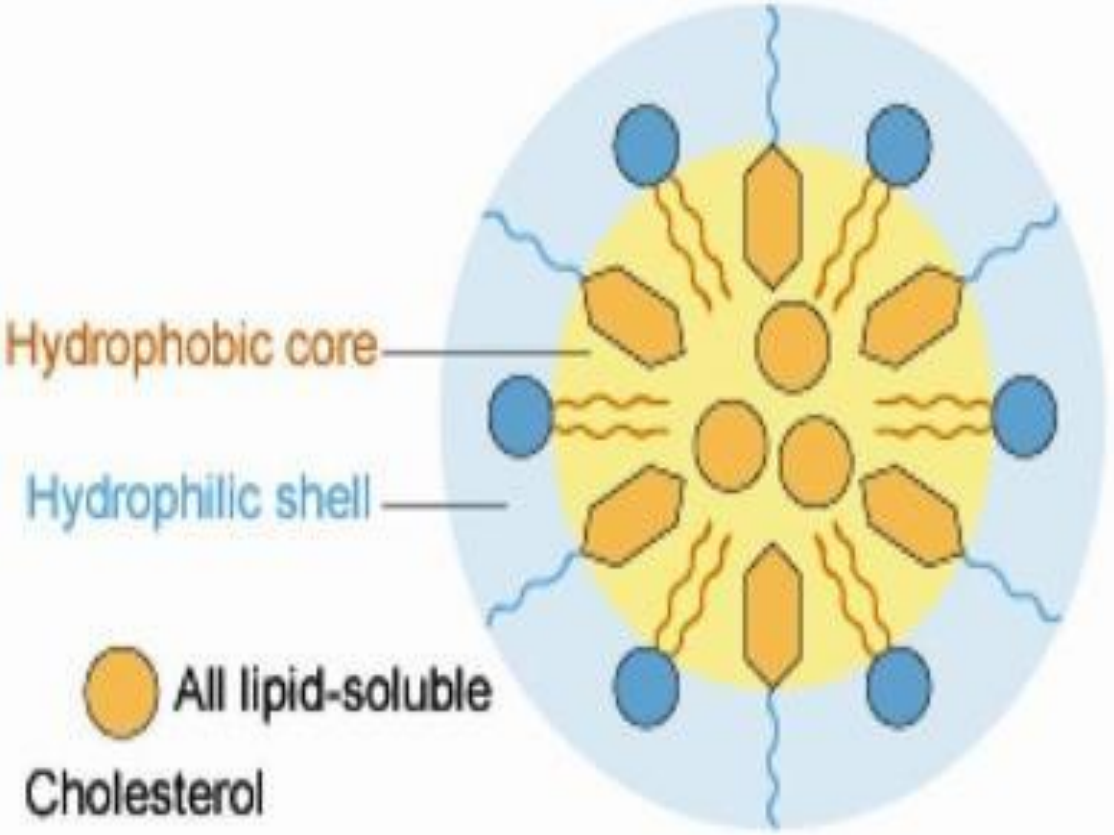
- *B*ile salt are amphipathic molecules, each composed of a sterol nucleus (fat-soluble) and a polar group (water-soluble).
- *Micelles are* small spherical, cylindrical globules 3 - 6 nm in diameter composed of 20 - 40 molecules of bile salts.
- The polar parts are (-) charged, they allow the entire micelle globule to dissolve in the water of the digestive fluids.

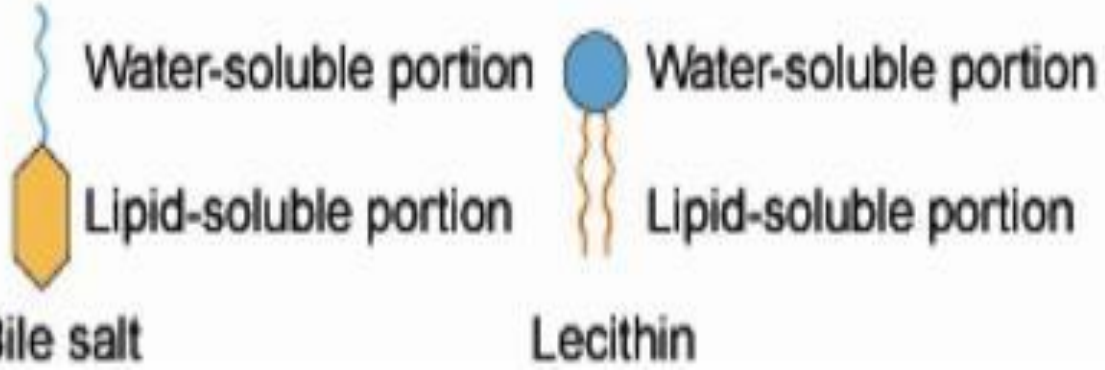




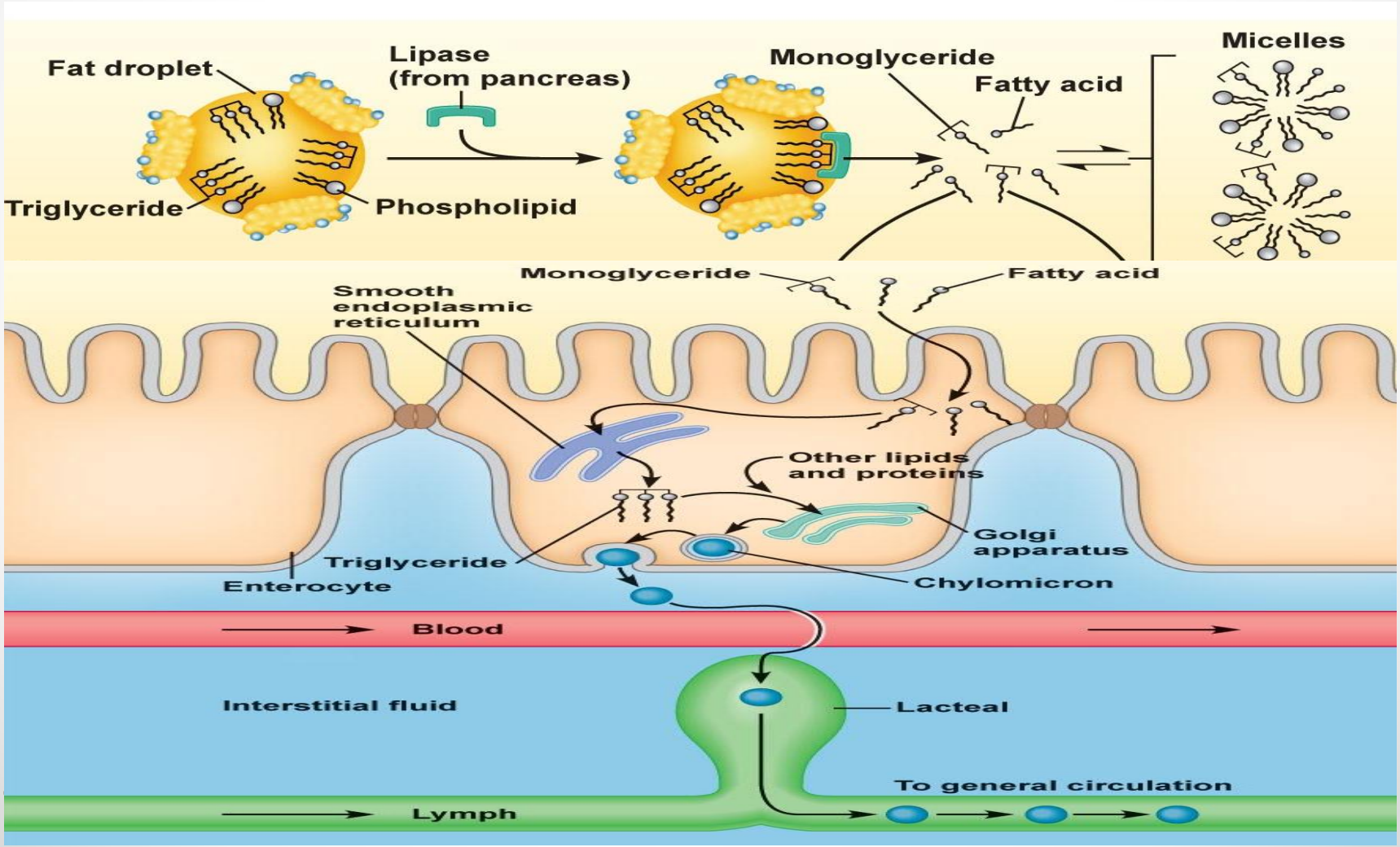


Micelle

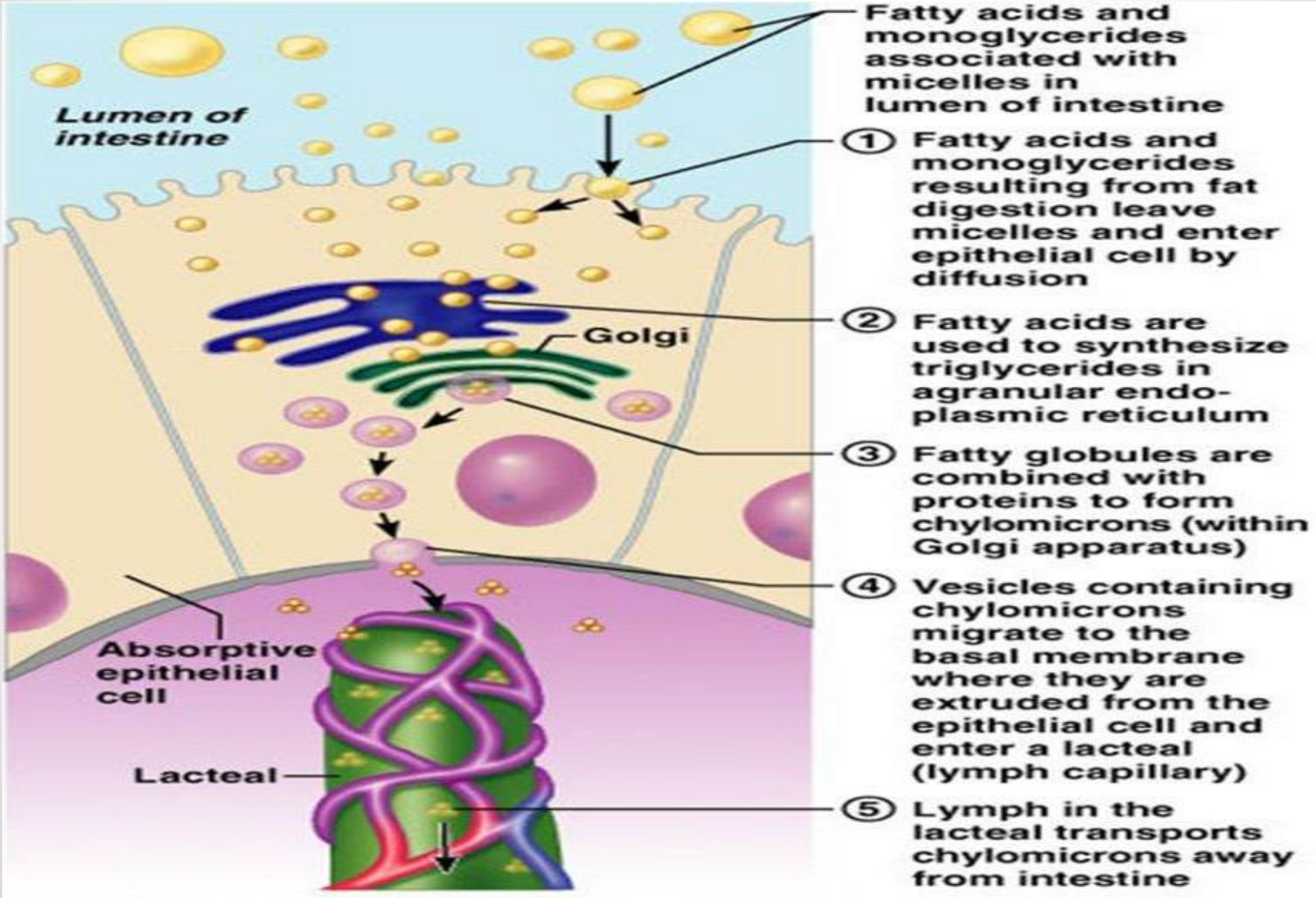

Hydrophobic core
Hydrophilic shell
All lipid-soluble
Cholesterol

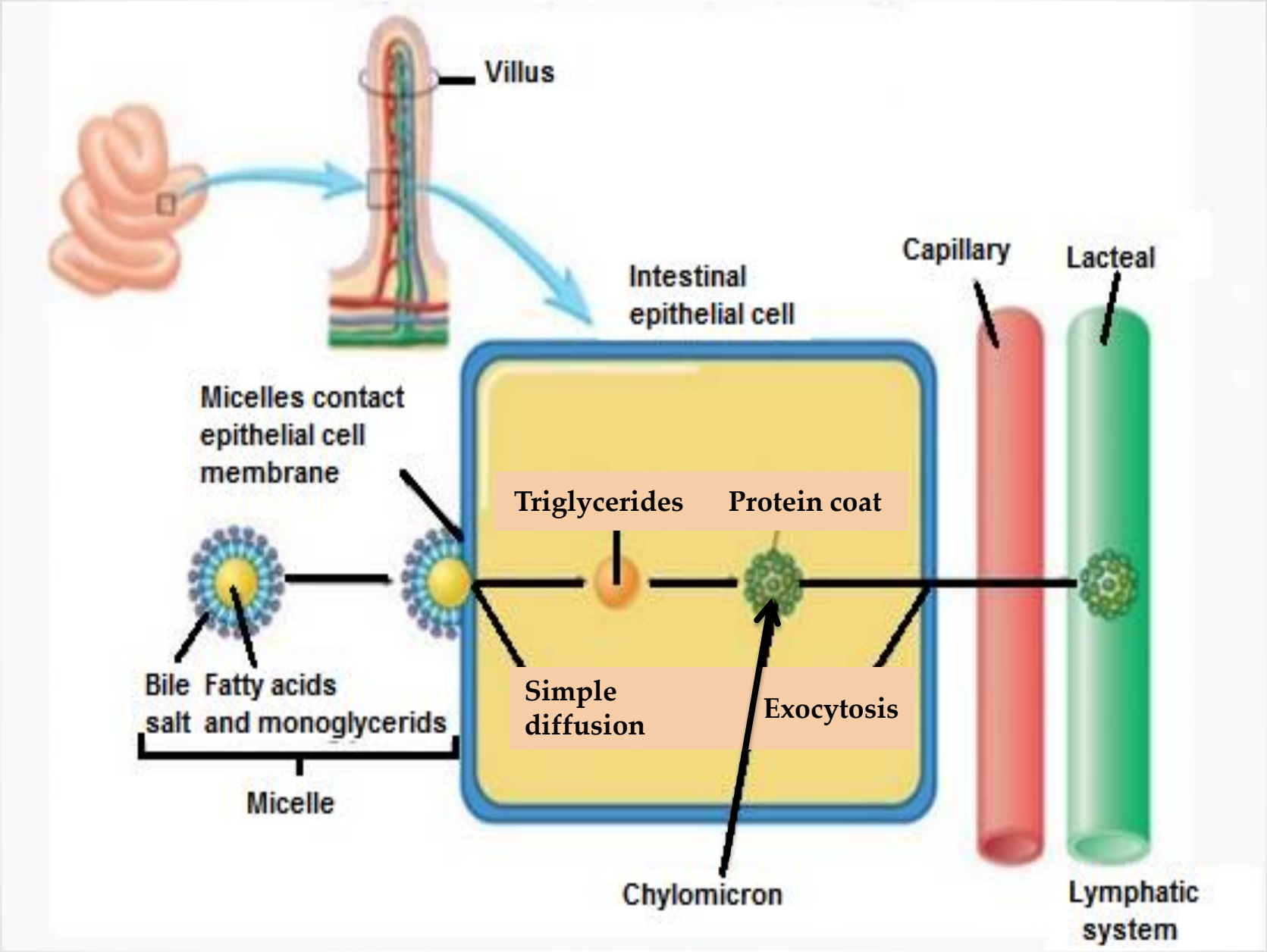

Water-soluble portion
Lipid-soluble portion
Bile salt
Water-soluble portion
Lipid-soluble portion
Lecithin

- The micelles act as a transport medium to carry the monoglycerides and free fatty acids to the brush borders of the intestinal epithelial cells.



# Steps of Fat Absorption




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 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 ileum and requires intrinsic factor

**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 cellular 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

# 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) $Na^+$-$Cl^-$ exchange
4) $Na^+$-$H^+$ exchange

- The next step in the transport process is osmosis of water into the paracellular spaces because a large osmotic gradient has been created by the elevated concentration of ions in the paracellular space.
- **Aldosterone Greatly Enhances $Na^+$ Absorption:**

This effect of aldosterone 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:

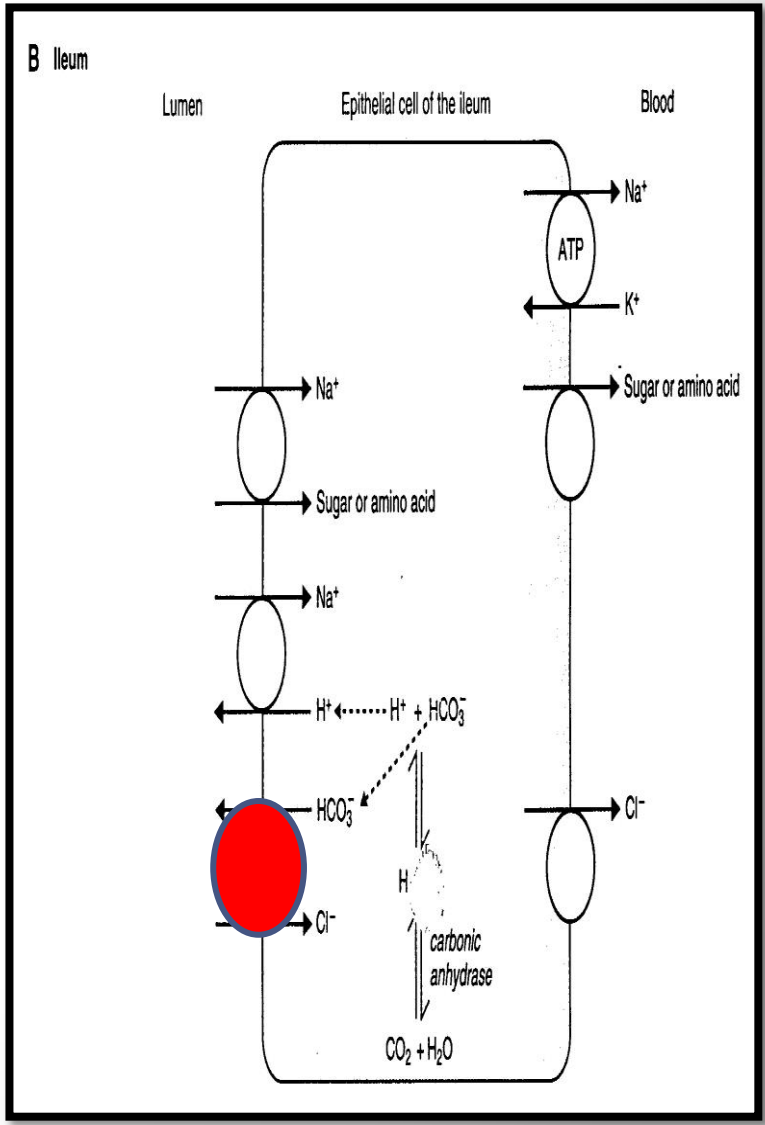
1) Passive diffusion
2) $Na^+$-$Cl^-$ cotransport
3) $Cl^-$-$HCO_3^-$ exchange

# Absorption and secretion of $K^+$

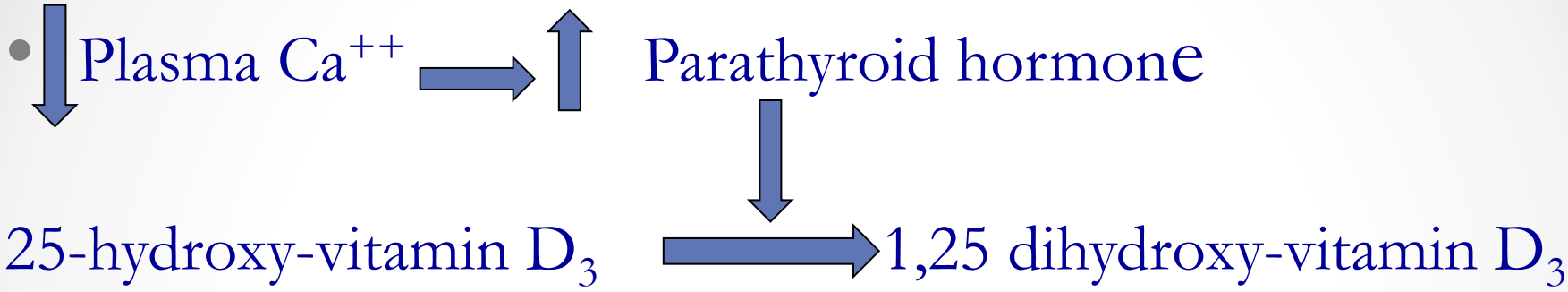
- ✓ $K^+$ is absorbed in the small intestine by passive diffusion
- ✓ $K^+$ secretion in the colon is stimulated by aldosterone
- ✓ Excessive loss of $K^+$ in diarrheal fluids causes hypokalemia

# 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

# 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 $Na^+$ channel (colon)
- Catecholamines = ⇩ intestinal secretion


Thank You