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Digestion, Absorption, Transport, and Excretion of Nutrients

(Session 4)

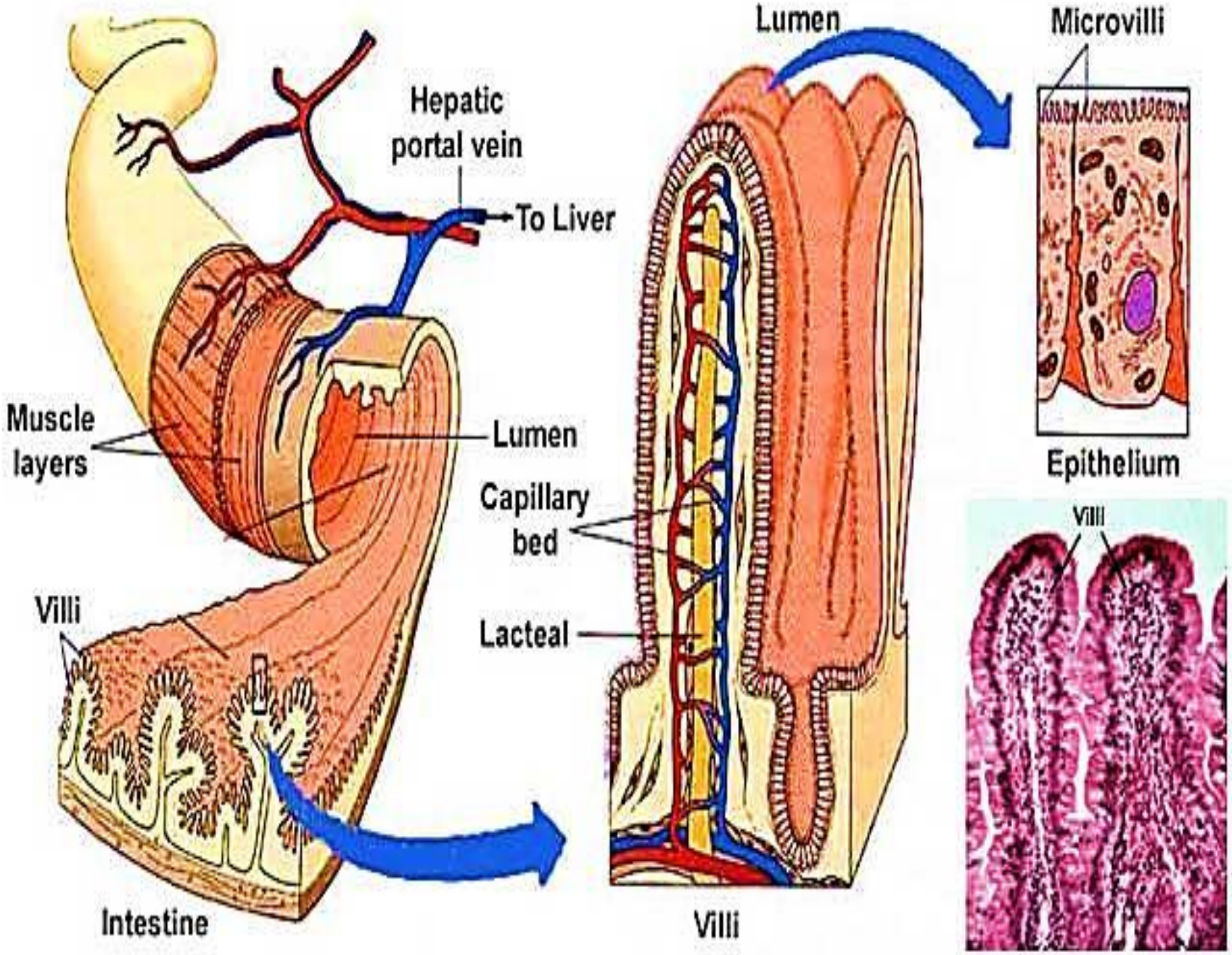
Mohsen Karamati
Department of Nutrition Sciences, Varastegan Institute for Medical Sciences, Mashhad, Iran
E-mail: karamatim@varastegan.ac.ir

The Small Intestine: Primary Site of Nutrient Absorption

Structure and Function

The primary organ of nutrient and water absorption is the small intestine.

The small intestine has characteristic folds in its surface called valvulae conniventes, which are covered with fingerlike projections called villi, which in turn are covered by microvilli, or the brush border.


Hepatic
portal vein
To Liver
Muscle
layers
Lumen
Villi
Intestine
Lumen
Capillary
bed
Lacteal
Villi
Microvilli
Epithelium
Villi

The combination of folds, villous projections, and microvillous border creates an enormous absorptive surface of approximately 200 to 300 m^2.

The villi rest on a supporting structure called the lamina propria.

Within the lamina propria, which is composed of connective tissue, **the blood and lymph vessels receive the products of digestion**.

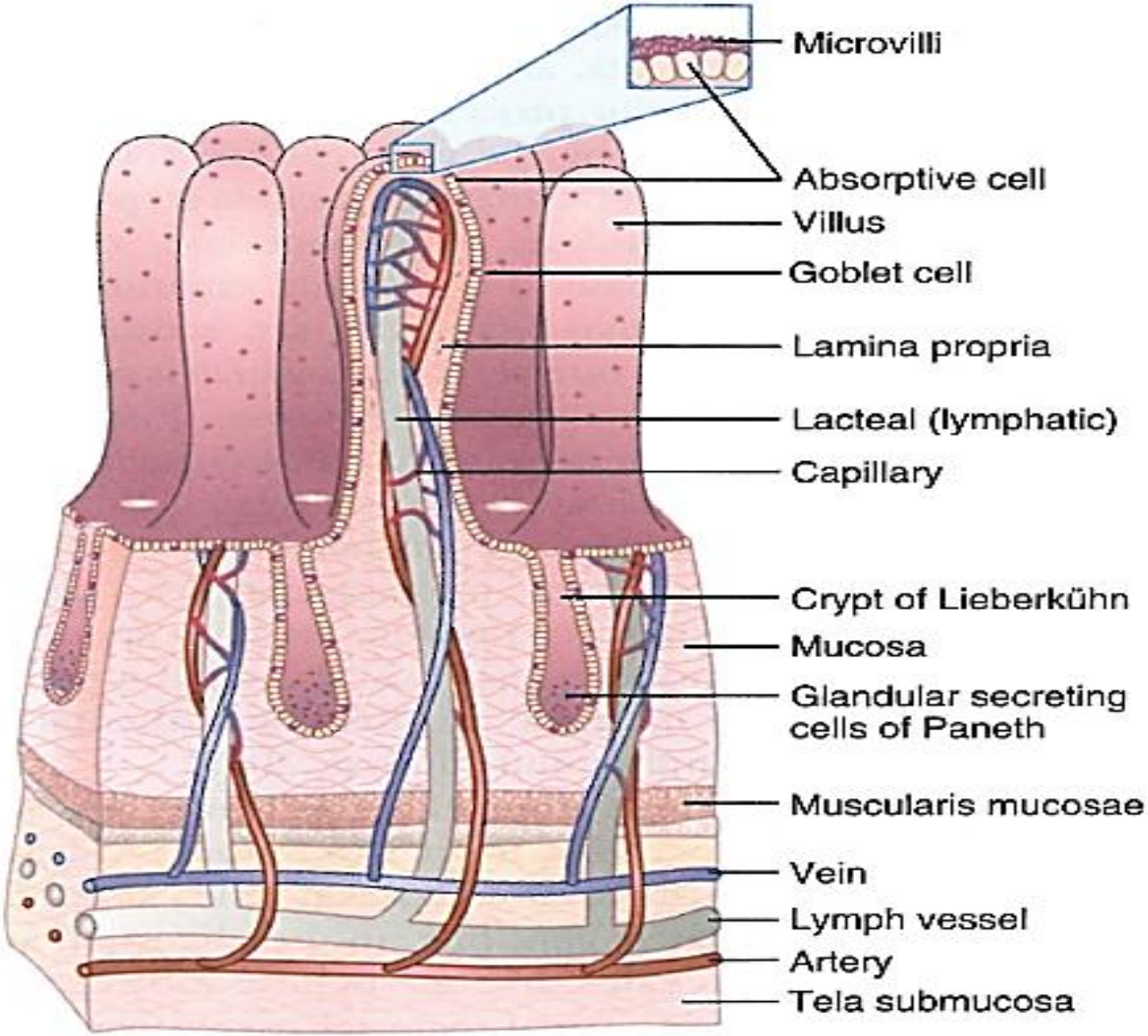


FIGURE 1-3 Structure of the villi of the human intestine showing blood and lymph vessels.

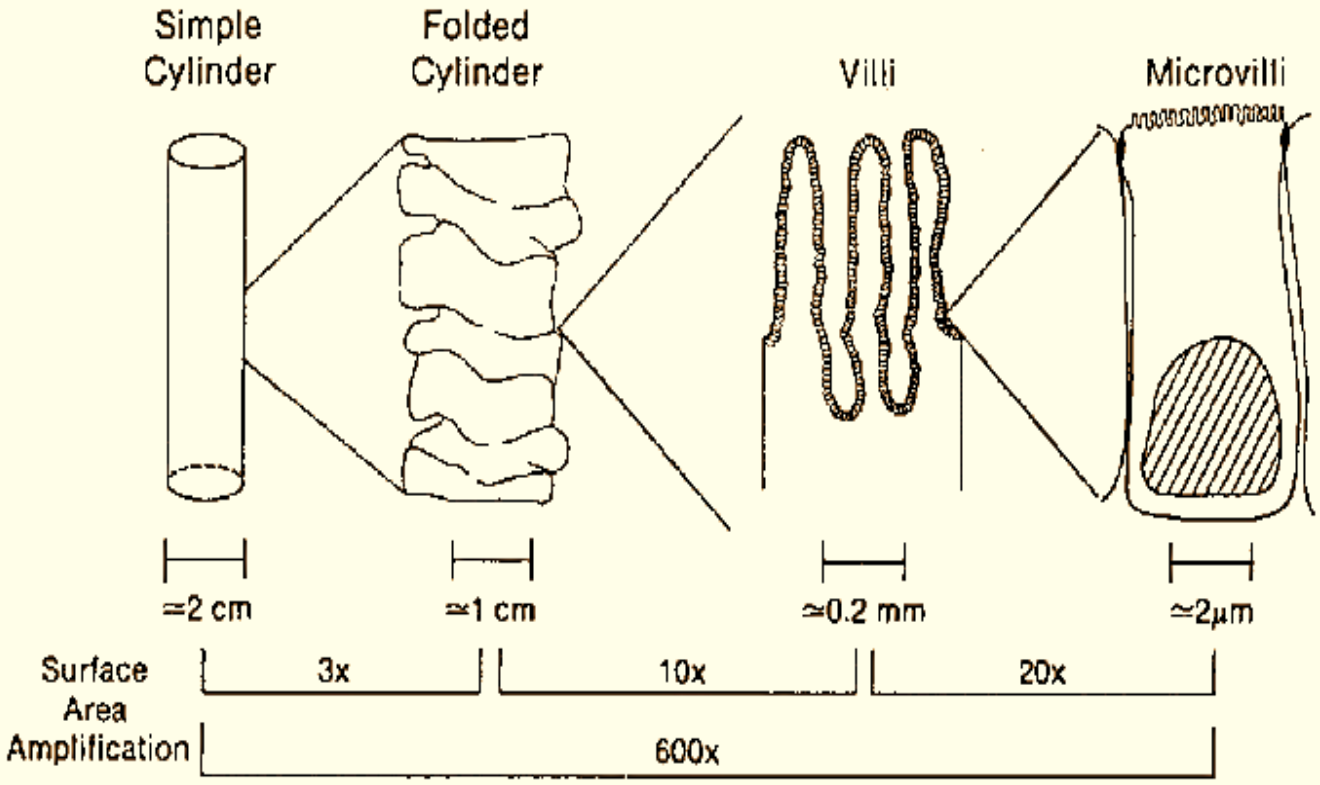


Fig. 42.4. The intestinal surface area is expanded by the presence of intestinal folds (plicae conniventes) and villi. Microvilli further expand the surface area of epithelial cells in contact with luminal contents. These structural features taken together expand the surface area of the small intestine by approximately 600-fold. (Reprinted with permission from Yamada T, Alpers DH, Owyang C et al, eds. Textbook of Gastroenterology. 2nd ed. Philadelphia: JB Lippincott, 1991:327.)

Each day, the small intestine absorbs 150 to 300 g of monosaccharides, 60 to 100 g of fatty acids, 60 to 120 g of amino acids and peptides, and 50 to 100 g of ions.

In the small intestine, all but 1 to 1.5 L of the 7 or 8 L of fluid secreted from the upper portions of the GIT, in addition to 1.5 to 3 L of dietary fluids, is absorbed by the time the contents reach the end of the lumen.

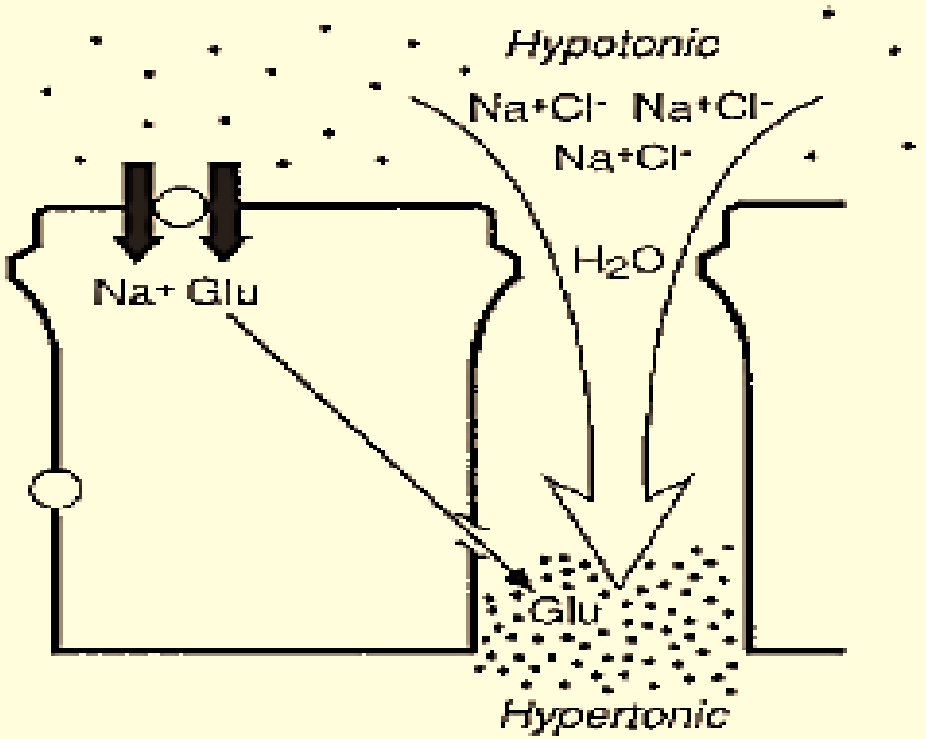
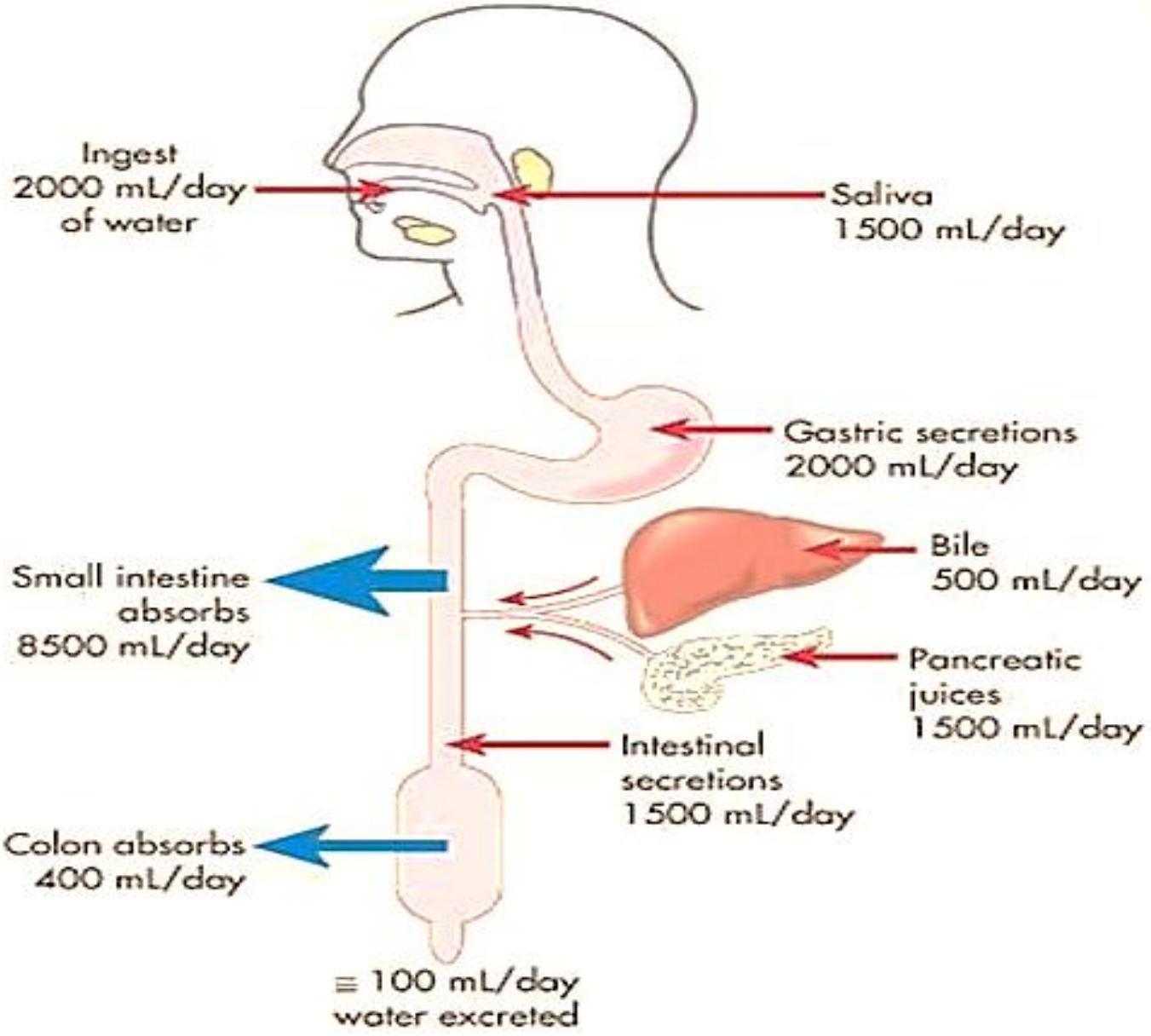


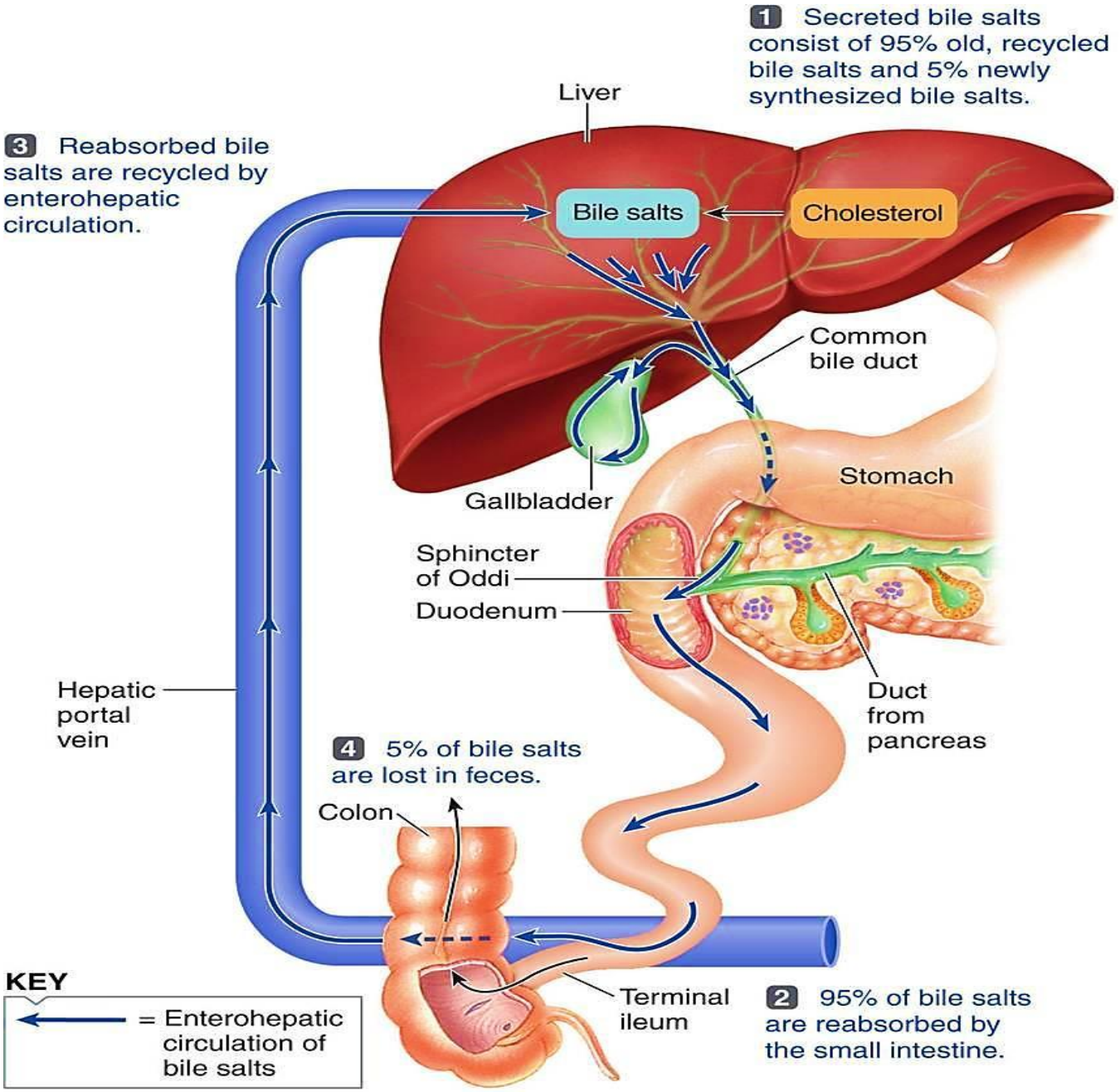
Fig. 42.11. Electrolyte and water absorption in the jejunum. The sodium (Na)–glucose (Glu) cotransporter present in the small intestine binds both sodium and glucose and transports them across the epithelial cell membrane. As glucose accumulates in the cell, it moves along its concentration gradient across the basolateral membrane via a specific transport carrier. Water is absorbed passively by both transcellular and paracellular routes in response to an increase in osmolarity of the intracellular and subepithelial spaces. The Na–nutrient cotransporter shown in this figure and the electroneutral Na chloride (NaCl) exchange transporter are responsible for most water absorption. Water absorbed between epithelial cells can increase the absorption of solutes present in water by "solvent drag."


Ingest
2000 mL/day
of water
Saliva
1500 mL/day
Gastric secretions
2000 mL/day
Bile
500 mL/day
Small intestine
absorbs
8500 mL/day
Pancreatic
juices
1500 mL/day
Intestinal
secretions
1500 mL/day
Colon absorbs
400 mL/day
≡ 100 mL/day
water excreted

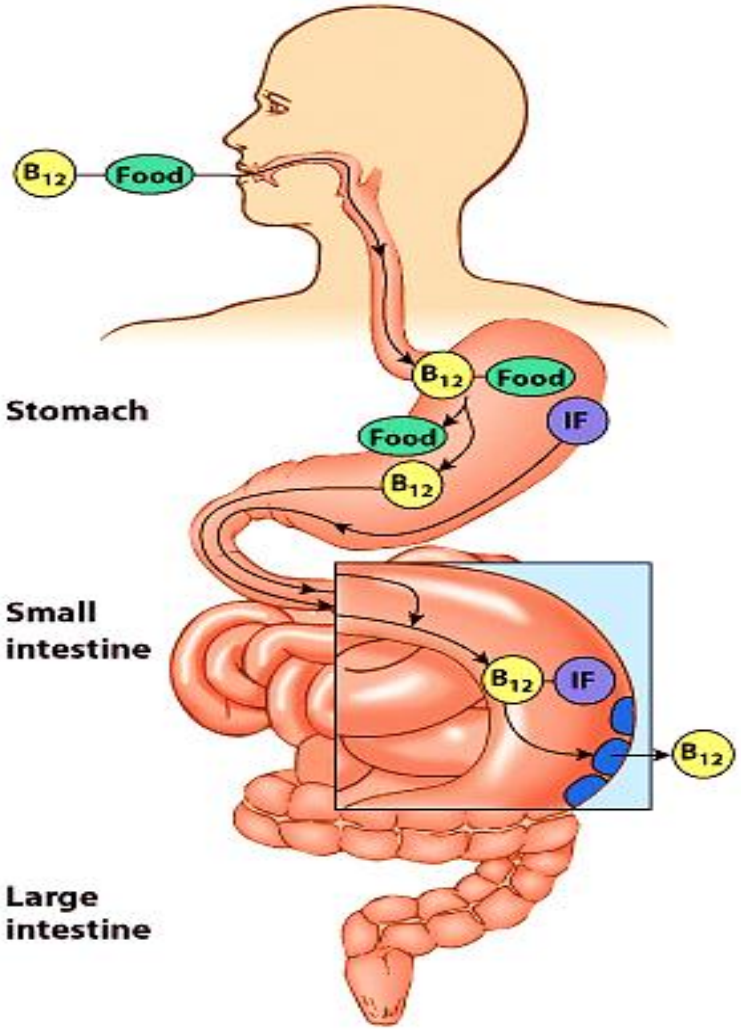
Approximately, **95% of the bile salts are reabsorbed as bile acids in the distal ileum through a process called enterohepatic circulation**.

Without enterohepatic circulation, synthesis of new bile acids in the liver would not keep pace with needs for adequate digestion.

Bile salt insufficiency becomes clinically important in patients who have resections of the distal small bowel and diseases affecting the small intestine, such as Crohn disease, radiation enteritis, and cystic fibrosis.


1 Secreted bile salts consist of 95% old, recycled bile salts and 5% newly synthesized bile salts.
Liver
3 Reabsorbed bile salts are recycled by enterohepatic circulation.
Bile salts
Cholesterol
Common bile duct
Gallbladder
Stomach
Sphincter of Oddi
Duodenum
Duct from pancreas
Hepatic portal vein
4 5% of bile salts are lost in feces.
Colon
Terminal ileum
2 95% of bile salts are reabsorbed by the small intestine.
KEY
= Enterohepatic circulation of bile salts

The distal ileum is also the site for vitamin B12(with intrinsic factor) absorption.



Emulsification of fats is followed by their digestion, by pancreatic lipase, into free fatty acids and 2-monoglycerides.

When the concentration of bile salts reaches a certain level, they form micelles (small aggregates of fatty acids, monoglycerides, cholesterol, bile salts, and other lipids), which are organized with the polar ends of the molecules oriented toward the watery lumen of the intestine.

The products of lipid digestion are rapidly solubilized in the central portion of the micelles and carried to the intestinal brush border.

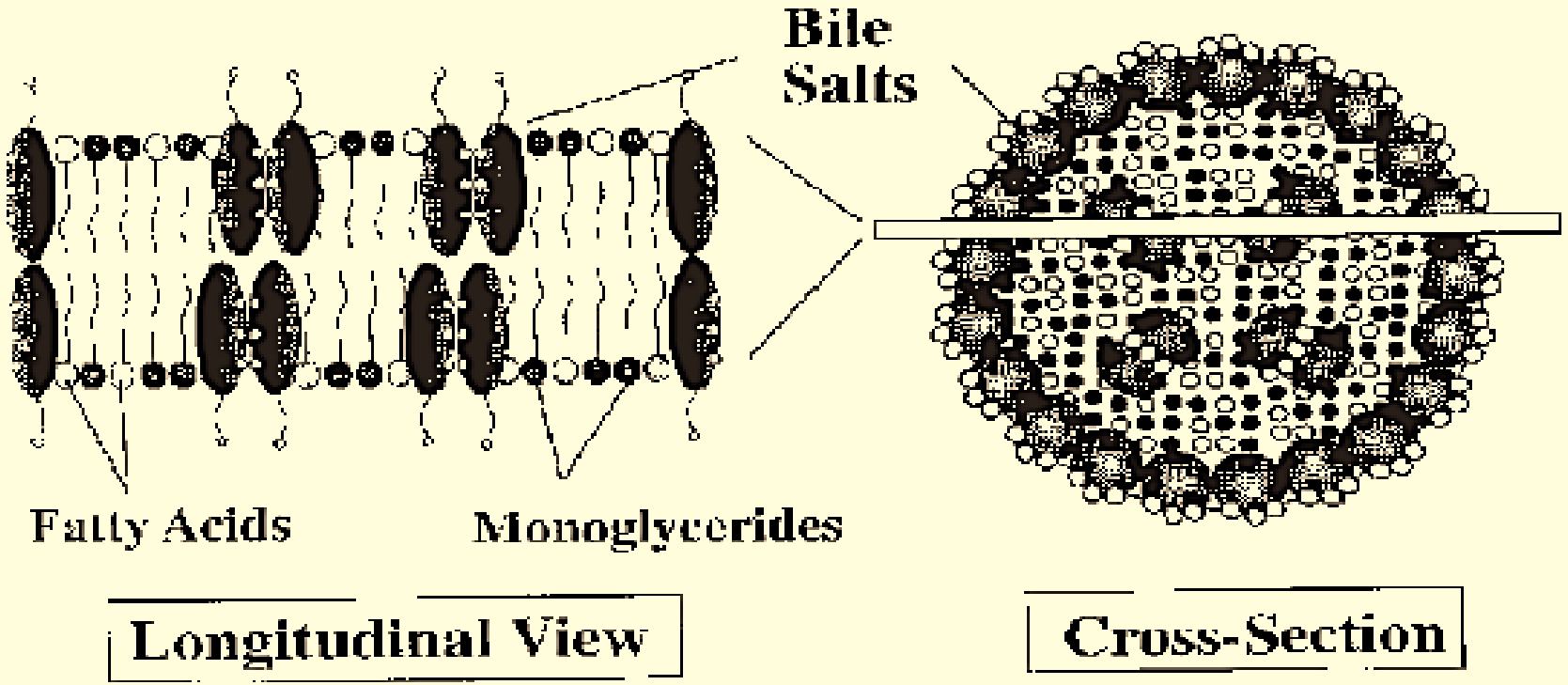


Fig. 42.12. Structure of a mixed lipid–bile salt micelle. The products of lipolysis are solubilized in the interior of the particle. The bile salt molecules orient with their hydroxyl groups *(black circles)* facing the aqueous phase or when they are in the interior of the micelle, facing each other. Fatty acids and monoglycerides orient in the micelle with their polar head groups in contact with the aqueous phase and their hydrocarbon tails in the interior of the micelle. (Reprinted with permission from Chang EB, Sitrin MD, Black DD, eds. Gastrointestinal, Hepatobiliary, and Nutritional Physiology. Philadelphia: Lippincott-Raven, 1996:147.)

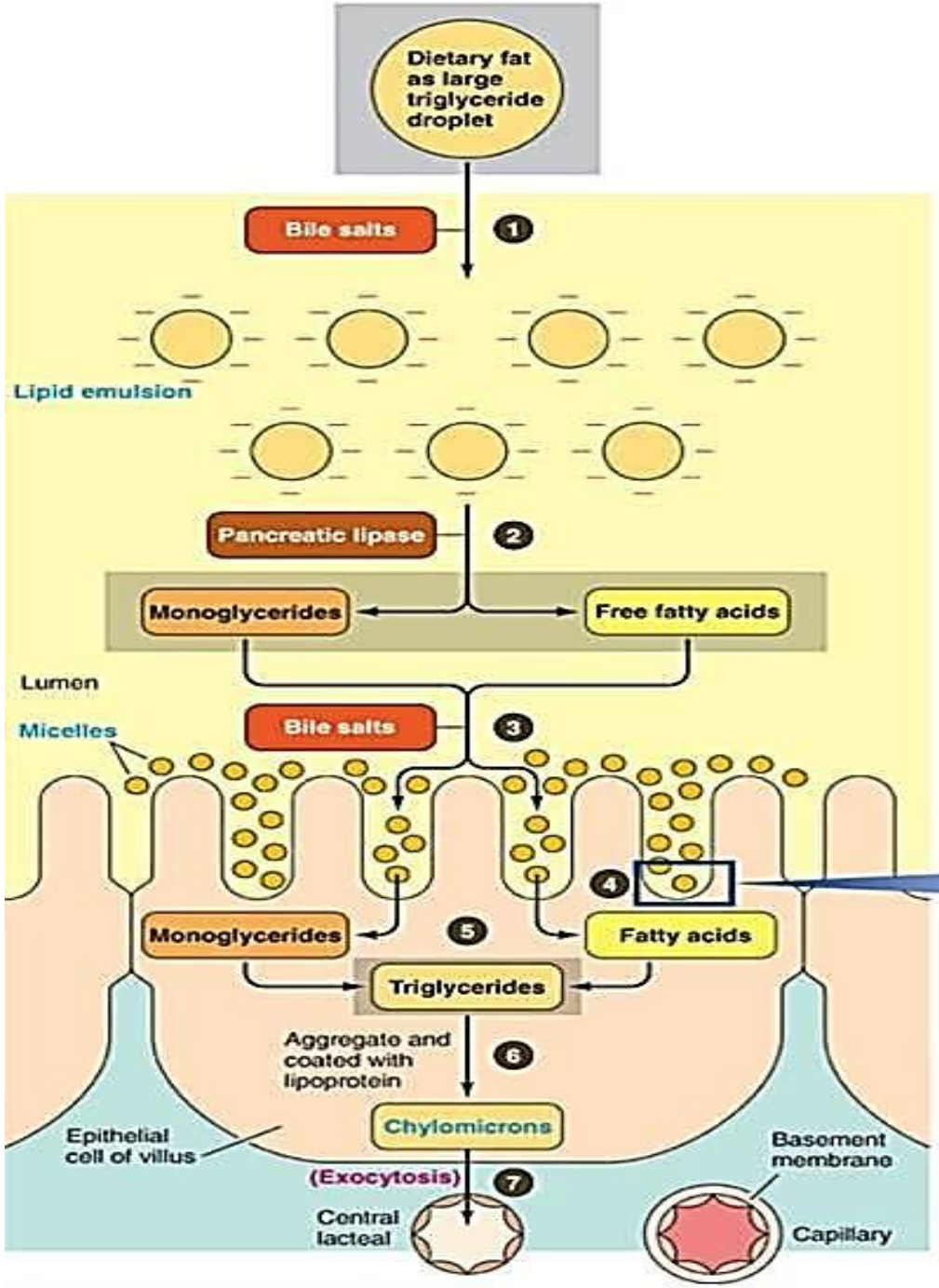
At the surface of the unstirred water layer (UWL), the slightly acidic and watery plate that forms a boundary between the intestinal lumen and the brush border membranes, **the lipids detach from the micelles**.

Remnants of the micelles return to the lumen for further transport, while the monoglycerides and fatty acids are left to make their way across the lipophobic UWL to the more lipid-friendly membrane cells of the brush border.

Lipids are taken up and transported through the endoplasmic reticulum and Golgi apparatus where fatty acids are re-esterified to triglyceride.

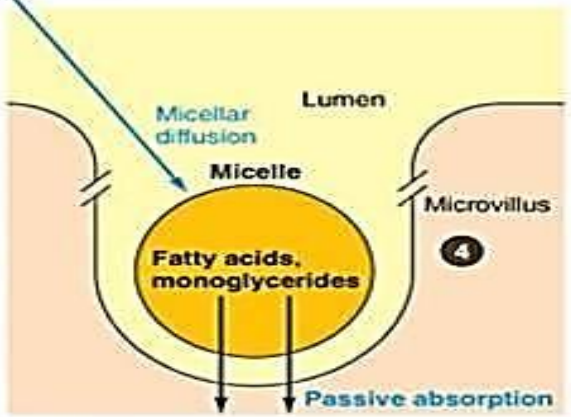
Triglycerides are packaged, along with other lipids, into chylomicrons, which are released into the lymphatic circulation.

Cholesterol absorption is facilitated by a protein transport system specific to cholesterol and not to other sterols.

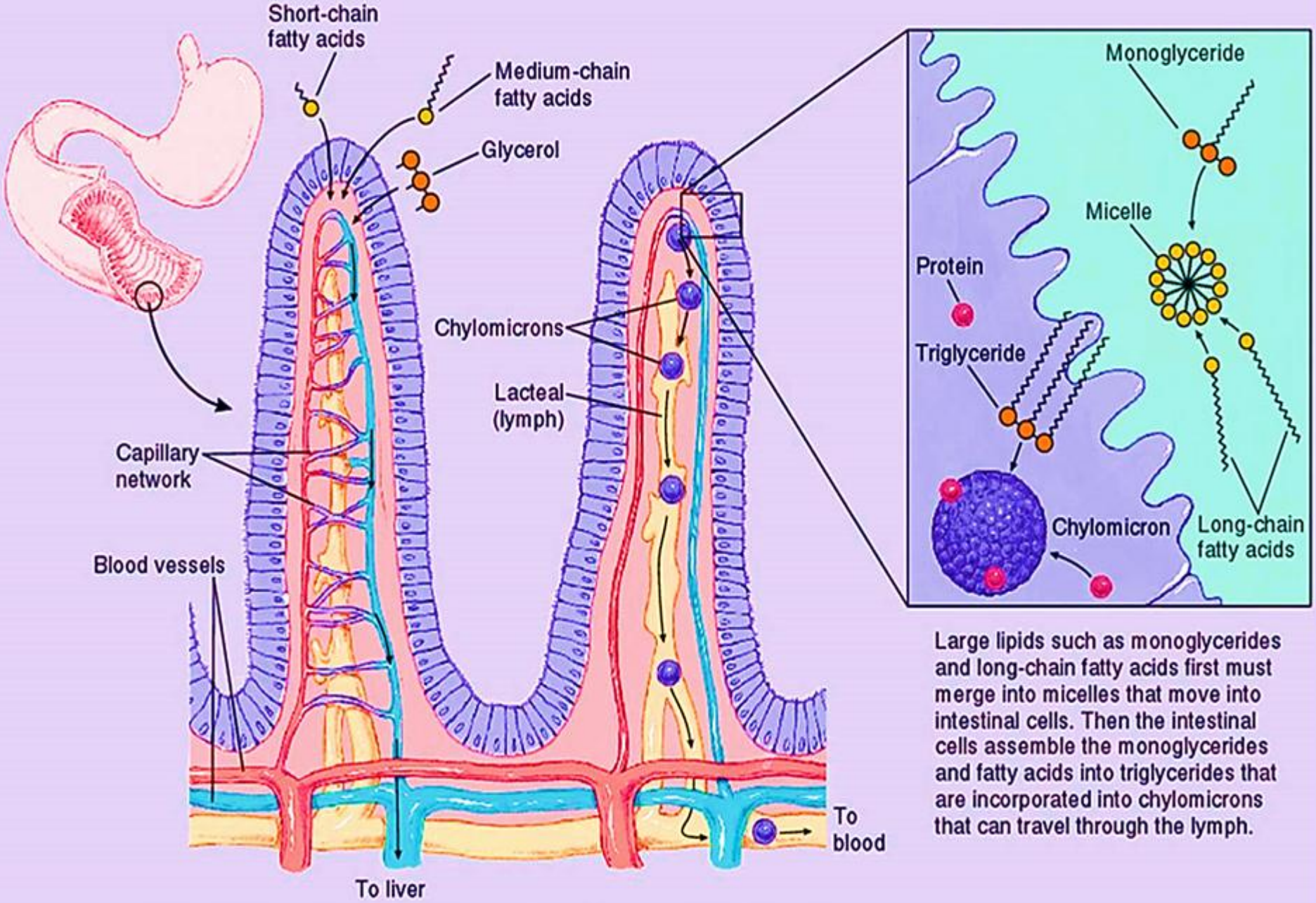


Because fat is not soluble in water, it must undergo a series of transformations in order to be digested and absorbed.

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 triglycerides into monoglycerides and free fatty acids.
3. These water-insoluble products are carried in the interior of water-soluble micelles, which are formed by bile salts and other bile constituents, to the luminal surface of the small intestine epithlial cells.
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.



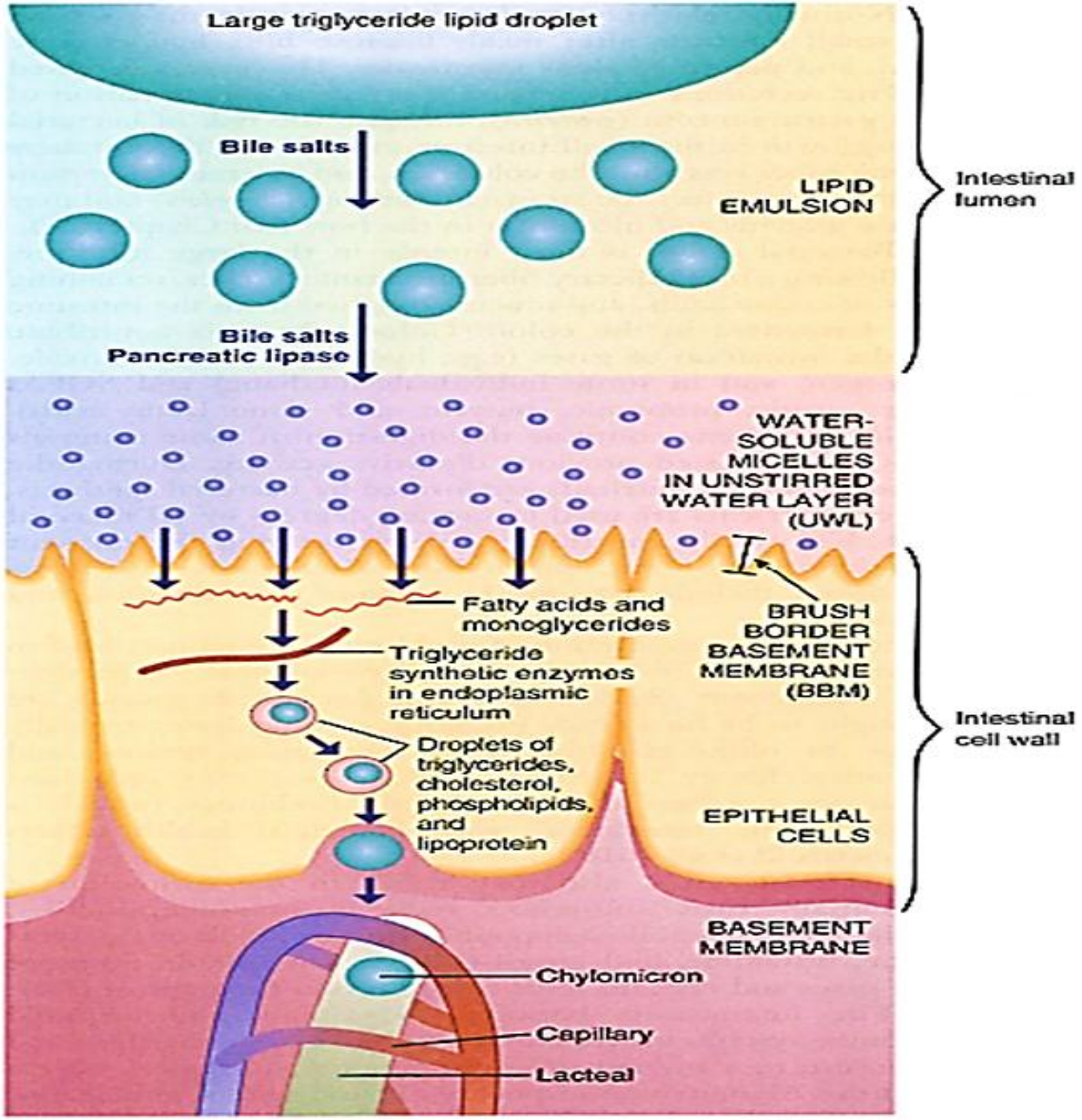
6. These triglycerides aggregate and are coated with a layer of lipoprotein to form water-soluble chylomicrons, which are extruded through the basal membrane of the cells by exocytosis.
7. Chylomicrons are unable to cross the basement membrane of blood capillaries, so instead they enter the lympathic vessels, the central lacteals.



Large lipids such as monoglycerides and long-chain fatty acids first must merge into micelles that move into intestinal cells. Then the intestinal cells assemble the monoglycerides and fatty acids into triglycerides that are incorporated into chylomicrons that can travel through the lymph.

The end products of fat digestion are mostly monoglycerides, some fatty acids, and very little glycerol. Glycerol and short- and medium-chain fatty acids can move directly into the bloodstream.

FIGURE 1-4 Summary of fat absorption.

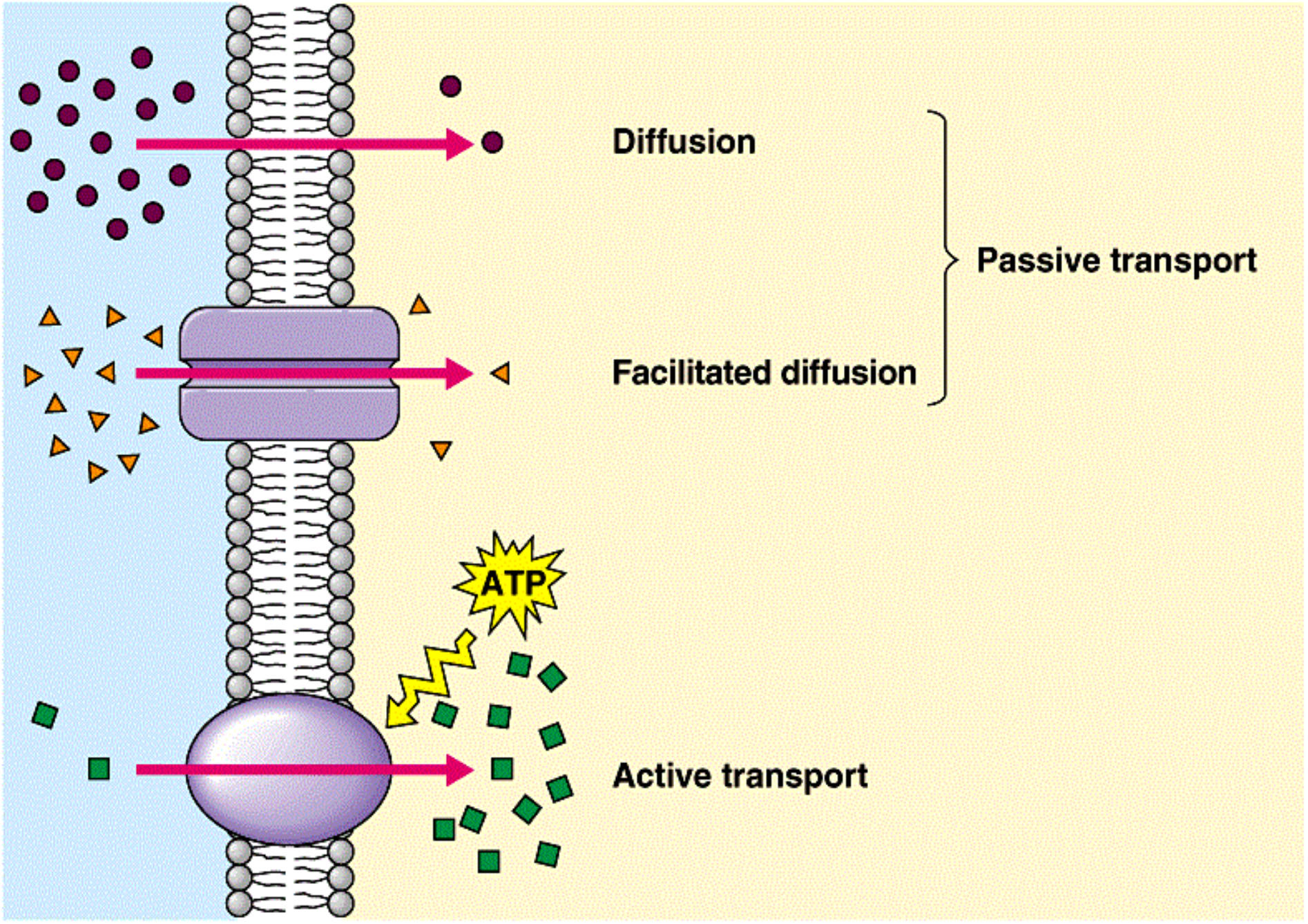


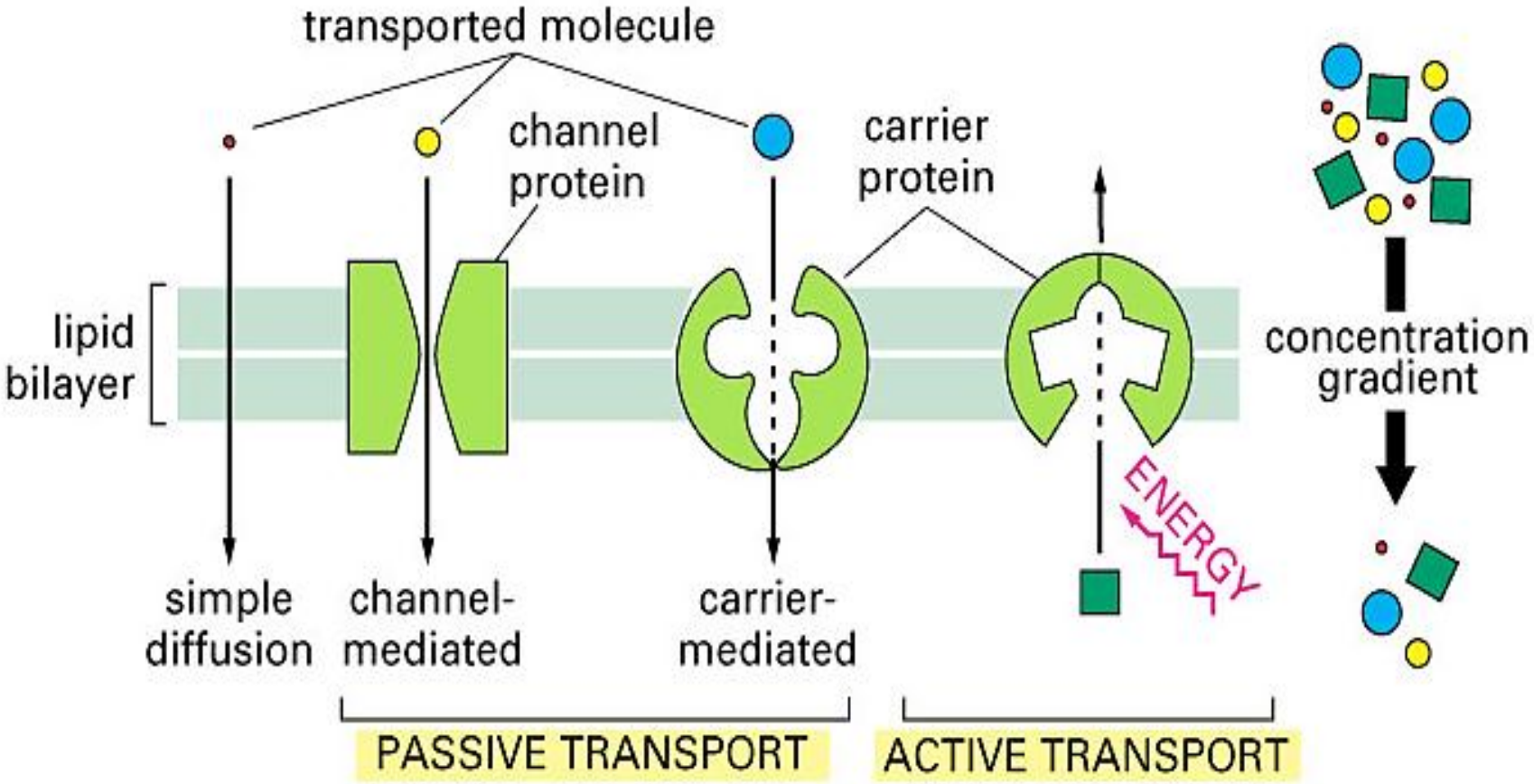
Absorptive and Transport Mechanisms

In absorption, nutrients pass through the intestinal mucosal cells by diffusion or active transport and make their way into the venous system or into the lymphatic circulation.

Diffusion involves random movement through openings in or between the membranes of the cells using channel proteins (passive diffusion) or carrier/transport proteins (facilitated diffusion).

Active transport involves the input of energy to move ions or other substances, in combination with a transport protein, across a cell membrane against an energy gradient.


Diffusion
Passive transport
Facilitated diffusion
ATP
Active transport


transported molecule
channel protein
carrier protein
lipid bilayer
concentration gradient
ENERGY
simple diffusion
channel-mediated
carrier-mediated
PASSIVE TRANSPORT
ACTIVE TRANSPORT

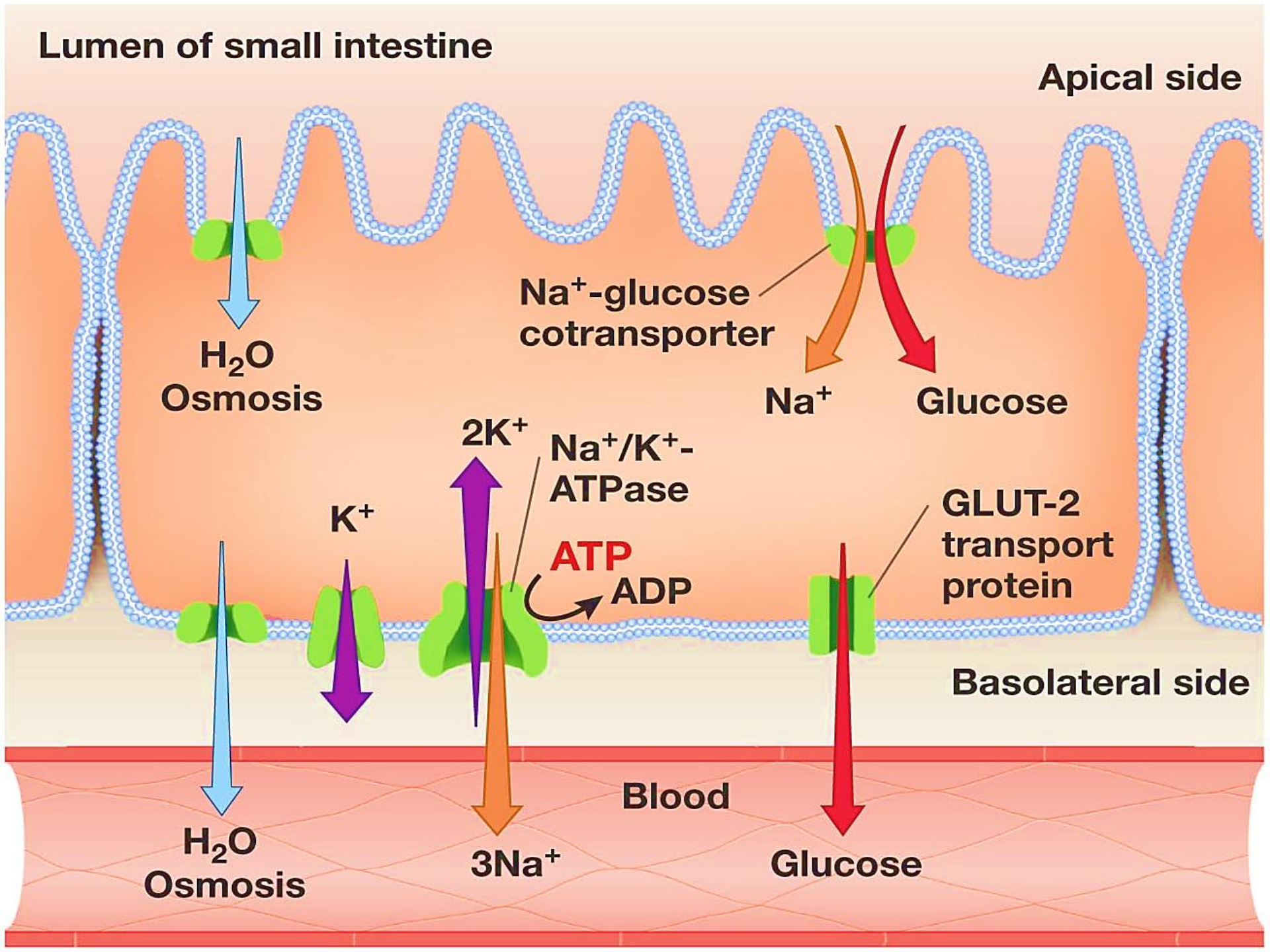
Some nutrients may share the same carrier and thus compete for absorption.

Transport or carrier systems can also become saturated, slowing the absorption of the nutrient.

A notable example of such a carrier is intrinsic factor, which is responsible for the absorption of vitamin B_{12}.

Some molecules are moved from the intestinal lumen into mucosal cells by means of pumps (e.g. Na-K pump), which require a carrier and energy from adenosine triphosphate.

The absorption of glucose, sodium, galactose, potassium, magnesium, phosphate, iodide, calcium, iron, and amino acids occurs in this manner.


Lumen of small intestine
Apical side
H_2O
Osmosis
Na^+-glucose
cotransporter
Na^+
Glucose
$2K^+$
Na^+/K^+-
ATPase
K^+
ATP
ADP
GLUT-2
transport
protein
Basolateral side
Blood
H_2O
Osmosis
$3Na^+$
Glucose

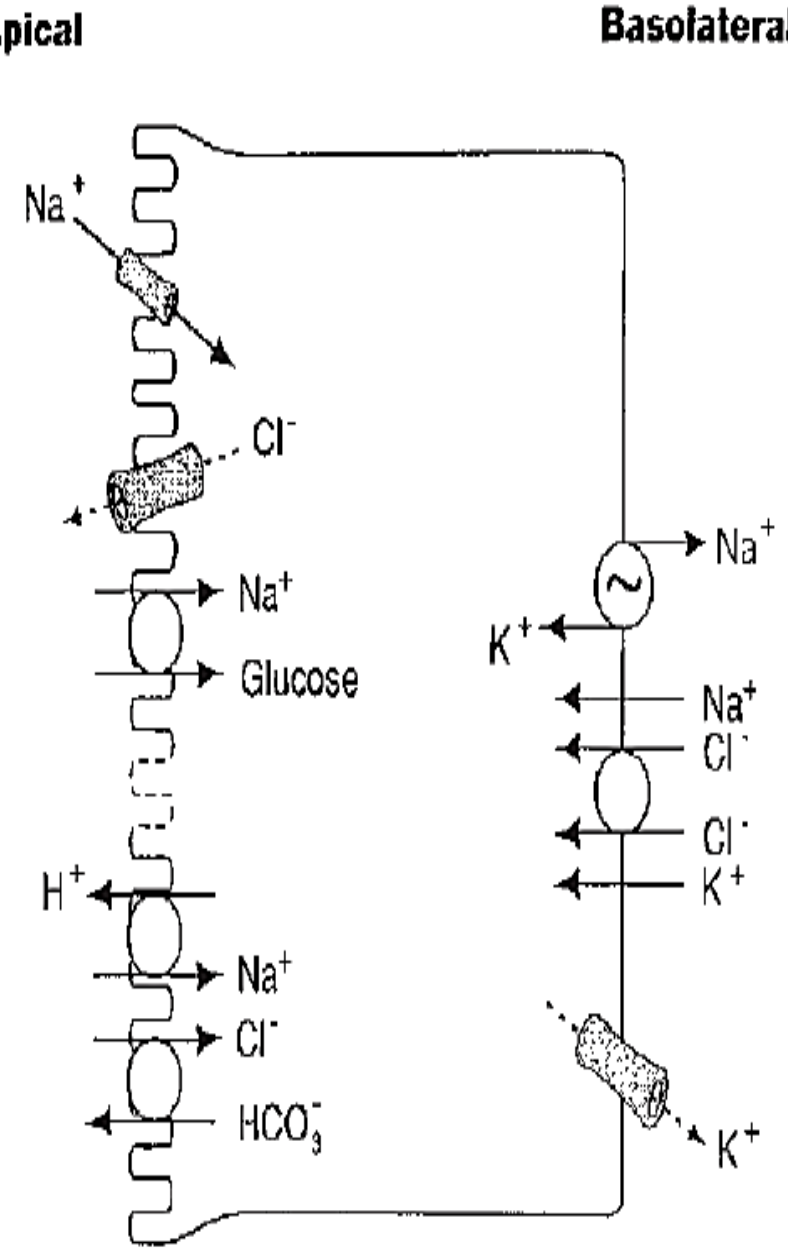
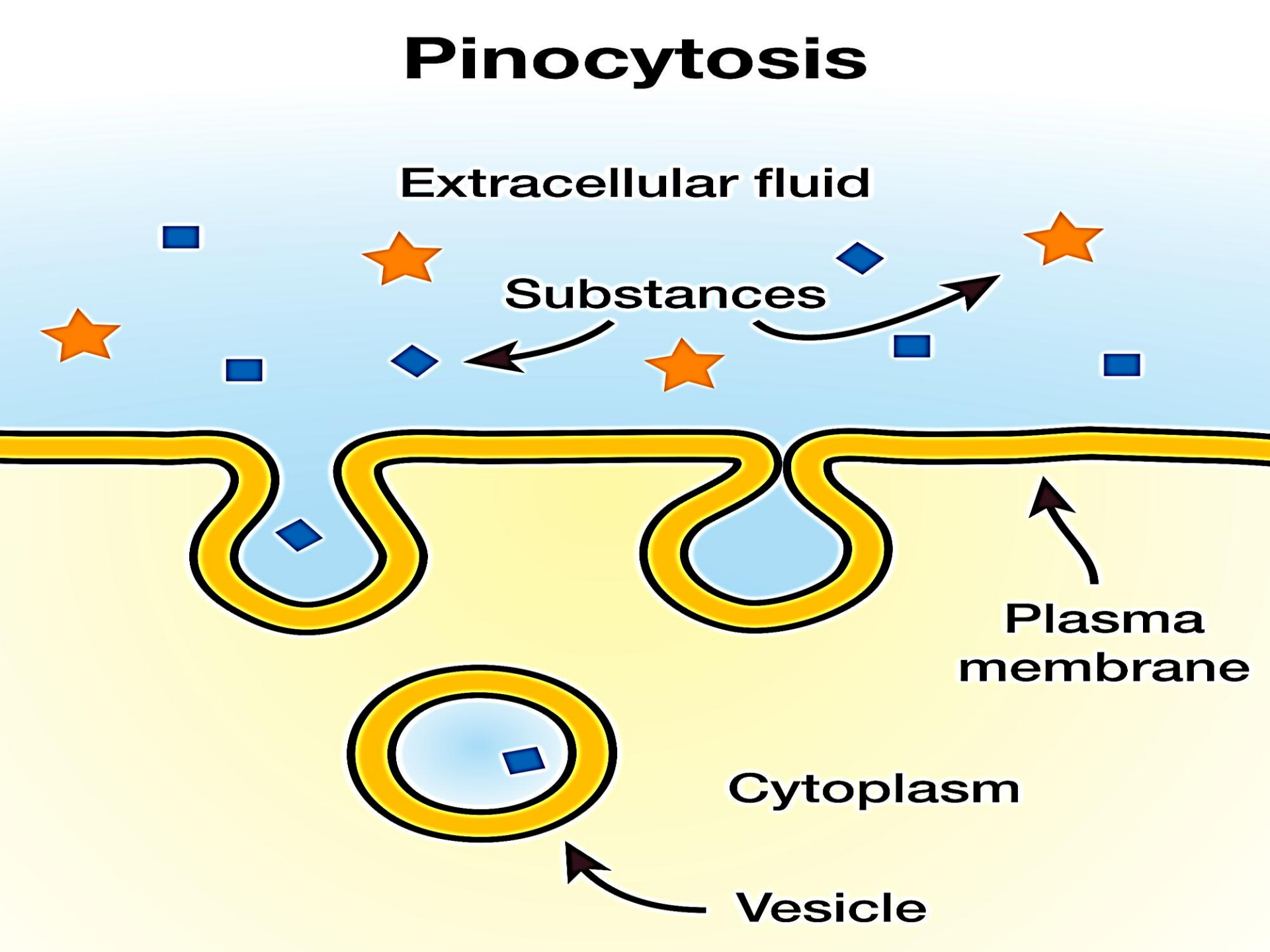


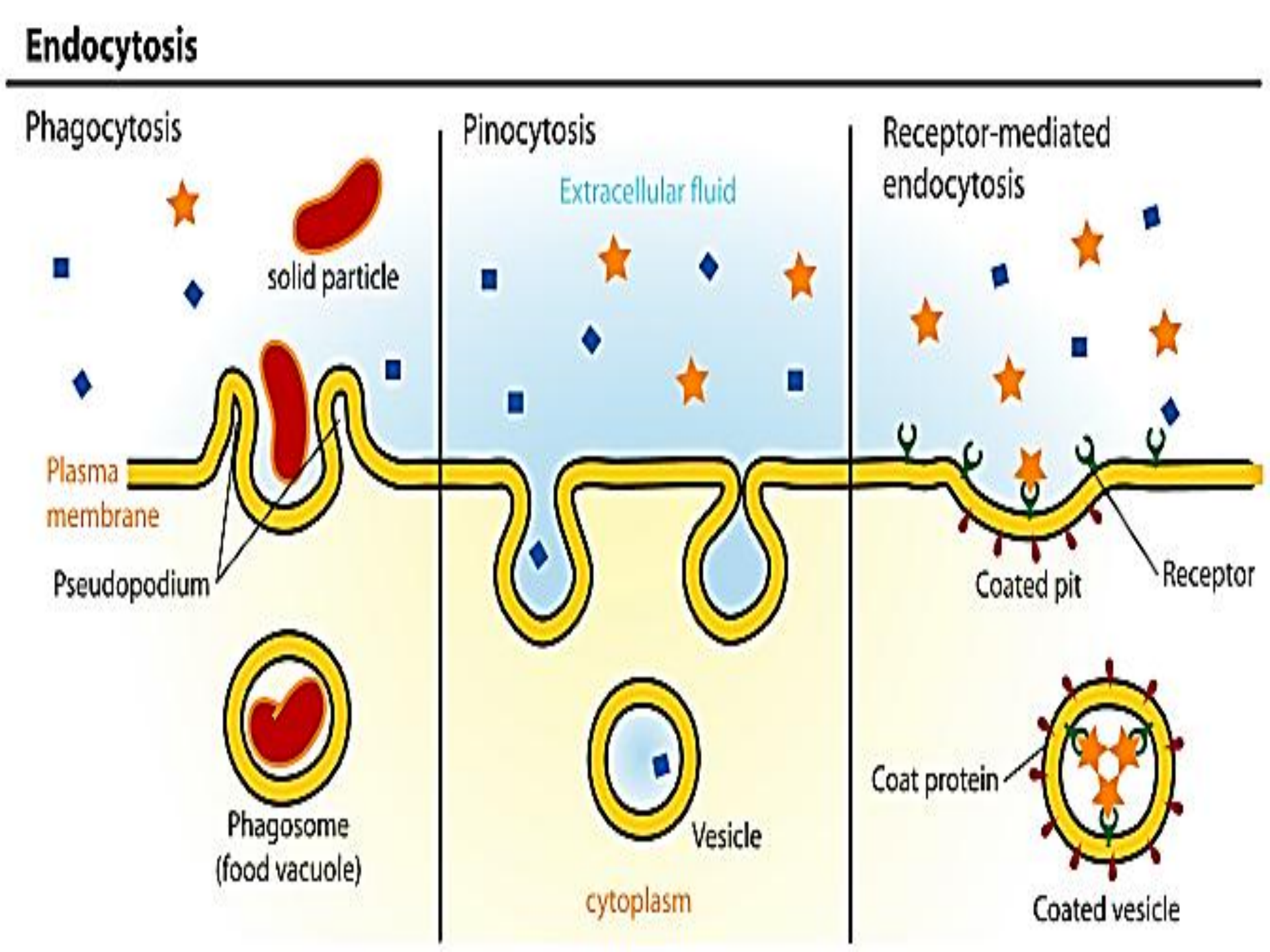
Fig. 42.10. Electrolyte and solute absorption. Sodium can travel from the intestinal lumen into the epithelial cell by (a) an ion channel (apical side **top**), (b) the sodium (Na^+)-glucose cotransporter (apical side **middle**), or (c) an Na^+-hydrogen (H) exchanger (apical side **bottom**). The release of H creates a favorable gradient for bicarbonate (HCO_3) exit, which facilitates chloride (Cl) entry through the Cl/HCO_3 exchanger. The Na/potassium (K)/Cl cotransporter in the basolateral membrane also increases Cl uptake. Electrogenic Cl secretion occurs via a Cl channel on the apical membrane. Intracellular glucose accumulation favors glucose transport across the basolateral membrane via a specific carrier protein. The Na pump (Na/K-adenosine triphosphatase [ATPase]) provides the energy for these processes by generating low intracellular Na concentrations and a transmembrane electrochemical gradient. (Reprinted with permission from Sleisinger MH, Fordtran JS, Scharschmidt BF et al, eds. Gastrointestinal Disease. 5th ed. Philadelphia: WB Saunders, 1993:954–76.)

Pinocytosis (a form of endocytosis) is another kind of active transport that allows large particles such as whole proteins (which sometimes have allergenic properties) to be absorbed in small quantities in the GIT.

The immunoglobulins from breast milk are probably absorbed through pinocytosis.


Pinocytosis
Extracellular fluid
Substances
Plasma membrane
Cytoplasm
Vesicle

Endocytosis



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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.
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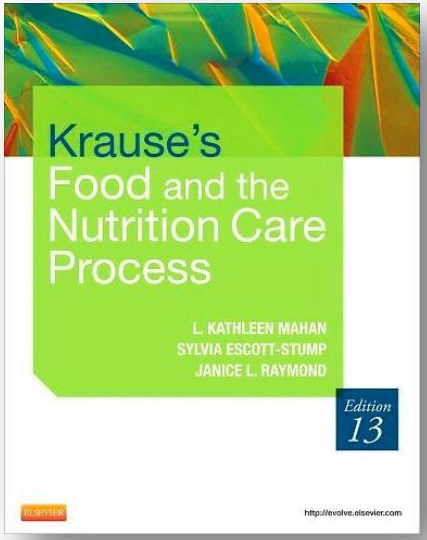
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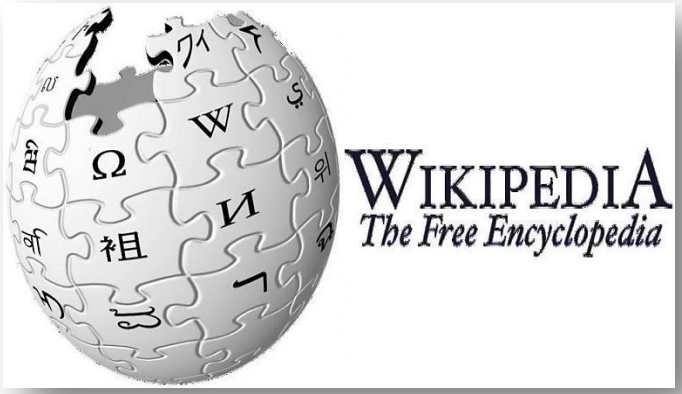
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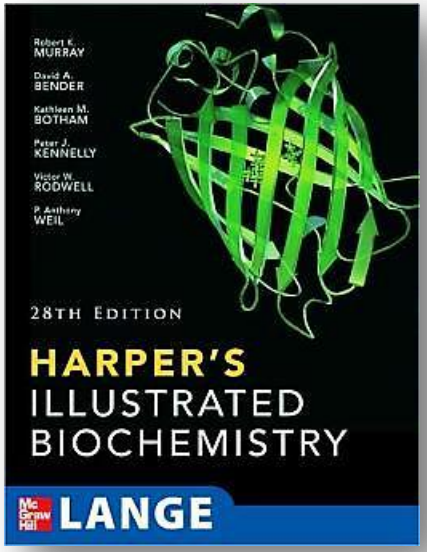
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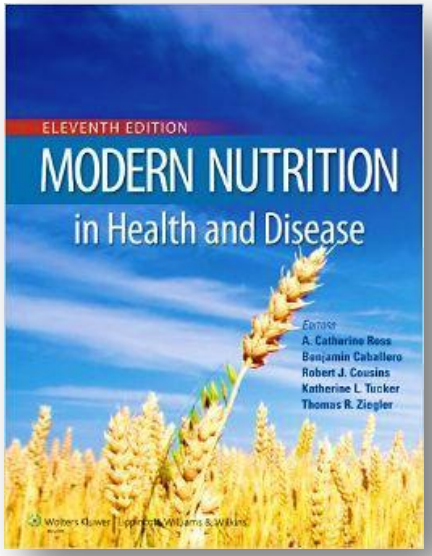
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