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BCH 445
Biochemistry of nutrition

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Carbohydrates

Carbohydrates:

- **Compounds composed of carbon, oxygen, and hydrogen arranged as monosaccharides or multiples of monosaccharides.**
- **Most, but not all, carbohydrates have a ratio of one carbon molecule to one water molecule: $(CH_2O)_n$.**

- **Glucose and its storage form glycogen provide about half of all the energy muscles and other body tissues use.**
- **Glucose is the precursor for synthesis of all the other carbohydrates in the body, including glycogen for storage; ribose and deoxyribose in nucleic acids; galactose for synthesis of lactose in milk, in glycolipids, and in combination with protein in glycoproteins and proteoglycans.**
- **All plant foods (whole grains, vegetables, legumes, and fruits) provide sufficient carbohydrate. Milk also contains carbohydrate.**

The dietary carbohydrate family includes:

Monosaccharides: carbohydrates of the general formula $C_nH_{2n}O_n$ that typically form a single ring. The most important sugars in nutrition symbolizes them as hexagons and pentagons.

The monosaccharides important in nutrition are hexoses, sugars with six atoms of carbon and the formula $C_6H_{12}O_6$.

- **Glucose:** a monosaccharide; sometimes known as blood sugar in the body or dextrose in foods.
- **Fructose:** a monosaccharide; sometimes known as fruit sugar or levulose. Fructose is found abundantly in fruits, honey, and saps.
- **Galactose:** a monosaccharide; part of the disaccharide lactose.

Physiological Importance of pentoses

Sugar	Source	Biochemical and Clinical Importance
D-Ribose	Nucleic acids and metabolic intermediate	Structural component of nucleic acids and coenzymes, including ATP, NAD(P), and flavin coenzymes
D-Ribulose	Metabolic intermediate	Intermediate in the pentose phosphate pathway
D-Arabinose	Plant gums	Constituent of glycoproteins
D-Xylose	Plant gums, proteoglycans, glycosaminoglycans	Constituent of glycoproteins
L-Xylulose	Metabolic intermediate	Excreted in the urine in essential pentosuria

Physiological Importance of Hexoses

Sugar	Source	Biochemical Importance	Clinical Significance
D-Glucose	Fruit juices, hydrolysis of starch, cane or beet sugar, maltose and lactose	The main metabolic fuel for tissues; "blood sugar"	Excreted in the urine (glucosuria) in poorly controlled diabetes mellitus as a result of hyperglycemia
D-Fructose	Fruit juices, honey, hydrolysis of cane or beet sugar and inulin, enzymic isomerization of glucose syrups for food manufacture	Readily metabolized either via glucose or directly	Hereditary fructose intolerance leads to fructose accumulation and hypoglycemia
D-Galactose	Hydrolysis of lactose	Readily metabolized to glucose; synthesized in the mammary gland for synthesis of lactose in milk. A constituent of glycolipids and glycoproteins	Hereditary galactosemia as a result of failure to metabolize galactose leads to cataracts
D-Mannose	Hydrolysis of plant mannan gums	Constituent of glycoproteins	

Disaccharides: sugars composed of pairs of monosaccharides linked together.

Maltose: a disaccharide composed of two glucose units; sometimes known as malt sugar.

Sucrose: a disaccharide composed of glucose and fructose; commonly known as table sugar, beet sugar, or cane sugar. Sucrose also occurs in many fruits and some vegetables and grains.

Lactose: a disaccharide composed of glucose and galactose; commonly known as milk sugar.

Physiological Importance of disaccharides

Sugar	Composition	Source	Clinical Significance
Sucrose	O-α-D-glucopyranosyl-(1→2)-β-D-fructofuranoside	Cane and beet sugar, sorghum and some fruits and vegetables	Rare genetic lack of sucrase leads to sucrose intolerance—diarrhea and flatulence
Lactose	O-α-D-galactopyranosyl-(1→4)-β-D-glucopyranose	Milk (and many pharmaceutical preparations as a filler)	Lack of lactase (alactasia) leads to lactose intolerance—diarrhea and flatulence; may be excreted in the urine in pregnancy
Maltose	O-α-D-glucopyranosyl-(1→4)-α-D-glucopyranose	Enzymic hydrolysis of starch (amylase); germinating cereals and malt	
Isomaltose	O-α-D-glucopyranosyl-(1→6)-α-D-glucopyranose	Enzymic hydrolysis of starch (the branch points in amylopectin)	
Lactulose	O-α-D-galactopyranosyl-(1→4)-β-D-fructofuranose	Heated milk (small amounts), mainly synthetic	Not hydrolyzed by intestinal enzymes, but fermented by intestinal bacteria; used as a mild osmotic laxative
Trehalose	O-α-D-glucopyranosyl-(1→1)-α-D-glucopyranoside	Yeasts and fungi; the main sugar of insect hemolymph	

Polysaccharides: large molecules composed of chains of monosaccharides. compounds composed of many monosaccharides linked together (Glycogen, starch and fibers). An intermediate string of 3 to 10 monosaccharides is an oligosaccharide.

Glycogen: an animal polysaccharide composed of glucose; a storage form of glucose manufactured and stored in the liver and muscles. Glycogen is not a significant food source of carbohydrate and is not counted as a dietary carbohydrate in foods.

Starches: plant polysaccharides composed of many glucose molecules.

Resistant starches: starches that escape digestion and absorption in the small intestine of healthy people.

phytic acid: a non nutrient component of plant seeds; also called phytate. Phytic acid occurs in the husks of grains, legumes, and seeds and is capable of binding minerals such as zinc, iron, calcium, magnesium, and copper in insoluble complexes in the intestine, which the body excretes unused.

Dietary fibers: in plant foods, the non starch polysaccharides that are not digested by human digestive enzymes, although some are digested by gastrointestinal tract bacteria.

Soluble fibers: non starch polysaccharides that dissolve in water to form a gel. An example is pectin from fruit, which is used to thicken jellies.

Insoluble fibers: non starch polysaccharides that do not dissolve in water. Examples include the tough, fibrous structures found in the strings of celery and the skins of corn kernels.

Monosaccharides and disaccharides (the sugars) are sometimes called simple carbohydrates, and polysaccharides (starches and fibers) are sometimes called complex carbohydrates.

Carbohydrates functions

- **Main source of energy: Formation ATP by the cells using glucose.**
- **Intermediates in the biosynthesis of fats and proteins.**
- **Form structural tissues in plants.**
- **Participate in biological transport, cell recognition, activation of growth factors, modulation of the immune system**

Digestion and Absorption of Carbohydrates

STARCH

Mouth and salivary glands
The salivary glands secrete saliva into the mouth to moisten the food. The salivary enzyme amylase begins digestion:

Starch —Amylase→ Small polysaccharides, maltose

Stomach
Stomach acid inactivates salivary enzymes, halting starch digestion.

Small intestine and pancreas

The pancreas produces an amylase that is released through the pancreatic duct into the small intestine:

Starch —(Pancreatic amylase)→ Small polysaccharides, maltose

Then disaccharidase enzymes on the surface of the small intestinal cells hydrolyze the disaccharides into monosaccharides:

Maltose —(Maltase)→ Glucose + Glucose

Sucrose —(Sucrase)→ Fructose + Glucose

Lactose —(Lactase)→ Galactose + Glucose

Intestinal cells absorb these monosaccharides.

FIBER

Mouth
The mechanical action of the mouth crushes and tears fiber in food and mixes it with saliva to moisten it for swallowing.

Stomach
Fiber is not digested, and it delays gastric emptying.

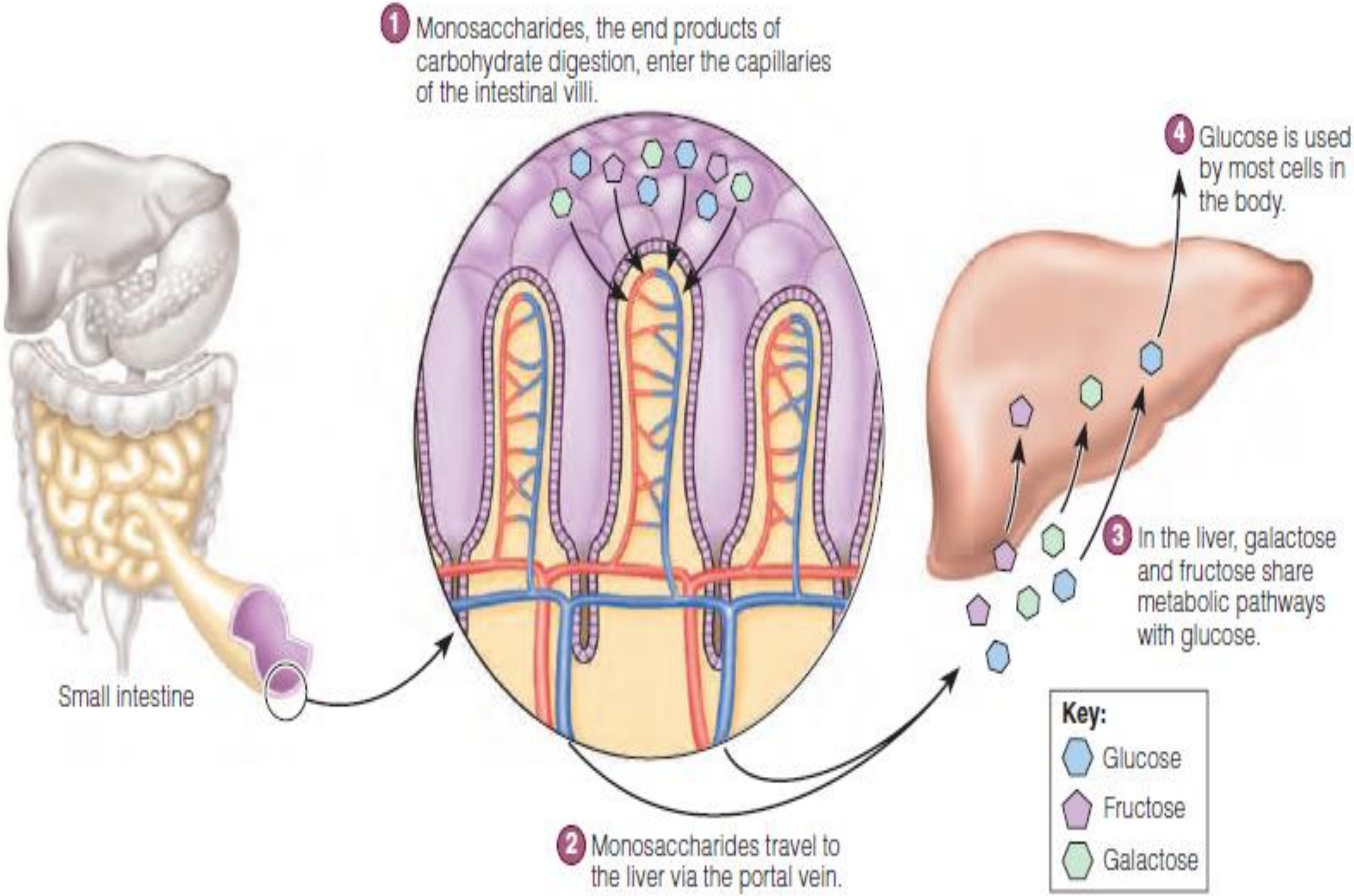
Small intestine
Fiber is not digested, and it delays absorption of other nutrients.

Large intestine

Most fiber passes intact through the digestive tract to the large intestine. Here, bacterial enzymes digest fiber:

Some fiber $\xrightarrow{\text{Bacterial enzymes}}$ Short-chain fatty acids, gas

Fiber holds water; regulates bowel activity; and binds substances such as bile, cholesterol, and some minerals, carrying them out of the body.


1 Monosaccharides, the end products of carbohydrate digestion, enter the capillaries of the intestinal villi.
4 Glucose is used by most cells in the body.
Small intestine
3 In the liver, galactose and fructose share metabolic pathways with glucose.
2 Monosaccharides travel to the liver via the portal vein.
Key:
Glucose
Fructose
Galactose

Carbohydrate Metabolism

Glucose plays the central role in carbohydrate metabolism.

Storing Glucose as Glycogen. After a meal, blood glucose rises, and liver cells link excess glucose molecules by condensation reactions into long, branching chains of glycogen. When blood glucose falls, the liver cells break down glycogen by hydrolysis reactions into single molecules of glucose and release them into the bloodstream. Thus glucose becomes available to supply energy to the brain and other tissues. The liver stores about one-third of the body’s total glycogen

Muscle cells can also store glucose as glycogen (the other two-thirds). The brain maintains a small amount of glycogen, which is thought to provide an emergency energy reserve during times of severe glucose deprivation. The body can store only enough glycogen to provide energy for relatively short periods of time less than a day during rest and a few hours at most during exercise.

Using Glucose for Energy. Glucose fuels the work of most of the body's cells. Inside a cell, a series of reactions can break glucose into smaller compounds that yield energy when broken down completely to carbon dioxide and water.

Making Glucose from Protein. The amino acids of protein can be used to make glucose (gluconeogenesis) to fuel the brain and other special cells.

Using Glucose to Make Fat. When carbohydrate is abundant fat is created (by using excess carbohydrate to make body fat). The fat then travels to the fatty tissues of the body for storage.

- Minimum 100 g/day to maintain adequate blood glucose levels.
- Recommended minimum 130 g/day.
- Recommended intake: 45–65% of total calorie intake; mostly complex carbohydrates.