

# THE DIGESTIVE SYSTEM

## Topic 5: Digestion and Absorption

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### Page 1: Title Page

- Chemical digestion involves breaking down food with enzymes into molecules (nutrients, salts, water) that can be absorbed
- Absorption involves moving those molecules through the GI epithelium and into the blood (most molecules) or lymph (lipids)

### Page 2: Goals

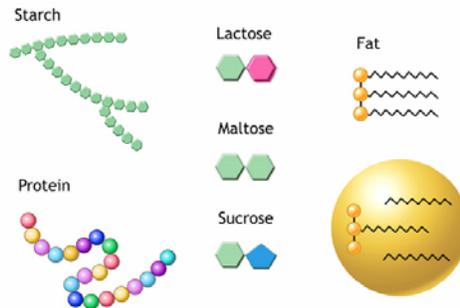
- To discuss the action of digestive enzymes (amylases, proteases, lipase) and bile salts
- To describe trans-epithelial transport of simple sugars (monosaccharides) and amino acids
- To discuss emulsification, chemical digestion, and absorption of lipids.

### Page 3: Food is broken down mechanically and chemically

- Ingested food first is broken down mechanically in the mouth (mastication or chewing) into pieces small enough to be swallowed, and then into even smaller particles in the stomach that can move into the small intestine



- These small particles contain both major nutrients (a.k.a. macronutrients) and minor nutrients (e.g. minerals)
- The major nutrients must be broken down enzymatically into their component parts, which then can be absorbed.
- The major nutrients are: carbohydrates, proteins, lipids

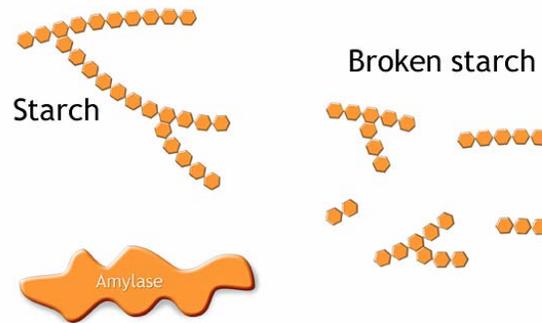


- The main dietary sources of carbohydrates include: starch (a polysaccharide), and the disaccharides sucrose (table sugar), lactose (milk sugar), and maltose (grain or brewer's sugar)
- All carbohydrates must be digested enzymatically into their component monosaccharides (the monomers of carbohydrates) for absorption. For example:
  - Starch is digested to glucose monomers
  - Sucrose is digested to one glucose monomer and one fructose monomer
  - Lactose is digested to one glucose monomer and one galactose monomer
  - Maltose is digested to two glucose monomers
- Proteins (both animal and plant) are digested to amino acids and small peptide chains of two (dipeptides) or three (tripeptides) amino acids
- Most dietary fat is in the form of neutral fats or triglycerides (a.k.a. triacylglycerols)
  - Each triglyceride molecule is broken down into one monoglyceride (= glycerol + one fatty acid) and two free fatty acids
- Non-polar products of digestion (e.g. lipid breakdown products) can be absorbed by simple diffusion (passive) through the phospholipids bi-layer of the intestinal epithelial cells; most polar substances are absorbed using either active (i.e. ATP-requiring) or passive carrier-mediated transport mechanisms

#### Page 4: Carbohydrate digestion begins in the mouth

- Plant starch and glycogen are long polymers of glucose; they are abundant in the diet.
- Chemical digestion of starch begins in the mouth with the enzyme, salivary amylase (optimal pH ~ 7).
- Amylase breaks down starch into the following components\*:
  - Maltose (a disaccharide)
  - Maltotriose (a trisaccharide)
  - Limit dextrin (small branched fragments)

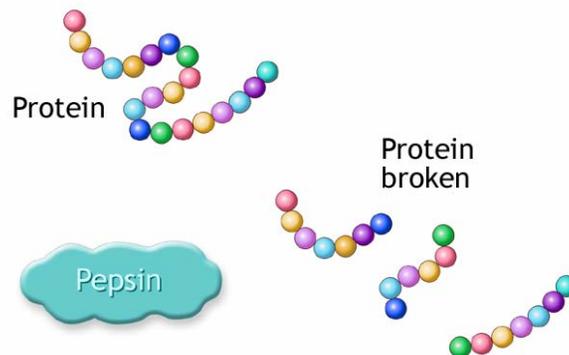
\*The interactive animation here illustrates these components nicely



- Stomach acid denatures salivary amylase

### Page 5: Protein digestion begins in the stomach

- The enzyme pepsin (activated from pepsinogen by HCl) begins the digestion of proteins in the stomach
- Pepsin (optimal pH ~2) breaks the peptide bond between tyrosine and phenylalanine amino acids, thereby producing peptide fragments and a few individual amino acids



- The neutral pH of the duodenum denatures pepsin, rendering it inactive

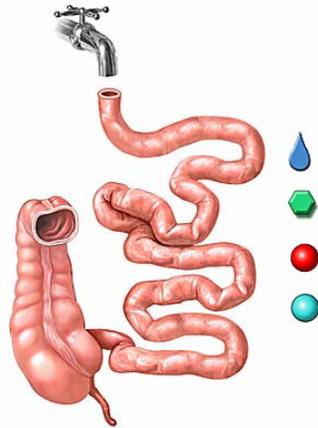
### Page 6: Most digestion and absorption occur in the small intestine

- Most chemical digestion and nearly all the absorption occur in the small intestine
- Pancreatic digestive enzymes alone are sufficient to digest carbohydrates and proteins
- Pancreatic lipase is essential for the bulk of fat digestion
- Cellulose and certain other plant complex carbohydrates cannot be digested by humans; we lack the enzymes to hydrolyze them
- Indigestible plant polysaccharides serve as an important source of dietary fiber
- Certain fiber types (insoluble) help to speed the movement of stool through the colon

- Vegetables and fruits contain many valuable vitamins, minerals, and other nutrients



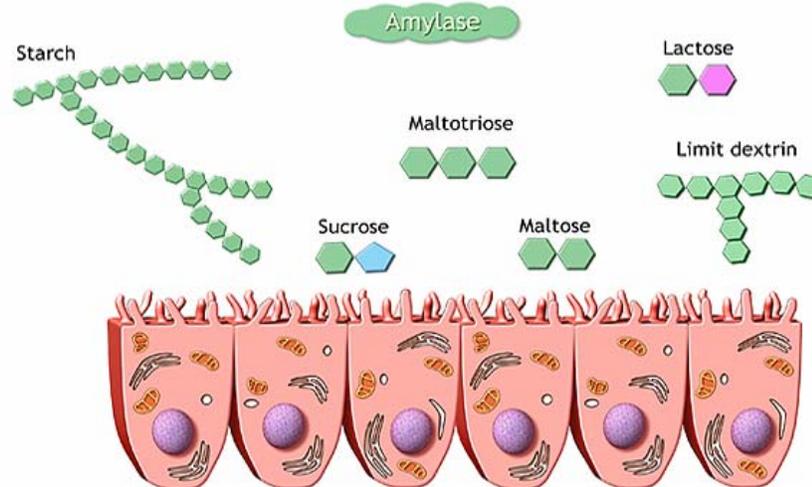
- Most dietary salt and water are absorbed in the small intestine by either transcellular (through cells) or paracellular (between cells) transport



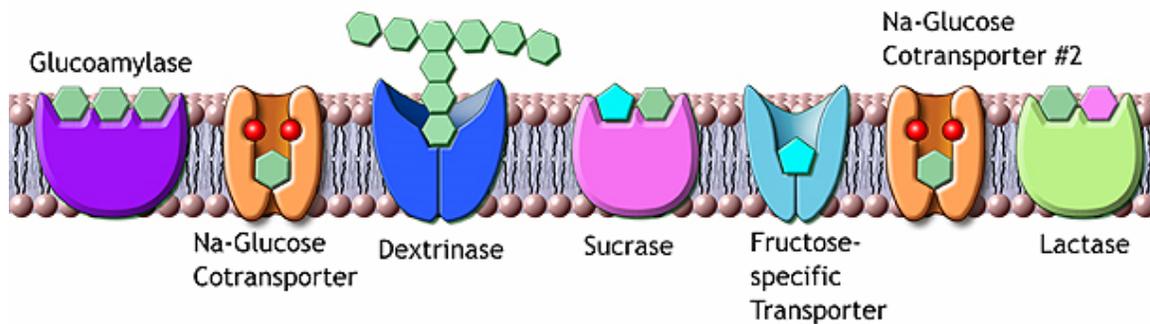
- Transcellular transport of water is linked to the active transport of sodium via sodium-potassium pumps
  - Sodium is actively pumped out of the digestive tract at the basolateral membrane of the epithelial cells
  - Sodium then moves passively from the GI lumen into the epithelial cells through ion channels (co-transported with glucose or amino acids) down its concentration gradient
  - Chloride follows sodium (electrochemical attraction)
  - Water follows passively via osmosis

## Page 7: Carbohydrates are digested and absorbed in the small intestine

- Pancreatic amylase (optimal pH ~7) continues the digestion of carbohydrates in the small intestine (duodenum)



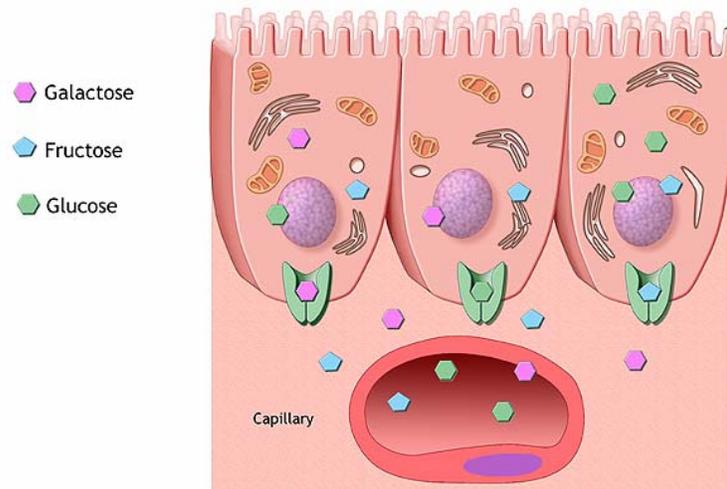
- Intestinal brush border enzymes complete the digestion of carbohydrates to monosaccharides, which then can be absorbed\*
  - Glucoamylase breaks down maltose and maltotriose
  - Dextrinase breaks down limit dextrin
  - Sucrase breaks down sucrose
  - Lactase breaks down lactose



- Most nutrients are absorbed by transepithelial transport
- Secondary active transport is the process by which glucose and galactose (co-transported w/sodium using the same transport protein) enter the luminal side of GI epithelial cells
- Fructose enters the epithelial cells on its own transporter via facilitated diffusion

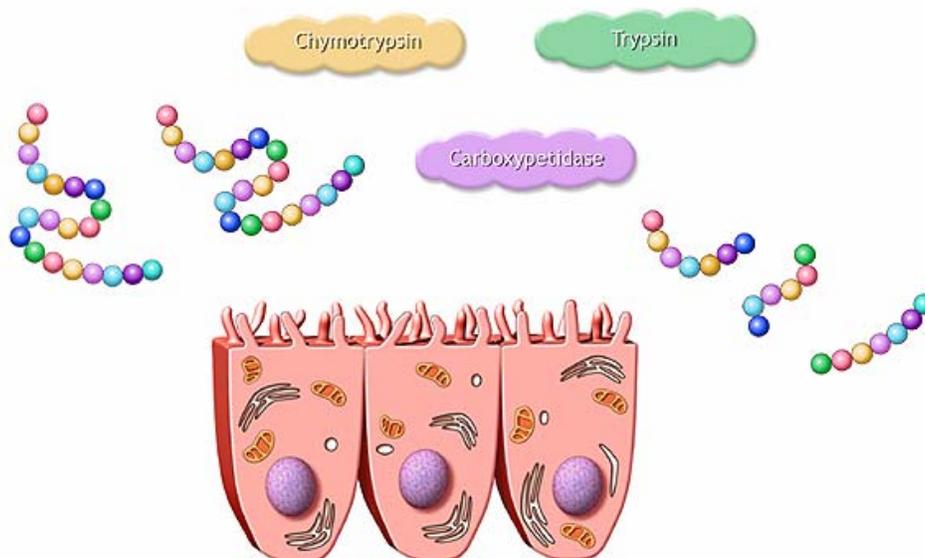
\*This interactive animation demonstrates enzymatic hydrolysis of these carbohydrates

- Once inside the epithelial cells, all monosaccharides exit the basolateral side of the cells on the same type of transport molecule via facilitated diffusion



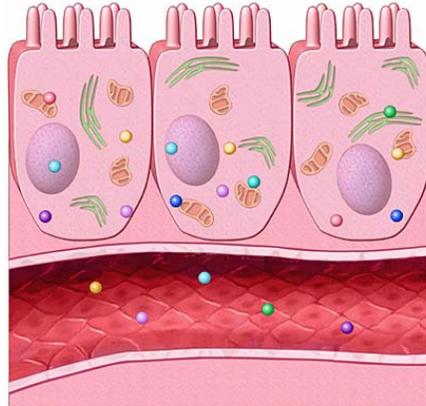
### Page 8: Protein is digested and absorbed in the small intestine

- A variety of proteins and protein breakdown products (e.g. peptides from pepsin digestion) enter the small intestine for their final enzymatic breakdown
- Trypsin (activated from trypsinogen), chymotrypsin (activated from chymotrypsinogen), and carboxypeptidase (activated from procarboxypeptidase) are the major pancreatic proteases (optimal pH ~ 7)\*



- Trypsin and chymotrypsin split proteins into smaller peptides and some single amino acids
- Carboxypeptidase splits single amino acids from the carboxyl end of proteins
- The brush border enzymes, aminopeptidase and dipeptidase continue the digestion of peptides.
- Single amino acids, dipeptides, and tripeptides are absorbed through the small intestine
- A number of amino acids (but not all) are co-transported into the luminal side of the epithelial cells with sodium via secondary active transport
- There are a number of different amino acid transporters

- Most protein is absorbed as dipeptides and tripeptides, which are further digested to single amino acids inside the GI epithelial cells

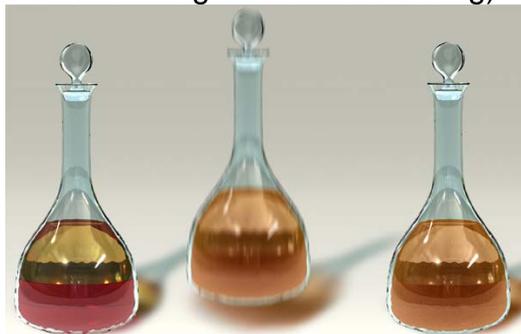


- More hydrophobic amino acids tend to leave the basolateral side of the epithelial cells via simple diffusion
- More hydrophilic amino acids tend to exit GI epithelial cells via facilitated diffusion or by cotransport with sodium

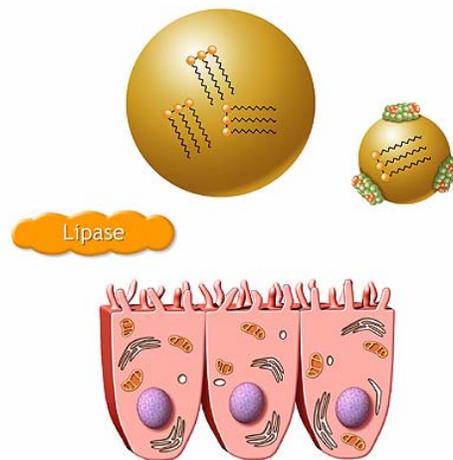
\* Now is a good time to view the function of these hydrolytic enzymes in the animation

### Page 9: Fat is digested and absorbed in the small intestine

- Most dietary fats are triglycerides, which are made up of three fatty acids (short, medium or long hydrocarbon chains) each bound to a glycerol molecule via an ester linkage
- Most lipid digestion occurs in the duodenum
- Two mechanisms act to increase the surface area of fats for subsequent chemical digestion:
  - **Segmentation** in the small intestine disperses fat into the aqueous layer (like oil and vinegar in salad dressing)

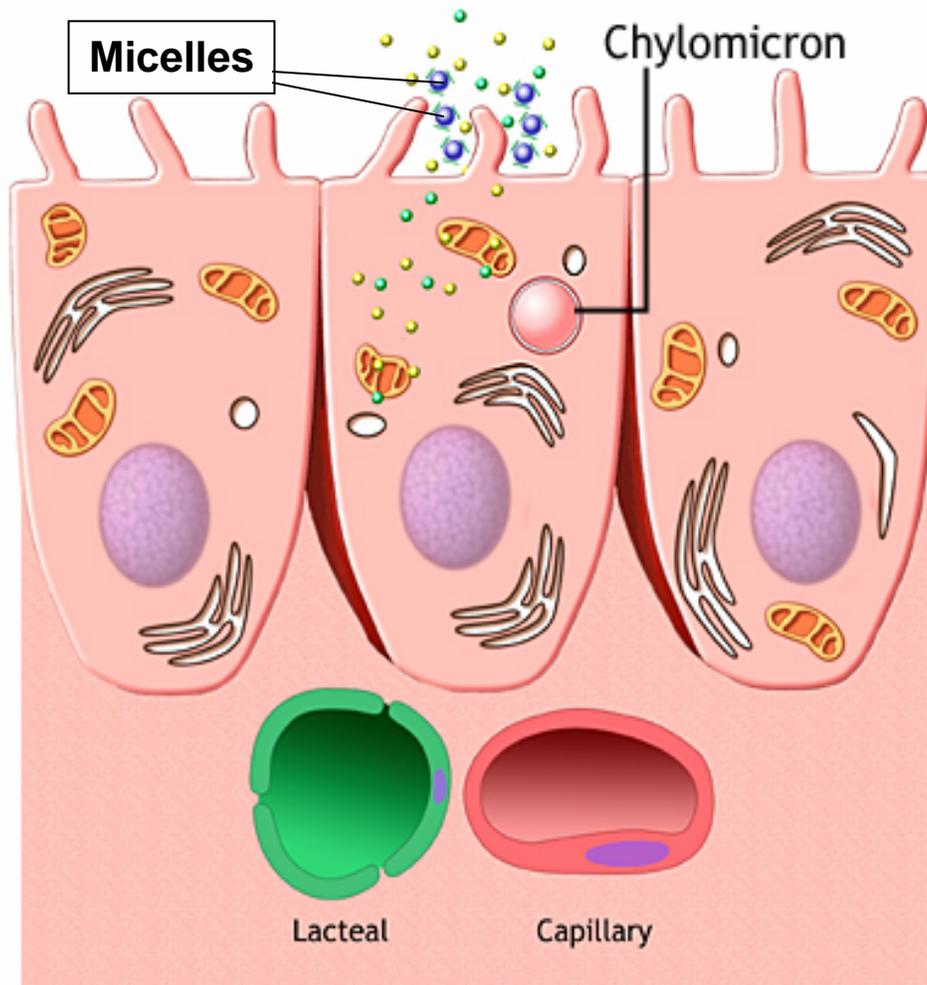


- **Bile** salts attach to smaller fat droplets to prevent them from coalescing into larger droplets
- Because bile salt molecules are amphipathic (polar on one side, non-polar on the other), they can surround small lipid droplets (with the non-polar side toward the lipid) and prevent them from coming together (because the polar regions of the bile salts face away from the attached lipid molecule), thereby increasing the total surface area of the lipid



- Increasing the surface area of the lipid allows for more efficient hydrolysis of the lipid by pancreatic lipase (pay close attention to the orientation of the bile salts on the lipid droplet in the animation; not that the bile salts do NOT hydrolyze the lipid droplet)
- Lipase digests triglycerides into monoglycerides and free fatty acids
- Bile salts also surround monoglycerides and free fatty acids to form tiny micelles droplets (about 1 million times smaller than emulsified fat droplets)

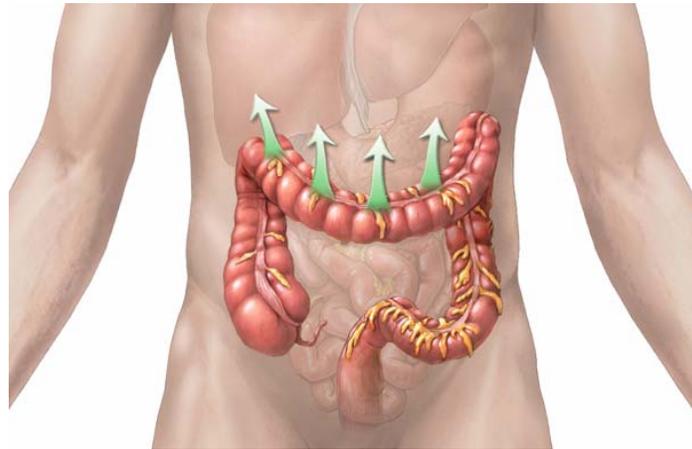
- When micelles come close to the luminal membrane of the epithelial cells, they release their monoglycerides and free fatty acids into the cells via simple diffusion through the lipid bilayer



- Monoglycerides and free fatty acids are reassembled into triglycerides once inside the cell, and then coated with lipoproteins to form chylomicrons to keep them emulsified
- Chylomicrons exit the basolateral surface of the epithelial cell via exocytosis and enter the lacteal lymphatic capillaries

**Page 10: Salt, water, and bacterial products are absorbed in the large intestine**

- Neither the large intestine's cells nor its secretions are digestive in function
- Symbiotic enteric (colic) bacteria can digest some of the indigestible carbohydrates enzymatically and then use the released nutrients
- By products of colic bacteria metabolism include small amounts of certain B complex vitamins and substantial quantities of vitamin K; both are absorbed in the large intestine
- Vitamin K is essential for producing certain blood clotting proteins
- The colon absorbs small quantities of salt and water as the feces are concentrated there and eventually eliminated through the rectum and anus



## **Study Questions on Digestion & Absorption: Digestive System:**

1. (Page 3.) Where does mechanical digestion occur?
2. (Page 3.) List the major nutrients (macronutrients) and briefly describe the primary dietary sources of each.
3. (Page 3.) List three major carbohydrate sources in the diet and their constituent monomers (monosaccharides).
4. (Page 3.) What are proteins enzymatically digested into?
5. (Page 3.) Describe the breakdown products of neutral fats.
6. (Page 3.) Briefly compare and contrast the different mechanisms required for absorption of polar versus non-polar nutrients.
7. (Page 4.) What is the name of the salivary enzyme that breaks down plant starch and glycogen?
8. (Page 4.) List the breakdown products of plant starch and glycogen in the mouth.
9. (Page 5.) What is the name of the gastric protease and what is its optimum pH?
10. (Page 5.) What happens to the gastric protease when it reaches the small intestine?
11. (Page 6.) Where do most of the digestive enzymes that function in the duodenum originate?
12. (Page 6.) Describe the function of cellulose in the diet.
13. (Page 6.) Why are vegetables and fruits important components of the diet?
14. (Page 7.) Describe the transcellular transport mechanism of water absorption in the small intestine.
15. (Page 7.) What enzymes are used to complete the digestion of carbohydrates in the duodenum?
16. (Page 7.) Describe the function of brush border enzymes in the duodenum.
17. (Page 7.) Compare and contrast the mechanisms for intestinal absorption of glucose and fructose. Be sure to describe both how they enter and exit the luminal epithelial cells.
18. (Page 8.) List the major pancreatic proteases. What is the optimum pH for these enzymes?
19. (Page 8.) How are pancreatic proteases activated?
20. (Page 8.) What are the breakdown products of each pancreatic protease?
21. (Page 8.) List the protein-digesting (proteolytic) brush border enzymes and briefly describe the function of each.
22. (Page 8.) How do many amino acids enter the luminal side of the intestinal epithelium?
23. (Page 8.) Compare and contrast the mechanisms by which hydrophilic and hydrophobic amino acids exit the basolateral side of the intestinal epithelial cells.
24. (Page 9.) Describe the two mechanisms that increase lipid surface area for digestion in the duodenum.

25. (Page 9.) What is the name of the enzyme that breaks down neutral fats in the duodenum and what are the breakdown products of this digestion?
26. (Page 9.) What are micelles?
27. (Page 9.) How do neutral fat breakdown products enter the luminal side of the intestinal epithelial cells?
28. (Page 9.) What happens to the breakdown products of neutral fats once inside the luminal cells?
29. (Page 9.) How do neutral fat breakdown products exit the luminal epithelial cells?
30. (Page 9.) How are fat breakdown products transported away from the small intestine?
31. (Page 10.) Describe the symbiotic relationship between colic bacteria and humans.
32. (Page 10.) What is the absorptive function of the colon?