Chapter 2. Carbohydrates

2.1 Carbohydrate Needs

Carbohydrates are obtained in the diet in plant and animal foods, additives and supplements. Determining and promoting ideal daily carbohydrate intake are two primary concentrations of nutrition research focused primarily on distinguishing between the many beneficial types of carbohydrates that are provided by **intrinsic sources** like fruits, vegetables and milk, and heightening awareness about the outcomes related **extrinsic sources** of carbohydrates added to enhance the aesthetic qualities of foods. The newest iteration of nutrition labeling laws requires that intrinsic and extrinsic carbohydrate sources be distinguished by using the term, "added" in the carbohydrate section of the NFP.

Currently, the **Adequate Intake** for daily total carbohydrate intake for healthy adults is 130 grams or 520 carbohydrate calories per day (1 gram of carbohydrates = 4 calories). This amount is adequate to maintain normal brain function and minimize toxic metabolic byproducts. The recommended proportion of carbohydrates ranges from **45-65% of total calories**, or in a 2000 kcal diet, 225-325 grams. The total carbohydrate content per serving of food relative to total daily carbohydrate need is presented on the NFP alongside the nutrient content as % Daily Values. Average Americans currently meet carbohydrate intake guidelines with an estimated 50% of their total calories, or 250 grams per day, coming from carbohydrates alone.

Daily intake guidelines for carbohydrate subgroups have also been developed. **Total daily fiber** needs have been determined: for men, 28 grams per day, and for women, 25 grams per day in the average diet, which is based on a standardized value of 14 grams per one thousand calories. As nutrition research reveals more about the importance of various fiber types and their unique physiologic functionality, compliance with fiber guidelines may improve but, currently, men and women in the US intake half of their daily fiber needs at 15 g and 12 g, respectively. Policy and promotion efforts are needed to better reflect the current understanding of total fiber so that recommendations better differentiate between dietary fiber, which is the natural, intact plant matter, and **functional fiber**, which contains isolated fibers that are added to food or consumed singularly for specific biological function. Current labeling requirements for fiber subtypes are stratified based on the analytical method that chemists use to isolate plant fiber in the lab (i.e., soluble and insoluble), but this does not adequately assist consumers in making sound decisions regarding the health benefits of fiber. Most experts recognize that there is room for improvement in labeling and promoting healthy fiber intake, including a need for a daily intake platform that includes not just total fiber, but also fiber subtypes, and an upper limit for total fiber.

Nutrition Facts

8 servings per container

Serving size	**2/3 cup (55g)**
Amount per 2/3 cup	
Calories	**230**
	% Daily Value*
Total Fat 8g	**12%**
Saturated Fat 1g	**5%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 160mg	**7%**
Total Carbohydrates 37g	**12%**
Dietary Fiber 4g	**14%**
Sugars 1g	
Added Sugars 0g	
Protein 3g	
Vitamin D 2mcg	10%
Calcium 260mg	20%
Iron 8mg	45%
Potassium 235mg	5%

* The % Daily Value (DV) tells you how much a nutrient in a serving of food constitutes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Figure 2.1. The Nutrition Facts Panel lists "added" sugars to distinguish them from sugars that are "natural"

Since **added sugars** are not nutrient requirements, the IOM did not establish a daily allowance but, using postprandial glycemia testing from hyperactivity trials, resulted in an upper limit (UL) for added sugars being set at 25% of total diet. Most dietetics professionals endorse a much lower percentage of added sugars to total diet, as reflected in the Dietary Guidelines for Americans, which promotes a level of no more than 10% of total calories from added sugars, with naturally occurring, intrinsic sugars like those in fruits, sweet vegetables, and dairy products not similarly restricted. Currently, Americans are getting approximately 15% of their total calories from added sugars.

DAILY INTAKE	Dietary Reference Intake			Dietary Guidelines
	Acceptable Range	Adequate Intake	Upper Limit	
Carbohydrate	45-65 percent calories	130 grams		
Fiber		14 grams /1000 calories		1:4 soluble:insoluble
Added Sugar			25 percent calories	10 percent calories

Table 2.1. Summary of Daily Carbohydrate Intake Guidelines

2.1 AI

Homework • Answered

The adequate intake for carbohydrates is __ grams per day.

- A 100
- B 130
- C 150
- D 175

Explanation

The median daily carbohydrate intake that is adequate for healthy adults is 130 grams.

Answered - Correct!

1 attempt left Retry

2.1 Homework 2

Homework • Answered

What is the daily carbohydrate intake range (in grams) that corresponds to a 50-60% carbohydrate, 2000 calorie diet?

- A 150-250
- B 200-250
- C 250-300 (selected)
- D 300-350
- E 350-400

Explanation

2000 x 50% = 1000 calories from carbohydrates. Every 1 grams of carbohydrate = 4 calories. 1000/4 = 250 grams
2000 x 60% = 1200 calories from carbohydrates. Every 1 grams of carbohydrate = 4 calories. 1200/4 = 300 grams

Answered - Correct!

1 attempt left Retry

2.1 Homework 4

Homework • Answered

Which of these foods are dense sources of intrinsic sugars? You may select multiple answers.

Multiple answers: You can select more than one option

- ○ **A** Soft drinks
- ○ **B** Candy
- ○ **C** Cakes and pastries
- ◉ **D** Milk
- ◉ **E** Yogurt
- ◉ **F** Fruit

Explanation

Correct. Sugars that occur naturally in foods, like milk and fruit are intrinsic sources. Added sugars that are highly concentrated in soft drinks, candy, and baked desserts are extrinsic.

Answered - Correct!

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2.2 Carbohdyrate Sources

Our largest sources of natural intrinsic carbohydrates are **whole plant foods** such as fruits, grains, starchy vegetables and legumes that convert water and atmospheric gas to carbohydrates using thermal energy from the sun. Rich carbohydrate sources like fruits, grains, and starchy vegetables provide approximately 15-18 grams of carbohydrates per serving. Other significant sources of intrinsic carbohydrates include legumes, providing up to 10 grams per serving, and milk that is produced by lactating animals. Milk from cows provides on average 12 grams of carbohydrates per 1 C serving, whereas human milk provides 17 grams per serving and has a unique **oligosaccharide** profile.

Carbohydrate sub-type classifications are made by biological functionality (i.e., reactivity), by the number of molecular carbon atoms, and by the state of their free sugar monomers. **Functional classes** include aldose, which contains a readily reducible aldehyde group, and ketose, which includes a ketone group that can also be reduced after partial isomerization (i.e., opening up) to enediol. Carbohydrate sub-types classified by **carbon atoms** include, most often, carbon chain lengths of six but certain carbohydrate isomers, mainly substituted sugars glyceraldehyde and ribose, contain only three and five carbon atoms. The third and primary classification system for dietary carbohydrates is based on the **singularity** or **joining**, of **hexose monomers**. Hexagonal- and pentagonal-shaped ring structures exist singularly or linked together by alpha 1-4 glycosidic bonds, form disaccharides (2 sugar monomers), oligosaccharides (3-10 sugar monomers), or polysaccharides (10+ sugar monomers). Single sugar monomers and disaccharides are referred to as simple carbohydrates whereas anything larger is considered a complex carbohydrate.

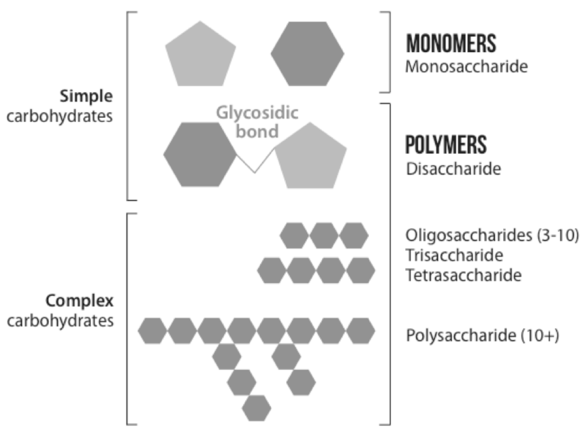


Figure 2.2. Sugar Classifications

The **simple–to-complex carbohydrate profile** of a given food is a product of genetic biosynthetic programming in plant DNA. It is also highly influenced, however, by environmental and temporal variations that impact the sweetness and textures across plants within species. A good example is that of the banana, which has a higher proportion of complex-to-simple sugars at harvest compared to older, riper bananas. The increasingly sweet taste bananas get over time is a result of more complex carbohydrates being hydrolyzed into simple sugars. Young baby carrots are another good example of how maturation impacts the simple-to-complex carbohydrate profile except, in carrots, the complex-to-simple sugar ratio increases over time, as evidenced by a subtle, less sweet taste.

Figure 2.3. Starch to Sugar Ratio Changes with Ripening.

Simple sugars are provided in the diet as monosaccharides and disaccharides. Both are sweet-tasting, soluble in water and have a light molecular weight. **Glucose**, a six-carbon aldose hexose monosaccharide is the direct product of plant photosynthesis and is the foundational building block for all dietary carbohydrates. Glucose is found in foods in free form, linked to other glucose isomers (i.e., maltose and dextrose). In plants, it can be hydrolyzed to fructose monosaccharide, and in milk products, it can be hydrolyzed to galactose monosaccharide. Glucose can also be partially fermented to produce lower-calorie yielding **sugar alcohols** that are used to sweeten products with about half the energy calories.

Galactose, the least sweet of the sugars, is a product of glucose and galactose bonding by **lactose** synthase in mammary tissues. Lactose is the largest non-water component of breast milk and is consumed in drinking milks as well as secondary dairy byproducts. Human breast milk has the highest total carbohydrate content and a unique proportion of oligosaccharides not found in other mammal milk like that from cows, goats or sheep. Human milk has not been commercialized, but many successful human milk cheese types and ice creams have been developed and marketed for a variety of purposes, many of which are attributed to its unique carbohydrate profile.

Figure 2.4. Monosaccharide Sugars

Fructose, the sweetest of the simple sugars, is actually isomerized (i.e., opened up, or partially broken down) glucose that exists in fruit cell cytoplasts. Fructose may exist in free monomer form or hydrolyzed to free glucose to form the disaccharide sugar, sucrose. The **monosaccharide to disaccharide profile** of fruits, much like the simple-to-complex carbohydrate profile, imparts distinctive levels of sweetness and functionality. For instance, grapes are high in total sugars that are in 100% free monosaccharide form that is more easily fermented to yield a high percent alcohol (e.g., ethanol); and apples, while comparably sweet, are about equal parts mono and disaccharide and higher in free fructose. Since fructose is two times, or 200% sweeter than free glucose, apples are perfect to concentrate for use in sweetening juices, like grapes are perfect for making wine.

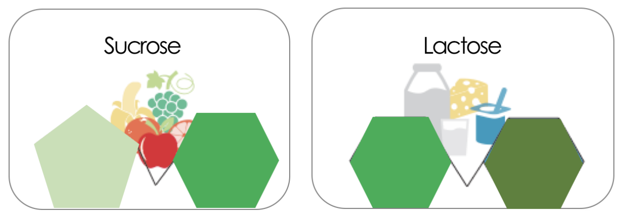


Figure 2.5. Disaccharide Sugars

Natural sucrose is a disaccharide sugar of hydrolyzed glucose and fructose. Pure natural sucrose is sweeter than glucose and less sweet than fructose or honey. Sources of natural sucrose include sugar beets, which store energy as 100% hydrolyzed sucrose, sugar cane likewise, and honey, which is actually an enzymatic by-product of bee digestion. Sugar beet and sugar cane are the most widely used source of sucrose-derived **sugar** in the US, with a variety of market forms including raw, bleached, brown, organic, non-GMO and re-crystallized. Sucrose is found in high concentrations in some other edible fruits like clementines, pineapples, and dried dates, and in relatively high proportions in starchy vegetables like peas and sweet potatoes. Intrinsic sucrose represents significantly less than half of total sucrose intake in the US.

The majority of sucrose-derived sugar consumed in the US is from **sweetening additives** found in baked goods, processed foods like breakfast cereals, snack crackers and cookies, ice cream, soft drinks and candy confections. A one tablespoon serving of sucrose sugar provides around 4 grams of sugar, which yeilds

Figure 2.6 Major Sources of Natural Sucrose (i.e. Sugar)

anywhere from 250-400 sugar calories per serving in many dessert and snack products. Food science innovations have kept up with sweet taste receptor research in identifying and developing compounds to replace sucrose as a sweetener to reduce food calories. These techniques essentially trick receptors into perceiving intense sweetness with just minuscule amounts used, hence the term **non-nutritive sweeteners**. Among many types, the non-nutritive sweetener most resembling sucrose structurally uses an indigestibility approach by replacing three hydroxyl groups with three Chlorine (Cl) molecules rendering the sweetener indigestible. More natural alternatives to reduce the use of added sugars utilize plant glycopro teins such as miraculin and curculin that trick the receptors into perceiving sweet taste in acidic and sour foods, as well as steviol glycosides, which are natural plant extracts perceived 150 times sweeter than sucrose by taste receptors. Certain research suggests that over one-third of *total carbohydrate* intake in the US is from added sugars used to sweeten formulated food and beverages – a fact not lost on companies whose products are founded on sweetness like soft drinks who, in a return to the past, are now touting the use of sucrose and natural sweeteners in their formula instead of unnatural derivatives of plant starch.

Figure 2.7. Sweetening Additives

Starch is the most abundant carbohydrate in the human diet. The major sources of starch worldwide are cereal grain seeds (rice, wheat and maize) and root vegetables (potatoes and cassava). In some climates, other widely available high starch foods include bananas, peas, arrowroot, and beans. Starches in various forms are used to make flour for dough and their secondary staple products like bread, pancakes, noodles, pasta and tortillas, and even less well-known novelty products like boba tea made from tapioca (i.e., cassava root starch). Starches consist of two very different types of relatively tasteless glucose polymers stored in plant cell amyloplast. Amylose, the first, is a small, compact and linear chain of alpha 1-4 linked glucose units that are soluble in water, whereas amylopectin, the second, is a much larger alpha 1-6 branched and coiled glucose formation that is completely insoluble in water. The majority of starches in plant amyloplast are amylopectin, which is 50 to 500 times heavier than amylose, which comprises only 25% or less of total plant starch by weight. Both starch polymers are soluble in high temperatures and swell in water in a process called gelatinization.

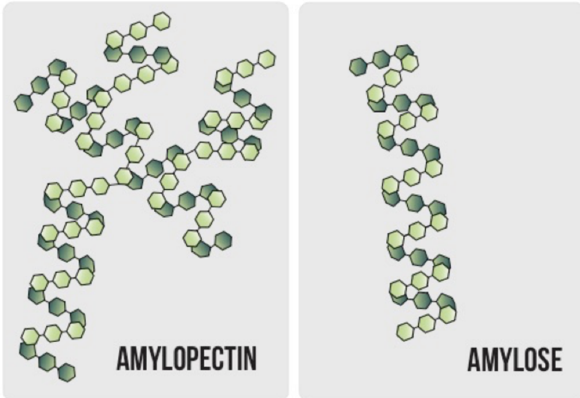
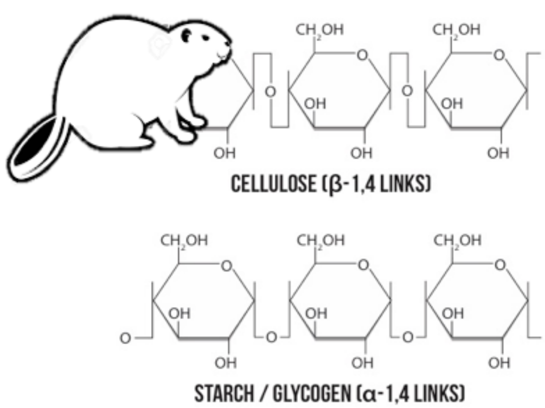


Figure 2.8. Types of Starch

The distinctive physiochemical properties of different plant starches are a product of the various shapes, structures and proportions of amylose to amylopectin. Starch gelatinization and gelling attributes are leveraged in food and ingredient applications that require thickening, emulsion stabilization, extending and binding in food products such as sauces, gravies, puddings, soups and dressings. The most common **modified starch thickeners** are corn- and potato-derived and need heat treatment to activate gelatinization. Cultivated waxy varieties of corn, rice and potato contain only amylopectin, which prevents the undesirable re-crystalizing of their granular structures when they are cooked and cooled. While waxy varieties are not modified starch per se, they are great examples of selective breeding techniques to modify natural starch content for favorable attributes. More direct examples of modified starch for home-use include thickening cooking starches and pre-gelatinized starch products, like instant puddings.

Starches can also be artificially hydrolyzed into sugars by acids, enzymes, or a combination of the two, to create **starch-derived artificial sugars**. The extent of conversion, typically quantified by dextrose equivalency, is roughly calculated by determining the percentage of the glycoside bonds in the starch that have been broken down. These treatment processes create sweeteners that can be used in lower concentrations than conventional sucrose to sweeten products less expensively. Most starch derivatives in the US diet are derived from corn, which is partially hydrolyzed to maltose, or as it appears on labels of products like sports drinks, **dextrin, maltodextrin, or dextrose**. In complete hydrolysis, 100% of starches have been hydrolyzed to pure glucose, or as it appears on ingredient lists, syrup. Often, syrups made with corn starch is further treated with the enzyme glucose isomerase for partial isomerization of glucose to fructose. The unnatural proportion of glucose to fructose in **high fructose corn syrup** (HFCS) creates an even sweeter syrup that can be used in even smaller concentrations. The biggest users of HFCS are soft drink and juice beverage manufacturers--products under great scrutiny for their easily ingested platform and milk-reducing repercussions in kids and adolescents.

Some plants that are naturally high in amylose also contain a higher proportion of starch that is resistant to digestion and absorption. There are several types of resistant starches that are found naturally in plants including physically inaccessible starches in seed casings (RS1) or in closed granule configuration (RS2), and also starch created from retrogradation (RS3) which occurs as a result of heating and cooling starchy - foods, and a fourth type that is artificial (RS4). A great source of RS1 and RS2 starches are raw whole oats, which provide 7 grams of RS per serving. Oats are also palatable consumed raw, and they do not become more digestible over time like some sources of resistant starch, like bananas which, when raw, can provide 8.5 grams of granular resistant starch whereas ripe bananas provide just 2 grams. Another example of starch dynamics is found in potatoes, the best source of granular starch, which are nearly 80% resistant to digestion until cooked, when all except 2% of the starch becomes digestible. Interestingly, cooling and reheating increases the potato's RS3 resistant starch content making cold potato salad, for instance, a more resistant starch than, say, hot mashed potatoes. Since natural starch is no longer resistant once heated (i.e., cooked) or ripened, resistant starch extracts are often made into "pre-biotic" or "functional fiber" supplements.



Dietary fiber is the indigestible portion of edible plant foods and contains at least 10 glucose monomers that are linked by **beta 1-4 bonds**. Most types of dietary fiber contain a plant wall structure and rigidity with cross-linked carbohydrate polymers, and strong beta-glycosidic linkages. Humans lack digestive enzymes that hydrolyze cellulose polymers to glucose (i.e., cellulase). Only certain physiologically equipped herbivores like cows and sheep can digest cellulose from grass like beavers and termites can process lignin from wood-covered portions of plants. Fiber dense foods include beans and legumes like navy beans, pinto beans, split green peas, kidney beans and lentils each providing on average eight grams per ½ C serving. Dark green vegetables like broccoli and kale provide on average 6-7 grams of fiber per 1 C serving, and whole grain cereals (i.e., oats and wheat bran) and breads provide on average 4-5 grams per serving ½ C or two slices, respectively. Less significant dietary contributions of dietary fiber come from nuts, and other fruits and vegetables like oranges, carrots, potatoes, apples, and bananas, which all provide anywhere from 2-4 grams per serving.

All edible plant foods have varying proportions of soluble and insoluble fibers. For example, wheat fiber is about 90% insoluble, oats are nearly equal parts soluble and insoluble, and psyllium is nearly 100% soluble. **Insoluble fiber** is the main type of dietary fiber that humans consume in plant foods. This type of fiber moves through the digestive system relatively intact, unaffected by digestive enzymes, and relatively unchanged in the presence of digestive liquids. The presence of this type of fiber provides bulk for fecal matter, speeding up the rate of transit and exit. The main types of insoluble fiber in food are **cellulose** and **hemicellulose**, which are the main structural components of plants like broccoli, wheat cereal, and root vegetables. Plant cellulose is commonly used to make fiber supplements, and may be used as an additive in pills, including non-fiber supplements, to provide bulk and binding to capsules. **Lignin** is another type of insoluble fiber from the hull of edible seeds like flax, sesame, strawberry, hemp and pumpkin and also in less expected high amounts in cruciferous vegetables, like broccoli and cauliflower.

Soluble fiber, a much smaller proportion of total indigestible fiber, swells in the presence of gastric juices. In plants, this type of fiber provides cell rigidity through gelling (i.e., pectin) and injury protection through glandular secretions (i.e., gums/mucilage). In the human intestinal tract, this type of fiber provides viscosity to stool for slowed rates of nutrient absorption and bacterial fermentation substrate. **Pectin**, a key gelling polymer found in the edible skins of high pectin fruits such as apples, strawberries, raspberries, and citrus fruits, is used to make jams, jellies and powder ingredient extracts used for thickening and stabilizing as well as supplementing. Whole oats, barley, mushrooms and leguminous plants like beans, peas and nuts provide an excellent source of gum fiber. The most known soluble gum fiber, **beta-glucan,** is found in relatively high amounts in whole rolled oats (1.5 grams per 1 C) and barley (2.5 grams per C). **Mucilage**, another type of gum fiber high in glycoproteins, has been gaining attention with flax and chia seed products that have leveraged their exterior gelling properties, comparable to starch derived tapioca products. Psyllium seed husk grounds provide pure 100% mucilage fiber, and as such, psyllium is a common ingredient for insoluble fiber supplements. Soluble fiber supplements are also formulated with oat fiber and wheat dextrin. Another viscous soluble fiber gaining interest in the scientific and pre-biotic supplement communities is fructan. **Fructan** is a polymer of fructose sugars found in naturally high concentrations in chicory root, some wheats, allium family members, onions, shallots, leeks, and Jerusalem artichokes, which are actually botanically classified in the daisy family. Chicory root is the richest source of the fructan subtype **inulin**, which is extracted, milled, and dried to use as a fiber additive that is marketed as a functional fiber, or pre-biotic (i.e., fermentable). Inulin can also be used to impart a light sweet taste at around one-third of the energy calories of regular sugar and impart textural qualities comparable to starch. The other type of fructan, inulin **oligofructosaccharide**, is most beneficial when paired with inulin, so many inulin supplements are now "oligofructo enriched."

2.2 Homework 2

Homework • Answered

Match each plant fiber to its solubility characteristic

Premise		Response
1 Cellulose	→	A Insoluble
2 Lignin	→	B Insoluble
3 Resistant starch	→	D Insoluble
4 Pectin	→	C Soluble
5 Beta-glucan	→	E Soluble
6 Mucilage	→	F Soluble
7 Fructan	→	G Soluble

Explanation

Yes!

Answered - Correct!

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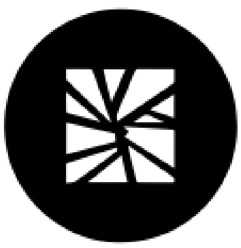
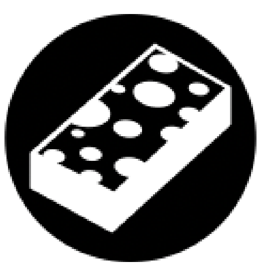
2.3 Carbohydrate Transformation

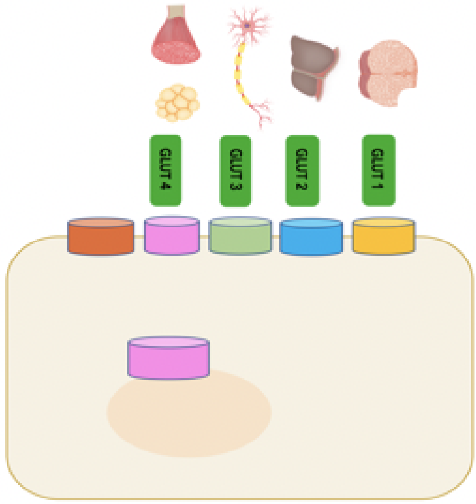
Carbohydrate digestion begins in the mouth with mastication and mixing of foods with **salivary amylase**. Alpha-amylase hydrolyzes plant starch at the interior of the alpha 1-4 glycosidic linkages of to yield oligocahcarides and dextrin. Amylose is more compact and thus less transformed in mouth digestion than amylopectin, which is larger and more exposed/susceptible to salivary enzymatic attack. Free sugars, partially digested starch polymers, and other ingested constituents are formed into a bolus that is pushed to a posterior position on the tongue in preparation for the journey down the esophagus and through the stomach for further processing in the upper small intestine.



Dietary sugars, polymers from starch digestion, and a small amount of remaining inactivated salivary amylase then enter the lumen of the upper small intestine. Pancreatic glucoamylase is released into the lumen to further hydrolyze remaining oligosaccharides to dextrin and ultimately to disaccharide maltose that, along with other disaccharide sugars, are further hydrolyzed by their corresponding brush border enzymes – maltase, sucrase, and lactase – to absorbable monosaccharide. Maltose is the third naturally occurring disaccharide that is produced in the process of starch digestion. It is found in very few dietary sources as synthetic malts in liquid form.

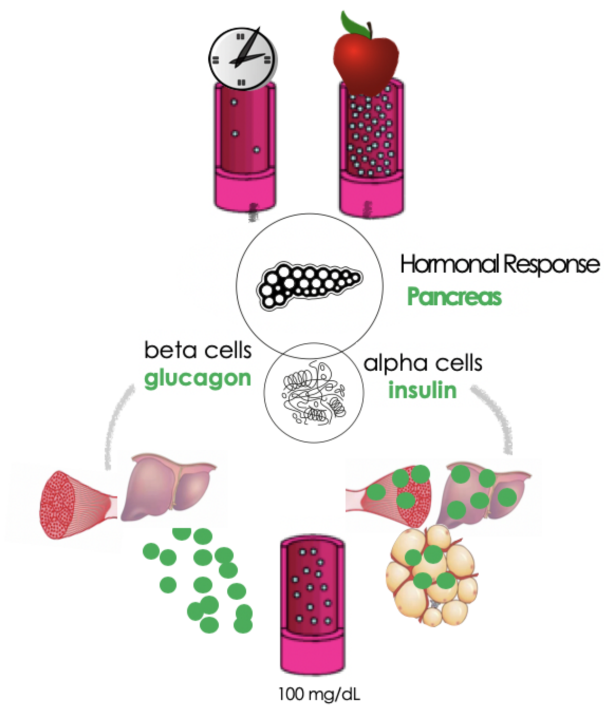


Single sugar monomers are absorbed across the intestinal enterocyte through different transporters and shuttles. Glucose and galactose are escorted by sodium across an energy-requiring transporter, SGLUT 1, at an extremely efficient 60 grams max per hour rate of absorption. Fructose is absorbed without consuming energy through GLUT 5, a much slower shuttle moving across at about half that speed. Once inside the intestinal enterocyte, all three monosaccharide sugars diffuse through GLUT 2 at the basolateral membrane to the capillary network. Regardless of rate, nearly all, or 95-97% of carbohydrates are effectively absorbed. The minuscule amounts of escaped digested starch and simple sugars move along to the first of three sections of the large intestine along with other fermentable and non-fermentable fibers. **Fermentable fibers** are metabolized by bacterial flora in the colon, which produces gas and short chain fatty acids, or butyric acid byproducts.



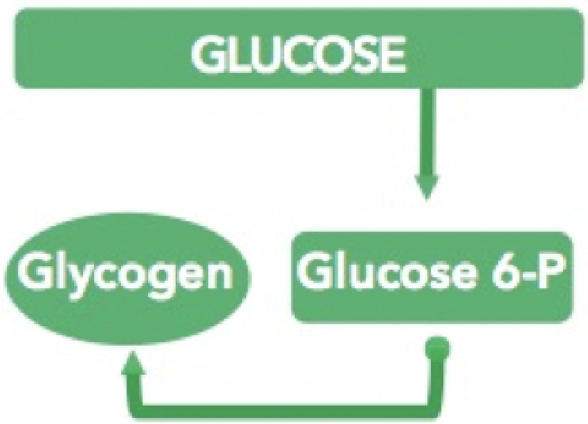
Once simple sugars diffuse from enterocyte into from capillary space, they collect into venules that feed into general circulation for transport. Fructose and galactose are transported directly to the liver where they diffuse across **hepatocyte GLUT 2** and undergo conversion to glucose. Glucose yielded from galactose is most often subjected to subsequent dehydration synthesis, and the majority of fructose is phosphorylated by liver phosphofructokinase to yield pyruvate for liver cells to use for energy. Both intestinally absorbed glucose and glucose made in the liver have a number of possible metabolic fates depending on the levels of immediate circulating nutrient and hormone levels.

Blood carbohydrate levels are maintained in the body with extreme precision through the action of counter-regulatory hormones, insulin and glucagon. In 5 liters of blood, a 4-grams carbohydrate level is maintained within one-hundredth of a gram.

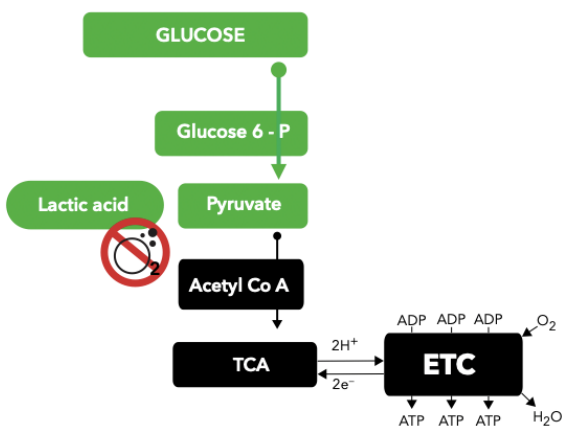


Following meals, when blood sugar levels are high, insulin is released from the pancreas. As **blood insulin levels rise**, insulin receptor binding activity is increased, and cells begin to take glucose in as it passes by in circulation. The highest priority destination for circulating glucose is the brain, which grants access to circulating glucose via a concentration gradient diffusion along GLUT 1. Skeletal muscles grant glucose cellular access by insulin-mediated intracellular GLUT 4 translocation and subsequent membrane GLUT 4 shuttling.

Once inside the muscle cell, insulin-activated hexokinase enzymes, mainly glycogen synthase, hydrolyze glucose monomers in a series of dehydration events that create alpha 1-4 linkages much like the plant starch polymers previously discussed in section 2.2. This anabolic pathway, **glycogenesis**, peaks during the post absorptive period in the presence of high serum insulin levels. Once skeletal muscle and hepatic glycogen storage capacities have been reached, and blood glucose levels are in excess of the normal range, glucose is directed to the kidneys for urinary elimination and to the liver to be converted to fat for shipment to the adipose tissue for storage.

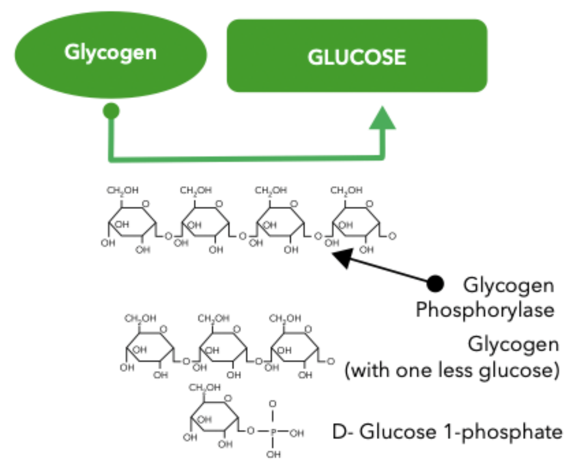


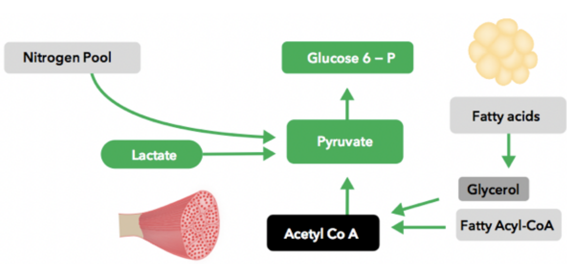
To maintain regular cell work, cellular glucose undergoes **glycolysis** to yield pyruvate and a net 2 ATP. If oxygen is available, pyruvate is further oxidized to carbon dioxide and water in the mitochondrial TCA cycle, yielding 34 more ATP. If oxygen is not available, **pyruvate** is converted to **lactate** by the enzyme **lactate dehydrogenase** to yield another net 2 ATP in a process called **anaerobic glycolysis**, or sometimes, the glycolytic pathway.



In times **between meals**, blood sugar drops and glucagon is released from the pancreas to initiate the hydrolysis of stored glycogen, mainly in the liver, which will be released into general circulation to restore blood sugar levels. The liver releases about 220 grams of carbohydrates into the bloodstream per day, about half from **glycogenolysis** and the other half from gluconeogenesis.

In the **gluconeogenesis** pathway, glucose is synthesized from other energy nutrients, such as amino acids and fatty acids, and also from metabolic intermediates and by-products, like ketones and pyruvate. This pathway is most active during longer periods of energy restriction and during long duration exercise, which will be discussed in Chapter 11 and 12, respectively.





2.3 Homework 1

Homework • Answered

Match each digestive activity to the gastrointestinal site in which is occurs.

Premise		Response
1 starch to polysaccharides	→	A mouth
2 facilitated diffusion of fructose	→	B small intestine
3 active absorption of glucose	→	D small intestine
4 viscous fiber fermented	→	C large intestine

Explanation

starch digestion in mouth
fiber fermented in large intestine
all sugars (fructose and glucose) absorbed in small intestine

Answered - Correct!

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2.3 Homework 2

Homework • Answered

After a meal, the regulatory hormone _______________ initiates the uptake and biosynthesis of stored carbohydrates; whereas between meals, the counter regulatory hormone _______________ initiates their catabolism.

- ◉ **A** insulin and glucagon
- ○ **B** cortisol and insulin
- ○ **C** glucagon and calcitriol
- ○ **D** aldosterone and glucagon

Explanation

Insulin and glucagon work together to maintain glucose homeostasis. Insulin, is an anabolic hormone secreted after a meal to lower blood glucose; glucagon, is a catabolic hormone that is secreted between eating to increase blood glucose.

Answered - Correct!

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2.3 Homework 3

Homework • Answered

If oxygen is not available in the cytosol for aerobic glycolysis, what metabolic byproduct accumulates?

A insulin

B lactate

C glucagon

D pyruvate

Explanation

In the absence of oxygen, muscle contraction is sustained with the glycolytic system, which ends with lactate production

Answered - Correct!

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2.4 Carbohydrate Function

The basic organic elements provided by dietary carbohydrates are used in a number of critical metabolic and biological reactions that sustain human life. The most critical function of the carbohydrate is to provide the body a reliable source of **circulating energy** that can be used quickly and flexibly. Carbohydrates are water-soluble and small, with a light molecular weight that makes them ideal for travel in blood and diffusion across cell membrane transporters.

Free glucose in cells is readily converted to cellular energy in glycolysis, whereby glucose monomers are broken down in the cell cytoplasm to release a small amount of energy that is available to cells, even when oxygen is not. The **unconditional energy** provides the cell the ability to perform everyday maintenance, as well as production functions, and most notably in instances where immediate fuel is needed to sustain high-intensity muscle contractions, at least momentarily, before blood (i.e., oxygen) supply is sufficient.

More often, oxygen is available to sustain a higher energy-yielding pathway, in which pyruvate, a glycolysis byproduct, is subsequently oxidized by the TCA cycle. The continuation pathway yields measurably more energy; thus, it is the primary fuel system for working skeletal muscles, and the exclusive fuel system for the brain. The brain, representing only around 2% of total body weight, uses 20% of the total body glucose respiration quotient, which is estimated at around 120 grams of saccharide per day. The majority of energy yielded by **brain cell respiration** is used to maintain cell function, while approximately a quarter of the energy is used to synthesize new brain tissues.

Carbohydrates are also easily hydrolyzed to highly compact storage polymers that provide a quickly accessible source of energy in postabsorptive states, as well as easily built upon base compounds for a number of structural and functional purposes.

Stored carbohdyrate (i.e., glycogen) functions as an **energy reservoir** to maintain blood homeostasis in times where blood sugar levels cannot be maintained through food intake. Hepatic glycogen storage is around 80-100 grams, and during non-fed states at rest, glucose output is around 150 mg/minute. Another function of stored carbohydrates, or intramuscular glycogen, is to provide **immediate fuel** for skeletal muscle contractions that recruit large fiber groups simultaneously, like those used for power and speedy locomotion. Total skeletal muscle glycogen is enough to sustain most daily activities, including exercise, and for the untrained adult, maxes at a capacity around 500 grams.

Carbohydrate polymers and sugars are also critical **structural compounds** in cell walls, genetic matter, non-essential amino acids and glandular milk saccharide. **Glycoproteins**, for instance, contain oligosaccharides that protrude from cells walls to communicate with other cells through cell to cell glycoprotein recognition mechanisms. Glycoproteins also create hydrogen bonds with extracellular fluids that stabilize membrane structure. **Amino sugars** are critical intermediates to building some of the larger cell polysaccharides such as those integrated into glycoproteins; glucosamine, for example, is the foundation for several cellular polysaccharides, glycoproteins included. Another structural component of human cells that is carbohydrate-based is the backbone of ribonucleic acid and deoxyribonucleic acids, more commonly known as RNA and DNA. RNA and DNA are 5 carbon (i.e., pentose) **deoxy sugars** that are classified as monosaccharides and derived in the human body from glucose. **Lactose** disaccharide from glandular hydrolysis of glucose and galactose is another critical carbohydrate based macromolecular compound in human breast milk.

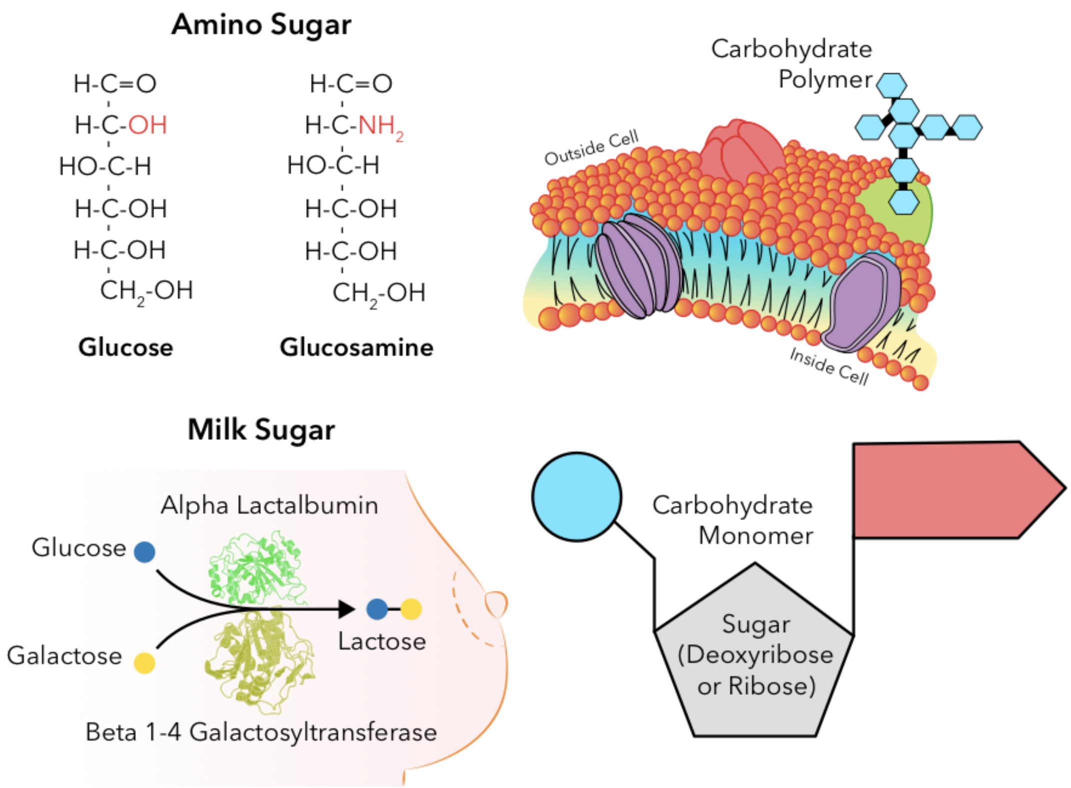

Figure 2.12 Major Physiologic Functions of Various Sugars

Indigestible carbohydrate polymers (i.e., fiber) provide aid to digestive systems. Insoluble fiber, for instance, enhances the texture of fecal matter so that the total **transit time** is shorter and less reliant on natural **gut motility**. Soluble fiber functions by a swelling mechanism, much like the one described with starch gelatinization, whereby a more viscous matter is created. This feature is helpful in that it **minimizes absorption** of dietary fat and cholesterol, and it lessens the **glycemic impact** of a mixed meal. Indigestible and partially digestible soluble fibers, oligosaccharides, like raffinose (3C) and stachnnose (2 C), and resistant starches (e.g., amylopectin and amylose) also have a functional role in aiding the survival and promotion of the trillions of intestinal bacteria that reside in the human colon. Resistant starch polymers, sometimes referred to as **pre-biotics**, are broken down by bacterial enzymes to yield energy and gaseous substrates that promote bacterial cell respiration and replication. By-products of starch fermentation are short chain fatty acids acetate, propionate and butyrate in about a 3:1:1 ratio, depending on the pH of the colon. Butyrate is used for energy by bacterial cells, with gaseous byproducts carbon dioxide and oxygen; propionate is fermented further to formate to produce gaseous methane for use by other non-starch degrading methanogen bacterium species; 95% of remaining butyrate, propionate, and acetate is rapidly absorbed by colon enterocytes for respiration, or for passage to portal circulation and subsequent liver gluconeogenesis and lipogenesis.

2.4 Homework 1

Homework • Answered

Which organ is solely reliant on glycolysis for energy?

- A liver
- B muscles
- C endocrine glands
- D brain

Explanation

The brain, while around 2% total body weight, uses up to 20% of the glucose that is consumed in daily whole body cell respiration

Answered - Correct!

1 attempt left Retry

2.4 Homework 2

Homework • Answered

The primary glycogen storing organs are the ______________.

- A brain and the liver
- B muscle and the liver
- C kidney and the muscle
- D brain and the muscle

Explanation

The major glycogen storing organs are the muscle and the liver. Together they can store around 2500 calories worth of glycogen. This is equivalent to around 600 grams.

Answered - Correct!

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2.4 Homework 3

Homework • Answered

Resistant starch is referred to as "pre-biotic" because it _____________ ?

- A promotes pro-biotic gut bacteria
- B inhibits pro-inflammatory hormones
- C produces carbohydrate containing pro-oxidants
- D there is more than one correct response provided

Explanation

Resistant starch is digestible to bacteria in the gut. These bacteria produce metabolic byproducts that are able to be used for energy by human GI cells and other intestinal microbes.

Answered - Correct!

1 attempt left Retry

2.4 Homework 4

Homework • Answered

Gastrointestinal bacteria metabolize resistant starches to yield what organic acid?

- A hydrochloric acid
- B butyric acid
- C citric acid
- D methane

Explanation

Butyric acid is an organic acid produced by bacterial fermentation of the indigestible, resistant starch passing though

Answered - Correct! No attempts left

2.5 Carbohydrate Status Measures

Blood carbohydrate levels are maintained in the body with extreme precision. In 5 liters of blood, a 4-gram carbohydrate is maintained within one-hundredth of a gram through the action of counter regulatory hormones insulin and glucagon. Fluctuations much outside of 80-100 mg per deciliter levels can have serious physiological ramifications with several acute and chronic biochemical, anthropometric and clinical manifestations.

Long-term excesses in dietary carbohydrate intake (i.e., sugars) is one factor that leads to chronic hyperglycemia. Clinical symptoms of chronic high blood sugar include dry mouth, thirst, frequent urination, weakness, headache and blurred vision. Other symptomatic clinical presentations of severe blood sugar excesses may present clinically as ruptures in small vessels of the eyes kidneys and peripheral nerve endings. Long-term excesses in carbohydrate calories can also lead to excess fat synthesis and storage resulting in anthropometric changes in accumulated body fat. Highly representative measures of biochemical changes related to chronic hyperglycemia include glycosylated hemoglobin and fasting serum glucose and insulin. Exaggerated insulin responses and persistent hyperglycemia in response to glucose doses in meals are also indicative of chronic carbohydrate intake and characteristic of insulin insensitivity diseases like Type II Diabetes Mellitus. Acuter biochemical changes include increased endogenous cholesterol production and increased hepatic lipogenesis, which is evaluated using serum cholesterol, free fatty acids, and even traveling lipogenic enzyme measurements.

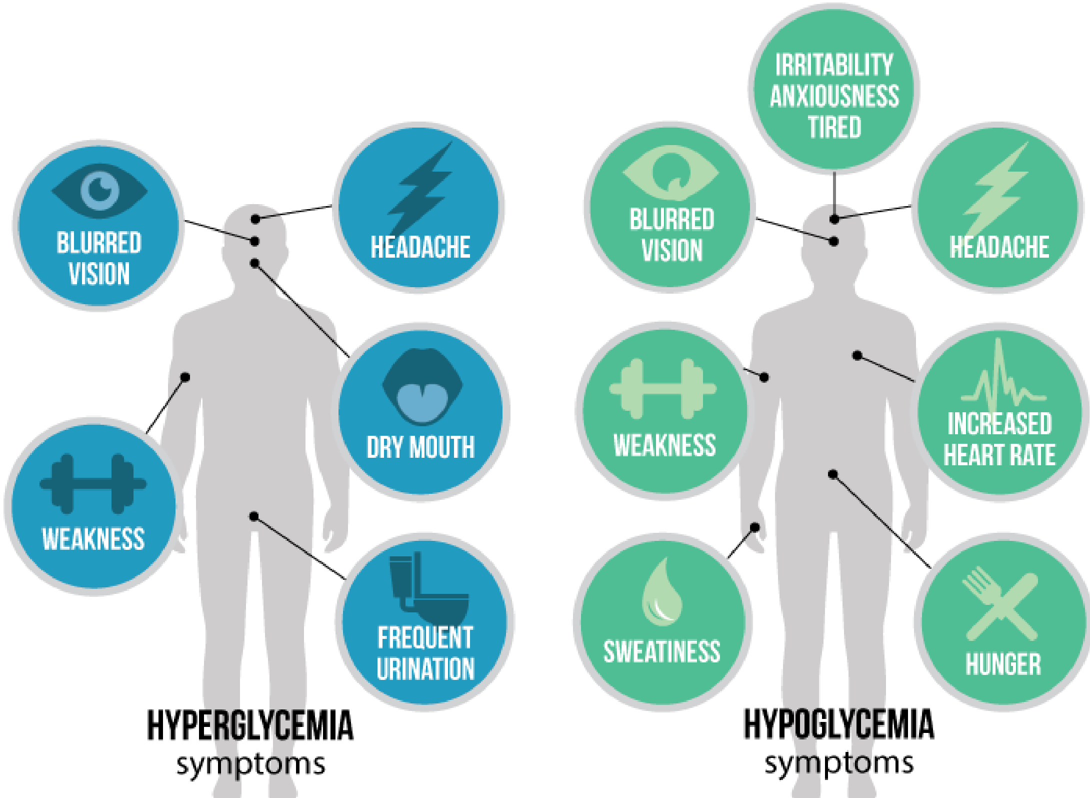

Figure 2.13. Symptoms of Hypoglycemia and Hyperglycemia .

In instances where carbohydrate intake is **limited** between meals (i.e., post-absorptive) and during fasting, reliance on liver glycogen and gluconeogenesis increases, and glucose utilization slows in all tissues except the brain and red blood cells. As blood sugar levels drop below 70 mg /dL., clinical symptoms of acute hypoglycemia including sweating and palor, irritability, impaired coordination and sleepiness occur. Hypoglycemia leads to an increased reliance on fat; thus, biochemical measures indicative of fat oxidation such as ketones, glycerol and free fatty acid concentrations, as well as gluconeogenic enzymes, are reliable secondary measures of carbohydrate status. In prolonged durations of restricted carbohydrate intake, the brain and other high dependent glucose tissues like red blood cells and nervous tissues adapt to endogenous carbohydrate sources, such as ketones, at the expense of accumulating toxic byproducts and anaerobic power.