Chapter 5
Digestion and Absorption

- Describe the functions of the gastrointestinal system and list its anatomical components and structures
- Describe the digestion processes of carbohydrate, fat, and protein
- Describe the absorption processes of carbohydrate, fat, and protein
- Describe the absorption process of water
- Describe the absorption processes of vitamins and minerals
- Describe the factors that regulate gastric emptying
- State the approximate transit times within each compartment of the gastrointestinal tract
- **Describe the effects of exercise on gastric emptying and absorption**
- **Describe the gastrointestinal problems that may occur during exercise and know which factors may augment or reduce these problems**

Lecture Breakdown

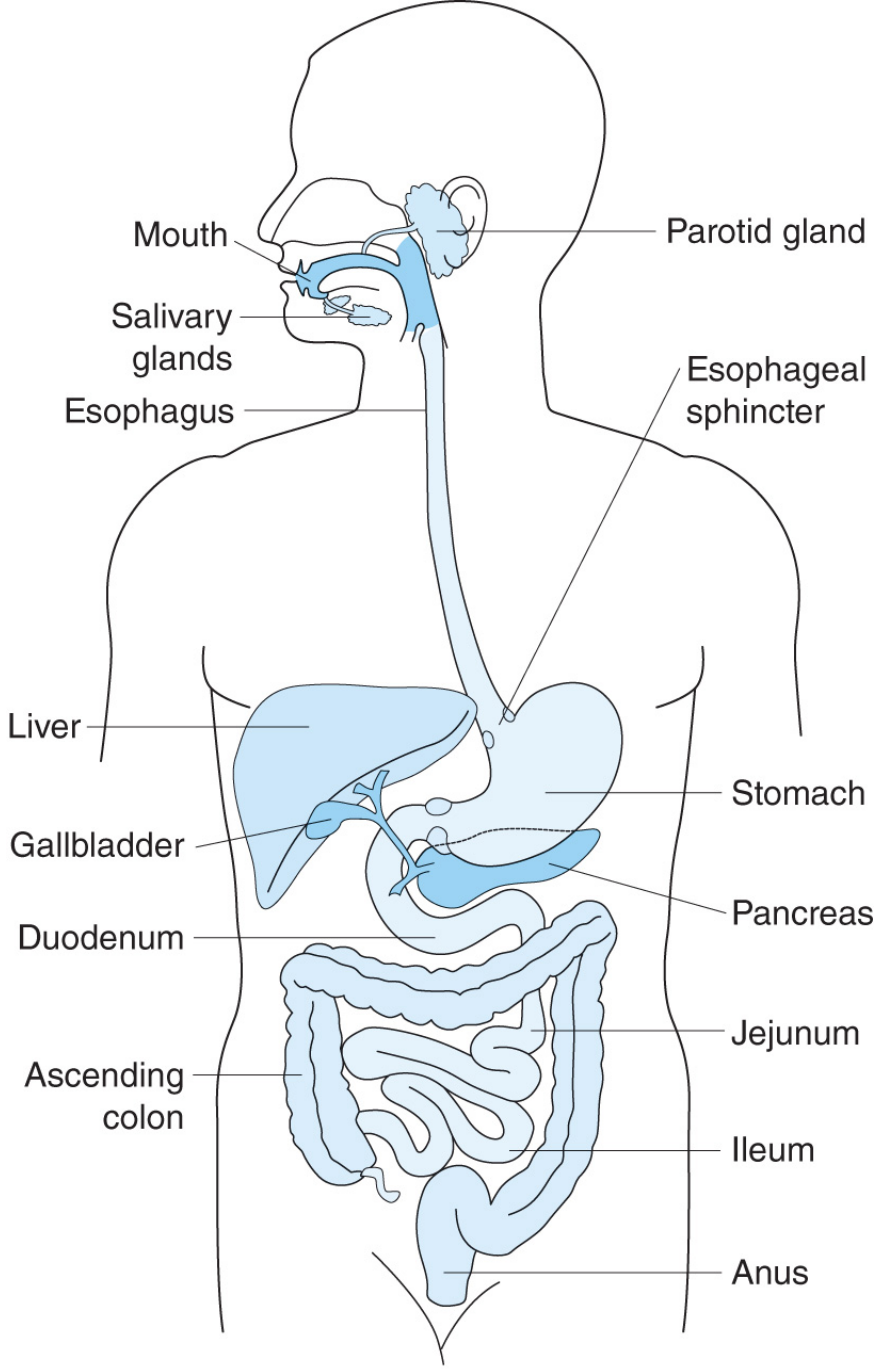
- Part 1 – Anatomy/Functions of GI Tract
- Part 2 – Digestion (CHO, FAT, PRO)
- Part 3 – Absorption (CHO, FAT, PRO)
- Part 4 – Absorption of Water, Vitamins, & Minerals
- Part 5 – Gastric Emptying & Digestive Problems

Part 1

Anatomy of GI Tract and Function of GI Organs

Function of GI Tract

- The primary function of the gastrointestinal (or alimentary) tract is to provide the body with nutrients
- GI tract is a 6 to 8 m long tubular structure that reaches from the mouth to the anus



Digestion & Absorption

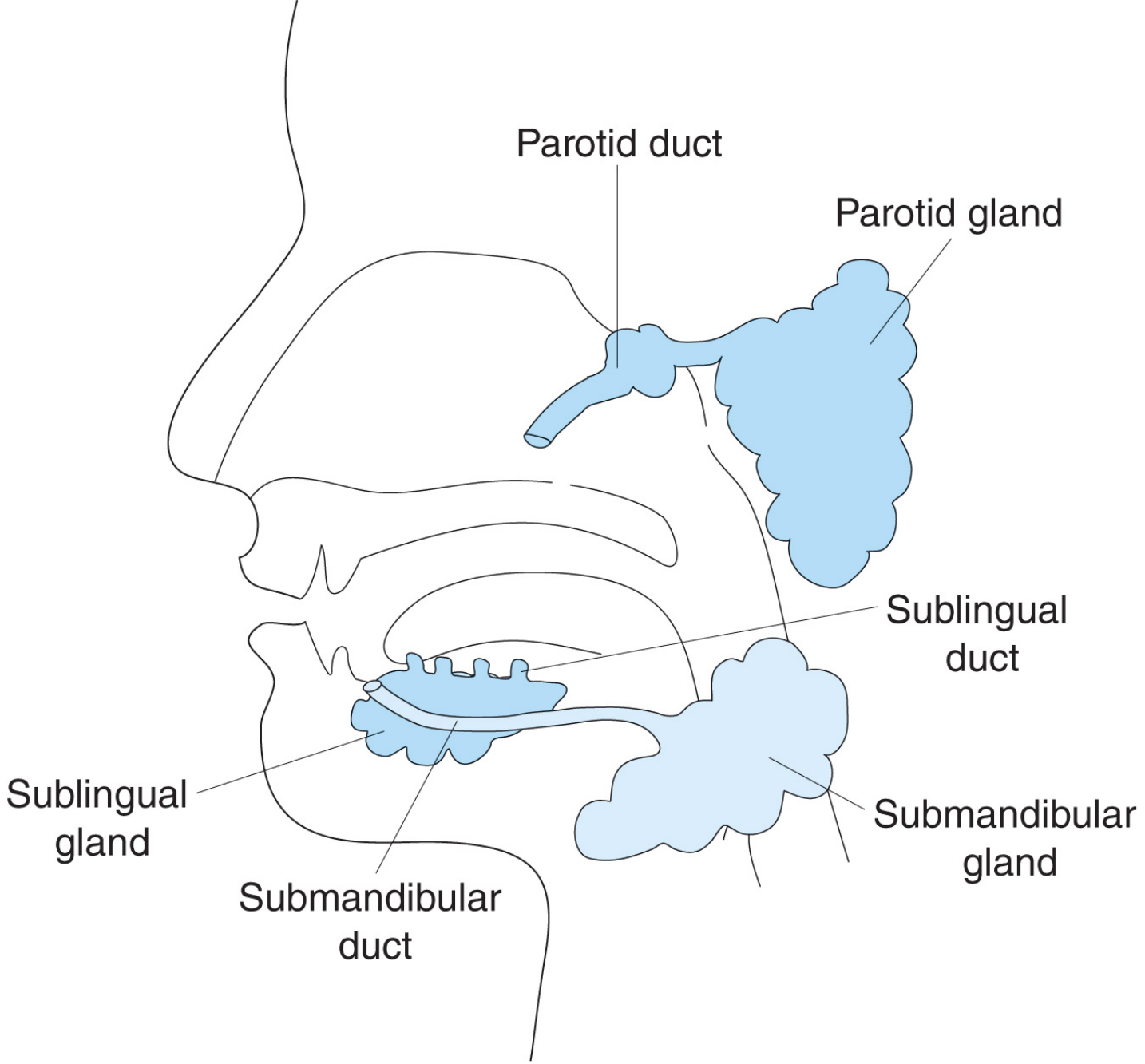
- Mouth, stomach, pancreas and gallbladder have predominantly digestive function
- Most of the absorption occurs in the SI and LI
- From there nutrients travel to liver and then enter main circulation

Functions of GI Organs

Mouth	→	Mechanical digestion (Mastication)
Salivary Glands	→	Secretion of salivary fluids
Esophagus	→	Moves food particles (bolus) via peristalsis
Stomach	→	Storage, mixing with HCL and proteases (enzymes that breakdown protein), regulation of emptying
Pancreas	→	Secretion of NaCHO3 (Sodium Bicarbonate) & digestive enzymes for carbs, protein, and fat
Liver	→	Secretion of bile acids
Gallbladder	→	Temporary storage & concentration of bile
Small Intestine	→	Digestion of food, absorption of water, nutrients & electrolytes (D, J, I)
Large Intestine	→	Absorption of electrolytes

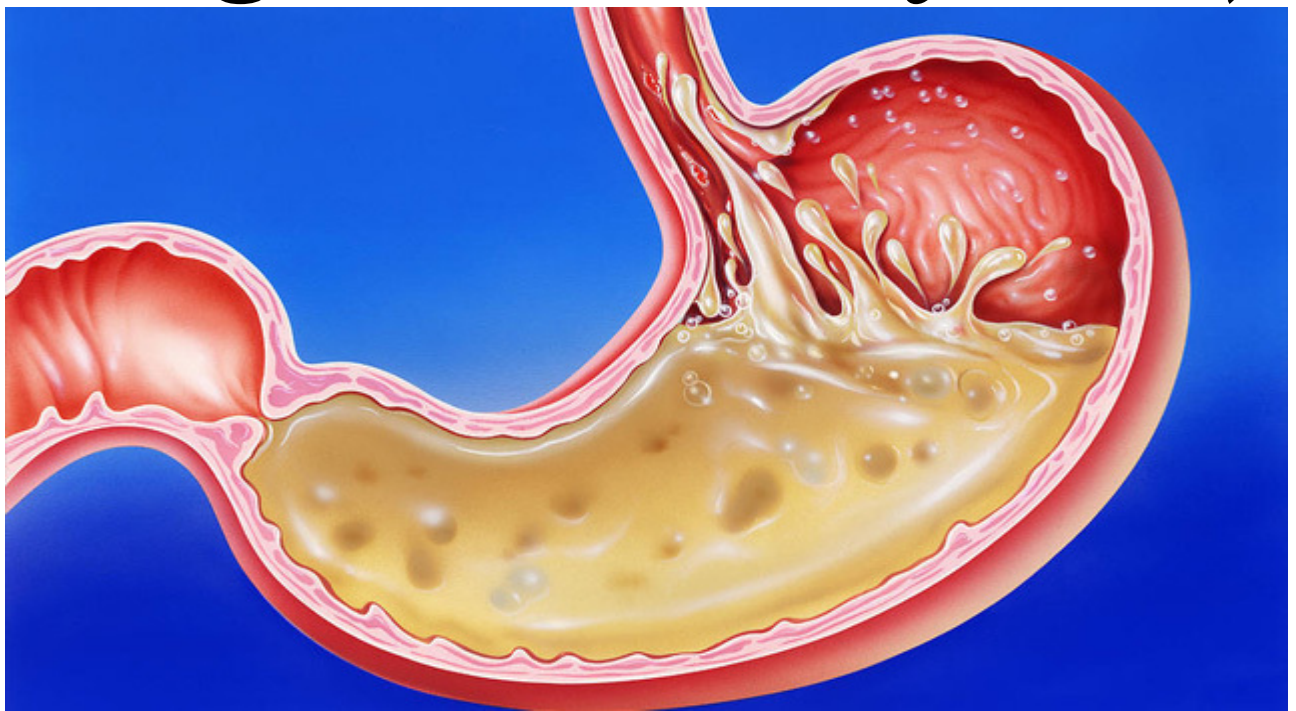
Chewing

- Chewing food reduces the size of the food particles and increases the surface area of the food, thereby increasing the contact area for digestive enzymes.
- Chewing also mixes the food particles with saliva and amylase, a digestive enzyme important in the breakdown of complex carbohydrates.



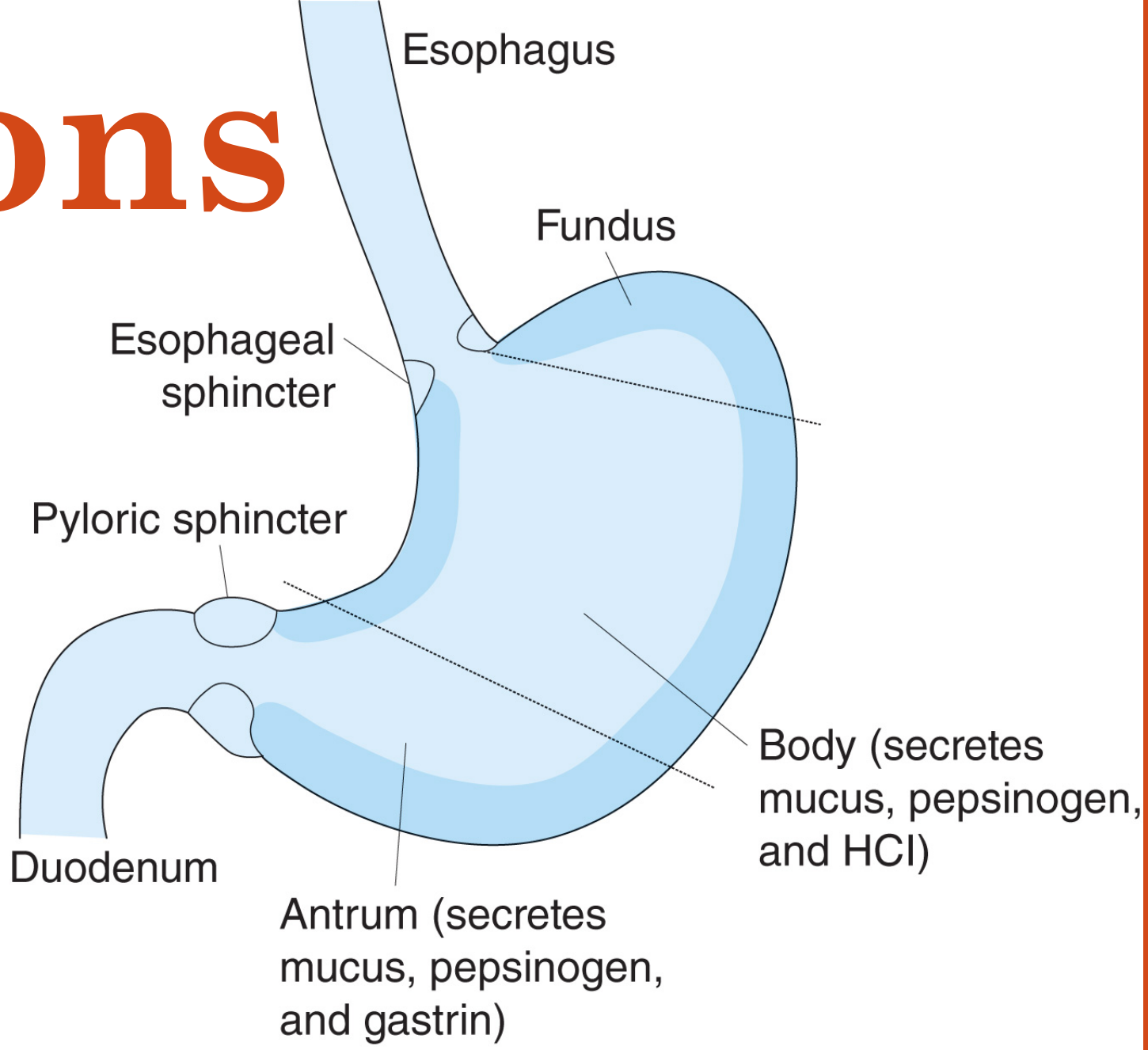
Stomach

- In the stomach, food is mixed with gastric secretions (hydrochloric acid and digestive enzymes)



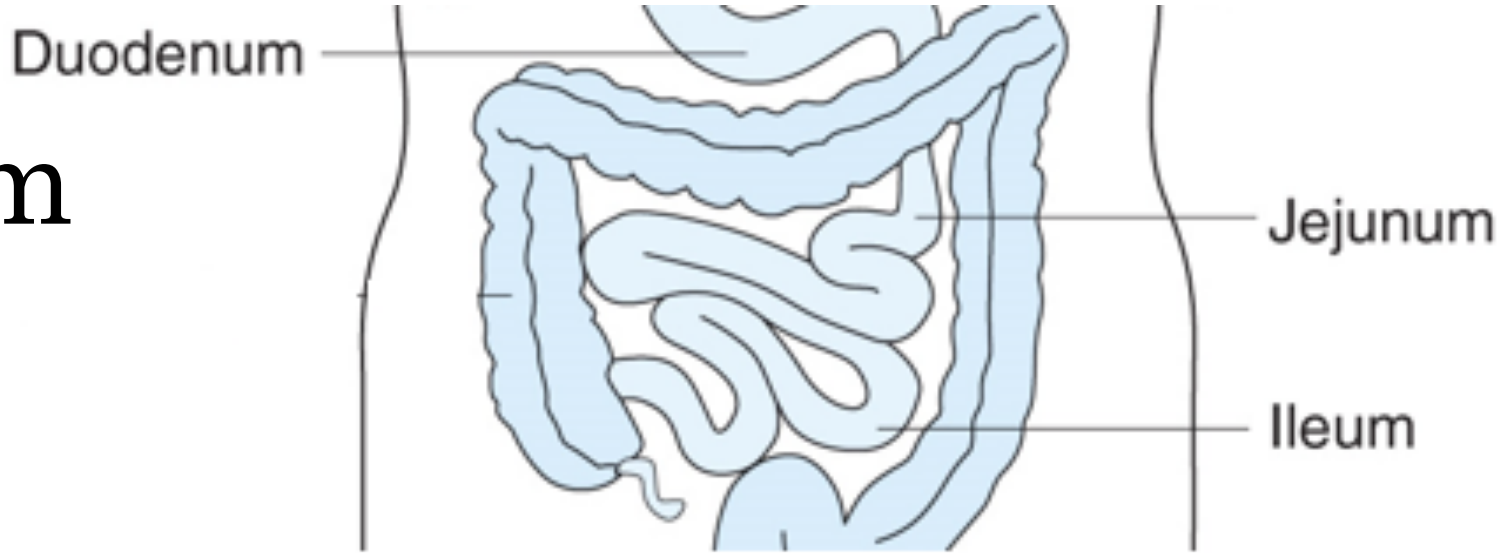
Functions

- Stores food for processing
- Mixes food to form chyme
- Regulates emptying into Duodenum



Small Intestine

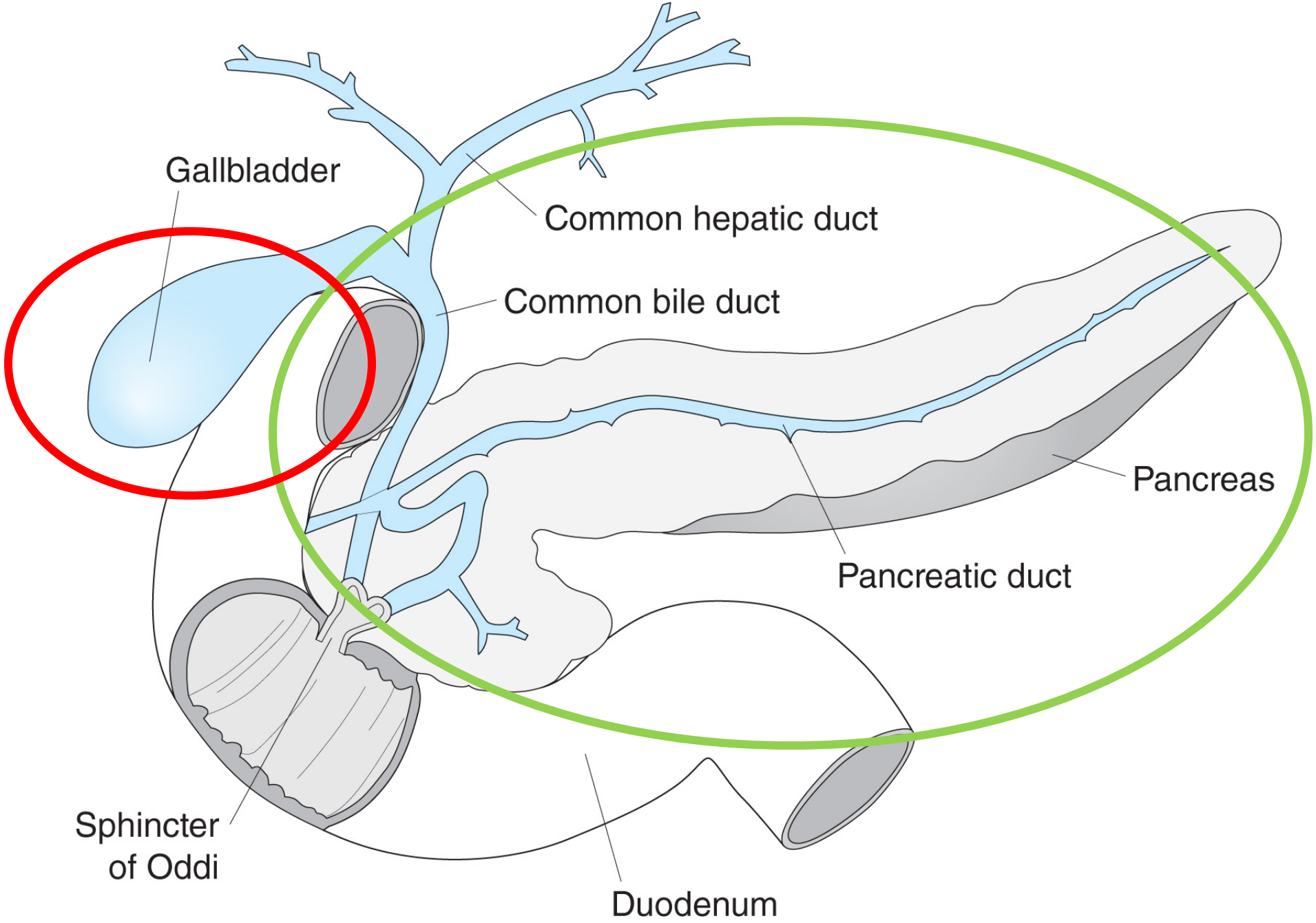
- 3 Parts
  - Duodenum
  - Jejunum
  - Ileum



- About 90% to 95% of all absorption takes place in the **duodenum** and **jejunum**

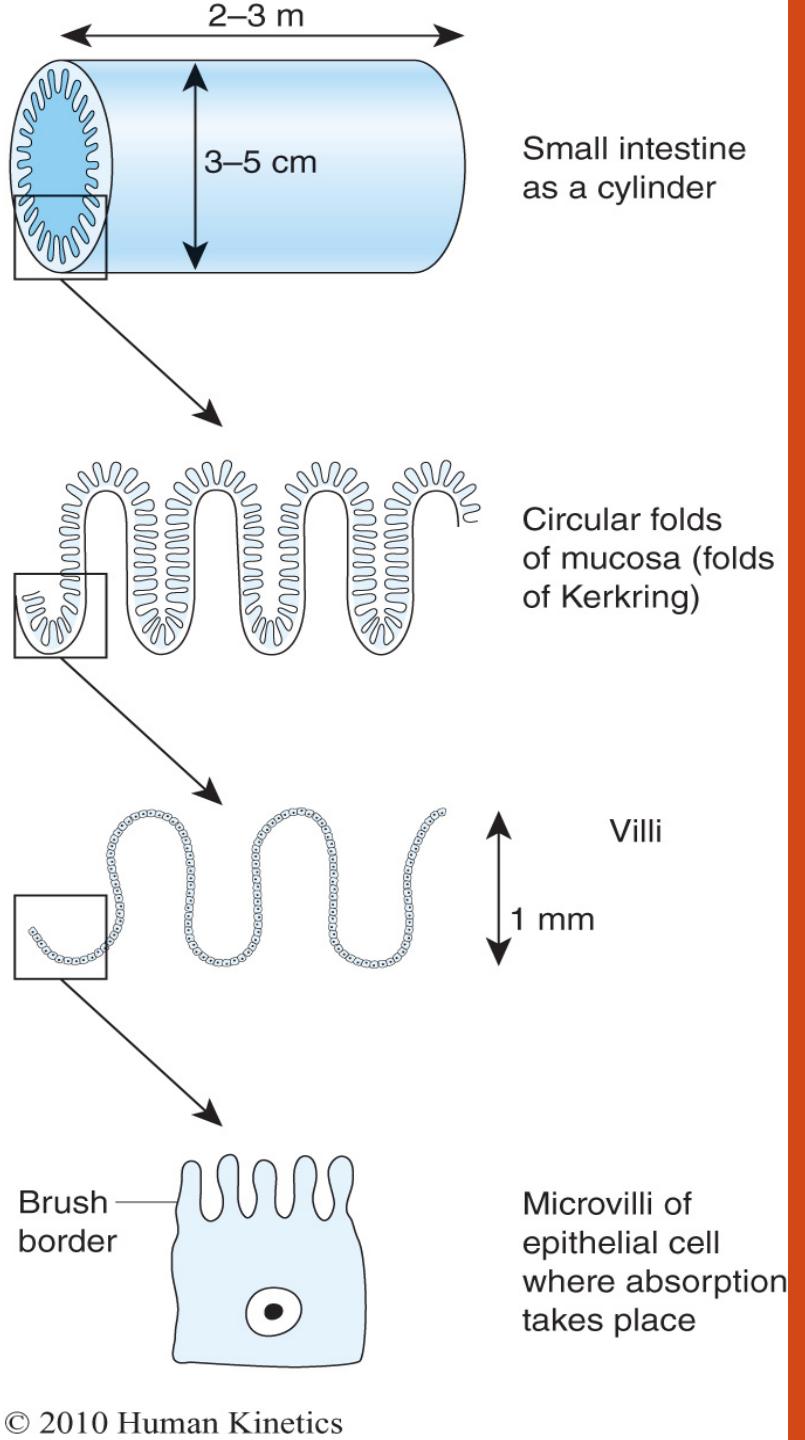
Pancreas

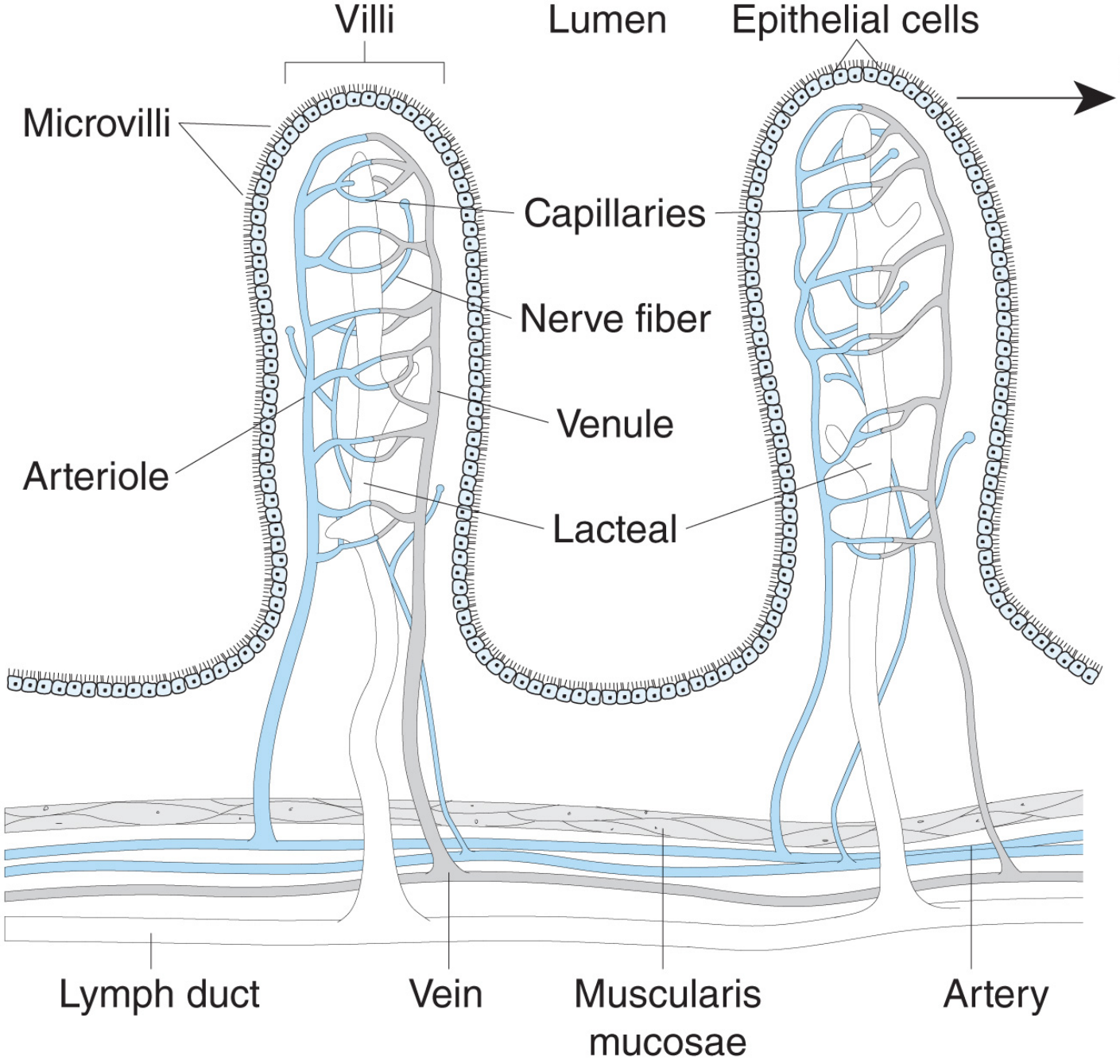
- Pancreatic juices and bile are added to the chyme in the duodenum to digest the carbohydrate, fat, and protein.
- Specialized enzymes split these macronutrients into the smallest subunits for absorption.
- Bile is added to emulsify lipid droplets and facilitate digestion and absorption.

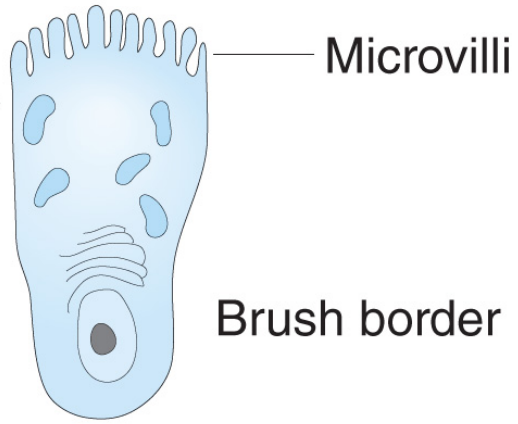


Small Intestine

- Villi and Microvilli increase surface area ~600 fold
- Absorptive surface is larger than the size of a tennis court





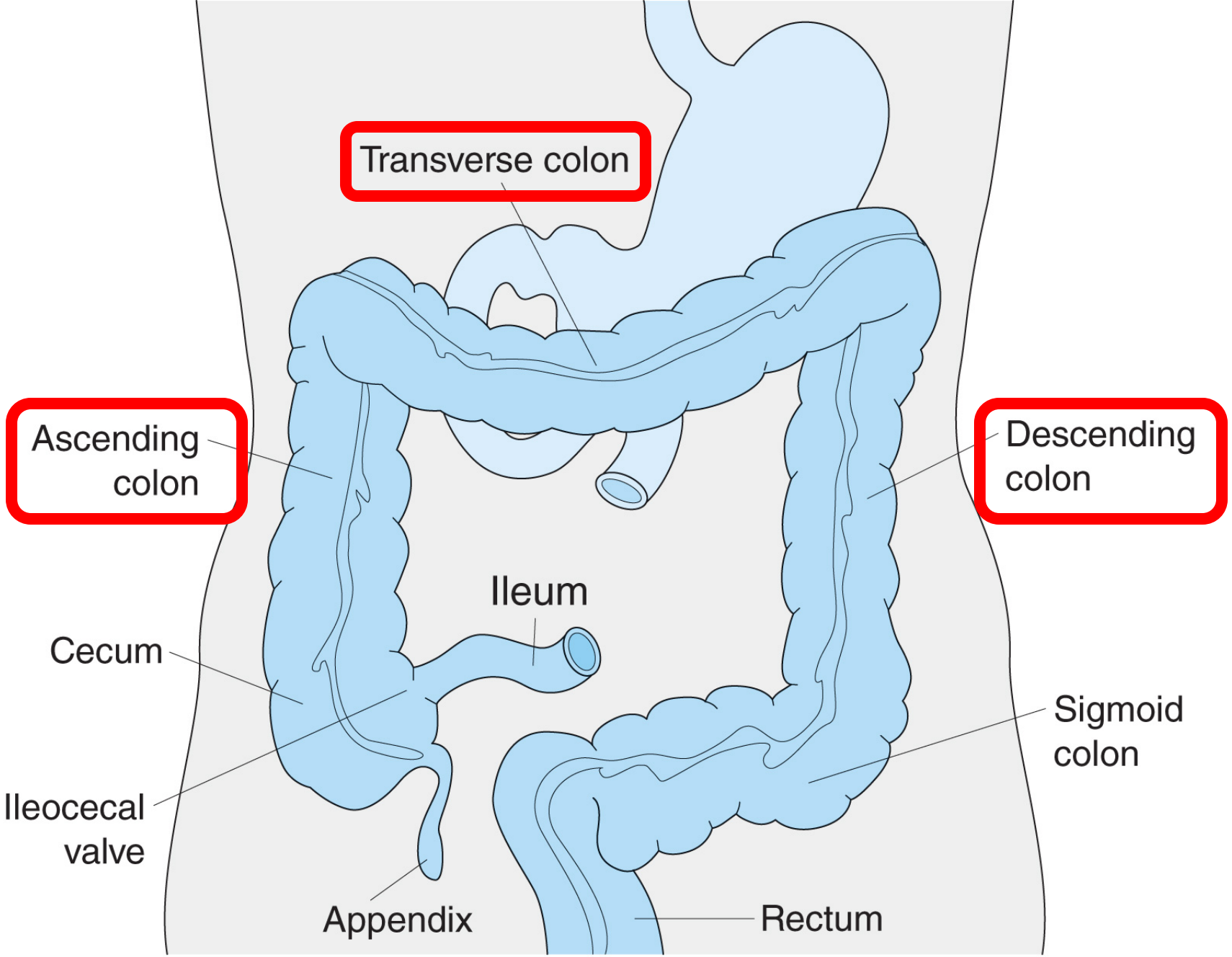


Water, water soluble particles and electrolytes are transported or diffuse across membrane & are transported to the liver via hepatic portal vein

Fats are taken up via lacteal and enter the lymphatic vessels which drain into the large veins around the heart.

Large Intestines

- The large intestine is a storage place for undigested food residues
- Final water and electrolyte absorption occurs here



Part 2

Digestion

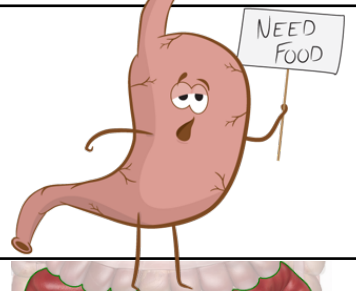
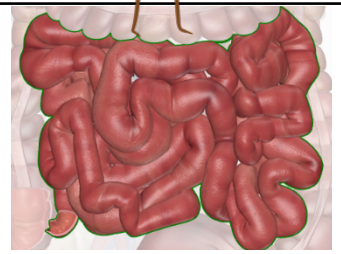
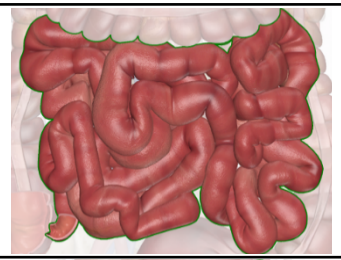
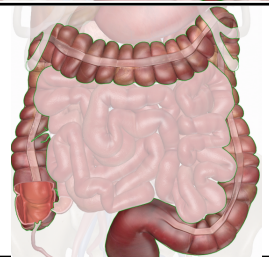
CHO | FAT | PRO

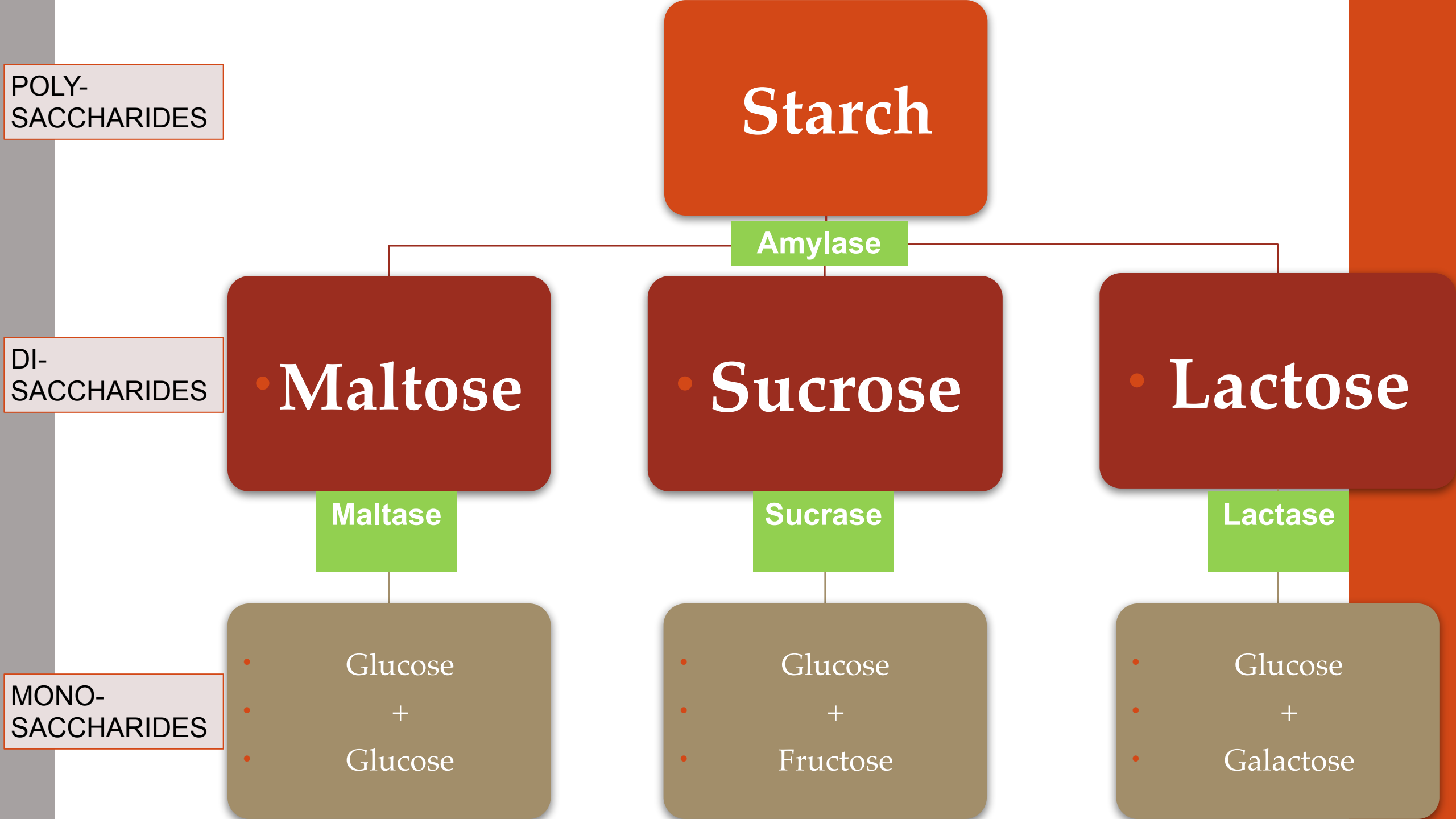
TABLE 5.3

Digestive Enzymes and Their Functions

Enzyme	Site of action	Source	Substrate	Product	Optimum pH
CARBOHYDRATES					
Salivary amylase	Mouth	Salivary glands	Starch	Maltose	6.7
Pancreatic amylase	Duodenum	Pancreatic juice	Starch	Maltose, maltotriose, and oligosaccharides	6.7–7.0
Maltase	Small intestine	Brush border	Maltose	Glucose	5.0–7.0
Sucrase	Small intestine	Brush border	Sucrose	Glucose and fructose	5.0–7.0
Lactase	Small intestine	Brush border	Lactose	Glucose and galactose	5.8–6.2
LIPIDS					
Lingual lipase	Mouth	Lingual salivary glands	Starch	Maltose	3.5–6.0
Pancreatic lipase	Small intestine	Pancreatic juice	Triacylglycerols	Fatty acids and monoacylglycerols	8.0
PROTEINS					
Pepsin	Stomach	Gastric glands	Protein	Polypeptides	1.6–2.4
Trypsin	Small intestine	Pancreatic juice	Polypeptides	Amino acids, dipeptides, and tripeptides	8.0
Chymotrypsin	Small intestine	Pancreatic juice	Polypeptides	Amino acids, dipeptides, and tripeptides	8.0
Carboxypeptidase	Small intestine	Pancreatic juice	Polypeptides	Amino acids, dipeptides, and tripeptides	8.0
Elastase	Small intestine	Pancreatic juice	Polypeptides	Amino acids, dipeptides, and tripeptides	8.5

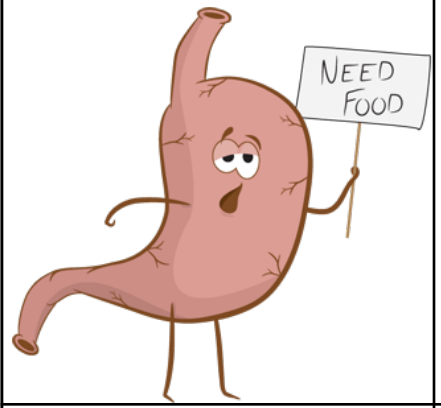
Carbohydrate Digestion

	• Amylase (ptyalin) – breakdown starch into smaller units
	• Amylase activity inhibited • Carb digestion slows
	• Duodenum – pancreatic amylase is secreted and increases carb hydrolysis
	• Brush Boarder – disaccharides digested by lactase, sucrase, and maltase
	• Fermentation of some fiber, the rest is excreted

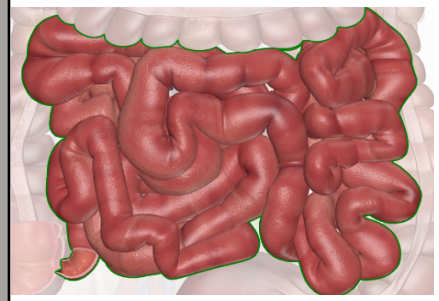

POLY-SACCHARIDES
DI-SACCHARIDES
MONO-SACCHARIDES
Starch
Amylase
Maltose
Sucrose
Lactose
Maltase
Sucrase
Lactase
Glucose
+
Glucose
Glucose
+
Fructose
Glucose
+
Galactose

Lipid Digestion

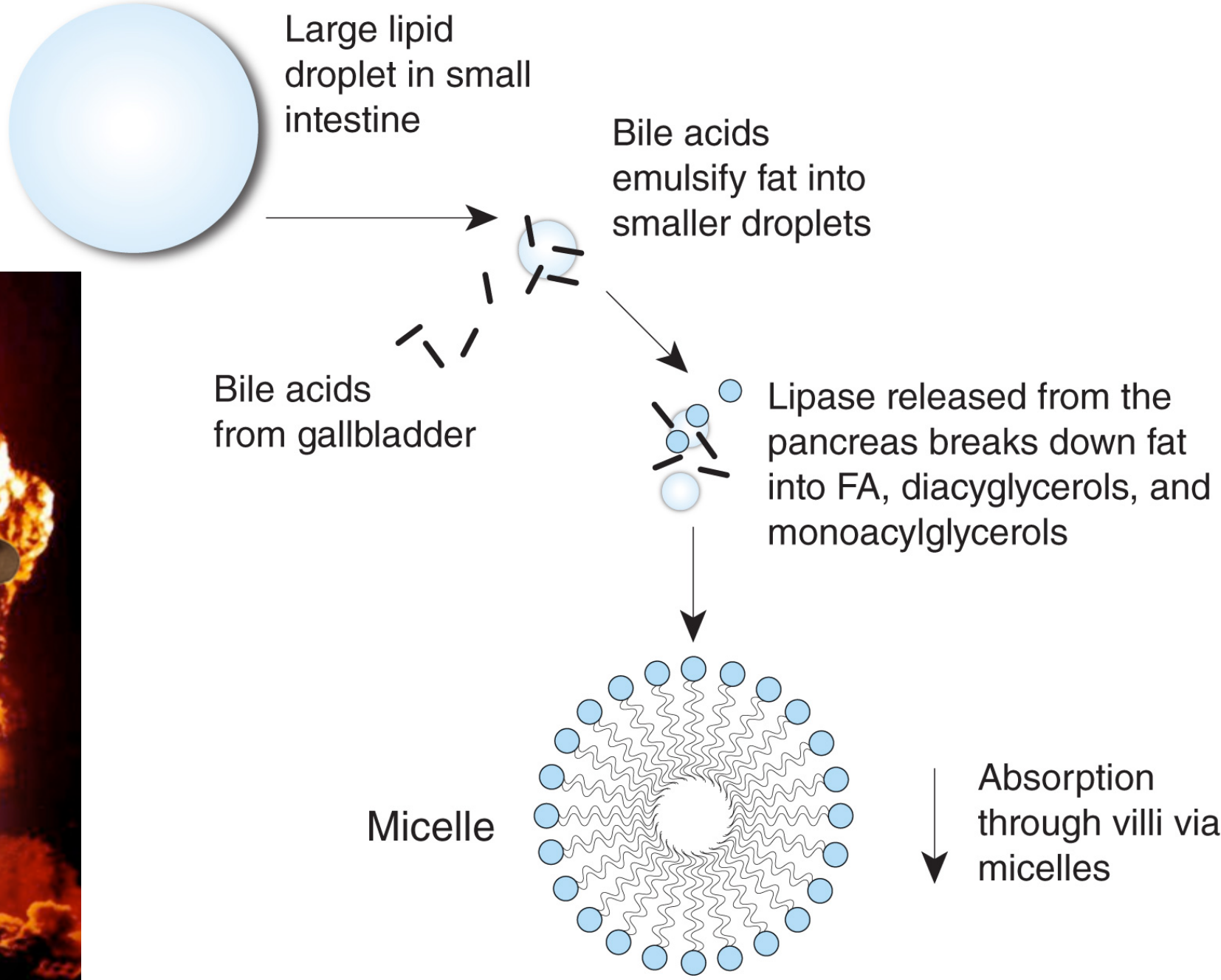
- Lingual Lipase – splits short & medium chain triglycerides into FA's and glycerol
- 10% - 30% of triglyceride digestion



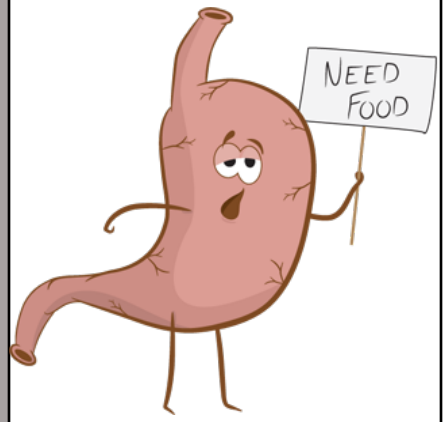
- Lingual & gastric lipase activity continues
- Slow digestions b/c fat & water-based saliva (which contains the lipase) don't mix well



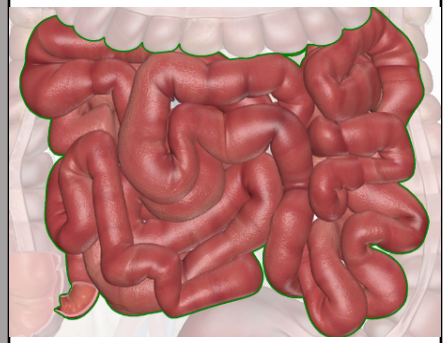
- Bile emulsifies large fat droplets into smaller droplets
- Pancreatic lipase breaks down triglycerides into di- and monoglycerols
- Large chain FA's are digested in the SI



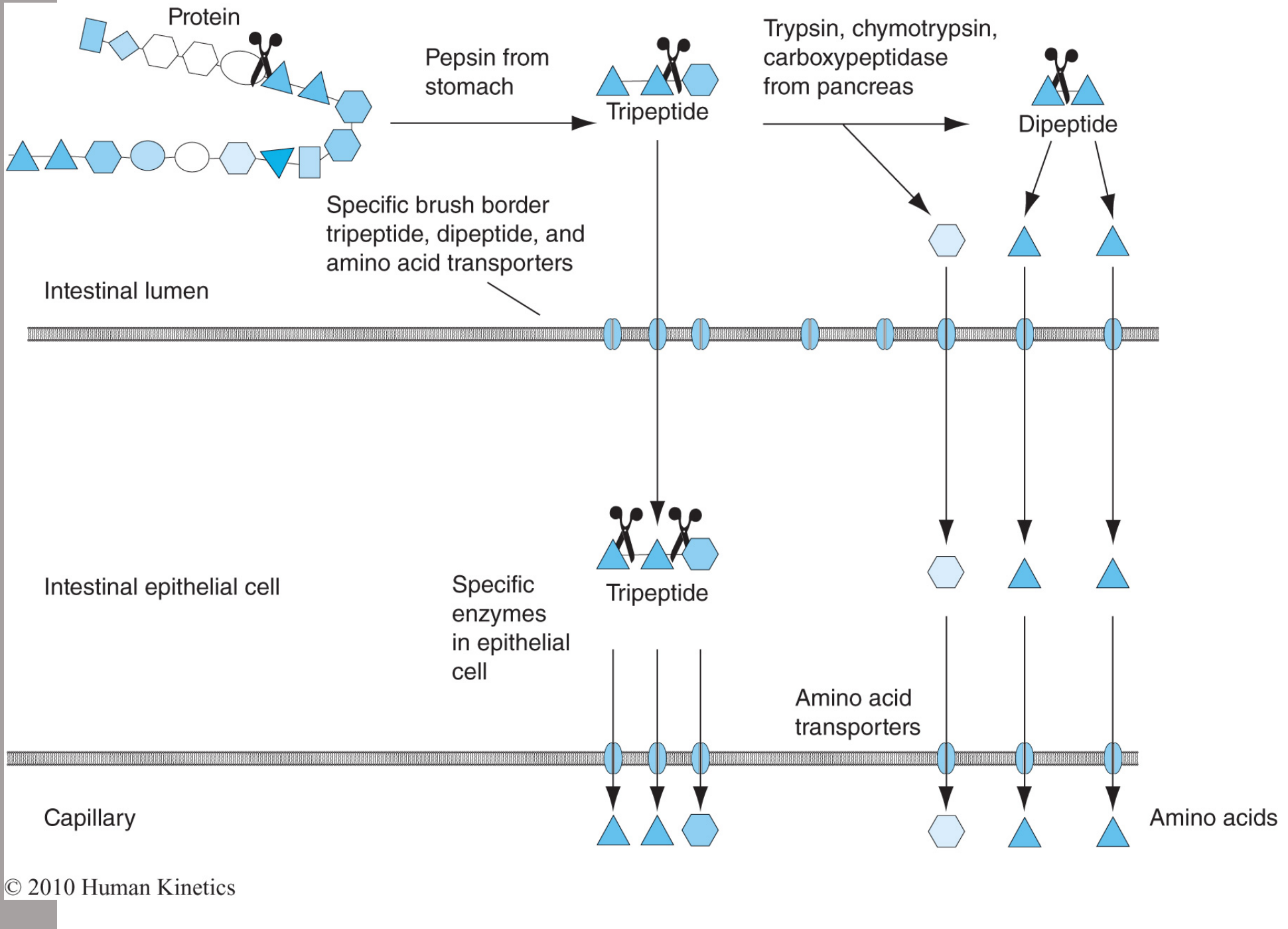
Protein Digestion



- Proteases – enzymes that break down protein down into amino acids, di- and tripeptides
- HCL released into the stomach
  - Activates Pepsin (protease enzyme)
  - Denatures food proteins making them more vulnerable to enzyme action



- Pancreatic juice released into SI contains many protease enzyme precursors
- These enzymes will break down any remaining proteins



Part 3

Absorption

CHO | FAT | PRO

Absorption

- Nutrient absorption across intestinal walls occurs via active transport, simple and facilitated diffusion

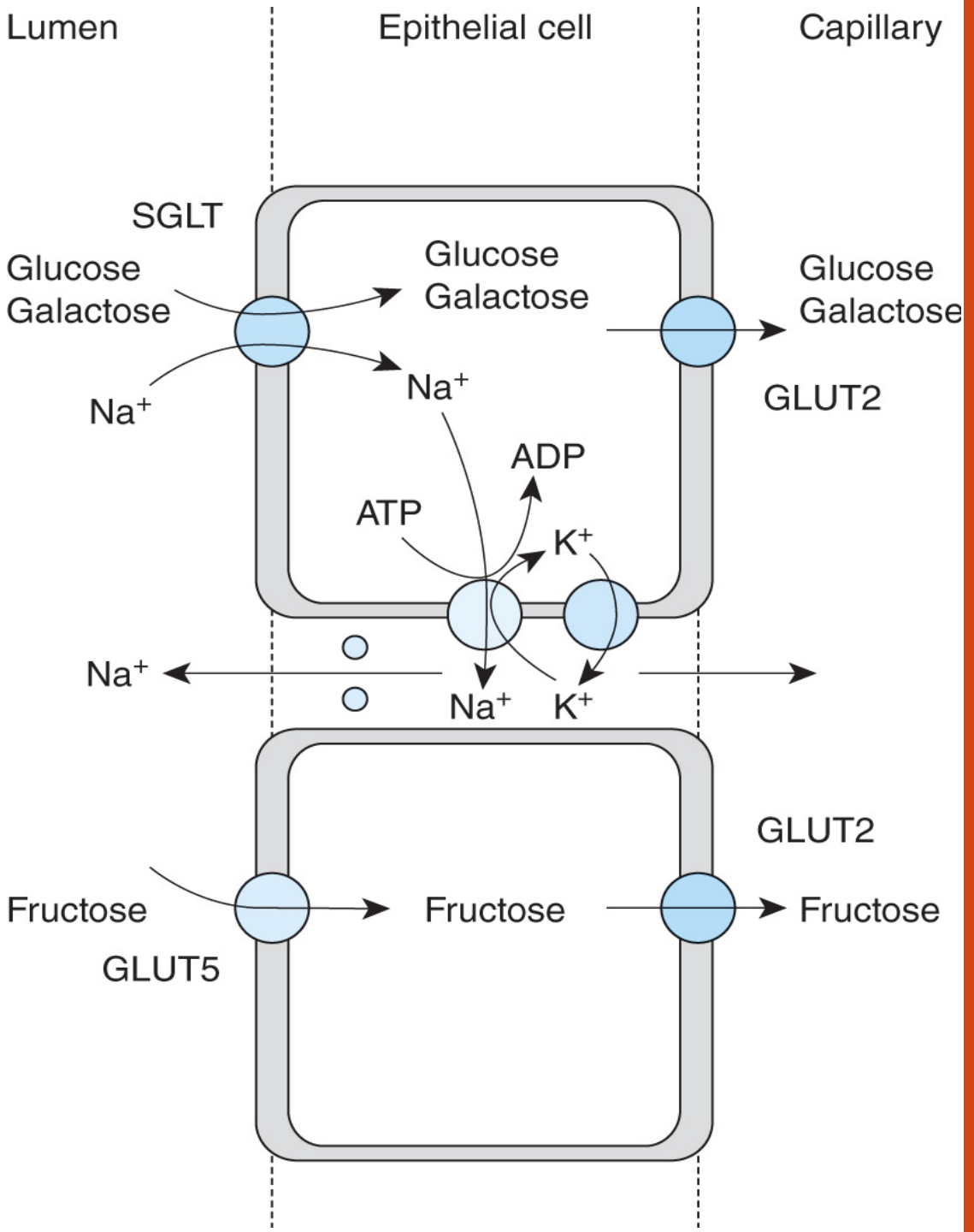
	ACTIVE TRANSPORT	SIMPLE DIFFUSION	FACILITATED DIFFUSION
REQUIRES ENERGY?	**YES**	**NO**	**NO**
REQUIRES TRANSPORT PROTEIN?	**YES**	**NO**	**YES**
EXAMPLE	**Amino Acids Dipeptides Tripeptides**	**Fatty Acids Water**	**Glucose Galactose Fructose**

Absorption of Carbohydrates

- Monosaccharides are absorbed by carrier mediated transport (glucose, fructose, galactose)

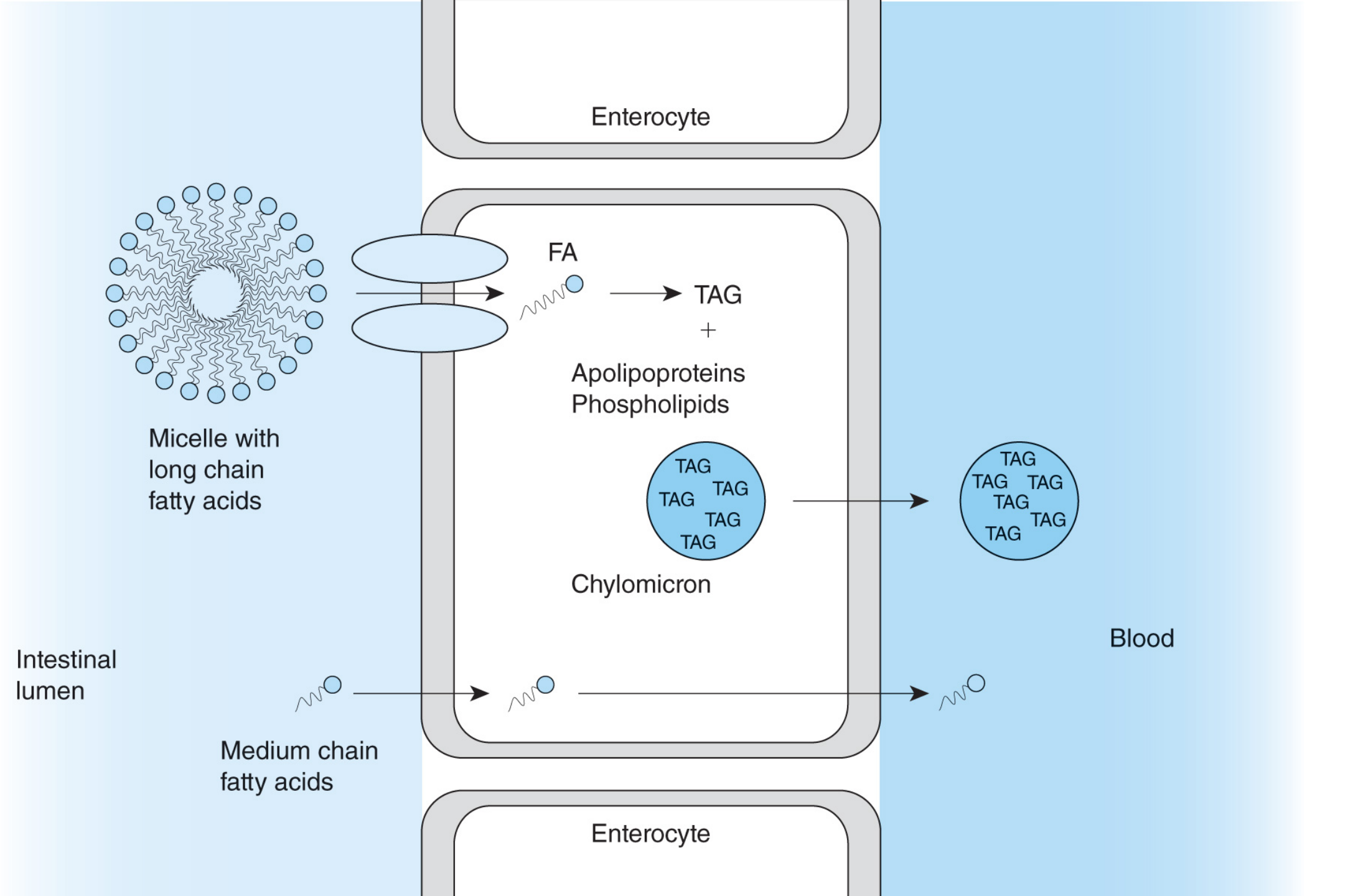
	SGLT1	GLUT5	GLUT2
Transports?	**Glucose Galactose**	**Fructose**	**Glucose Galactose Fructose**
Transport Location?	**FROM: SI Lumen TO: Epithelial Cell**	**FROM: SI Lumen TO: Epithelial Cell**	**FROM: Epithelial Cell TO: Capillary**

- Monosaccharides enter circulation in the hepatic portal vein which transports them to the liver



Absorption of Fats

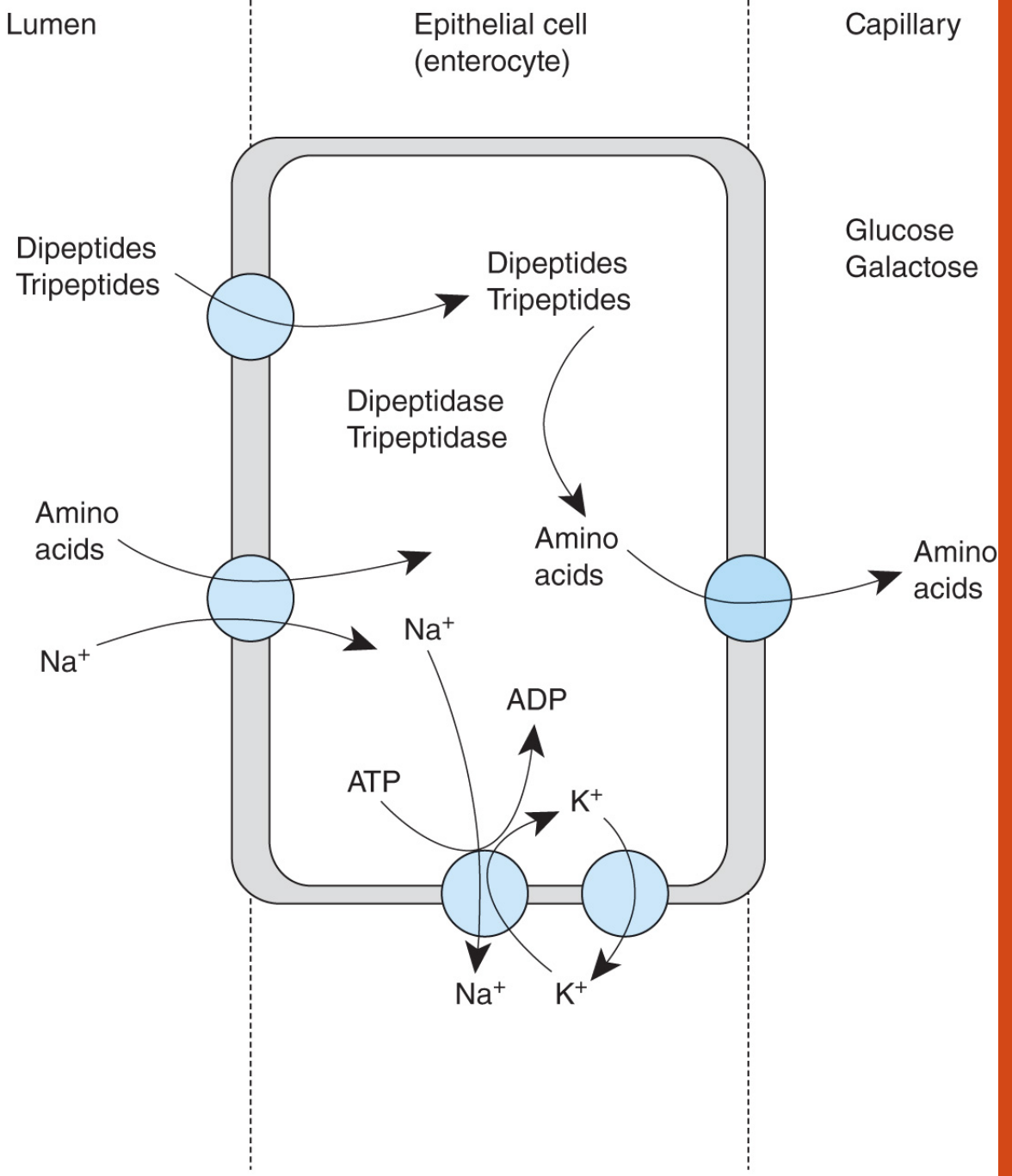
- Fatty acids (FA's) are incorporated into micelles with the help of bile salts from the gallbladder
  - With bile salts (micelles) - 97% fat absorption
  - Without bile salts - 50% FA are absorbed
- Micelles transport FA's to microvilli where FA's are diffused across the epithelial cell
- Within the epithelial cell FA's are packed into Chylomicrons and absorbed into the lymphatic system


Enterocyte
FA
TAG
+
Apolipoproteins
Phospholipids
Micelle with
long chain
fatty acids
TAG
TAG
TAG
TAG
TAG
Chylomicron
TAG
TAG
TAG
TAG
TAG
Blood
Intestinal
lumen
Medium chain
fatty acids
Enterocyte

Absorption of Amino Acids

- AAs, dipeptides & tripeptides are absorbed by active transport in the SI and delivered to the liver via the hepatic portal vein
- Most AAs are transported across the epithelium against a concentration gradient
  - Carrier mediated transport is needed
- 7 brush boarder specific protein transporters have been identified
- Most AA use more than 1 transporter for absorption

- Once through the epithelium- transported to the liver where they are converted to glucose, fat or released in to blood as free AA



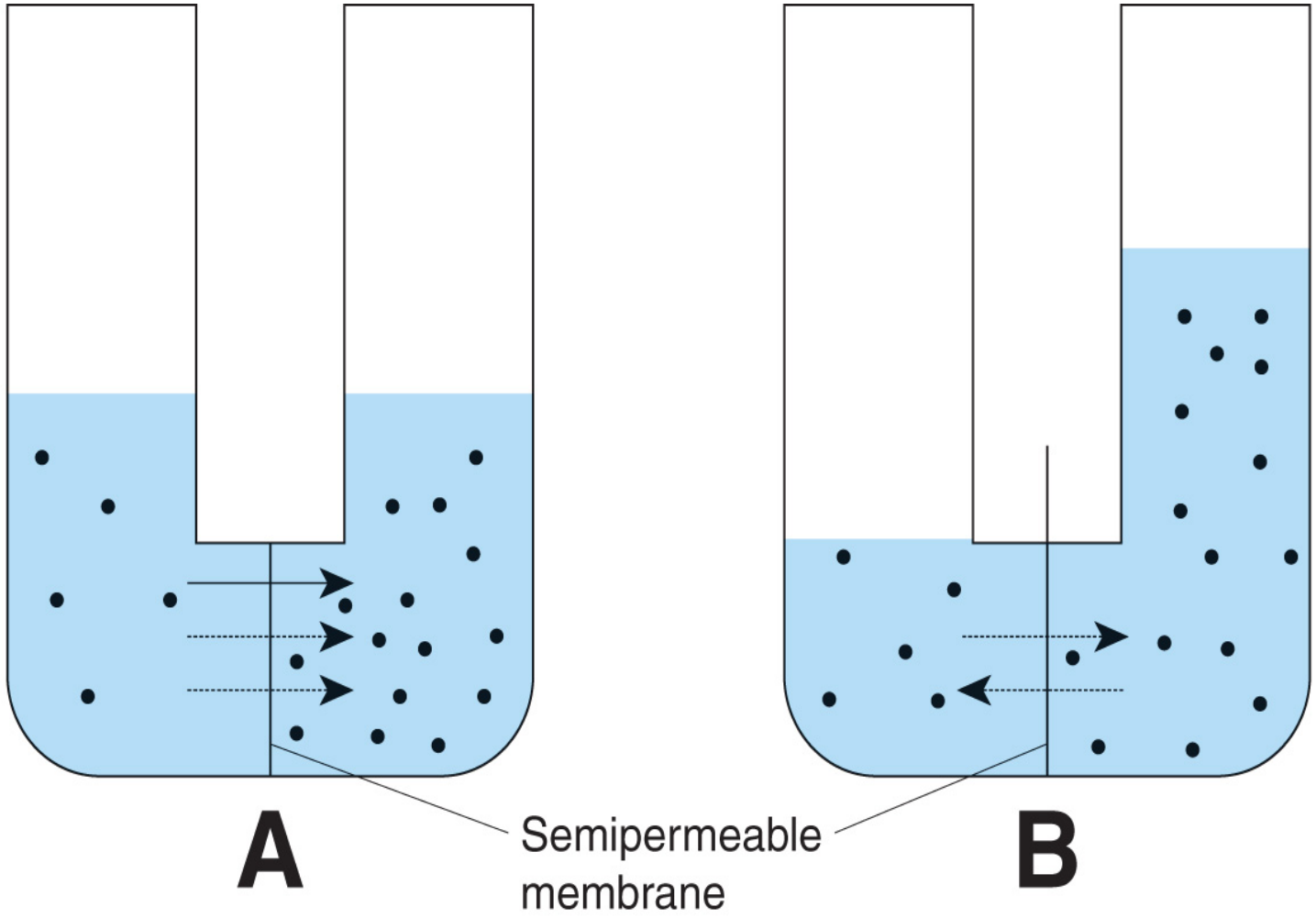
Part 4

Absorption

Water | Vitamins | Minerals

Absorption of Water

- 99% of water absorption occurs in the SI (duodenum) by simple diffusion
- Water diffuses across in both directions but relatively more water flows toward the compartment with lower water concentration (higher solute concentration)
- This net movement of water eventually results in a similar solute concentration on both sides of the membrane



Net water movement

Water diffusion

• Impermeable solute

Solute	5 mOsm	15 mOsm	Solute	5 mOsm	15 mOsm
Volume	1 Liter	1 Liter	Volume	0.5 Liter	1.5 Liter
Osmolarity	5 mOsm/L	15 mOsm/L	Osmolarity	10 mOsm/L	10 mOsm/L

Osmolality of most body fluids is 290 mOsm/L

Therefore if osmolarity of chime is high (>300 mOsm/L with a concentrated glucose solution) water moves into the gut lumen.

With the absorption of solutes (glucose & sodium) the osmotic gradient pulls water into the epithelium)

Fluid Intake

- Secretions into the SI can amount to up to 7L/d- produced from salivary glands, stomach wall, gallbladder, pancreas & intestines
- Daily water intake may average 2L
- Total daily water absorption may be 9L
- During ex in hot conditions water absorption can be <10L

Absorption of Vitamins

- Most occurs in the J & I
- Passive process
- A, D, E & K fat soluble vitamins are absorbed with FAs, incorporated into chylomicrons and transported through the lymph into systemic circulation to liver and other tissues
- Water soluble vitamins (B's & C) are absorbed via diffusion & not retained. They are mostly excreted in urine

TABLE 5.5

Absorption of Vitamins

Vitamin	Absorption mechanism
Vitamin C	Almost all absorption (90%) takes place in the distal portion of the small intestine.
Thiamine	Absorption occurs predominantly in the jejunum.
Riboflavin	Absorption occurs in the proximal part of the small intestine.
Niacin	Some absorption occurs in the stomach, but most occurs in the small intestine.
Pantothenic acid	This vitamin exists as part of coenzyme A, but absorption occurs readily throughout the small intestine when the vitamin is released from CoA.
Biotin	Absorption occurs in upper one-third to one-half of the small intestine.
Folic acid	Absorption occurs in small intestine with the help of a specialized intestinal enzyme system called conjugase.
Vitamin B_6	Absorption occurs in the jejunum.
Vitamin B_{12}	Absorption occurs mainly in the ileum and requires an intrinsic factor secreted from parietal cells of the stomach.

Absorption of Minerals

- Minerals - poorly absorbed therefore intake usually far exceeds need
  - Iron - Heme 15% absorbed| Non-Heme 2-10%
  - Calcium - 35%
  - Magnesium - 20-30%
  - Zinc - 14-41%
- Excretion rates in the urine are also high
  - 65% of absorbed Phosphorus (P) excreted by urine
  - 50% of absorbed Calcium (Ca) excreted by urine

Sodium

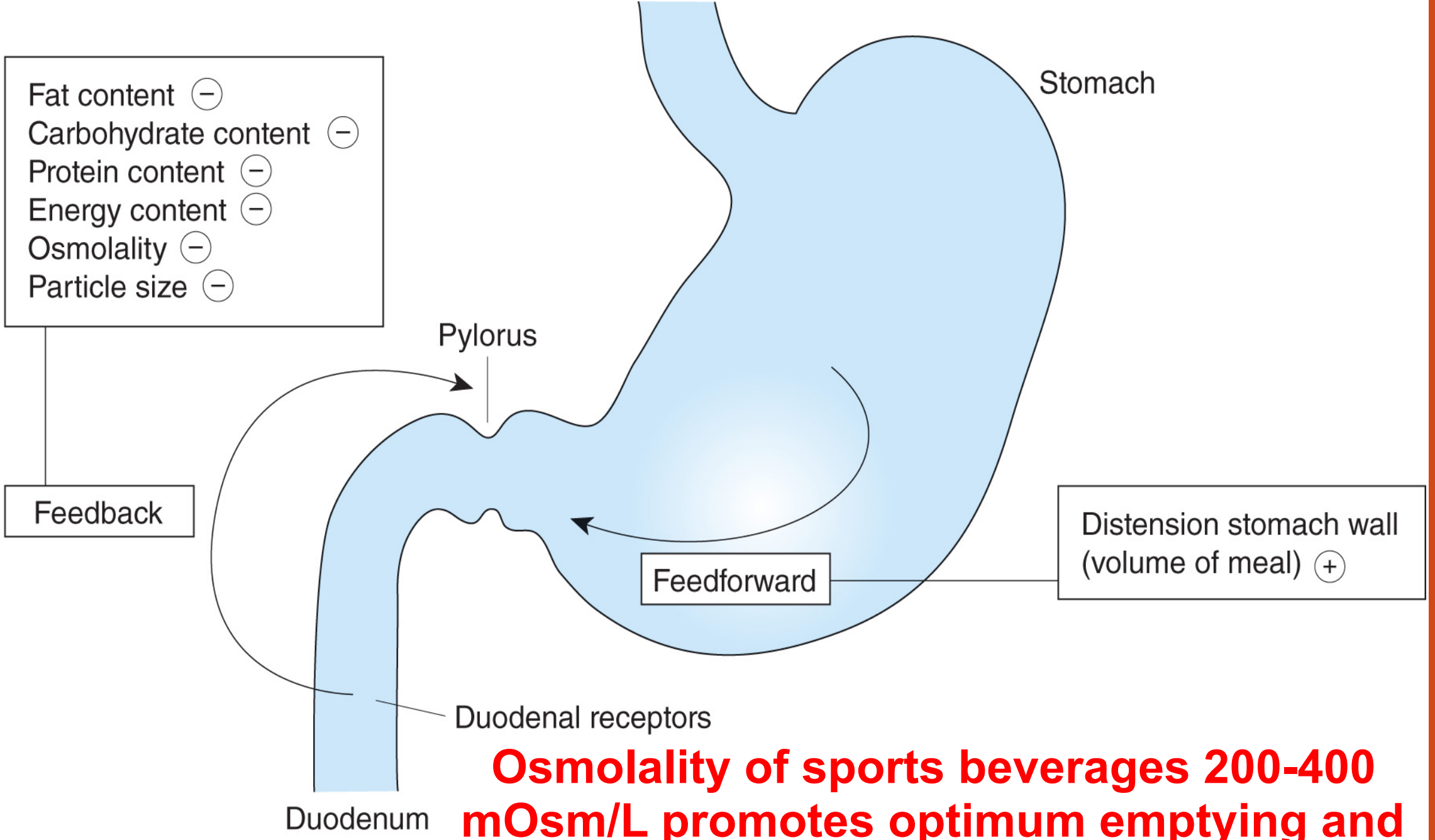
- About 30g of Sodium is secreted in intestinal secretions daily
- Ingestions is about 5-8g/d
- About 25-35 g of sodium must be resorbed daily

Part 5

Gastric Emptying & GI Digestive Issues

Regulation of Gastric Emptying

- Gastric emptying is influenced by:
  - smell and sight of food
  - thought of food
  - volume of food
  - energy density
  - osmolality
  - dehydration
  - psychological stress and anxiety,
  - and to a lesser degree (possibly by)
    - exercise intensity, meal temperature, gender



Osmolality of sports beverages 200-400 mOsm/L promotes optimum emptying and absorption

GI Problems in Athletes

- Gastrointestinal problems are a common phenomenon, mainly among endurance athletes, and the incidence is increased by:
  - Physiological factors
  - Mechanical factors
  - Nutrition
- Nausea, reflux, abdominal pain, loose stool, diarrhea, or even bloody diarrhea and vomiting
- Upper GI vs Lower GI vs Related Symptoms
- Very common in runners

GI Problems in Athletes

Upper GI	Lower GI	Related Symptoms
Heartburn	Urge to defecate	Nausea
Bloating	Loose stool	Dizziness
Vomiting	Diarrhea	Side ache (Stich)
	Bleeding	Urge to urinate

Causes of GI Problems

- Physiological causes
  - Reduced blood flow (80%)
  - Anxiety effects hormones which affect gut motility
- Mechanical causes
  - Impact or posture can lead to damage to intestinal lining
  - Hemorrhagic colitis or ischemic colitis
- Nutritional causes
  - Fiber, fat, protein, fructose can all cause problems as well as dehydration and high osmolarities (>500 mOsm/L)

Prevention of GI Problems

- Avoid milk product high in lactose
- Avoid high fiber foods in the days leading up to competition
- Avoid NSAIDS & aspirin
- Avoid high fructose foods & drinks with high concentrations
  - Digested more slowly and less well tolerated
  - Can cause cramping, loose stool and diarrhea
- Avoid dehydration - can cause GI distress
- Practice new nutrition strategies in advance