King Saud University
College of Sciences
Biochemistry Department

الأيض (١)
Metabolism (1)
BCH 340

Lecture 2: Digestion of carbohydrates

Intended learning outcomes (ILOs)

By the end of this lecture, students will be able to:

- Understand the process of carbohydrate digestion, including:
  - the enzymes involved
  - the breakdown of different carbohydrates
  - the absorption of resulting monosaccharides

- Explain different mechanisms involved in glucose transportation into cells.

- Recognize the pathways involved in the utilization of glucose within cells.

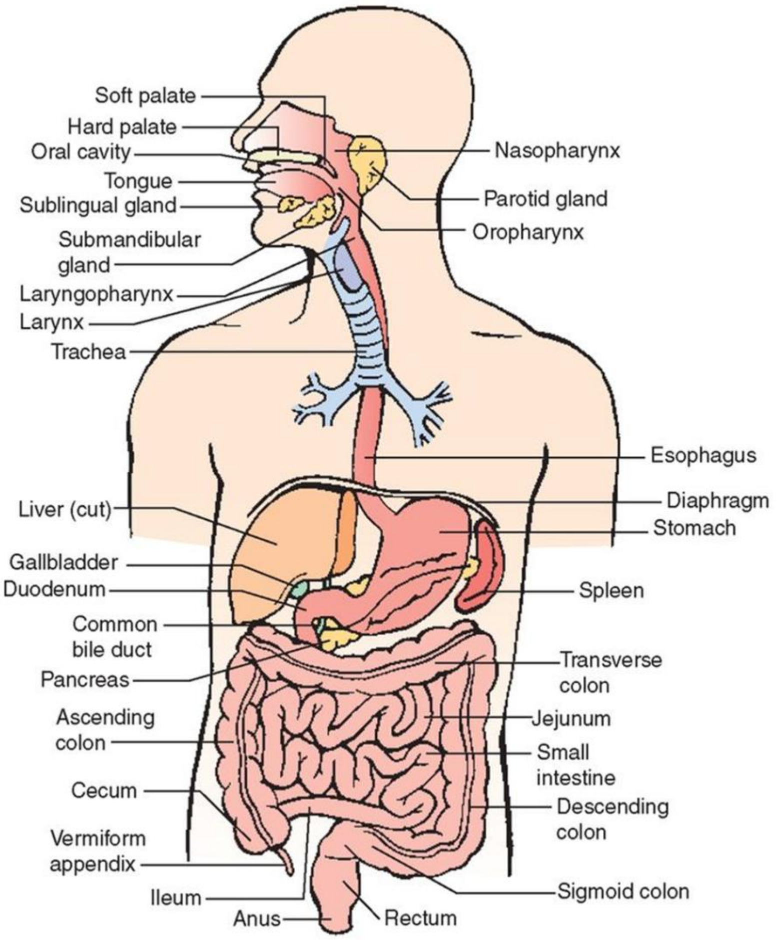
Introduction to digestion

- Digestion is a fundamental physiological process that breaks down large (complex) food molecules into smaller (simpler) units.
- These small nutrients can be absorbed into the bloodstream and transported to cells throughout the body where they can be used for energy, growth, and maintenance of various bodily functions.
- Digestion involves a series of mechanical and chemical processes that occur in the digestive system (the gastrointestinal tract).

Key concepts in digestion

I. Human digestive system:

- It includes organs such as the mouth, esophagus, stomach, intestine (small and large), liver, gallbladder, and pancreas.
- Each of these organs play a specific role in the digestive process.



Key concepts in digestion (cont.)

II. Mechanical digestion:

- It involves the physical breakdown of food into smaller particles.
- It is facilitated by processes like chewing in the mouth, churning in the stomach, and segmentation in the small intestine.

III. Chemical digestion:

- It involves the action of enzymes that breakdown complex molecules into simpler ones.
- Enzymes are secreted by various organs, with specific enzymes targeting proteins, carbohydrates, and fats.

Key concepts in digestion (cont.)

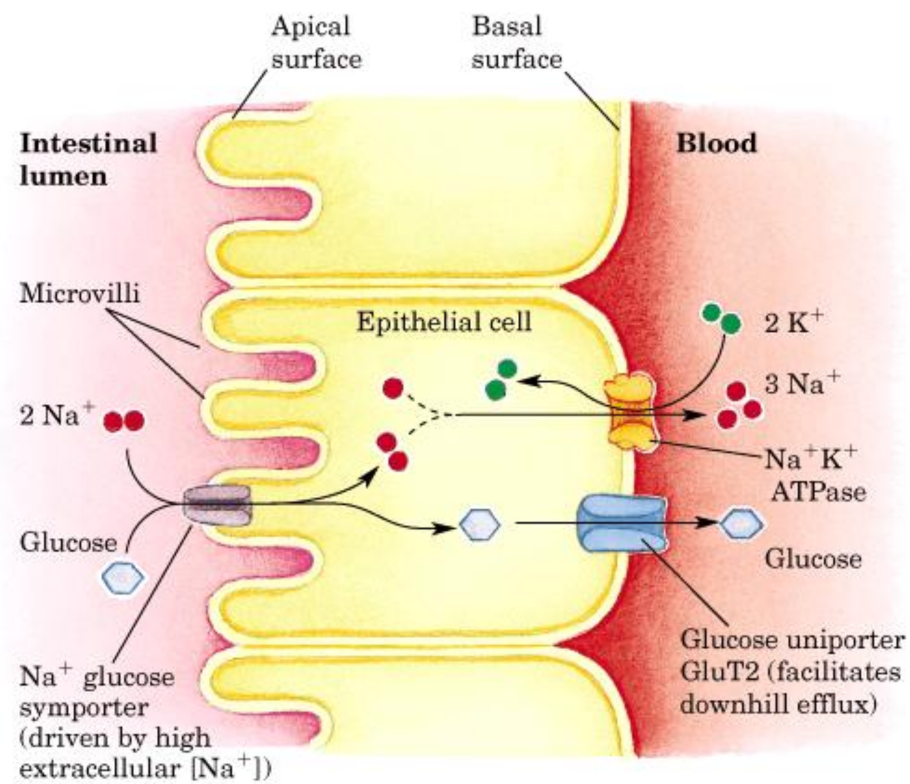
IV. Digestive enzymes:

- Examples of digestive enzymes include *amylase* (for carbohydrates), *pepsin* (for proteins), *lipase* (for fats), and various brush border enzymes in the small intestine.
- These enzymes catalyze reactions that facilitate the breakdown of macromolecules.

Key concepts in digestion (cont.)

V. Absorption:

- Once nutrients are broken down into smaller components (such as amino acids, fatty acids, and glucose), they are absorbed through the walls of the small intestine and transported to cells via the bloodstream.



Key concepts in digestion (cont.)

VI. Nutrient utilization:

- Absorbed nutrients are used by cells for:
  - Energy production
  - Building and repairing tissues
  - Supporting various physiological functions

VII. Waste elimination:

- Indigestible materials and waste products are formed during digestion. These are eliminated from the body through the excretory process.

Carbohydrates

- Carbohydrates are classified into three main groups based on their chemical structure:

- **Monosaccharides (simple sugars):**

  Examples: glucose, fructose, galactose, and ribose.

- **Oligosaccharides (2 – 10 sugar units):**

  Examples: sucrose, lactose, maltose, raffinose.

- **Polysaccharides (complex sugars):**

  Examples: glycogen, cellulose, starch, etc.

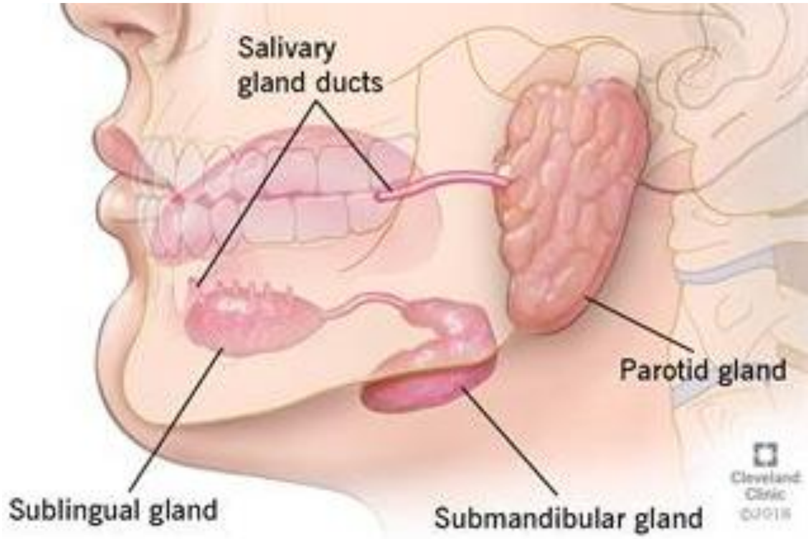
Digestion of carbohydrates

In the mouth:

- The digestion of carbohydrates begins in the mouth with the intake of food and incorporates both mechanical and chemical processes.

- The process of chewing (mastication) breaks down food into smaller particles, increasing its surface area for enzymatic action.

- Salivary glands secrete salivary *α-amylase*, which begins a brief chemical breakdown of dietary carbohydrates (mainly starches) by breaking the α(1→4) bonds between monomeric sugar units.



Digestion of carbohydrates (cont.)

In the stomach:

- The stomach is not a primary site for carbohydrates digestion due to:
  - The high acidity of the stomach (due to the secretion of hydrochloric acid).
  - The absence of gastric enzymes to digest carbohydrates.

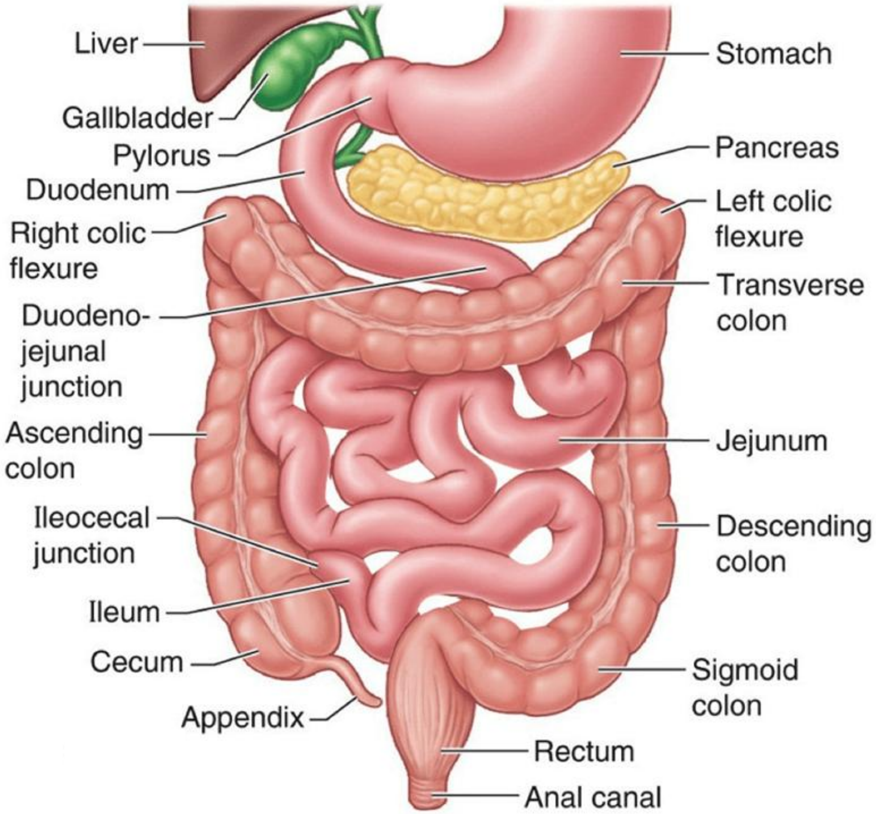
- The high acidic environment in the stomach halts carbohydrate digestion as it inactivates the salivary *α-amylase*.

Digestion of carbohydrates (cont.)

In the small intestine:

- Carbohydrates (still in a partially digested form) continue into the small intestine for further digestion.

- When the acidic stomach contents (known as **chyme**) enters the duodenum (the first part of the small intestine), pancreas releases pancreatic juice through a duct.



Digestion of carbohydrates (cont.)

In the small intestine (cont.):

- This pancreatic juice contains the enzyme, pancreatic *α-amylase*, which further breakdown of polysaccharides into shorter and shorter carbohydrate chains (a mixture of oligo- and mono-saccharides).

Note:

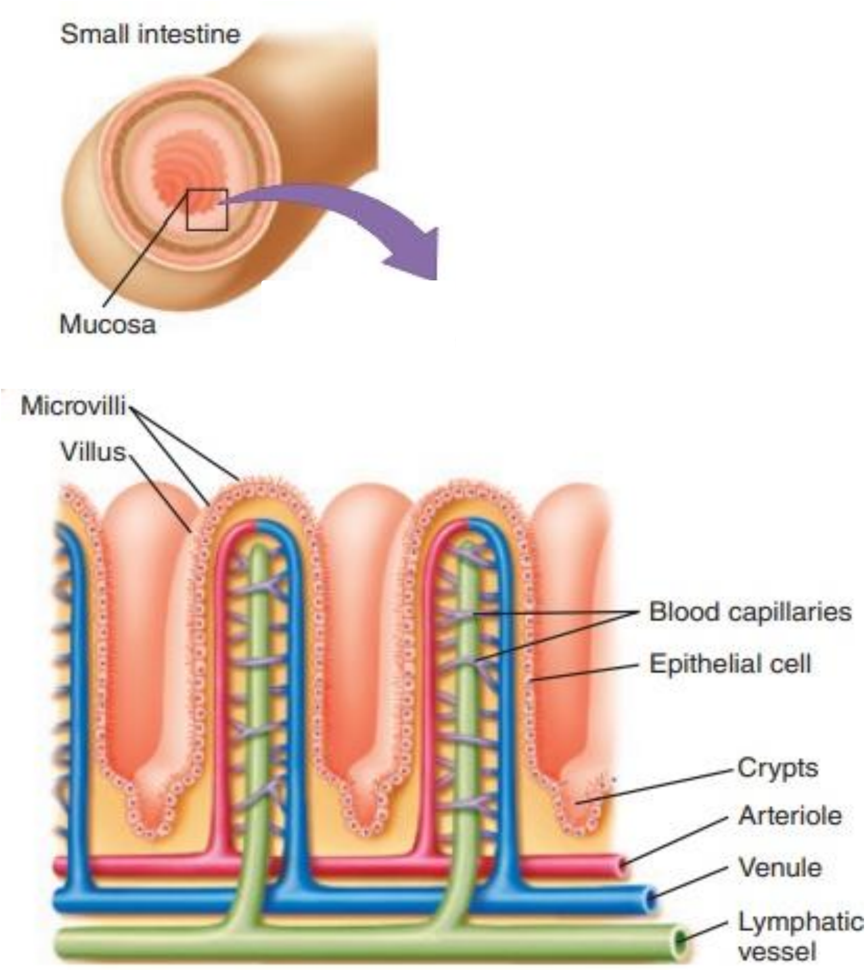
- The presence of bicarbonate in the pancreatic juice helps neutralizing the chyme, rising the pH into the optimal range for the action of the intestinal enzymes.

Digestion of carbohydrates (cont.)

The action of brush board enzymes:

- Final carbohydrate digestion takes place in the mucosal lining of the small intestine.

- Several enzymes are associated with the brush border of the small intestine (including maltase, sucrase, isomaltase, and lactase) further breakdown disaccharides into monosaccharides.



Digestion of carbohydrates (cont.)

The action of brush board enzymes (cont.):

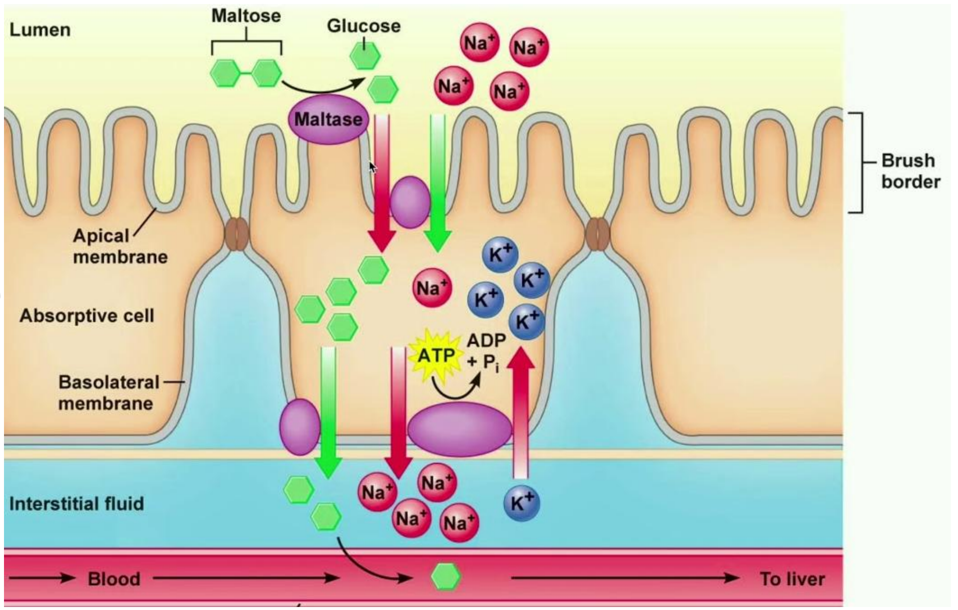
- The brush board enzymes are located near to the transporters, which facilitate the absorption of the digested monosaccharides.
- These enzymes include:

Maltose —*Maltase*→ Glucose + **Glucose**

Sucrose —*Sucrase*→ Glucose + **Fructose**

Lactose —*Lactase*→ Glucose + **Galactose**

Isomaltose —*Isomaltase*→ Glucose + **Glucose**



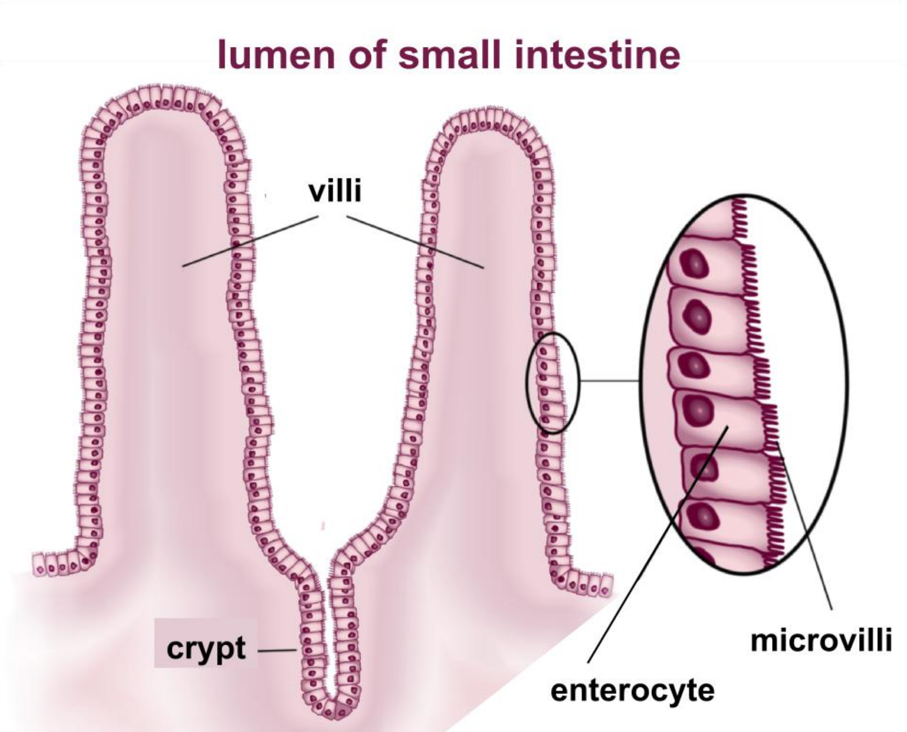
Transport of glucose into cells

Absorption of monosaccharides:

- The final products generated by the digestion of dietary carbohydrates (glucose, fructose, and galactose) are absorbed by intestinal mucosal (epithelial) cells.

- The absorptive surface area is significantly increased by the presence of tiny finger-like projections (villi and microvilli).

- The absorption occurs via active transport or facilitated diffusion, depending on the specific monosaccharide.

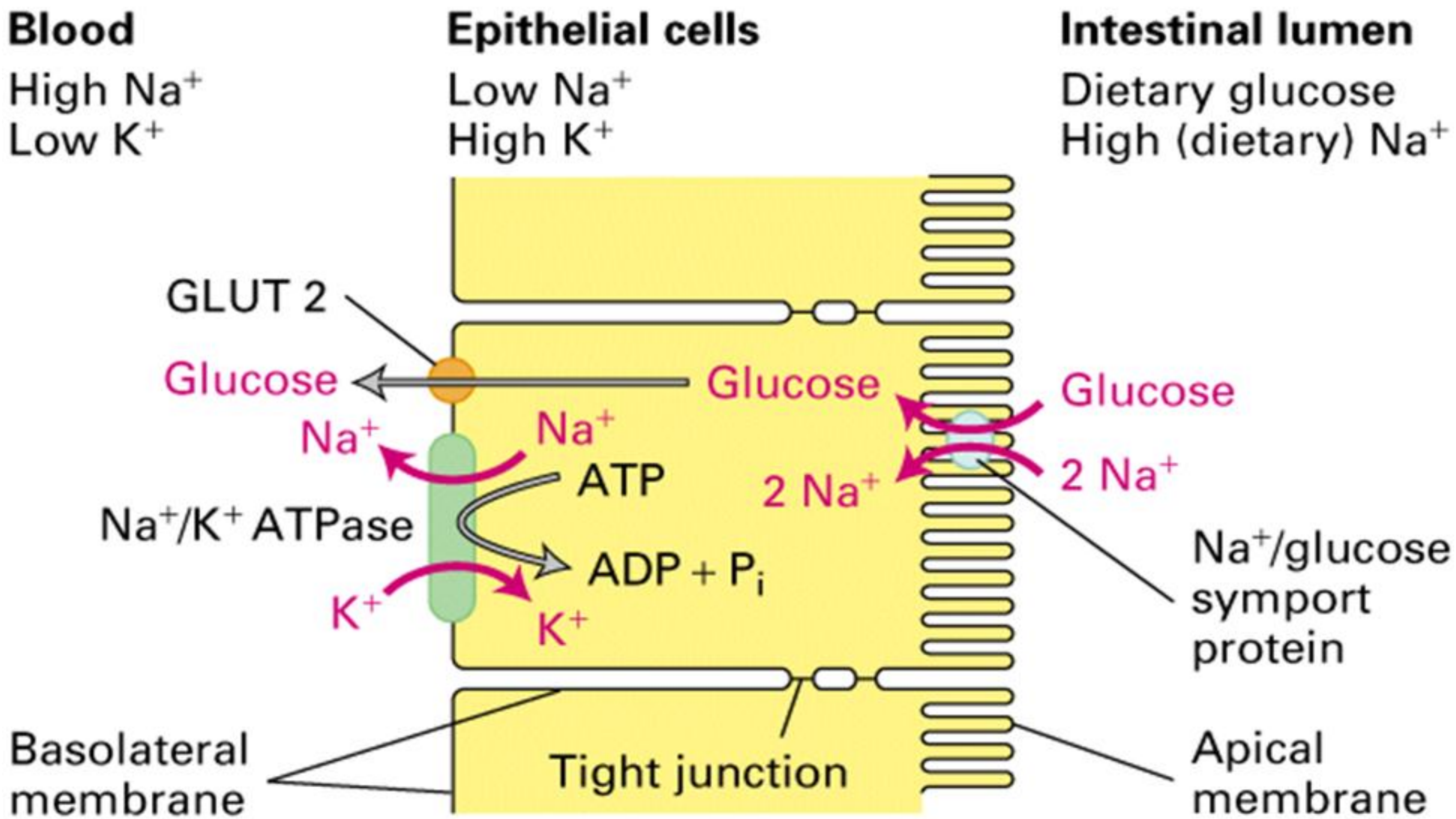


Transport of glucose into cells (cont.)

- Specific transport proteins on the surface of the mucosal cells facilitate the movement of monosaccharides into the cells (moving down a concentration gradient).
- Glucose and galactose are transported by sodium-dependent glucose transporter (SGLT-1) using energy generated from co-transporting two sodium ions with glucose (active transport).
- Fructose is absorbed through facilitated diffusion via glucose transporter protein (GLUT-5).
- All the three monosaccharides are then pass out of the intestinal mucosal cells into the portal circulation by passive transport through the action of transport protein, GLUT-2.

Transport of glucose into cells (cont.)

Transport of glucose across the intestinal mucosal cells



Transport of glucose into cells (cont.)

- Glucose can NOT diffuse directly into cells, but diffuses across cell membranes by one of two transport mechanisms:
  - Concentration gradient-dependent facilitated transport.
  - Carrier-mediated active transport.

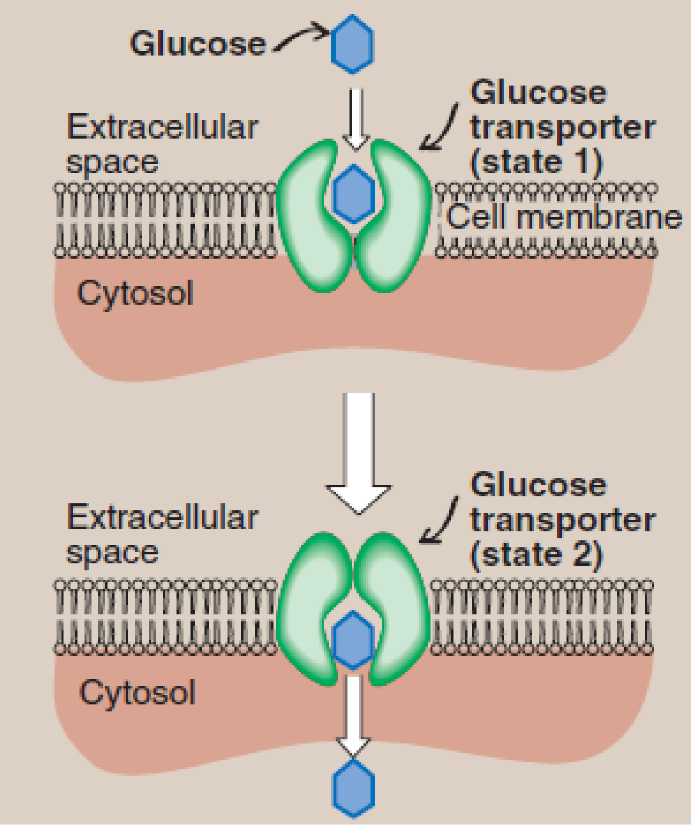
Passive transport (facilitated diffusion):

- Glucose uptake by cells is mediated by a family of glucose transporters that are integral membrane proteins.
- This family is comprised of at least 14 glucose transporters isoforms (GLUT-1 to GLUT-14).
- They facilitate the diffusion of glucose across the cell membrane, from an area of high concentration (outside the cell) to an area of low concentration (inside the cell).

Transport of glucose into cells (cont.)

Passive transport (facilitated diffusion):

- The glucose transporters display a tissue-specific pattern of expression:
  - GLUT-3 is the primary glucose transporter in neurons.
  - GLUT-1 is abundant in erythrocytes and blood brain barrier, but is low in adult muscle.
  - GLUT-4 is abundant in adipose tissue and skeletal muscle.



Regulation of glucose transportation

- Insulin is a peptide hormone produced by the β-cells of the pancreas.
- It regulates the glucose uptake and utilization by some tissues.

Insulin-independent glucose transportation:

- This mechanism of glucose transportation is not directly regulated by insulin.
- It is mediated predominantly by glucose transporter (GLUT-1), which is widely distributed in different tissues, including brain, hepatocytes, and red blood cells.

Regulation of glucose transportation (cont.)

Insulin-dependent glucose transportation:

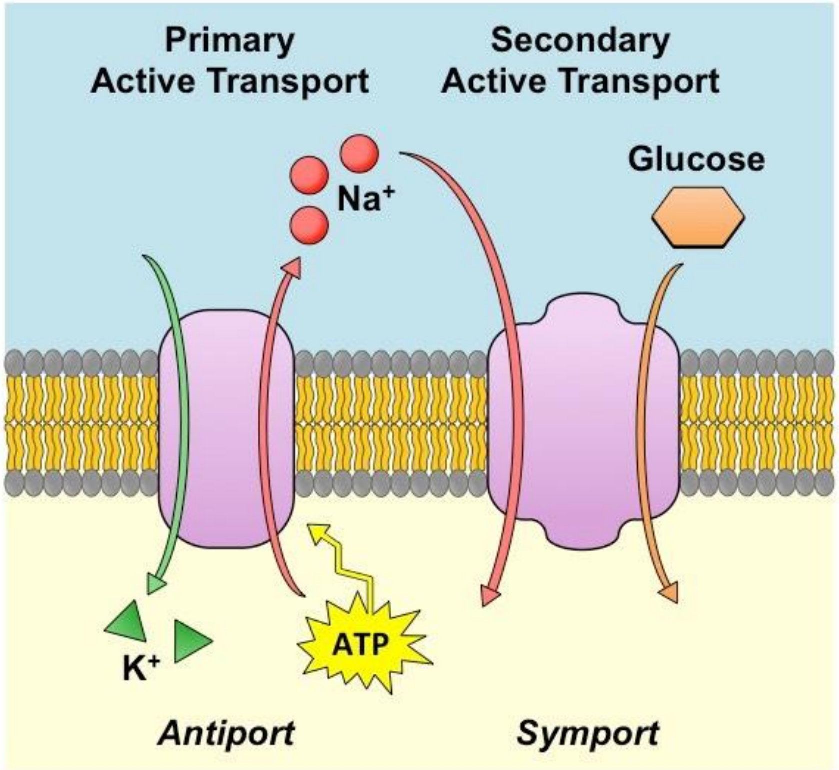
- It facilitates the uptake of glucose into the cell, where it can be utilized or stored.
- It occurs primarily in insulin-sensitive tissues such as skeletal muscles and adipose tissues.
- Insulin binding to its receptors (on the surface of the cell membrane) facilitates glucose transportation inside the cell.
  - Mainly by enhancing acute translocation of GLUT-4 transporter from intracellular vesicles to the cell membrane).

Transport of glucose into cells (cont.)

Active transport (sodium-glucose cotransport):

- This is an energy-requiring process that transports glucose "against" a concentration gradient (from low glucose concentrations outside the cell to higher concentrations within the cell).

- This system is a carrier-mediated process in which the movement of glucose is coupled to the concentration gradient of sodium ions, which is transported into the cell at the same time (Na^+/glucose symporter).



Transport of glucose into cells (cont.)

Active transport (sodium-glucose cotransport):

- This type of transport is mediated by a family of sodium-dependent glucose transporters (SGLTs).
- It occurs in the epithelial cells of the intestine and renal tubules.
- Once glucose is transported into the cell, it can be used for energy production via glycolysis or stored as glycogen.

Metabolic fate of glucose

- After the absorption of digested monosaccharides (glucose, galactose, and fructose), the liver takes up all sugars, where galactose and fructose convert into glucose.
- The major fates of glucose in humans, animals, and plants, include:
  - Oxidation
  - Storage
  - Conversion
  - Excretion

Metabolic fate of glucose (cont.)

1. Oxidation:

- Once inside the cell, glucose is oxidized through:

  a. Glycolysis and Krebs' cycle to produce energy (ATP) and metabolic intermediates.

  b. Pentose phosphate pathway to yield ribose 5-phosphate for nucleic acid synthesis and NADPH for reductive biosynthetic processes.

  c. Uronic acid pathway, to produce glucuronic acid used in the detoxification of xenobiotic compounds and the formation of mucopolysaccharide.

Metabolic fate of glucose (cont.)

2. Storage:

- Excess glucose is converted into glycogen through glycogenesis.
  - Glycogen is a polysaccharide that serves as a stored form of glucose primarily in the liver and muscles.

- When the body reaches its storage capacity for glycogen, the liver converts the excess glucose into triglycerides (lipogenesis) which is then transported and stored in the adipose tissue.

Metabolic fate of glucose (cont.)

3. Conversion:

- Glucose can be converted to substances of biological importance; such as converting into:
  - Ribose and deoxyribose to form RNA and DNA, respectively.
  - Lactose for milk production.
  - Sugar amines (glucosamine and galactosamine) to produce mucopolysaccharides.
  - Glucuronic acid to produce mucopolysaccharides.
  - Fructose to form the seminal fluid.

Metabolic fate of glucose (cont.)

4. Excretion of glucose in urine:

- In a healthy individual, the kidneys filter the blood, reabsorbing nearly all of the glucose and preventing its excretion in urine.
- However, when the glucose concentration in the blood exceeds the renal threshold (the maximum amount the kidneys can reabsorb; 180 mg/dL), excess glucose spills into the urine.
- This condition is known as glycosuria and might be associated with:
  - Diabetes Mellitus
  - Kidney dysfunction
  - Pregnancy

Summary

- The digestion of carbohydrates is a dynamic and intricate process that involves both mechanical and enzymatic actions throughout the digestive system.

- The absorption of resulting monosaccharides into cells, facilitated by specific transport proteins employing both passive and active transport mechanisms to ensure a steady supply of glucose for cells.

- This highly coordinated digestive process provides the body with a vital energy source and supports various physiological functions, emphasizing the importance of a balanced diet for overall health.