CHAPTER 4

CARBOHYDRATES

LEARNING OBJECTIVES

1 | Identify and describe the different types of carbohydrates.

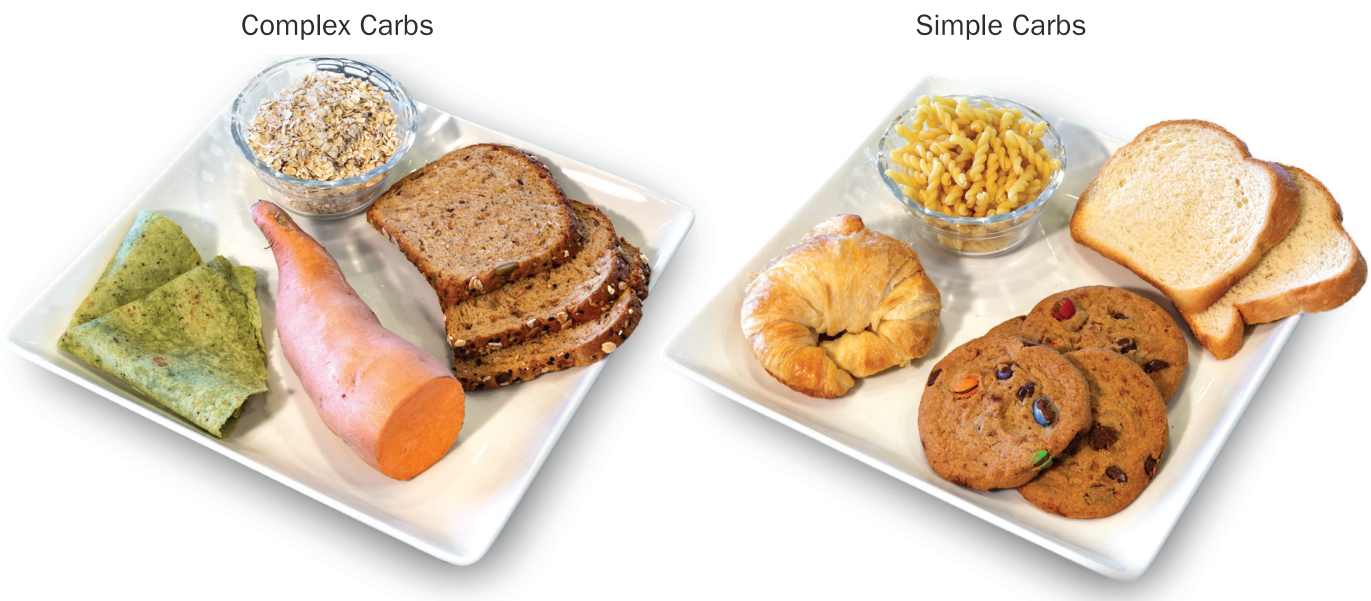
2 | Explain the importance of fiber.

3 | Explain how glucose is stored and used for energy.

4 | Describe how the human body digests carbohydrates.

Carbohydrates are a macronutrient that may be just as confusing as fats are for most individuals. There are several types of carbohydrates classified by their digestion process and they provide a large energy source for the human body. However, too much of anything can prove harmful, so a balance must be established with the other macronutrients for a balanced and healthy diet.

Figure 4.1 Types of Carbohydrates



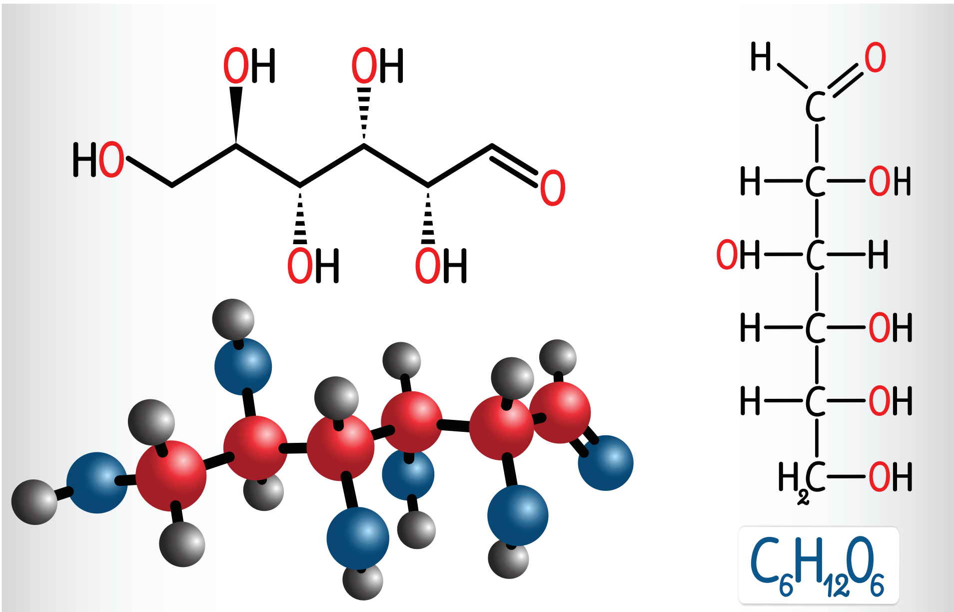
CARBOHYDRATES

Carbohydrates are organic molecules that are used primarily for energy. In fact, they are the main source of energy for the human body. Often referred to as carbs, they protect muscle mass (protein) from being catabolized during exercise and they provide the main energy source for the brain and nervous system when it is broken down into **glucose** during digestion.

GLUCOSE:
A simple sugar made of 6 carbon, 12 hydrogen, and 6 oxygen that provides energy in the body.

Glucose is a simple sugar consisting of 6 carbons, 12 hydrogens, and 6 oxygens. One molecule of glucose produces about 30 molecules of adenosine triphosphate (ATP) via glycolysis during cellular metabolism.

Figure 4.2 The Structure of Glucose



There are several types of dietary carbohydrates that provide energy—for instance, simple carbohydrates, or sugars, and complex carbohydrates, or **starch**.

The different types of carbohydrates are based on the number of sugar units and chemical structure. Some of the scientific classification categories include **monosaccharides**, **disaccharides**, **oligosaccharides**, and **polysaccharides**.

SIMPLE CARBOHYDRATES

There are two types of **simple carbohydrates**:

- **Monosaccharides**. Monosaccharide carbohydrates consist of one sugar unit. They are the simplest form of sugar that make up more complex carbohydrate molecules. Examples include glucose (also referred to as dextrose), galactose, mannose, and **fructose**.
- **Disaccharides**. Disaccharides consist of two sugar units. Examples include sucrose, which is made of one molecule each of glucose and fructose; maltose, made of two molecules of glucose; and lactose, made of one molecule each of glucose and galactose.

STARCH: The energy source of plants; a polysaccharide consisting of multiple molecules of bonded glucose.

MONOSACCHARIDES: Carbohydrates consisting of one sugar unit.

DISACCHARIDES: Carbohydrates consisting of two sugar units.

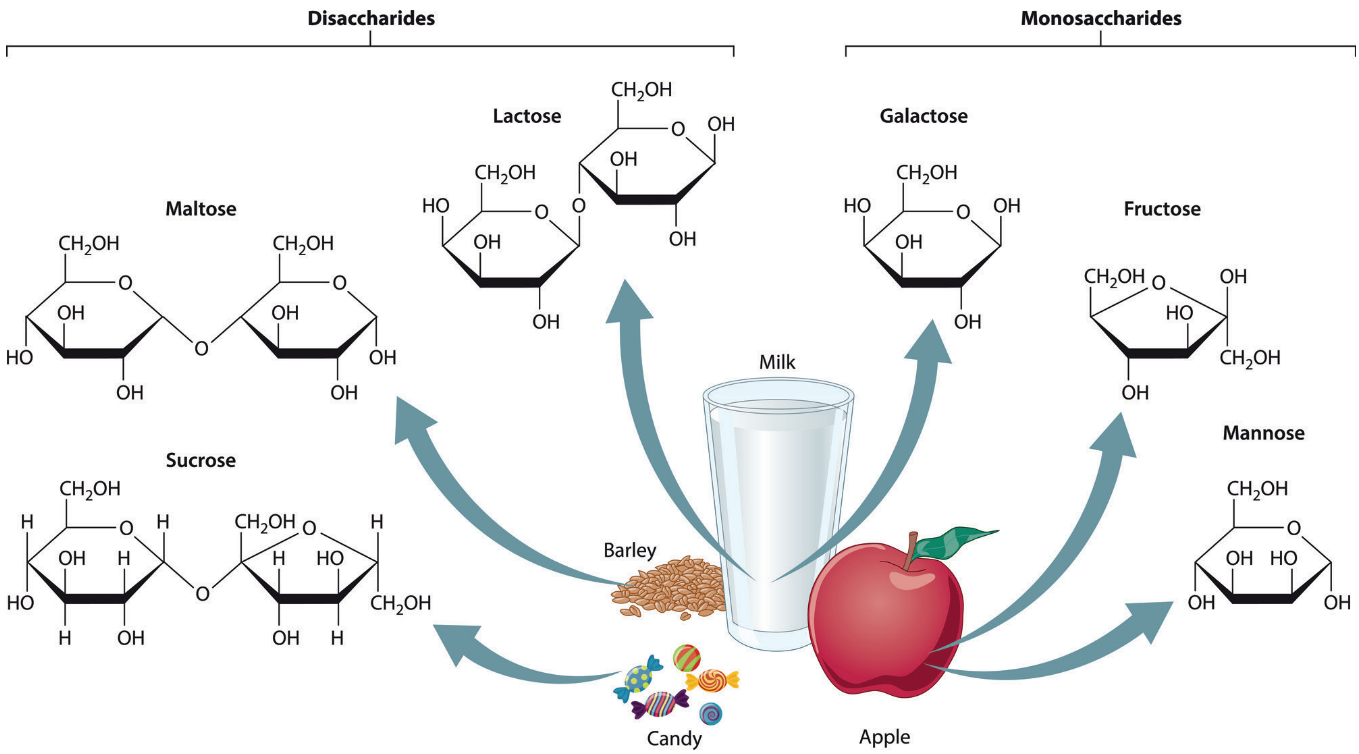
OLIGOSACCHARIDES: Carbohydrates with 3 to 10 sub-units of sugar.

POLYSACCHARIDES: Complex carbohydrates that have 10 or more monosaccharide sub-units linked together.

SIMPLE CARBOHYDRATE: Sugars, made of just one or two monosaccharides, digested quickly in the body as a fast energy source.

FRUCTOSE: A simple sugar found mostly in fruits.

Figure 4.3 Disaccharides and Monosaccharides



Sugar is a catchall term that refers to different types of simple carbohydrates. For example, table sugar is sucrose. Blood sugar refers to the glucose present in the blood. Blood sugar level is influenced by the types of carbohydrates consumed.

The principal monosaccharides in food are glucose and fructose. Glucose is found commonly in fruit, sweet corn, corn syrup, certain roots, and honey. It is also a subunit of some complex carbohydrates, like starch.

FRUCTAN:
A polymer of fructose molecules found in some fruits, legumes, and vegetables.

Fructose, which is also called levulose or fruit sugar, is found as free monosaccharides in fruits and other foods. It is also a sub-unit of the sucrose molecule, found in fruit and table sugar, and is a component of the carbohydrates known as **fructan**.

Although both fructose and glucose are common simple sugars in the diet, they function differently as energy sources. Glucose is used more quickly and efficiently by muscles, while fructose is used more slowly.

DID YOU KNOW?

Glucose is one of the most commonly encountered sugars in the diet. Fructose became more popular with the discovery that it does not trigger changes in blood sugar as rapidly as glucose.

Researchers realized this in the early 1980s when they undertook the first extensive comparisons of the different carbohydrates and carbohydrate-containing foods. Fructose must be converted to glucose in the liver before being used by most cells in the body which explains the slower rise in blood sugar after eating fructose.

COMPLEX CARBOHYDRATES

There are two main types of complex carbohydrates:

- **Oligosaccharides**. Complex carbohydrates with 3 to 10 sub-units of sugar are oligosaccharides. Some examples include raffinose and stachyose.
- **Polysaccharides**. Polysaccharides are complex carbohydrates that have 10 or more monosaccharide sub-units linked together. Starch, composed of amylose and amylopectin, is a main dietary complex carb. Both amylose and amylopectin are made of units of glucose. **Glycogen** is another polysaccharide that is used to store carbohydrate energy in the body.

GLYCOGEN:
A complex carbohydrate that occurs only in animals; the form in which glucose is stored in the body.

Regardless of the form in which glucose and other carbs are ingested, each gram of carbohydrate provides approximately four kilocalories of energy. The biggest difference between types of carbs consumed is in how they are digested and used. The more complex the bonds between the units of different sugar types, the slower the digestion and absorption. Each type of carb requires different enzymes and reactions to break them down and be metabolized.

FIBER

Fiber is a special type of complex carbohydrate not digested and not absorbed in the small intestine. Fiber is sometimes called roughage or non-starchy polysaccharides.

Some examples of fiber include cellulose, hemicellulose, pectin, fructans, beta-glucans, and a variety of gums, mucilage, and algal polysaccharides. Fibers are usually components of plant cell walls and intracellular structures. Although largely indigestible, fiber plays an important role in the diet. Fiber helps promote efficient intestinal functioning and aids in the absorption of sugars and other nutrients into the bloodstream.

There are two types of dietary fiber, and most plant foods contain some of each kind:

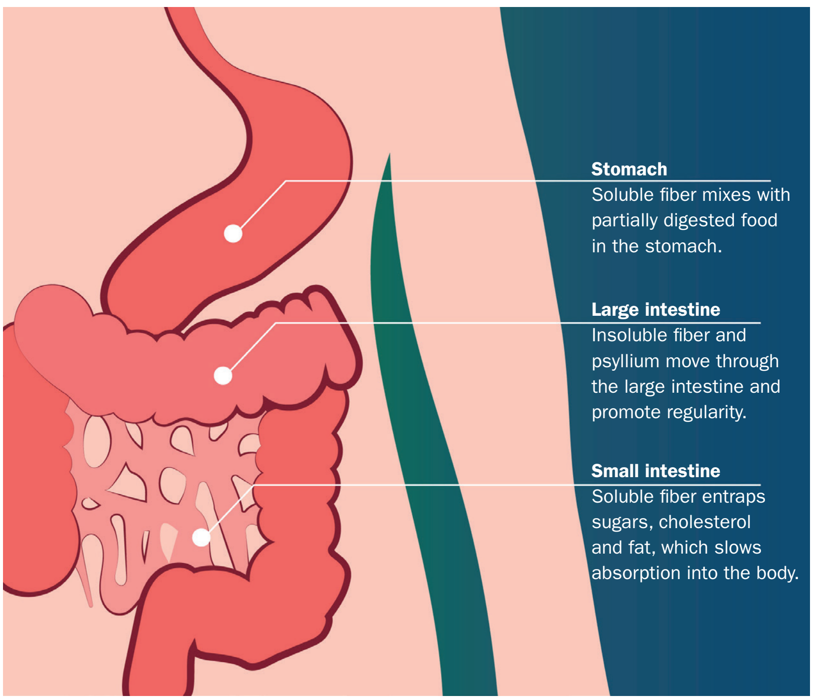
- **Soluble fiber**. Soluble fiber dissolves in fluids in the stomach to form a thick gel-like substance. It is broken down by bacteria in the large intestine and provides some calories, about two kilocalories per gram. Soluble fiber can interfere with the absorption of dietary fat and cholesterol. This, in turn, can help lower low-density lipoprotein (LDL) cholesterol levels in the blood. It also slows digestion and the rate at which carbohydrates and other nutrients are absorbed into the bloodstream which prevents rapid spikes in blood glucose after eating.
- **Insoluble fiber**. Insoluble fiber does not dissolve in water and passes through the gastrointestinal tract relatively intact and is not a source of calories. Insoluble fiber provides bulk for stool formation and speeds up the movement of food and waste through the digestive system.

Fiber is usually found along with digestible simple and complex carbohydrates in various plant foods, such as fruits, leaves, stalks, and the outer coverings of grains, nuts, seeds, and legumes. Dietary fiber helps soften the stool and encourages normal elimination. Fiber-rich diets, both soluble and insoluble, also promote satiety. In addition, research has shown that people who eat high-fiber diets experience reduced rates of cardiovascular disease, colon cancer, and diabetes. It is important to include plenty of fluids in a high-fiber diet to move them through the digestive tract.

DID YOU KNOW?

Both fiber and digestible carbohydrates contribute to helpful gut bacteria. The **gut microbiome** depends on nourishment just like any other ecosystem. Prebiotic and probiotic supplements and foods provide nutrition to support friendly, so-called good bacteria in the gut, which can aid in digestive health and proper functioning. Research suggests that gut bacteria particularly prefer fructans and cellulose.

GUT MICROBIOME: The specific and individualized accumulation of anaerobic bacteria and other microorganisms that populate the gastrointestinal tract.



THE ROLE OF GLYCOGEN IN THE BODY

Glycogen is the main storage unit of glucose that the body uses for energy. It is like the starch that is found in plants in that it consists of chains of glucose units. However, glycogen and starch differ in structure. Due to the human body's limited storage capacity for glycogen, a relatively constant supply of carbohydrates is needed throughout the day.

The body converts a portion of all ingested complex carbohydrates into glycogen, replenishing its short supply. Depending on individual factors, the total glycogen supply in the body is limited to 1,800 to 2,600 calories. The body constantly stores and releases glucose to and from glycogen. Whether glucose is released or stored depends on food ingested, time between eating, and shifting energy demands related to physical activity.

Glycogen is stored in all cells, but it is mostly found in liver and muscle cells. They serve as reservoirs for glucose. The liver's glycogen supply is used to regulate the blood sugar level and is the main source of energy for the brain. The brain can use more than 400 calories of glucose per day from the liver's glycogen store.

Each ounce of glycogen is stored in the liver with about three ounces of water. This means that when glycogen is used, water is also removed from the body. Many fad diets take advantage of this phenomenon by limiting carbs and increasing protein consumption, which causes liver and muscle glycogen to become quickly depleted. This results in a loss of several pounds of water, which many dieters mistake for a loss of bodyfat. However, research suggests that fasting can impact glycogen levels and encourage the body to use adipose tissue as an energy source.

Physically active individuals sometimes have a feeling of being bogged down or mentally sluggish. This is often due to a low level of liver glycogen. Eating an adequate amount of complex carbohydrates, especially at night, replenishes the glycogen supply and restores mental alertness and physical energy.

CARBOHYDRATE DIGESTION

Carbohydrates take different amounts of time to break down depending on type. Thorough and complete chewing of food is the first step in digestion and is important to making the process quicker and more efficient.

FROM MOUTH TO STOMACH

MASTICATION:
Chewing.

BOLUS:
A mass of chewed food.

AMYLASE:
An enzyme found largely in saliva that breaks starch into simpler sugars.

Digestion begins in the mouth with the act of chewing, or **mastication**. Chewing breaks down food mechanically by grinding it into smaller units. Saliva lubricates the **bolus** to help it travel down the esophagus. Chemical digestion of carbohydrates begins when an enzyme in the saliva starts breaking down carbohydrate chains.

This enzyme is called **amylase**. It breaks the bonds that hold together disaccharides, oligosaccharides, and starches. Amylase also breaks down amylose and amylopectin into shorter chains of glucose—called dextrins—and maltose. Maltose is a disaccharide that makes starches taste sweet.

Only about 5 percent of starches are broken down in the mouth. The mechanical breakdown continues in the stomach and prevents the presence of excess glucose in the mouth that can lead to dental caries. The contraction and relaxation of the stomach mixes carbohydrates into a substance called chyme.

FROM STOMACH TO SMALL INTESTINE

Once the chyme enters the small intestine, the pancreas releases pancreatic juice. This includes pancreatic amylase, which helps to break the dextrins into shorter chains. Enzymes excreted from the **villi** in the intestinal walls—lactase, maltase, and sucrase—break down specific molecules.

- Lactase breaks lactose into galactose and glucose.
- Maltase breaks the bond between two units of maltose.
- Sucrase breaks sucrose into glucose and fructose.

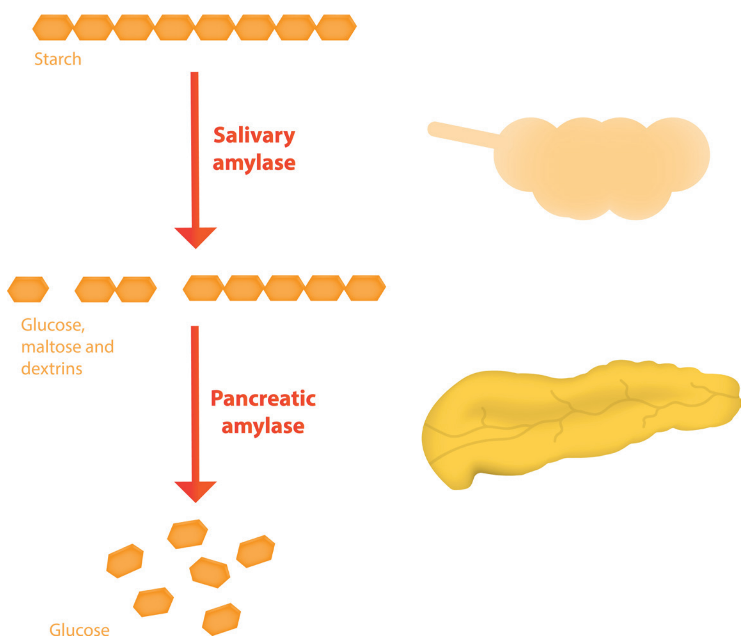
Once these carbohydrate chains have been broken down into simple sugar units, they are transported into the intestinal cells called enterocytes.

VILLI:
Fingerlike projections on the inside surface of the intestines that absorb nutrients and secrete enzymes.

DID YOU KNOW?

Lactose intolerance results from insufficient lactase production. Undigested lactose makes its way to the large intestine, where bacteria break it down. This process creates gas, diarrhea, bloating, and abdominal cramps.

Figure 4.4 The Breakdown of Starch to Glucose



From the mouth with salivary amylase, the breakdown continues in the small intestine with pancreatic amylase.

ABSORPTION INTO BLOODSTREAM

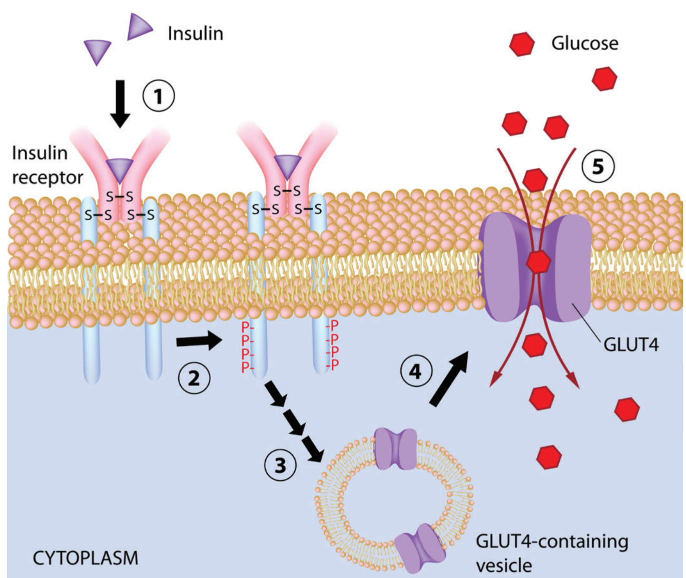
Monosaccharides enter the bloodstream with the help of transport proteins. There are 12 glucose transporters named GLUT 1 through 12. All facilitate the diffusion of sugars into the bloodstream.

INSULIN:
A hormone made by the pancreas that helps move glucose from the blood to muscle and other tissues.

DID YOU KNOW?

Though GLUT4 transporters are always found in cells to some degree, the binding of **insulin** to its receptor increases the transporter activity in a cell's membrane. Exercise has been shown to have the same effect, resulting in more control over blood sugar levels without the use of insulin. This is one reason an active lifestyle can help prevent the insulin tolerance associated with type 2 diabetes.

Effect of Insulin on Glucose Uptake



1. Insulin binds to the cell membrane insulin receptor
2. The receptor is polarized by the phosphorylation of ATP (energy)
3. Polarization activates the GLUT4 vesicle
4. The vesicle stimulates glucose transport with the GLUT4 membrane transport protein

Monosaccharides are transported to the liver by the portal vein. The liver is the first destination for fructose, galactose, and glucose. In the liver

- galactose is converted to glucose,
- fructose is broken down, and
- glucose is stored as glycogen.

The pancreas and liver regulate blood glucose levels. Glucose also self-regulates through a negative feedback loop similar to a thermostat in the home. A specific temperature is set, and when the home reaches that temperature, the thermostat shuts off the system. The glucose thermostat is in the pancreas.

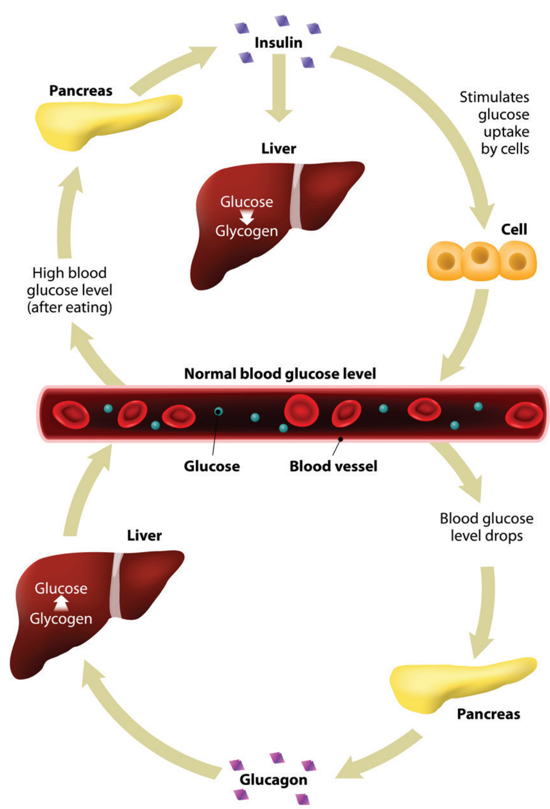
After eating carbohydrates, blood glucose levels rise. Generally, blood glucose levels begin to rise 10 to 15 minutes after a meal. After about 60 minutes, they reach their peak. However, the extent and speed of the rise depend on many factors.

When blood glucose levels increase, insulin-secreting cells in the pancreas release insulin into the blood. Insulin acts as a messenger, telling the body's cells to absorb glucose from the blood. Cells take up the glucose and use it for energy production via glycolysis.

At some point after eating, blood glucose levels decrease. **Glucagon** secreting cells in the pancreas sense the decreased concentration and release glucagon into the bloodstream. Glucagon is the messenger hormone that tells the cells to stop using glucose and to release stored glucose back into the blood.

GLUCAGON:
A pancreatic hormone that raises glucose levels in the blood.

Figure 4.5 Insulin and Glucagon



DID YOU KNOW?

Preventing **hypoglycemia**, or low blood sugar, is possible with the aid of cortisol, growth hormone, and glucagon. They ensure glucose is always available for the brain and work to prevent low blood sugar. These hormones are both inhibited and stimulated by the fluctuation of other hormones.

HYPOGLYCEMIA:
A state of low blood sugar levels with many causes, including diabetes treatments.

GLYCEMIC INDEX

GLYCEMIC INDEX (GI):
A ranking of carbohydrate-based foods on a scale from 0 to 100 according to the extent to which they raise blood sugar levels after eating.

The **glycemic index (GI)** is a ranking of carbohydrate-based foods on a scale from 0 to 100 according to the extent to which they raise blood sugar levels after eating. This is measured and ranked compared to a reference food, usually glucose with a GI of 100 and proteins and fats are not scored on this index.

Foods with a high GI are rapidly digested, absorbed, and metabolized, leading to large fluctuations in blood sugar. A diet with too many high-GI foods may lead to overconsumption and weight gain. High-GI foods increase insulin levels quickly which creates a higher physiological response resulting in hypoglycemia shortly after a meal. This, in turn, will signal the hormonal response to indicate hunger.

GHRELIN:
A hormone released from the stomach that stimulates appetite.

LEPTIN:
A hormone made from adipose tissue and the enterocytes of the small intestines that regulate energy balance and inhibit hunger.

Eating low-GI foods results in smaller, slower changes in blood sugar levels and therefore lower insulin levels. This helps maintain fullness longer and prevents overeating since the hunger hormones **ghrelin** and **leptin** are controlled. Research has shown that diets rich in low-GI foods increase weight loss and reduce the risk for developing obesity, type 2 diabetes, and cardiovascular disease.

The GI of a food depends on several factors:

- **Type of sugar**. Glucose has a value of 100, sucrose has a value of 65, and fructose has a value of 19.
- **Starch structure**. Amylose and amylopectin molecules make up starch. Foods high in amylose are more difficult to digest and therefore have a lower GI.
- **Processing**. Processed foods generally have a higher GI value than whole foods.
- **Preparation**. The longer a food, like pasta, is cooked, the higher the GI.
- **Ripeness**. The complex carbohydrates in fruit break down into simple carbohydrates as the fruit ripens. For example, an unripe banana has a GI of 30, and an overripe banana has a GI of 48.

There are some limitations to using the GI to score foods:

- The index does not account for how portion size affects GI value.
- Combining foods changes the GI for the overall meal. For example, beans and rice together will have a different GI effect than the rice alone.
- Proteins and fats do not have GI scores. Adding these macronutrients to a GI food may change the digestion timing and, thus, the GI score.

The GI of a food is typically considered to be low, medium, or high according to the following ranges:

Low GI: 0 to 55 **Medium GI: 56 to 69** **High GI: 70 and above**

Table 4.1 Glycemic Index of Foods

LOW GLYCEMIC FOODS LIST 0 - 55	MEDIUM GLYCEMIC FOODS LIST 56 - 69	HIGH GLYCEMIC FOODS LIST 70+
Most non starchy vegetable **< 15**	Canned kidney beans **52**	Bagel **72**
Peanuts **< 15**	Kiwifruit **52**	Corn chips **72**
Low-fat yogurt, no sugar **< 15**	Orange juice **52**	Watermelon **72**
Tomatoes **15**	Banana **53**	Honey **73**
Cherries **22**	Potato chips **54**	Mashed potatoes **73**
Peas **22**	Special K **54**	Cheerios **74**
Plum **24**	Sweet potato **54**	Puffed wheat **74**
Grapefruit **25**	Brown Rice **54**	Doughnuts **75**
Pearled barley **25**	Linguine **55**	French fries **76**
Peach **28**	Oatmeal cookies **55**	Vanilla wafers **77**
Can peaches, natural juice **30**	Popcorn **55**	White bread **79**
Soy milk **30**	Sweet corn **55**	Jelly beans **80**
Baby lima beans **32**	Muesli **5**	Pretzels **81**
Fat-free milk **32**	White rice **56**	Rice cakes **82**
Low-fat yogurt, with sugar **33**	Pita bread **57**	Mashed potatoes, instant **83**
Apple **36**	Blueberry muffin **59**	Cornflakes **84**
Pear **36**	Bran muffin **60**	Baked potato **85**
Whole wheat spaghetti **37**	Hamburger bun **61**	Rice, instant **91**
Tomato soup **38**	Ice cream **61**	French bread **95**
Carrots, cooked **39**	Canned apricots, light syrup **64**	Parsnips **97**
Apple juice **41**	Macaroni and cheese **64**	Dates **100**
All-Bran **42**	Raisins **64**	
Canned chickpeas **42**	Couscous **65**	
Custard **43**	Quick-cooking porridge **65**	
Grapes **43**	Rye crisp-bread **65**	
Orange **43**	Table sugar (sucrose) **65**	
Canned lentil soup **44**	Instant porridge **66**	
Macaroni **45**	Pineapple **66**	
Pineapple juice **46**	Taco shells **68**	
Banana bread **47**	Whole wheat bread **68**	
Long-grain rice **47**		
Bulgur **48**		
Canned baked beans **48**		
Grapefruit juice **48**		
Green peas **48**		
Oat bran bread **48**		
Old-fashioned porridge **49**		

GLYCEMIC LOAD

The GI of a food provides an estimate of how a food raises blood sugar levels but does not consider portions or quantity.

The glycemic load (GL) is a calculation that considers both GI value (carbohydrate quality) and portion size (carbohydrate quantity).

The GL is calculated as follows:

$$\frac{(\text{GI value of the food} \times \text{the quantity of carbohydrates of the serving in grams})}{100}$$

For example, for a food with a GI of 54 and an available 20 grams of carbohydrate per serving, the GL value is $(54 \times 20) / 100 = 10.8$

Watermelon is a good example of the importance of considering both GI and GL for foods. The GI for watermelon is high, in the 80s. But the actual quantity in grams of carbohydrates in a serving of watermelon is so low that it has only a minimal effect on blood sugar, and therefore a lower GL.

Both the GI and GL measures can be useful for determining the role carbohydrate-containing foods or meals play in the body. They help determine how blood sugar levels, and in turn insulin, will react after eating.

FOOD SOURCES OF CARBOHYDRATES

Carbohydrates are inexpensive and common in most diets. For example, clients can purchase several pounds of sweet potatoes for only a few dollars and have a week's supply of high-quality complex carbohydrates. Some other foods high in carbohydrates (over 60 percent of calories) include ready-to-eat and cooked cereals, whole grain breads, crackers, popcorn, rice, pasta, corn, potatoes, winter squash, and yams. Other food types and specific examples that contain carbs include the following:

- **Grains**. Bread, noodles, pasta, and cereal
- **Fruits**. Apples, bananas, berries, mangoes, melons, and oranges
- **Dairy**. Milk and yogurt
- **Legumes**. Dried beans, lentils, and peas
- **Snack foods and sweets**. Cakes, cookies, candy, and other desserts
- **Drinks**. Juices, soft drinks, sports drinks, and energy drinks that contain sugars
- **Vegetables**. Potatoes, carrots, broccoli, beets, and sweet potatoes

Vegetables high in starch, like potatoes, have more carbohydrates per serving than non-starchy vegetables, but they all have some carbohydrates. Examples of non-starchy vegetables are asparagus, broccoli, carrots, celery, green beans, lettuce and other salad greens, peppers, spinach, tomatoes, and zucchini.

Table 5.2 Common Foods and Carbohydrate Content (per 100 grams)

Carbohydrate Source	Grams of carbohydrates per 100 grams of source
Almonds	4 g
Apple	9 g
Asparagus	1 g
Banana	19 g
Barbeque Sauce	8 g
Beef Sirloin	0 g
Beer	2 g
Wheat Bread (4 slices)	56 g
Broccoli	2 g
Butter	Trace
Cashews	28 g
Celery	1 g
Cheddar Cheese	Trace
Cheese Pizza	25 g
Cheesecake	35 g
Chicken	0 g
Coconut	6 g
Cod	0 g
Coffee	0 g
Crab	0 g
Cream Cheese (Plain)	Trace

Carbohydrate Source	Grams of carbohydrates per 100 grams of source
Doughnut	49 g
Flounder	0 g
Goat Milk	5 g
Grapes	13 g
Hamburger	22 g
Hardboiled Egg	Trace
Honey	76 g
Human Milk (Breast Milk)	7 g
Jelly	69 g
Lettuce	1 g
Mango	15 g
Margarine	Trace
Mayonnaise	Trace
Mandarin Orange	14 g
Onion	5 g
Orange	6 g
Oysters (Raw)	Trace
Peanut Butter	13 g
Peanuts	6 g
Pickles	6 g
Pineapple	12 g

Carbohydrate Source	Grams of carbohydrates per 100 grams of source
Pistachios	19 g
Plain Yogurt	6 g
Pork Chop	0 g
Potato	20 g
Prawns/Shrimp	0 g
Raisins	64 g
Red Wine	Trace
Rice	30 g
Salami (Sliced)	2 g
Salmon	0 g
Scallops	Trace
Skim Milk	5 g
Spinach	1 g
Sponge Cake	53 g
Swiss Cheese	Trace
Tuna	0 g
Turkey (Roasted)	0 g
Vegetable Oil	0 g
Vinegar	1 g
Walnuts	5 g
Whole Milk	5 g

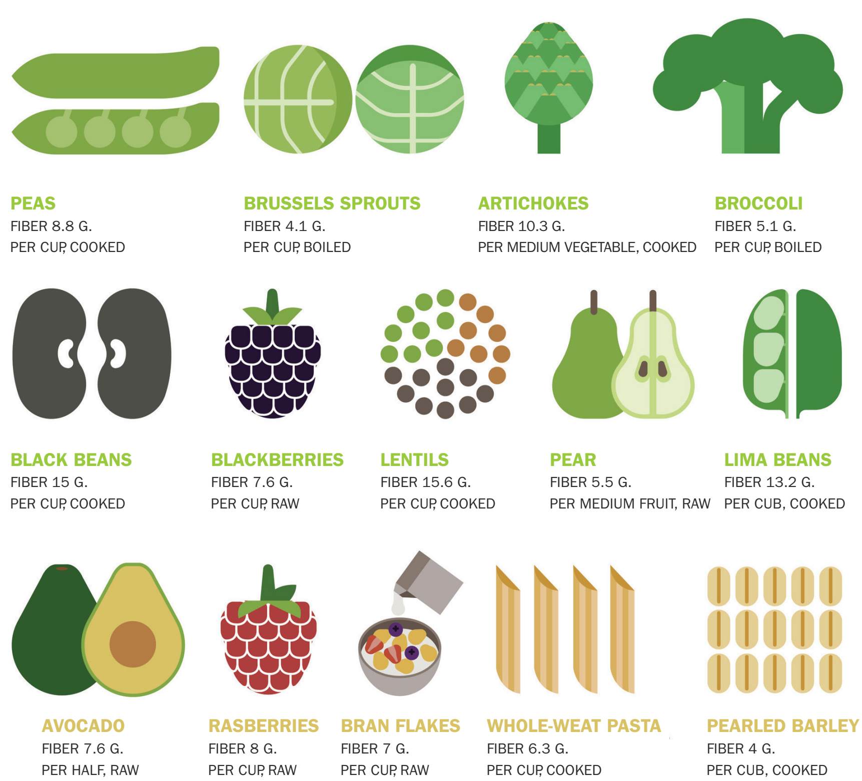
RECOMMENDED DIETARY ALLOWANCES FOR CARBOHYDRATES

Carbohydrates are essential nutrients that most people need in their diets in significant quantities for good overall health. The acceptable macronutrient distribution range for daily carbohydrate intake for adults is 45 to 65 percent of total daily calories, as reported by the National Academy of Medicine (NAM). This means that for a diet of 2,000 calories per day, carbohydrate intake should be around 900 to 1,300 calories. For weight loss, daily carbohydrate intake can drop to as low as 25 to 40 percent.

The National Research Council states that the optimal range for fiber per day is 21 to 38 grams. Some health experts recommend higher amounts and most adults in the US get only 12 to 18 grams of fiber per day. The 2015 Dietary Guidelines by the NAM recommend 14 grams of fiber per 1,000 calories consumed, so for a 2,000-calorie-per-day diet, this would mean 28 grams per day.

Due to individual differences, the amount of fiber needed to maintain a healthy and diverse gut microbiome varies. The recommended guidelines are general and clients can improve fiber intake by eating foods high in fiber or by using a fiber supplement.

Figure 4.5 Good Sources of Fiber



Healthy carbohydrate intake means consuming lower amounts of simple refined sugars, increasing fiber intake, and including more whole grain foods and complex carbohydrates. When choosing carbohydrates, it is also important to select more foods that have a lower GI value.

A simple place to start when choosing carbohydrates is to focus on a diversity of vegetables. Carbs from vegetables are moderate or low on the GI, are rich in fiber, and maximize vitamins and minerals without supplementation.

CARBOHYDRATES AND ATHLETES

The amount of carbohydrates an individual needs is based on their total output of energy throughout the day. Getting 40 percent of daily calories from **net carbohydrates** is a good baseline. Adjustments can then be made for appropriate recovery and progress with respect to an athlete's activity level and training phases.

NET CARBOHYDRATES: The total amount of carbohydrates minus dietary fiber.

When the timing of carbohydrate ingestion is right, this nutrient is used more quickly for energy and does not cause a rapid rise in insulin that could conflict with glucagon function and energy production. These functions are vital for high-performance muscle contractions during athletic activities. This also spares the body's glycogen stores. Proper timing means that the body is active and using energy as the ingested carbs enter the bloodstream.

When the body runs out of stored glycogen and is forced to use fatty acids as the primary source of energy, physical performance declines. Under glycogen depletion conditions, the body may also use proteins and amino acids for energy. This process is called **gluconeogenesis**. Endurance athletes call this "hitting the wall," when their body's glycogen stores become depleted and they must rely on other nutrients for energy production during training or events.

GLUCONEOGENESIS: The process of converting a non-carbohydrate substance into glucose for energy.

DID YOU KNOW?

The benefits of carbohydrate and electrolyte drinks for performance are less clear for exercise lasting under 90 minutes, assuming glycogen levels have been replenished before exercise. The benefits might not be immediate but may help reserve glycogen stores and prevent glycogen depletion on a day-to-day basis. Research indicates that many athletes may suffer from chronic glycogen depletion, with decreased performance and increased recovery time. Drinking pre-exercise and during-exercise carbohydrate beverages, with personalized hydration and electrolytes, is an important sports nutrition practice to help athletes maintain a high level of performance.

For peak performance and health, athletes must consider the type of carbohydrates they eat, the time of day they eat them, their intake of nutrient **cofactors**, and adequate intake of the other essential nutrients. All these elements together help to maintain the body's glycogen stores and enhance energy production during exercise.

COFACTORS: Substances that must be present for another substance to be able to perform a certain function.