

# Biochemical Aspects of Digestion of Proteins and Carbohydrates

(GNT/Hematology Block)

# Learning outcomes

**By the end of this lecture, the student should be able to:**

- Understand the overall process of dietary proteins' and carbohydrates' digestion, the organs involved, the enzymes required, and the end products.
- Implement the basic science knowledge of the process of proteins & carbohydrates digestion to understand the clinical manifestations of diseases that involve defective proteins' or carbohydrates' digestion &/or absorption.

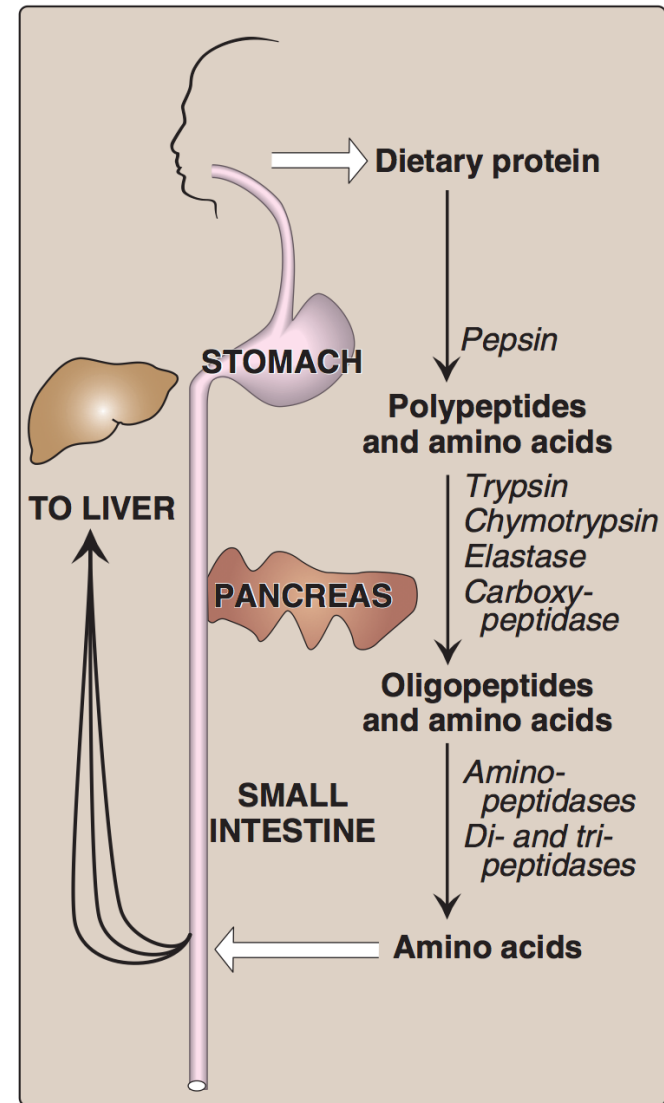
# Biochemical Aspects of Digestion of Dietary Proteins

# Protein Digestion

- Dietary proteins constitute 70-100 g/day.
- Proteins are generally too large to be absorbed by the intestine.
- They must, therefore, be hydrolyzed to their constituent amino acids, which can be absorbed.

# The Source of Proteolytic Enzymes Responsible for Degrading Dietary Proteins

1. The stomach
2. The pancreas
3. The small intestine



# 1- Digestion of proteins by gastric secretion

- The gastric juice contains 2 components important for protein digestion:
  1. Hydrochloric acid.
  2. Pepsin.

Digesting agent	Description
Hydrochloric acid	<ol style="list-style-type: none"><li>1. kills some bacteria</li><li>2. Denatures proteins → denatured proteins are more susceptible to hydrolysis by proteases.</li></ol>
Pepsin	<ul style="list-style-type: none"><li>• Acid-stable</li><li>• Endopeptidase</li><li>• Secreted as inactive zymogen (pepsinogen)</li><li>• Pepsinogen is activated by:<ol style="list-style-type: none"><li>1. hydrochloric acid</li><li>2. pepsin, i.e. autocatalysis</li></ol></li><li>• Protein digestion by stomach → Polypeptides + few free amino acids</li></ul>

# 2- Digestion of proteins in small intestine

**a) digestion by pancreatic enzymes.**

**b) digestion by intestinal aminopeptidase.**

- The digestion in small intestine is hormonally controlled.
- Two small peptide hormones are released from cells of the upper part of small intestine:

**1. Cholecystokinin (CCK)**

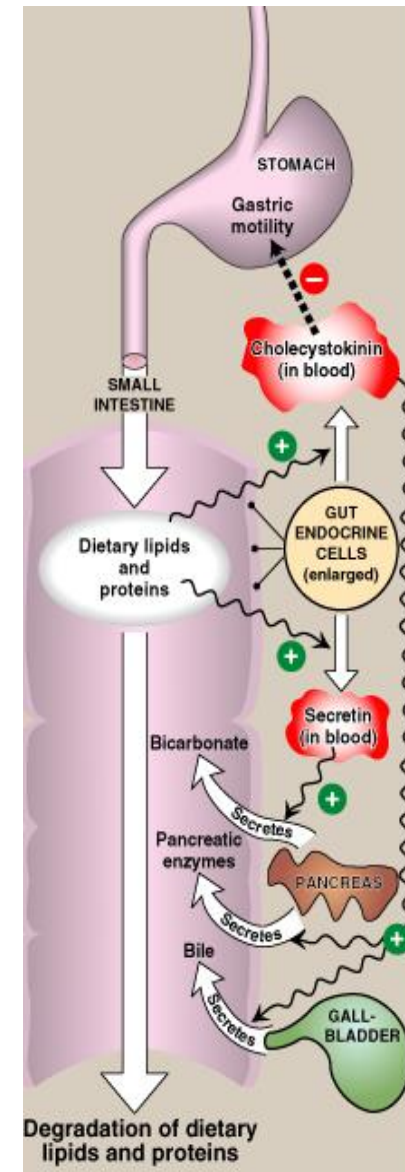
**2. Secretin**



# Hormonal control of digestion in small intestine:

## Cholecystikin (CCK):

1. Secretion of pancreatic enzymes.
2. Bile secretion.
3. Slow release of gastric contents.



## Secretin:

Release of watery solution rich in bicarbonate by pancreas.

# The gut hormones

The gut hormone	Stimulus for secretion	Effects
<b>1- Cholecystokinin (CCK)</b>	The presence of partially digested proteins (& lipids) in the upper small intestine	<ol style="list-style-type: none"><li>1. Stimulates the release of pancreatic digestive enzymes</li><li>2. Stimulates the contraction of the gall bladder &amp; release of bile</li><li>3. Decreases gastric motility → slower release of gastric contents into the small intestine</li></ol>

# The gut hormones: *continued...*

The gut hormone	Stimulus for secretion	Effects
<b>2- Secretin</b>	Low pH of the chyme entering the intestine	Stimulates the pancreas to release a watery solution rich in bicarbonate to neutralize the pH of the intestinal contents (to reach the optimum pH for digestive activity by pancreatic enzymes)

# Pancreatic enzymes for digestion of proteins

- The pancreatic secretion contains a group of pancreatic proteases
- Each of these enzymes has different specificity for the cleavage sites
- These proteases are synthesized and secreted as inactive zymogens

# Activation of pancreatic enzymes

- **Enteropeptidase:** It converts trypsinogen to trypsin

**Trypsin then activates all the other pancreatic zymogens  
(including itself)**

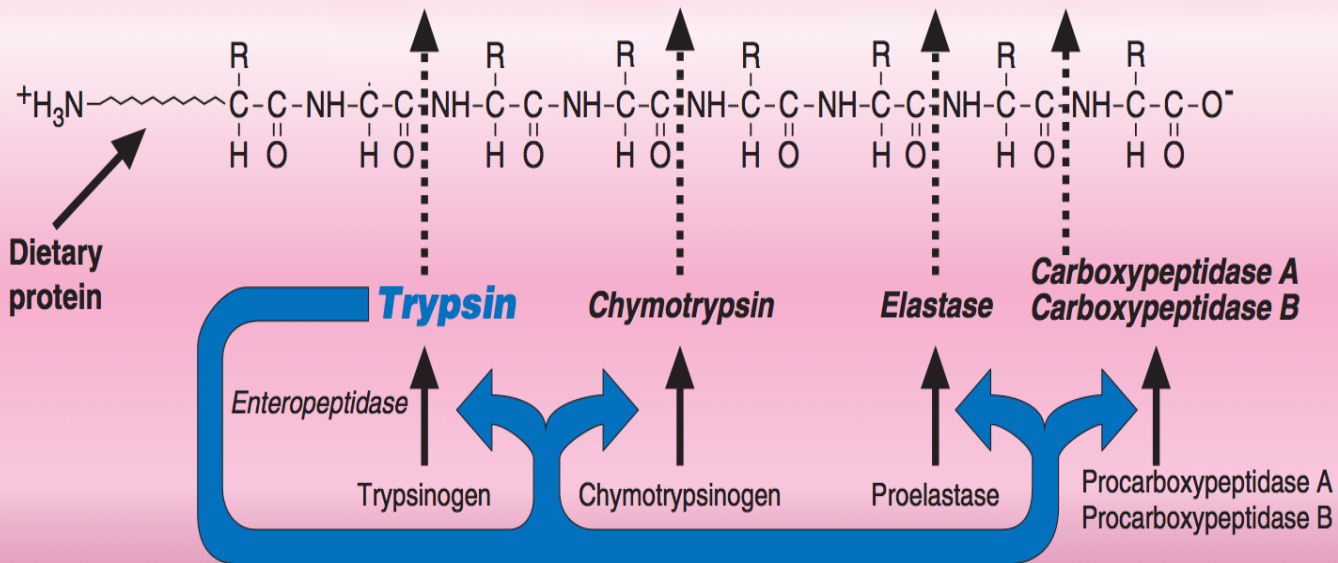
- *Enteropeptidase is an enzyme synthesized by, and present on the luminal surface of intestinal mucosal cells of the brush border membrane.*

# Pancreatic enzymes: *continued ...*

Zymogen	Active enzyme	Activating enzyme
Trypsinogen	Trypsin (endopeptidase)	1- Enteropeptidase 2- Trypsin (autocatalysis)
Chymotrypsinogen	Chymotrypsin (endopeptidase)	Trypsin
Proelastase	Elastase (endopeptidase)	Trypsin
Procarboxypeptidases	Carboxypeptidases (exo-peptidases)	Trypsin

# Activation of pancreatic enzymes: *continued ...*

SMALL INTESTINE



## 2- Digestion of proteins in small intestine: *continued ...*

### **b) digestion by intestinal aminopeptidase.**

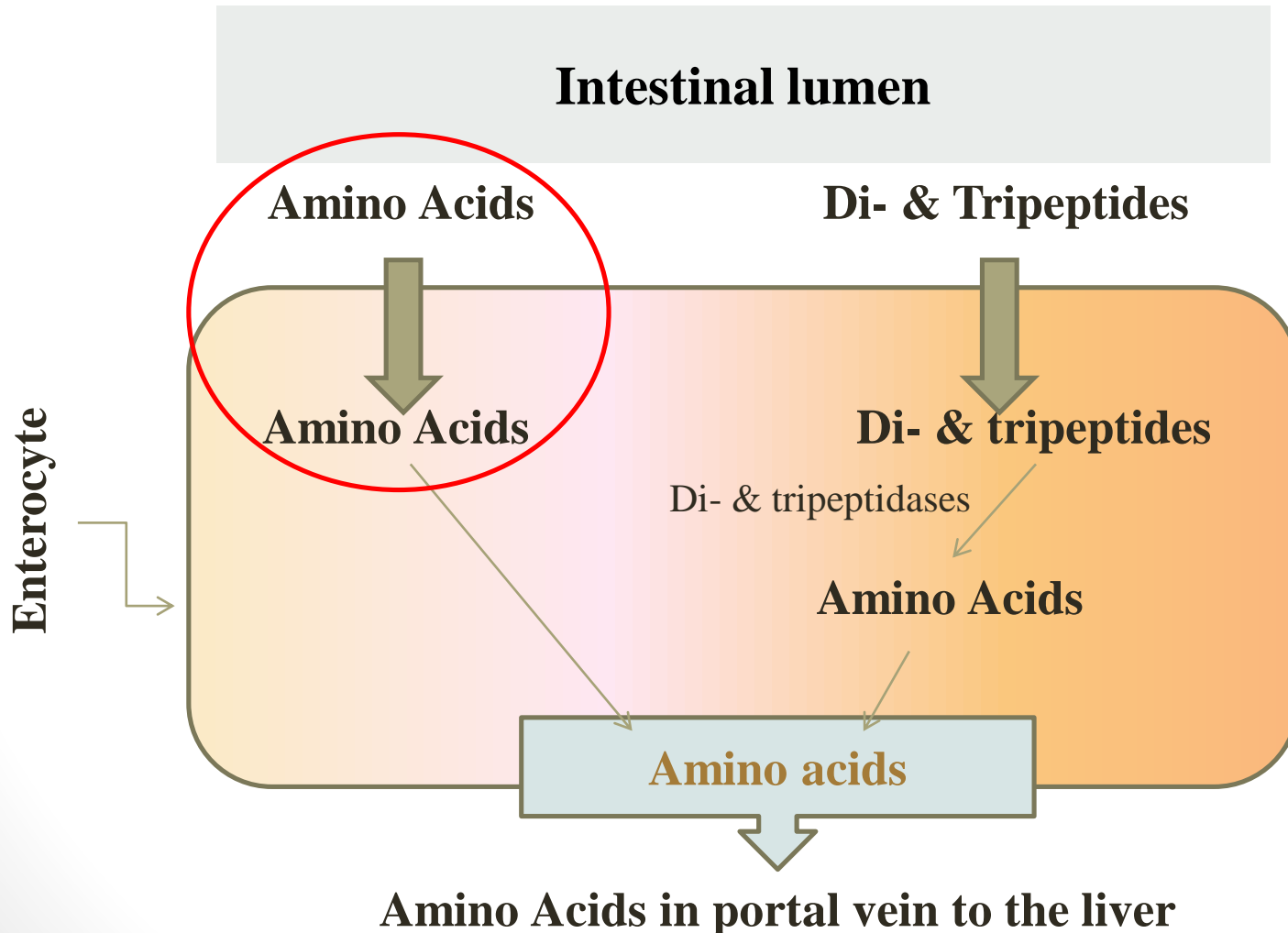
Oligopeptides that result from the action of pancreatic proteases are cleaved into free amino acids and smaller peptides (di- & tri-peptides) by

**intestinal aminopeptidase**

(an exopeptidase on the luminal surface of the intestine)



# Absorption of digested proteins



# Genetic Errors in Amino Acids Transport

- Cystinuria is one of the most common genetic error of amino acid transport
- It is an example of inherited disorder in the transport of certain amino acids
- It affects the transport of Cystine and dibasic amino acids
- The organs affected are the small intestine and the kidney
- Cystine and dibasic amino acids appear in the urine
- Clinically: there is kidney stones formation
- Oral hydration (drinking lots of water) is an important part of treatment (to prevent kidney stones formation)

# Abnormalities of protein digestion

Pancreatic insufficiency, e.g., chronic pancreatitis, cystic fibrosis,  
surgical removal of the pancreas



incomplete digestion & absorption of lipids & proteins



abnormal appearance of lipids (steatorrhea) & undigested  
proteins in the feces

# Celiac Disease (Celiac sprue)

- It is a disease of malabsorption resulting from immune-mediated damage to the villi of the small intestine in response to ingestion of gluten.
- Gluten is a protein found in wheat, rye, and barley.

# Biochemical Aspects of Digestion of Dietary Carbohydrates

# Carbohydrates digestion

- **Carbohydrates digestion is rapid:**

Generally completed by the time the gastric contents reach the junction of the duodenum & jejunum.

- **Sites for digestion of dietary carbohydrates:**

- The mouth
- The intestinal lumen

# Dietary Carbohydrates

- **Mainly:**

- **Polysaccharides:**

- Starch from plant origin
      - Glycogen from animal origin
    - Cellulose from plant origin
- } Contain  $\alpha$  (1 $\rightarrow$ 4) &  $\alpha$  (1 $\rightarrow$ 6) bonds
- $\longrightarrow$  Contains  $\beta$  (1 $\rightarrow$ 4) bonds

- **Oligosaccharides**

- **Disaccharides:**

- Sucrose
    - Lactose
    - Maltose

- **Monosaccharides:** Little amounts

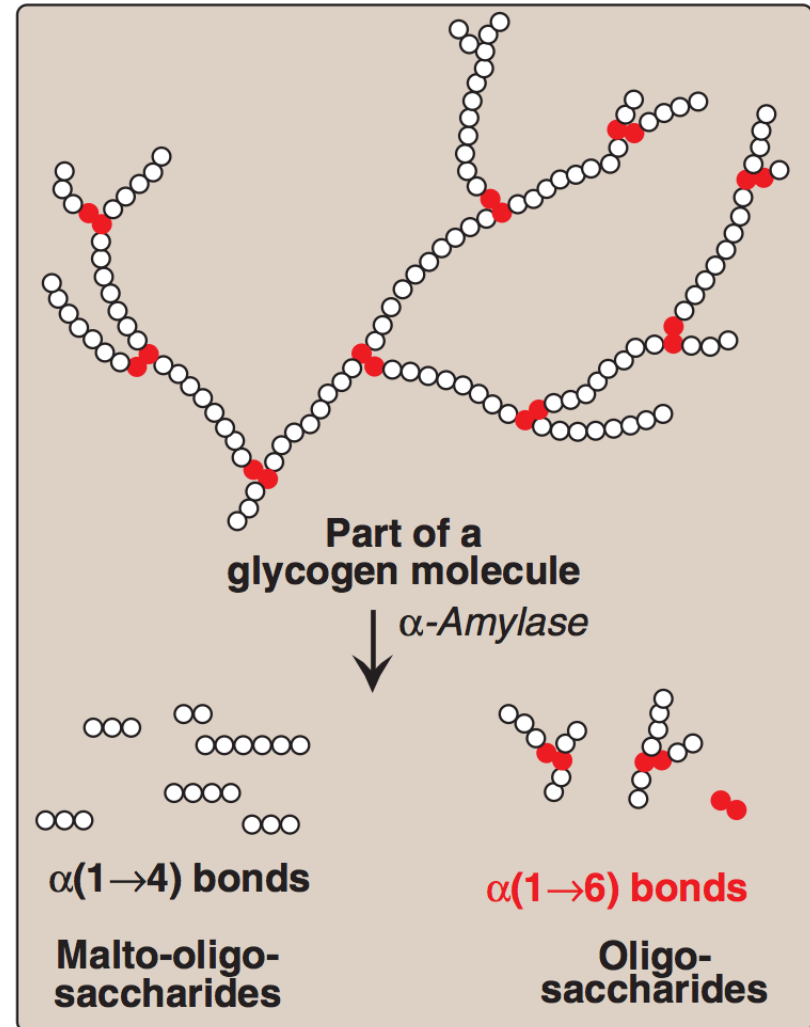
# Enzymes for Digestion of Dietary Carbohydrates

- **$\alpha$ -amylase** (Both salivary & pancreatic).  
**Substrate:** Polysaccharides
- **Disaccharidases** (Intestinal).  
**Substrate:** Disaccharides
- **Isomaltase &  $\alpha(1,6)$  glucosidase** (Intestinal).  
**Substrate:** Branch points of oligo- and di-saccharides



# Effects of $\alpha$ -amylase on Glycogen

- **Hydrolysis of:**
  - $\alpha(1,4)$  glycosidic bonds
- **Products:**
  - Mixture of short oligosaccharides (both branched & unbranched)
  - Disaccharides:
    - Maltose and isomaltose



# Enzymes for Digestion of Dietary Carbohydrates: continued ...

- **No dietary carbohydrate digestion occurs in the stomach** (*the high acidity of the stomach inactivates the salivary  $\alpha$ -amylase*).
- **Pancreatic  $\alpha$ -amylase continues the process of starch & glycogen digestion in the small intestine.**  
(*Secreted by pancreas and works in small intestine*)

# Serum level of $\alpha$ -amylases

- **Normal level in serum:** 25 -125 U/L
- **The clinical significance of rising circulating levels of  $\alpha$ -amylase activity:**
  - **Diagnosis of acute pancreatitis:**  
(*damage of pancreatic cells → release & activation of the intracellular enzymes into the blood*)
    - Its level starts to rise within few hours.
    - Reaches a peak within 12- 72 hours.
    - Then returns to normal within few days.

# Final digestion of carbohydrates by intestinal enzymes in the small intestine

- **Enzymes:**

- Disaccharidases
- $\alpha(1,6)$  Glucosidase (for branched oligosaccharides)

- **Source:**

Secreted by & remain associated with the luminal side of the brush border membranes of the intestinal mucosal cells

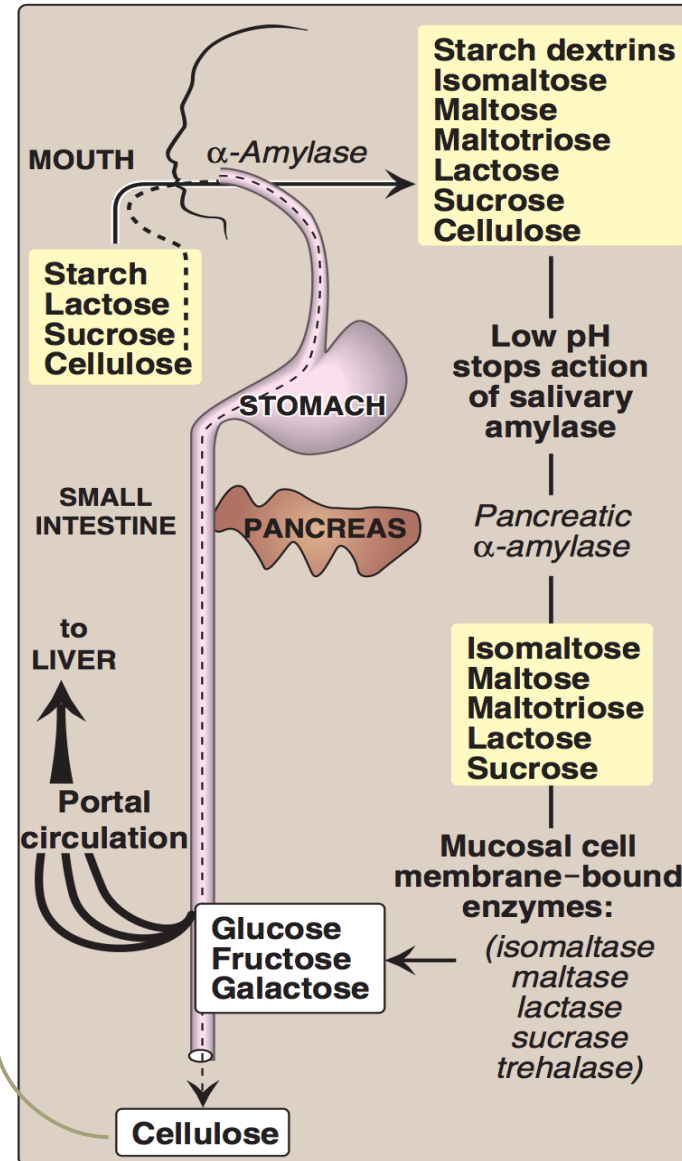
- **Location of their action:** the mucosal lining of the jejunum.

# Intestinal disaccharidases

Enzyme	Substrate	Product
Isomaltase	isomaltose	2 Glucose
Maltase	maltose	2 Glucose
Sucrase	sucrose	Glucose & fructose
Lactase ( $\beta$ -galactosidase)	lactose	Glucose & galactose

# Digestion of Carbohydrates

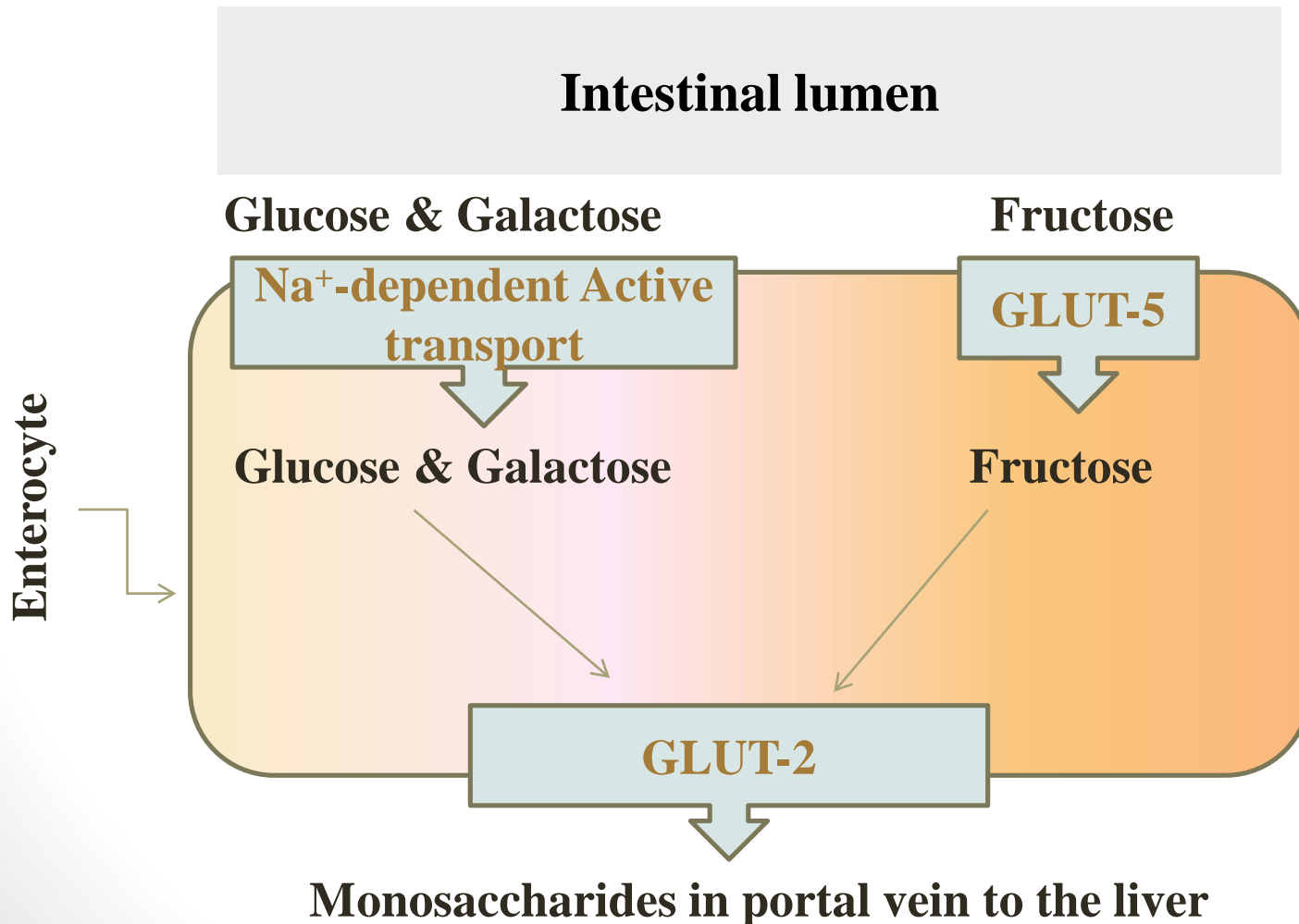
Dietary cellulose cannot be digested due to the absence of enzyme that can cleave  $\beta$  (1-4) bonds. It passes through the GIT largely intact. Despite that, it has several beneficial effects.



# Absorption of Monosaccharides by Intestinal Mucosal Cells

- **Location:** Duodenum & upper jejunum.
- **Insulin:** is **NOT** required for the uptake of glucose by intestinal cells.
- **Different monosaccharides have different mechanisms of absorption:**
  1. Facilitated diffusion (GLUT-mediated)
  2. Active transport (Energy-dependent): Co-transport with  $\text{Na}^+$

# Absorption of digested carbohydrates



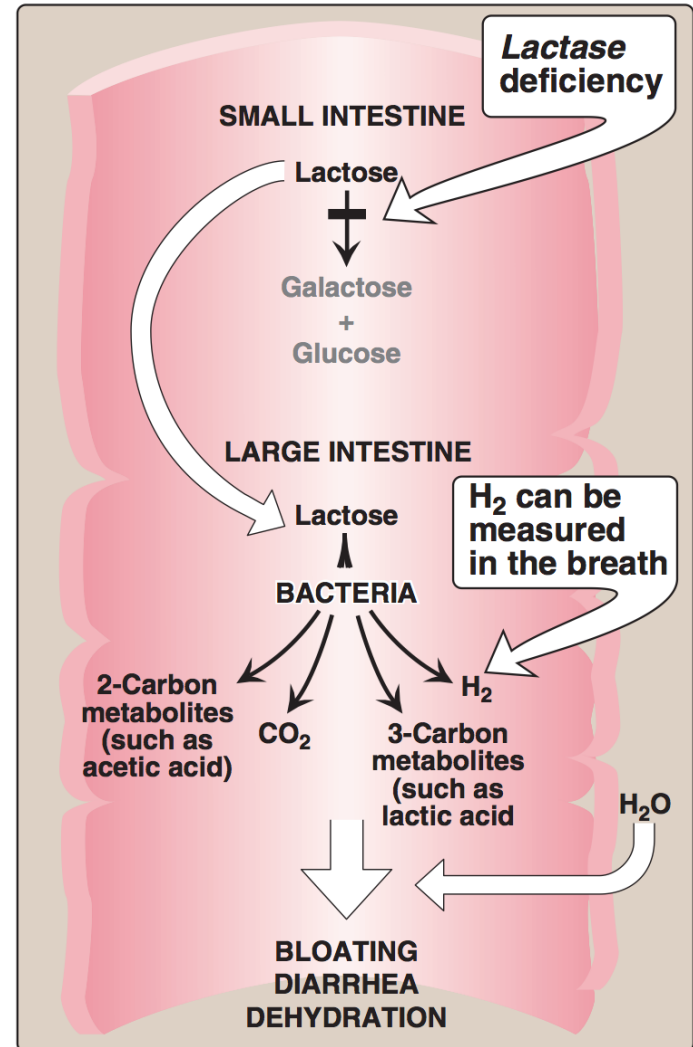


# Abnormal digestion of disaccharides (e.g. of lactose)

## Lactose intolerance (Lactase deficiency)

Lactase ( $\beta$ -galactosidase) deficiency  $\rightarrow$   
Undigested carbohydrate in large  
intestine  $\rightarrow$  osmotic diarrhea.

Bacterial fermentation of the undigested  
compounds in the large intestine  $\rightarrow$   $\text{CO}_2$ ,  
 $\text{H}_2$  gas  $\rightarrow$  abdominal cramps, diarrhea &  
distension (flatulence)



# Take Home Messages

## Digestion of Dietary proteins

- Proteolytic enzymes responsible for digestion of dietary proteins are produced by the stomach, the pancreas & the small intestine.
- The digestion of proteins in the stomach is the result of the action of HCl and pepsin.
- Pancreatic proteases are, like pepsin, synthesized and secreted as inactive zymogens.

# Take Home Messages

## Digestion of Dietary proteins

- The intestinal digestion of proteins occurs in the small intestine's lumen, on the luminal surface of the small intestine, and is completed intracellularly to produce free amino acids.
- In pancreatic insufficiency, the digestion and absorption of fat & protein is incomplete → steatorrhea & appearance of undigested proteins in the feces.

# Take Home Messages

## Digestion of Dietary carbohydrates

- Salivary  $\alpha$ -amylase acts on dietary glycogen & starch in the mouth.
- Pancreatic  $\alpha$ -amylase continues the process of polysaccharide digestion in small intestine.
- The final digestive processes of carbohydrates into monosaccharides occur at the mucosal lining of the small intestine by disaccharidases &  $\alpha(1,6)$  glucosidase.

# Take Home Messages

## Digestion of Dietary carbohydrates

- Dietary cellulose cannot be digested due to the absence of enzyme that can cleave  $\beta$  (1-4) bonds, so it passes through the GIT largely intact. Despite that, it has several beneficial effects.
- Absorption of the monosaccharides requires specific transporters (GLUTs).
- Lactose intolerance is due to deficiency of lactase enzyme and causes abdominal cramps, diarrhea & flatulence

# Reference

Lippincott's Illustrated reviews: Biochemistry 6<sup>th</sup> edition –  
chapters 7 and 19.