Carbohydrates: Plant-Derived Energy Nutrients

**Test Yourself**  **True or False?**

1. Carbohydrates are the primary fuel source for the brain and body tissues.  
   T or F

2. Carbohydrates are fattening.  T or F

3. Type 2 diabetes is seen only in adults.  T or F

4. Diets high in sugar cause hyperactivity in children.  T or F

5. Alternative sweeteners, such as aspartame, are safe for us to consume.  T or F

*Test Yourself answers are located in the Chapter Review.*

**Chapter Objectives**  
*After reading this chapter, you will be able to:*

1. Describe the difference between simple and complex carbohydrates, *pp. 119–122.*
2. Describe the difference between alpha and beta bonds, and discuss how these bonds are related to the digestion of fibre and lactose intolerance, *pp. 121–122.*
4. Discuss how carbohydrates are digested and absorbed by the body, *pp. 124–127.*
5. List four functions of carbohydrates in the body, *pp. 130–132.*
7. Identify the potential health risks associated with diets high in simple sugars, *pp. 135–137.*
8. List five foods that are good sources of carbohydrates, *pp. 139–140.*
10. Describe type 1 and type 2 diabetes, and discuss how diabetes differs from hypoglycemia, *pp. 145–150.*
What Are Carbohydrates?

It was a typical day at a large medical centre in downtown Toronto: two patients were having toes amputated, another had nerve damage, one was being treated for kidney failure, another for infection, and another was blind. Despite their variety, these problems were due to just one disease: diabetes. In 2000, it was estimated that total healthcare costs related to diabetes in Canada were $4.66 billion. That figure is expected to increase to $8.14 billion by the year 2016. Older Canadians, those experiencing household food insufficiency, and Aboriginal people have a significantly higher risk of developing diabetes; however, more and more children are being diagnosed with the disease. It is expected that the incidence of type 2 diabetes in children in Canada will increase by up to 50% by the year 2025.

What is diabetes, and why are we discussing it in a chapter on carbohydrates? Does the consumption of carbohydrates somehow lead to diabetes—or, for that matter, to obesity or any other disorder? Several popular diets—including the Zone Diet, Sugar Busters, and Dr. Atkins’ New Diet Revolution—claim that carbohydrates are bad for your health and advocate reducing carbohydrate consumption and increasing protein and fat intake. Are carbohydrates a health menace, and should we reduce our intake? If you noticed that a friend regularly consumed four or five soft drinks a day, plus chips, cookies, candy, and other high-carbohydrate snacks, would you say anything?

In this chapter, we explore the differences between simple and complex carbohydrates and learn why some carbohydrates are better than others. We also learn how our bodies break down carbohydrates and learn why some carbohydrates are better than others. We also learn how our bodies break down carbohydrates and use them to maintain our health and to fuel our activity and exercise. Because carbohydrate metabolism sometimes does go wrong, we’ll also discuss its relationship to some common health disorders.

Energy from sun

Carbon dioxide from air

Glucose stored in plant

Figure 4.1 Plants make carbohydrates through the process of photosynthesis. Water, carbon dioxide, and energy from the sun are combined to produce glucose.

What Are Carbohydrates?

As we mentioned in Chapter 1, carbohydrates are one of the three macronutrients. As such, they are an important energy source for the entire body and are the preferred energy source for nerve cells, including those of the brain. We will say more about their functions later in this chapter.

The term carbohydrate literally means “hydrated carbon.” Water (H₂O) is made of hydrogen and oxygen, and when something is said to be hydrated, it contains water. Thus, the chemical abbreviation for carbohydrate (CHO) indicates the atoms it contains: carbon, hydrogen, and oxygen.

We obtain carbohydrates predominantly from plant foods such as fruits, vegetables, and grains. Plants make the most abundant form of carbohydrate, called glucose, through a process called photosynthesis. During photosynthesis, the green pigment of plants, called chlorophyll, absorbs sunlight, which provides the energy needed to fuel the manufacture of glucose. As shown in Figure 4.1, water absorbed from the earth by the roots of plants combines with carbon dioxide present in the leaves to produce the carbohydrate glucose. Plants continually store glucose and use it to support their own growth. Then, when we eat plant foods, our bodies digest, absorb, and use the stored glucose.
What’s the Difference Between Simple and Complex Carbohydrates?

Carbohydrates can be classified as simple or complex. Simple carbohydrates contain either one or two molecules, whereas complex carbohydrates contain hundreds to thousands of molecules.

Simple Carbohydrates Include Monosaccharides and Disaccharides

Simple carbohydrates are commonly referred to as sugars. Four of these sugars are called monosaccharides because they consist of a single sugar molecule (mono, meaning “one,” and saccharide, meaning “sugar”). The other three sugars are disaccharides, which consist of two molecules of sugar joined together (di, meaning “two”).

Glucose, Fructose, Galactose, and Ribose Are Monosaccharides

Glucose, fructose, and galactose are the three most common monosaccharides in our diet. Each of these monosaccharides contains 6 carbon atoms, 12 hydrogen atoms, and 6 oxygen atoms (Figure 4.2). Very slight differences in the structure of these three monosaccharides cause major differences in their level of sweetness.

Given what you’ve just learned about how plants manufacture glucose, it probably won’t surprise you to discover that glucose is the most abundant monosaccharide found in our diets and in our bodies. Glucose does not generally occur by itself in foods but attaches to other sugars to form disaccharides and complex carbohydrates. In our bodies, glucose is the preferred source of energy for the brain, and it is a very important source of energy for all cells.

Fructose, the sweetest natural sugar, occurs naturally in fruits and vegetables. Fructose is also called levulose, or fruit sugar. In many processed foods, it is a component of high-fructose corn syrup. This syrup is made from corn and is used to sweeten soft drinks, desserts, candies, and jellies.

Galactose does not occur alone in foods. It joins with glucose to create lactose, one of the three most common disaccharides.

Ribose is a five-carbon monosaccharide. Very little ribose is found in our diets; our bodies produce ribose from the foods we eat, and ribose is contained in the genetic material of our cells: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

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**Monosaccharides**

<table>
<thead>
<tr>
<th>Glucose</th>
<th>Fructose</th>
<th>Galactose</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Glucose Structure" /></td>
<td><img src="image2.png" alt="Fructose Structure" /></td>
<td><img src="image3.png" alt="Galactose Structure" /></td>
</tr>
<tr>
<td>Most abundant sugar molecule in our diet; good energy source</td>
<td>Sweetest natural sugar; found in fruit, high-fructose corn syrup</td>
<td>Does not occur alone in foods; binds with glucose to form lactose</td>
</tr>
</tbody>
</table>

**Figure 4.2** The three most common monosaccharides. Notice that all three monosaccharides contain identical atoms: 6 carbon, 12 hydrogen, and 6 oxygen. It is only the arrangement of these atoms that differs.
What’s the Difference Between Simple and Complex Carbohydrates?

The three most common disaccharides found in foods are lactose, maltose, and sucrose (Figure 4.3). Lactose (also called milk sugar) consists of one glucose molecule and one galactose molecule. Interestingly, human breast milk has a higher amount of lactose than cow’s milk, which makes human breast milk taste sweeter.

Maltose (also called malt sugar) consists of two molecules of glucose. It does not generally occur independently in foods but results as a by-product of digestion. Maltose is also the sugar that results from fermentation during the production of beer and liquor products. Fermentation is the anaerobic process in which an agent, such as yeast, causes an organic substance to break down into simpler substances and results in the production of adenosine triphosphate (ATP). Thus, maltose is formed during the anaerobic breakdown of sugar into alcohol. Contrary to popular belief, very little maltose remains in alcoholic beverages after the fermentation process; thus, alcoholic beverages are not good sources of carbohydrate.

Sucrose is composed of one glucose molecule and one fructose molecule. Because sucrose contains fructose, it is sweeter than lactose or maltose. Sucrose provides much of the sweet taste found in honey, maple syrup, fruits, and vegetables. Table sugar, brown sugar, powdered sugar, and many other products are made by refining the sucrose found in sugarcane and sugar beets. You will learn more about the different forms of sucrose commonly used in foods later in this chapter. Are honey and other naturally occurring forms of sucrose healthier than manufactured forms? The Nutrition Myth or Fact? box investigates this question.

Lactose, Maltose, and Sucrose Are Disaccharides

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Maltose (also called malt sugar) consists of two molecules of glucose. It does not generally occur by itself in foods but rather is bound together with other molecules. As our bodies break these larger molecules down, maltose results as a by-product. Maltose is also the sugar that results from fermentation during the production of beer and liquor products. Fermentation is the anaerobic process in which an agent, such as yeast, causes an organic substance to break down into simpler substances and results in the production of adenosine triphosphate (ATP). Thus, maltose is formed during the anaerobic breakdown of sugar into alcohol. Contrary to popular belief, very little maltose remains in alcoholic beverages after the fermentation process; thus, alcoholic beverages are not good sources of carbohydrate.

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**Lactose** Also called milk sugar, a disaccharide consisting of one glucose molecule and one galactose molecule; found in milk, including human breast milk.

**Maltose** A disaccharide consisting of two molecules of glucose; does not generally occur independently in foods but results as a by-product of digestion; also called malt sugar.

**Fermentation** The anaerobic process in which an agent causes an organic substance to break down into simpler substances and results in the production of ATP.

**Sucrose** A disaccharide composed of one glucose molecule and one fructose molecule; sweeter than lactose or maltose.
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NUTRITION MYTH OR FACT?

Is Honey More Nutritious Than Table Sugar?

Ming is dedicated to eating nutritious foods. She works hard to avoid white sugar and to eat foods that contain honey, molasses, or raw sugar. Ming believes that these sweeteners are more natural and nutritious than refined white sugar. To critically assess her belief, consider Table 4.1 and work through the questions below.

Thinking Critically

1. How does the carbohydrate composition of white sugar compare with that of honey?
2. How does the nutrient composition of white sugar compare with that of honey?
3. How do the micronutrients in honey compare to the recommended dietary reference intakes (DRI) for a 22-year-old female?
4. Is raw sugar more nutritious than table sugar?
5. Blackstrap molasses is the syrup that remains when sucrose is made from sugarcane. Is blackstrap molasses a more nutritious choice than white sugar?
6. What advice would you give to Ming about sweeteners?

Table 4.1  Nutrient Comparison of 15 mL of Four Different Sweeteners

<table>
<thead>
<tr>
<th></th>
<th>White Sugar</th>
<th>Honey</th>
<th>Blackstrap Molasses</th>
<th>“Raw” Sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kcal)</td>
<td>49.0</td>
<td>65.0</td>
<td>49.0</td>
<td>49.0</td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>12.7</td>
<td>17.7</td>
<td>12.6</td>
<td>12.7</td>
</tr>
<tr>
<td>Sugars, total (g)</td>
<td>12.7</td>
<td>17.6</td>
<td>8.9</td>
<td>12.7</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>0</td>
<td>0.06</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fibre (g)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vitamin C (mg)</td>
<td>0</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vitamin A (IU)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Thiamine (mg)</td>
<td>0</td>
<td>0</td>
<td>0.007</td>
<td>0.001</td>
</tr>
<tr>
<td>Riboflavin (mg)</td>
<td>0.002</td>
<td>0.008</td>
<td>0.01</td>
<td>0.001</td>
</tr>
<tr>
<td>Folate (µg)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Calcium (mg)</td>
<td>0</td>
<td>1.0</td>
<td>179.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Iron (mg)</td>
<td>0</td>
<td>0.09</td>
<td>3.6</td>
<td>0.24</td>
</tr>
<tr>
<td>Sodium (mg)</td>
<td>0</td>
<td>1.0</td>
<td>11.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Potassium (mg)</td>
<td>0</td>
<td>11.0</td>
<td>518.0</td>
<td>45.0</td>
</tr>
</tbody>
</table>


The two monosaccharides that compose a disaccharide are attached by a bond between an oxygen atom and one carbon atom on each of the monosaccharides (Figure 4.4). Two forms of this bond occur in nature: an alpha bond and a beta bond. As you can see in Figure 4.4a, sucrose is produced by an alpha bond joining a glucose molecule and a fructose molecule. The disaccharide maltose is also produced by an alpha bond. In contrast, lactose is produced by alpha bond. A type of chemical bond that can be digested by enzymes found in the human intestine.

beta bond  A type of chemical bond that cannot be easily digested by enzymes found in the human intestine.
Complex Carbohydrates Include Oligosaccharides and Polysaccharides

**Complex carbohydrates**, the second major classification of carbohydrate, generally consist of long chains of glucose molecules. Technically, any carbohydrate with three or more monosaccharides is considered to be a complex carbohydrate.

**Oligosaccharides** are carbohydrates that contain 3 to 10 monosaccharides (oligo, meaning “few”). Two of the most common oligosaccharides found in our diets are *raffinose* and *stachyose*. Raffinose is composed of galactose, glucose, and fructose. It is commonly found in beans, cabbage, Brussels sprouts, broccoli, and whole grains. Stachyose is composed of two galactose molecules, a glucose molecule, and a fructose molecule. It is found in many beans and legumes.

Raffinose and stachyose are part of the raffinose family of oligosaccharides (RFOs). Because humans do not possess the enzyme needed to break down these RFOs, they pass into the large intestine undigested. Once they reach the large intestine, they are fermented by bacteria that produce gases such as carbon dioxide, methane, and hydrogen. The product Beano® contains the enzyme alpha-galactosidase; this is the enzyme needed to break down the RFOs in the intestinal tract. Thus, this product can help to reduce the intestinal gas caused by eating beans and various vegetables.

Most **polysaccharides** consist of hundreds to thousands of glucose molecules (poly, meaning “many”). The polysaccharides include starch, glycogen, and most fibres (Figure 4.5).

**Starch Is a Polysaccharide Stored in Plants**

Plants store glucose not as single molecules but as polysaccharides in the form of **starch**. The two forms of starch are amylose and amyllopectin (see Figure 4.5). Amylose is a straight chain of glucose molecules, whereas amyllopectin is highly branched. Both forms of starch are found in starch-containing foods. The more open-branched structure of amyllopectin increases its surface area and thus its exposure to digestive enzymes. Consequently, amyllopectin is more rapidly digested than amylose, and thus it raises blood glucose more quickly than amylose.

Excellent food sources of starch include grains (wheat, rice, corn, oats, and barley), legumes (peas, beans, and lentils), and tubers (potatoes and sweet potatoes). Our cells cannot use the complex starch molecules exactly as they occur in plants. Instead, the body
must break them down into the monosaccharide glucose, from which we can then fuel our energy needs.

Our bodies easily digest most starches, in which alpha bonds link the numerous glucose units; however, starches linked by beta bonds are largely indigestible and are called resistant. Technically, resistant starch is classified as a type of fibre. When our intestinal bacteria ferment resistant starch, a short-chain fatty acid called butyrate is produced. Consuming resistant starch may be beneficial: some research suggests that butyrate reduces the risk of cancer. Legumes contain more resistant starch than do grains, fruits, or vegetables. This quality, plus their high protein and fibre content, makes legumes a healthy food.

Glycogen Is a Polysaccharide Stored by Animals

Glycogen is the storage form of glucose for animals, including humans. After an animal is slaughtered, most of the glycogen is broken down by enzymes found in animal tissues. Thus, very little glycogen exists in meat. Glycogen does not exist at all in plants either. Therefore, glycogen is not a dietary source of carbohydrate. We can very quickly break down the glycogen stored in the body into glucose when we need it for energy. We store glycogen in our muscles and liver; the storage and use of glycogen are discussed in more detail on pages 126–127.

Fibre Is a Polysaccharide That Gives Plants Their Structure

Like starch, fibre is composed of long polysaccharide chains; however, the body does not easily break down the bonds that connect fibre molecules. This means that most fibres pass through the digestive system without being digested and absorbed, so they contribute no energy to our diet. However, fibre offers many other health benefits (see page 132).

There are currently a number of definitions of fibre. Recently, the Food and Nutrition Board of the Institute of Medicine proposed three distinctions: dietary fibre, functional fibre, and total fibre:

- **Dietary fibre** (also referred to as resistant starch) is the non-digestible part of plants that form the support structures of leaves, stems, and seeds (see Figure 4.5). In a sense, you can think of dietary fibre as the plant’s “skeleton.”
- **Functional fibre** consists of non-digestible forms of carbohydrates that are extracted from plants or manufactured in a laboratory and have known health benefits. Functional fibre is added to foods and is the form found in fibre supplements. Examples of functional fibre sources you might see on nutrition labels include cellulose, guar gum, pectin, and psyllium.
- **Total fibre** is the sum of dietary fibre and functional fibre.

Fibre can also be classified according to its chemical and physical properties as soluble or insoluble.

**Soluble Fibres** Soluble fibres dissolve in water. They are also viscous, forming a gel when wet, and they are fermentable; that is, they are easily digested by bacteria in the colon. Soluble fibres are typically found in citrus fruits, berries, oat products, and beans.

Research suggests that regular consumption of soluble fibres reduces the risks for cardiovascular disease and type 2 diabetes by lowering blood cholesterol and blood glucose levels. The possible mechanisms by which fibre reduces the risk for various diseases are discussed in more detail on pages 132–134.
Examples of soluble fibres include the following:

- **Pectins** contain chains of galacturonic acid and other monosaccharides. Pectins are found in the cell walls and intracellular tissues of many fruits and berries. They can be isolated and used to thicken foods such as jams and yogourts.
- **Gums** contain galactose, glucuronic acid, and other monosaccharides. Gums are a diverse group of polysaccharides that are viscous. They are typically isolated from seeds and are used as thickening, gelling, and stabilizing agents. Guar gum and gum arabic are common gums used as food additives.
- **Muclages** are similar to gums and contain galactose, mannose, and other monosaccharides. Two examples include psyllium and carrageenan. Psyllium is the husk of psyllium seeds, which are also known as plantago or flea seeds. Carrageenan comes from seaweed. Muclages are used as food stabilizers.

**Insoluble Fibres**  
Insoluble fibres are those that do not typically dissolve in water. These fibres are usually non-viscous and cannot be fermented by bacteria in the colon. They are generally found in whole grains such as wheat, rye, and brown rice and are also found in many vegetables. These fibres are not associated with reducing cholesterol levels but are known for promoting regular bowel movements, alleviating constipation, and reducing the risk for a bowel disorder called diverticulosis (discussed later in this chapter). Examples of insoluble fibres include the following:

- **Lignins** are non-carbohydrate forms of fibre. Lignins are found in the woody parts of plant cell walls and are found in carrots and in the seeds of fruits and berries. Lignins are also found in brans (or the outer husk of grains such as wheat, oats, and rye) and other whole grains.
- **Cellulose** is the main structural component of plant cell walls. Cellulose is a chain of glucose units similar to amylose, but unlike amylose, cellulose contains beta bonds that are non-digestible by humans. Cellulose is found in whole grains, fruits, vegetables, and legumes. It can also be extracted from wood pulp or cotton, and it is added to foods as an agent for anti-caking, thickening, and texturizing of foods.
- **Hemicelluloses** contain glucose, mannose, galacturonic acid, and other monosaccharides. Hemicelluloses are found in plant cell walls and they surround cellulose. They are the primary component of cereal fibres and are found in whole grains and vegetables. Although many hemicelluloses are insoluble, some are also classified as soluble.

**RECAP**

Complex carbohydrates include oligosaccharides and polysaccharides. Raffinose and stachyose are two of the most common oligosaccharides found in our diet. The three types of polysaccharides are starch, glycogen, and fibre. Starch is the storage form of glucose in plants, while glycogen is the storage form of glucose in animals. Fibre forms the support structures of plants. Soluble fibres dissolve in water, are viscous, and can be digested by bacteria in the colon, whereas insoluble fibres do not dissolve in water, are not viscous, and cannot be digested.

**How Do Our Bodies Break Down Carbohydrates?**

Glucose is the form of sugar that our bodies use for energy, and the primary goal of carbohydrate digestion is to break down polysaccharides and disaccharides into monosaccharides that can then be converted to glucose. Chapter 3 provided an overview of digestion of the three types of macronutrients, as well as vitamins and minerals. Here, we focus specifically and in more detail on the digestion and absorption of carbohydrates. **Figure 4.6** provides a visual tour of carbohydrate digestion.
Chapter 4 Carbohydrates: Plant-Derived Energy Nutrients

Carbohydrate Digestion

Carbohydrate digestion begins in the mouth (Figure 4.6, step 1). As you saw in Chapter 3, the starch in the foods you eat mixes with your saliva during chewing. Saliva contains an enzyme called salivary amylase, which breaks down starch into smaller particles and eventually into the disaccharide maltose. The next time you eat a piece of bread, notice that you can actually taste it becoming sweeter; this indicates the breakdown of starch into maltose. Disaccharides are not digested in the mouth.

As the bolus of food leaves the mouth and enters the stomach, all digestion of carbohydrates ceases. This is because the acid in the stomach inactivates the salivary amylase enzyme (Figure 4.6, step 2).

The majority of carbohydrate digestion occurs in the small intestine. As the contents of the stomach enter the small intestine, an enzyme called pancreatic amylase is secreted by the pancreas into the small intestine (Figure 4.6, step 3). Pancreatic amylase continues to digest any remaining starch into maltose. Additional enzymes found in the microvilli of the mucosal cells that line the intestinal tract work to break down disaccharides into monosaccharides. Maltose is broken down into glucose by the enzyme maltase. Sucrose is broken down into glucose and fructose by the enzyme sucrase. The enzyme lactase breaks down lactose into glucose and galactose (Figure 4.6, step 4). Enzyme names are identifiable by the suffix -ase.

Carbohydrate Absorption

Once digestion of carbohydrates is complete, all monosaccharides are then absorbed into the mucosal cells lining the small intestine, where they pass through and enter into the bloodstream. Glucose and galactose are absorbed across the enterocytes via active transport using a carrier protein saturated with sodium. This process requires energy from the breakdown of ATP. Fructose is absorbed via facilitated diffusion and therefore requires no energy. (Refer back to Chapter 3 for a description of these transport processes.) The absorption of fructose takes longer than that of glucose or galactose. This slower absorption rate means that fructose stays in the small intestine longer and draws water into the intestines.
via osmosis. This not only results in a smaller rise in blood glucose when consuming fructose, but it can also lead to diarrhea.

**Carbohydrate Metabolism**

Once the monosaccharides enter the bloodstream, they travel to the liver, where fructose and galactose are converted to glucose (Figure 4.6, step 5). If needed immediately for energy, the glucose is released into the bloodstream, where it can travel to the cells to provide energy. If glucose is not immediately needed by the body for energy, it is stored as glycogen in the liver and muscles. Enzymes in liver and muscle cells combine glucose molecules to form glycogen (an anabolic, or building, process) and break glycogen into glucose (a catabolic, or destructive, process), depending on the body’s energy needs. On average, the liver can store 70 g (or 280 kcal) and the muscles can store about 120 g (or 480 kcal) of glycogen. Between meals, our bodies draw on liver glycogen reserves to maintain blood glucose levels and support the needs of our cells, including those of our brain, spinal cord, and red blood cells (Figure 4.7). The glycogen stored in our muscles continually provides energy to the muscles, particularly during intense exercise. Endurance athletes can increase their storage of muscle glycogen from two to four times the normal amount through a process called glycogen, or carbohydrate, loading (see Chapter 15). Any excess glucose is stored as glycogen in the liver and muscles and saved for such future energy needs as exercise. Once the carbohydrate storage capacity of the liver and muscles is reached, any excess glucose can be stored as fat in adipose tissue.

**Carbohydrate Excretion**

As previously mentioned, humans do not possess enzymes in the small intestine that can break down fibre. Thus, fibre passes through the small intestine undigested and enters the large intestine, or colon. There, bacteria ferment some previously undigested carbohydrates, causing the production of gases such as hydrogen, methane, and sulphur and a few short-chain fatty acids such as acetic acid, butyric acid, and propionic acid. The cells of the large intestine use these short-chain fatty acids for energy. It is estimated that fermented fibres yield about 1.5 to 2.5 kcal/g. This is less than the 4 kcal/g provided by carbohydrates that are digested and absorbed in the small intestine; the discrepancy is due to the fact that fermentation of the

![Figure 4.7](image)

**Figure 4.7** Glucose is stored as glycogen in both the liver and muscle. The glycogen stored in the liver maintains blood glucose between meals; muscle glycogen provides immediate energy to the muscle during exercise and cannot be released back into the blood.
fibres in the colon is an anaerobic process, which yields less energy than the aerobic digestive process of other carbohydrates. Obviously, the fibres that remain totally undigested contribute no energy to our bodies. Fibre remaining in the colon adds bulk to our stools and is excreted in feces (Figure 4.6, step 6). In this way, fibre assists in maintaining bowel regularity. The health benefits of fibre are discussed later in this chapter (pages 132–134).

**Regulation of Blood Glucose Levels**

Our bodies regulate blood glucose levels within a fairly narrow range to provide adequate glucose to the brain and other cells. A number of hormones, including insulin, glucagon, epinephrine, norepinephrine, cortisol, and growth hormone, assist the body with maintaining blood glucose.

When we eat a meal, our blood glucose level rises. But glucose in our blood cannot help the nerves, muscles, and other tissues to function unless it can cross into their cells. Glucose molecules are too large to cross the cell membranes of our tissues independently. To get in, glucose needs assistance from the hormone **insulin**, which is secreted by the beta cells of the pancreas (Figure 4.8a). Insulin is transported in the blood to the cells of tissues throughout the body, where it stimulates special carrier proteins, called **glucose transporters**, located in cells. The arrival of insulin at the cell membrane stimulates glucose transporters to travel to the surface of the cell, where they assist in transporting glucose across the cell membrane and into the cell. Insulin can thus be thought of as a key that opens the gates of the cell membrane, enabling the transport of glucose into the cell interior, where it can be used for energy. Insulin also stimulates the liver and muscles to take up glucose and store it as glycogen.

When you have not eaten for some period of time, your blood glucose level declines. This decrease in blood glucose stimulates the alpha cells of the pancreas to secrete another hormone, **glucagon** (Figure 4.8b). Glucagon acts in an opposite way to insulin: it causes the liver to convert its stored glycogen into glucose, which is then secreted into the bloodstream and transported to the cells for energy. Glucagon also assists in the breakdown of body proteins to amino acids so the liver can stimulate **gluconeogenesis** (or “generating new glucose”), the production of glucose from amino acids.

Epinephrine, norepinephrine, cortisol, and growth hormone are additional hormones that work to increase blood glucose. Epinephrine and norepinephrine are secreted by the adrenal glands and nerve endings when blood glucose levels are low. They act to increase glycogen breakdown in the liver, resulting in a subsequent increase in the release of glucose into the bloodstream. They also increase gluconeogenesis. These two hormones are also responsible for our “fight or flight” reaction to danger; they are released when we need a burst of energy to respond quickly. Cortisol and growth hormone are secreted by the adrenal glands to act upon liver, muscle, and adipose tissue. Cortisol increases gluconeogenesis and decreases the use of glucose by muscles and other body organs. Growth hormone decreases glucose uptake by the muscles, increases our mobilization and use of fatty acids stored in our adipose tissue, and also increases the liver’s output of glucose.

Normally, the effects of these hormones balance each other to maintain blood glucose within a healthy range. If this balance is altered, it can lead to health conditions such as diabetes (pages 145–148) or hypoglycemia (pages 149–150).

**Recap**

Carbohydrate digestion starts in the mouth and continues in the small intestine. Glucose and other monosaccharides are absorbed into the bloodstream and travel to the liver, where non-glucose monosaccharides are converted to glucose. Glucose is either used by the cells for energy, converted to glycogen and stored in the liver and muscles for later use, or converted to fat and stored in adipose tissue. Various hormones are involved in regulating blood glucose. Insulin lowers blood glucose levels by facilitating the entry of glucose into cells. Glucagon, epinephrine, norepinephrine, cortisol, and growth hormone raise blood glucose levels by a variety of mechanisms.
How Do Our Bodies Break Down Carbohydrates?

The Glycemic Index Shows How Foods Affect Our Blood Glucose Levels

The **glycemic index** refers to the potential of foods to raise blood glucose and insulin levels. Foods with a high glycemic index cause a sudden surge in blood glucose. This in turn triggers a large increase in insulin, which may be followed by a dramatic drop in blood glucose. Foods with

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**Figure 4.8** Regulation of blood glucose by the hormones insulin and glucagon. (a) When blood glucose levels increase after a meal, the pancreas secretes insulin. Insulin opens gates in the cell membranes of body tissues to allow the passage of glucose into the cell. (b) When blood glucose levels are low, the pancreas secretes glucagon. Glucagon enters the cell, where it stimulates the breakdown of stored glycogen into glucose. This glucose is then released into the bloodstream.
a low glycemic index cause low to moderate fluctuations in blood glucose. When foods are assigned a glycemic index value, they are often compared with the glycemic effect of pure glucose or white bread.

The glycemic index of a food is not always easy to predict. Figure 4.9 ranks certain foods according to their glycemic index. Do any of these rankings surprise you? Most people assume that foods containing simple sugars have a higher glycemic index than starches, but this is not always the case. For instance, compare the glycemic index for apples and instant potatoes. Although instant potatoes are a starchy food, they have a glycemic index value of 83, while the value for an apple is only 38.

The type of carbohydrate, the way the food is prepared, and its fat and fibre content can all affect how quickly the body absorbs it. It is important to note that we eat most of our foods combined into a meal. In this case, the glycemic index of the total meal becomes more important than the ranking of each food.

For determining the effect of a food on a person’s glucose response, some nutrition experts believe the glycemic load is more useful than the glycemic index. The glycemic load of a food is the total grams of carbohydrate it contains multiplied by the glycemic index of that particular carbohydrate. For instance, carrots are recognized as a vegetable having a relatively high glycemic index of about 68; however, the glycemic load of carrots is only 3.10 This is because there is very little total carbohydrate in a serving of carrots. The low glycemic load of carrots means that carrot consumption is unlikely to cause a significant rise in glucose and insulin.

Why do we care about the glycemic index and glycemic load? Foods or meals with a lower glycemic load are a better choice for someone with diabetes because they will not...
trigger dramatic fluctuations in blood glucose. They may also reduce the risk of heart disease and colon cancer because they generally contain more fibre, and it is known that fibre helps decrease fat levels in the blood. Recent studies have shown that people who eat lower-glycemic-index diets have higher levels of high-density lipoprotein, or HDL (a healthy blood lipid), and lower levels of low-density lipoprotein, or LDL (a blood lipid associated with increased risk for heart disease), and their blood glucose values are more likely to be normal.15–13 Diets with a low glycemic index and load are also associated with a reduced risk for prostate cancer.14 Despite some encouraging research findings, the glycemic index and glycemic load remain controversial. Many nutrition researchers feel that the evidence supporting their health benefits is weak. In addition, many believe the concepts of the glycemic index/load are too complex for people to apply to their daily lives. Other researchers insist that helping people to choose foods with a lower glycemic index/load is critical to the prevention and treatment of many chronic diseases. Until this controversy is resolved, people are encouraged to eat a variety of fibre-rich and less-processed carbohydrates such as beans and lentils, fresh vegetables, and whole-wheat bread, because we know these forms of carbohydrates are lower in glycemic load and they also contain a multitude of important nutrients.

**Did You Know?**

The glycemic index (GI) was developed in the early 1980s by a team of researchers at the University of Toronto, led by Dr. David Jenkins. They challenged the notion that all simple carbohydrates cause a rapid rise in blood glucose levels and, conversely, that eating complex carbohydrates results in a slow release of glucose into the bloodstream. They found that carbohydrates in white bread caused subjects’ blood glucose to rise higher than those in ice cream and coined the term “glycemic index” to describe the effect of foods on blood glucose levels in the body.15 Ongoing research by this team has assessed the relevance of using the GI in planning diets and its effects on type 2 diabetes.

**RECAP**

The glycemic index is a value that indicates the potential of foods to raise blood glucose and insulin levels. The glycemic load is the amount of carbohydrate in a food multiplied by the glycemic index of the carbohydrate in that food. Foods with a high glycemic index/load cause sudden surges in blood glucose and insulin, whereas foods with a low glycemic index/load cause low to moderate fluctuations in blood glucose. Diets with a low glycemic index/load are associated with a reduced risk for chronic diseases such as cardiovascular disease, type 2 diabetes, and prostate cancer.

**Why Do We Need Carbohydrates?**

We have seen that carbohydrates are an important energy source for our bodies. Let’s learn more about this and discuss other functions of carbohydrates.

**Carbohydrates Provide Energy**

Carbohydrates, an excellent source of energy for all of our cells, provide 4 kcal of energy per gram. Some of our cells can also use lipids and even protein for energy if necessary.
However, our red blood cells can use only glucose, and the brain and other nervous tissues rely primarily on glucose. This is why you get tired, irritable, and shaky when you have not eaten carbohydrates for a prolonged period of time.

**Carbohydrates Fuel Daily Activity**

Many popular diets—such as Dr. Atkins’ New Diet Revolution and the Sugar Busters plan—are based on the idea that our bodies actually “prefer” to use dietary fats and/or protein for energy. They claim that current carbohydrate recommendations are much higher than we really need.

In reality, the body relies mostly on both carbohydrates and fats for energy. In fact, as shown in Figure 4.10, our bodies always use some combination of carbohydrates and fats to fuel daily activities. Fats are the predominant energy source used by our bodies at rest and during low-intensity activities such as sitting, standing, and walking. Even during rest, however, our brain cells and red blood cells still rely on glucose.

**Carbohydrates Fuel Exercise**

When we exercise, whether running, briskly walking, bicycling, or performing any other activity that causes us to breathe harder and sweat, we begin to use more glucose than lipids. Whereas lipid breakdown is a slow process and requires oxygen, we can break down glucose very quickly either with or without oxygen. Even during very intense exercise, when less oxygen is available, we can still break down glucose very quickly for energy. That’s why when you are exercising at maximal effort, carbohydrates are providing the majority of the energy your body requires.

If you are physically active, it is important to eat enough carbohydrates to provide energy for your brain, red blood cells, and muscles. In Chapter 15, we discuss in more detail the carbohydrate recommendations for active people. In general, if you do not eat enough carbohydrate to support regular exercise, your body will have to rely on fat and protein as alternative energy sources (the consequences of which are discussed shortly). If you or someone you know is trying to lose weight, you may be wondering whether exercising at a lower intensity will result in more stored fat being burned for energy. This is a question that researchers are still trying to answer. Weight-loss studies show that, to lose weight and keep it off, it is important to exercise daily. A low-intensity activity such as walking is generally recommended because it is easy to do and can be done for longer periods of time than high-intensity exercise; thus, it can result in the expenditure of more energy. Also, we know that fat stores provide much of the energy we need for walking. However, a study of highly trained athletes found that they actually lost more body fat when they performed very-high-intensity exercise! Although the exact mechanism for this fat loss is unknown, the researchers speculated that very-high-intensity exercise activated enzymes that increased the metabolism of fat, leading to a reduction in body fat. Based on the evidence currently available, the recommended activities for weight loss combine aerobic-type exercises, such as walking, jogging, or bicycling, with strength-building exercises. (For more information on weight loss, see Chapter 14.)

**Low Carbohydrate Intake Can Lead to Ketoacidosis**

When we do not eat enough carbohydrates, the body seeks an alternative source of fuel for the brain and begins to break down stored fat. This process, called *ketosis*, produces an

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When we exercise at relatively high intensities, or perform any other activity that causes us to breathe harder and sweat, we begin to use more glucose than fat.
alternative fuel called **ketones**. The metabolic process of ketosis is discussed in more detail in Chapter 7.

Ketosis is an important mechanism for providing energy to the brain during situations of fasting, low carbohydrate intake, or vigorous exercise. However, ketones also suppress appetite and cause dehydration and acetone breath (the breath smells like nail polish remover). If inadequate carbohydrate intake continues for an extended period of time, the body will produce excessive amounts of ketones. Because many ketones are acids, high ketone levels cause the blood to become very acidic, leading to a condition called **ketoacidosis**. The high acidity of the blood interferes with basic body functions, causes the loss of lean body mass, and damages many body tissues. People with untreated diabetes are at high risk for ketoacidosis, which can lead to coma and even death. (See pages 145–149 for further details about diabetes.)

**Carbohydrates Spare Protein**

If the diet does not provide enough carbohydrate, the body will make its own glucose from protein. As noted earlier, this process, called gluconeogenesis, involves breaking down the proteins in blood and tissues into amino acids, then converting them to glucose.

When our bodies use proteins for energy, the amino acids from these proteins cannot be used to make new cells, repair tissue damage, support the immune system, or perform any of their other functions. During periods of starvation or when eating a diet that is very low in carbohydrate, our body will take amino acids from the blood first, and then from other tissues such as muscles and the heart, liver, and kidneys. Using amino acids in this manner over a prolonged period of time can cause serious, possibly irreversible, damage to these organs. (See Chapter 6 for more details on using protein for energy.)

**Complex Carbohydrates Have Health Benefits**

Complex carbohydrates contain fibre and other nutrients that can reduce the risk for obesity, heart disease, and type 2 diabetes. The relationship between carbohydrates and these chronic diseases is the subject of considerable controversy. On the one hand, proponents of low-carbohydrate diets claim that eating carbohydrates makes you overweight and promotes changes in blood lipids and insulin that contribute to heart disease and type 2 diabetes. However, fat is more than twice as energy-dense as carbohydrate, and anyone who consumes extra kilocalories, whether in the form of sugar, starch, protein, or fat, may eventually become obese. As we'll discuss later in this chapter, studies indicate that people who are obese have a significantly increased risk of both heart disease and type 2 diabetes. On the other hand, eating carbohydrates that are high in fibre and other nutrients has been shown to reduce the risk for obesity, heart disease, and type 2 diabetes. Thus, all carbohydrates are not bad, and complex carbohydrates are significantly beneficial. Even small amounts of simple carbohydrates can be included in a healthy diet. People who are very active and need more calories can eat more simple carbohydrates, whereas those who are older, less active, or overweight should limit their consumption of simple carbohydrates and focus on complex carbohydrates.

**Fibre Helps Us Stay Healthy**

Although we cannot digest fibre, it is still an important substance in our diet. Research indicates that it helps us stay healthy and may play a role in preventing many digestive and chronic diseases. The potential benefits of fibre consumption include the following:

- May reduce the risk of colon cancer. While there is still some controversy surrounding this issue, many researchers believe that fibre binds cancer-causing substances and speeds their elimination from the colon.
- Helps prevent hemorrhoids, constipation, and other intestinal problems by keeping our stools moist and soft. Fibre gives gut muscles “something to push on” and makes it easier to eliminate stools.
• Reduces the risk of **diverticulosis**, a condition that is caused in part by trying to eliminate small, hard stools. A great deal of pressure must be generated in the large intestine to pass hard stools. This increased pressure weakens intestinal walls, causing them to bulge outward and form pockets (**Figure 4.11**). Feces and fibrous materials can get trapped in these pockets, which become infected and inflamed. This painful condition is typically treated with antibiotics or surgery.

• May reduce the risk of heart disease by delaying or blocking the absorption of dietary cholesterol into the bloodstream (**Figure 4.12**).
How Much Carbohydrate Should We Eat?

Carbohydrates are an important part of a balanced, healthy diet. The Recommended Dietary Allowance (RDA) for carbohydrate is based on the amount of glucose the brain uses. The current RDA for carbohydrate for adults 19 years of age and older is 130 g of carbohydrate per day. It is important to emphasize that this RDA does not cover the amount of carbohydrate needed to support daily activities; it covers only the amount of carbohydrate needed to supply adequate glucose to the brain.

As introduced in Chapter 1, carbohydrates and the other macronutrients have been assigned an Acceptable Macronutrient Distribution Range (AMDR). This is the range of intake associated with a decreased risk of chronic diseases. The AMDR for carbohydrates is 45% to 65% of total energy intake.

Most Canadians Eat Too Much Simple Carbohydrate

The average carbohydrate intake per person in Canada is approximately 50% of total energy intake. Most of that carbohydrate is consumed in the form of breads, pasta, rice, grains, and milk; however, between 16% and 20% of total carbohydrate intake comes from foods containing added sugars. Added sugars are defined as sugars and syrups that are added to foods during processing or preparation.

A common source of added sugars in the Canadian diet is sweetened soft drinks, which account for 11.3% of “other food” calories. Sweetened beverage consumption by children and teens is of particular concern. On average, boys aged 14–18 years drink one 355 mL can of a regular soft drink daily. Consider that one can of regular cola contains 33.4 g of sugar, or almost 35 mL. If a teenage boy drinks the average amount, he is consuming more than 11 750 g of sugar each year! Other common sources of added sugars include cookies, cakes, pies, and candy. In addition, a surprising number of processed foods you may not think of as “sweet” actually contain a significant amount of added sugar, including many brands of peanut butter and flavoured rice mixes.

Added sugars are not chemically different from naturally occurring sugars. However, foods and beverages with added sugars have lower levels of vitamins and minerals than foods that naturally contain simple sugars. With these nutrient limitations in mind, the Institute of Medicine recommends that our diets contain 25% or less of total energy from simple sugars, with no more than 10% coming from added sugars. Although data are limited in Canada, it has been estimated that average intakes of added sugars in Canada
are approximately 13% of total energy intake. People who are very physically active have a higher daily energy expenditure and therefore are able to consume relatively more added sugars, whereas smaller or less active people should consume relatively less. The Nutrition Facts table found on products includes a listing of total sugars, but does not distinguish between added and naturally occurring sugars. Thus, you should check the ingredient list. (See Highlight: Forms of Sugars Commonly Used in Foods for a list of terms indicating added sugars.) To eat a diet low in added sugars, limit foods in which a form of added sugar is listed as one of the first few ingredients on the label.

**Simple Carbohydrates Are Blamed for Many Health Problems**

Why do simple carbohydrates have such a bad reputation? First, they are known to contribute to tooth decay. Second, they have been criticized as a possible cause of hyperactivity in children. Third, many researchers believe that eating a lot of simple carbohydrates increases the levels of unhealthy lipids in our blood, increasing our risk for heart disease. High intakes of simple carbohydrates have also been blamed for causing diabetes and obesity. Let’s now learn the truth about these accusations related to simple carbohydrates.

### HIGHLIGHT

**Forms of Sugars Commonly Used in Foods**

- **Brown sugar**  A highly refined sweetener made up of approximately 99% sucrose and produced by adding either molasses or burnt table sugar to white table sugar for colouring and flavour.
- **Concentrated fruit juice sweetener**  A form of sweetener made with concentrated fruit juice, commonly pear juice.
- **Confectioner’s sugar**  A highly refined, finely ground white sugar; also referred to as powdered sugar.
- **Corn sweeteners**  A general term for any sweetener made with corn starch.
- **Corn syrup**  A syrup produced by the partial hydrolysis of corn starch.
- **Dextrose**  An alternative term for glucose.
- **Fructose**  A monosaccharide that occurs in fruits and vegetables. Also called levulose, or fruit sugar.
- **Galactose**  A monosaccharide that joins with glucose to create lactose.
- **Glucose**  The most abundant monosaccharide; it is the preferred source of energy for the brain and an important source of energy for all cells.
- **Granulated sugar**  Another term for white sugar or table sugar.
- **High-fructose corn syrup**  A type of corn syrup in which part of the sucrose is converted to fructose, making it sweeter than sucrose or regular corn syrup; most high-fructose corn syrup contains 42% to 55% fructose.
- **Honey**  A sweet, sticky liquid sweetener made by bees from the nectar of flowers; contains glucose and fructose.
- **Invert sugar**  A sugar created by heating a sucrose syrup with a small amount of acid. Inverting sucrose results in its breakdown into glucose and fructose, which reduces the size of the sugar crystals. Because of its smooth texture, it is used in making candies such as fondant and some syrups.
- **Lactose**  A disaccharide formed by one molecule of glucose and one molecule of galactose. Occurs naturally in milk and other dairy products.
- **Levulose**  Another term for fructose, or fruit sugar.
- **Maltose**  A disaccharide consisting of two molecules of glucose. Does not generally occur independently in foods but results as a by-product of digestion. Also called malt sugar.
- **Mannitol**  A type of sugar alcohol.
- **Maple sugar**  A sugar made by boiling maple syrup.
- **Molasses**  A thick brown syrup that is separated from raw sugar during manufacturing. It is considered the least refined form of sucrose.
- **Natural sweeteners**  A general term used for any naturally occurring sweeteners, such as sucrose, honey, and raw sugar.
- **Raw sugar**  The sugar that results from the processing of sugar beets or sugarcane. It is approximately 96% to 98% sucrose. True raw sugar contains impurities and is not stable in storage; the raw sugar available to consumers has been purified to yield an edible sugar.
- **Sorbitol**  A type of sugar alcohol.
- **Turbinado sugar**  The form of raw sugar that is purified and safe for human consumption. Sold as “Sugar in the Raw” in Canada.
- **White sugar**  Another name for sucrose, or table sugar.
- **Xylitol**  A type of sugar alcohol.
Simple Carbohydrates Cause Tooth Decay

Simple carbohydrates do play a role in dental problems because the bacteria that cause tooth decay thrive on them. These bacteria produce acids that eat away at tooth enamel and can eventually cause cavities and gum disease (Figure 4.13). Eating sticky foods that adhere to teeth—such as caramels, crackers, sugary cereals, and licorice—and sipping sweetened beverages over a period of time increase the risk of tooth decay. This means that people shouldn’t slowly sip soda or juice and that babies should not be put to sleep with a bottle unless it contains water. As we have seen, even breast milk contains sugar, which can slowly drip onto the baby’s gums. As a result, infants should not routinely be allowed to fall asleep at the breast.

To reduce your risk for tooth decay, brush your teeth after each meal and especially after drinking sugary drinks and eating candy. Drinking fluoridated water and using a fluoride toothpaste also will help protect your teeth.

There Is No Link Between Simple Carbohydrates and Hyperactivity in Children

Although many people believe that eating simple carbohydrates, particularly sugar, causes hyperactivity and other behavioural problems in children, there is little scientific evidence to support this claim. However, it is important to emphasize that most studies of sugar and children’s behaviour have only looked at the effects of sugar a few hours after ingestion. We know very little about the long-term effects of sugar intake on the behaviour of children. Behavioural and learning problems are complex issues, most likely caused by a multitude of factors. Because of this complexity, the Institute of Medicine has stated that, overall, there currently does not appear to be enough evidence that eating too much sugar causes hyperactivity or other behavioural problems in children. Thus, a Tolerable Upper Intake Level has not been set for sugar.

High Simple Carbohydrates Intake Can Lead to Unhealthy Levels of Blood Lipids

Research evidence suggests that consuming a diet high in simple carbohydrates, particularly fructose, can lead to unhealthy changes in blood lipids. You will learn more about blood lipids (including cholesterol and lipoproteins) in Chapter 5. Briefly, higher intakes of simple carbohydrates are associated with increases in our blood of both triglycerides and LDLs. LDL is commonly referred to as “bad cholesterol.” At the same time, high simple carbohydrate intake appears to decrease our HDLs, which are protective and are often referred to as “good cholesterol.” These changes are of concern, as increased levels of triglycerides and LDLs and decreased levels of HDLs are known risk factors for heart disease. However, there is not enough scientific evidence at the present time to state with confidence that eating a diet high in simple carbohydrates causes heart disease. Based on our current knowledge, it is prudent for a person at risk for heart disease to eat a diet low in simple carbohydrates. Because high-fructose corn syrup is a component of many processed foods, careful label reading is advised.

High Simple Carbohydrate Intake Does Not Cause Diabetes but May Contribute to Obesity

There is no scientific evidence that eating a diet high in simple carbohydrates causes diabetes. In fact, studies examining the relationship between simple carbohydrate intake and type 2 diabetes are equivocal, reporting either no association between simple carbohydrate intake and diabetes, an increased risk of diabetes associated with increased simple carbohydrate intake and weight gain, or a decreased risk of diabetes with increased simple carbohydrate intake. However, people who have diabetes need to moderate their intake of simple carbohydrates and closely monitor their blood glucose levels.

We have somewhat more evidence linking simple carbohydrate intake with obesity. For example, a recent study found that overweight children consumed more sugared soft drinks than did children of normal weight. Another study found that for every extra sugared soft drink consumed by a child per day, the risk of obesity increases by 60%. We also know that if you consume more energy than you expend, you will gain weight. It makes intuitive
sense that people who consume extra energy from high-sugar foods are at risk for obesity, just as people who consume extra energy from fat or protein gain weight. In addition to the increased potential for obesity, another major concern about high-sugar diets is that they tend to be low in nutrient density because the intake of high-sugar foods tends to replace that of more nutritious foods. The relationship between sugared soft drinks and obesity is highly controversial and discussed in more detail in the Evidence-informed Decision Making section on pages 157–159.

The RDA for carbohydrate is 130 g per day; this amount is sufficient only to supply adequate glucose to the brain. The AMDR for carbohydrate is 45% to 65% of total energy intake. Added sugars are sugars and syrups added to foods during processing or preparation. Our intake of simple carbohydrates should be 25% or less of our total energy intake each day, with no more than 10% coming from added sugars. Simple carbohydrates contribute to tooth decay but do not appear to cause hyperactivity in children. Higher intakes of simple carbohydrates are associated with increases in triglycerides and low-density lipoproteins. Diets high in simple carbohydrates are not confirmed to cause diabetes but may contribute to obesity.

**Recap**

The RDA for carbohydrate is 130 g per day; this amount is sufficient only to supply adequate glucose to the brain. The AMDR for carbohydrate is 45% to 65% of total energy intake. Added sugars are sugars and syrups added to foods during processing or preparation. Our intake of simple carbohydrates should be 25% or less of our total energy intake each day, with no more than 10% coming from added sugars. Simple carbohydrates contribute to tooth decay but do not appear to cause hyperactivity in children. Higher intakes of simple carbohydrates are associated with increases in triglycerides and low-density lipoproteins. Diets high in simple carbohydrates are not confirmed to cause diabetes but may contribute to obesity.

**Most Canadians Eat Too Little Complex Carbohydrate**

Do you eat enough complex carbohydrate each day? If you are like most people in Canada, you eat fewer than five servings of fruits or vegetables (including legumes) each day; this is far below the recommended amount.

Breads and cereals are another potential source of complex carbohydrates, and they’re part of most Canadians’ diets. But are the breads and cereals you eat made with whole grains? If you’re not sure, check out the ingredients lists on the labels of your favourite breads and breakfast cereals. Do they list whole-wheat flour or just wheat flour? And what’s the difference? To help you answer this question, we’ve defined some terms in Table 4.2 commonly used on labels for breads and cereals. As you can see, whole-wheat flour is made from whole grains: only the germ and some of the bran have been removed. In contrast, the term wheat flour can be used to signify a flour that has been highly refined, with the bran and other fibre-rich portions removed.

**Table 4.2 Terms Used to Describe Grains and Cereals on Nutrition Labels**

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour, white flour, enriched flour or</td>
<td>Refined flour made from wheat that has been fortified with added thiamine,</td>
</tr>
<tr>
<td>enriched white flour¹</td>
<td>riboflavin, niacin, folic acid, and iron and may be bleached</td>
</tr>
<tr>
<td>Whole wheat flour or entire wheat flour²</td>
<td>Flour made from wheat from which a part of the outer bran may have been</td>
</tr>
<tr>
<td></td>
<td>separated; must contain not less than 95% of the total weight of the wheat</td>
</tr>
<tr>
<td></td>
<td>from which it was milled</td>
</tr>
<tr>
<td>Whole grain²</td>
<td>Contain all parts of the grain (bran, germ, and endosperm) in the same</td>
</tr>
<tr>
<td></td>
<td>relative proportions found in the original grain</td>
</tr>
<tr>
<td>Refined grains¹</td>
<td>Whole grains that have had the germ and the bran removed</td>
</tr>
<tr>
<td>Enriched white bread¹</td>
<td>Bread made from enriched flour and fortified with skim milk solids, whey</td>
</tr>
<tr>
<td></td>
<td>powder or proteins from pea or soy</td>
</tr>
<tr>
<td>Whole-grain bread²</td>
<td>Bread made from whole-grain flour</td>
</tr>
<tr>
<td>Whole-wheat bread²</td>
<td>Bread which is made from not less than 60% whole wheat flour</td>
</tr>
</tbody>
</table>


### Table: Nutrients and fibre in three kinds of bread

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Whole-grain bread</th>
<th>Whole-wheat bread</th>
<th>Enriched white bread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
<td></td>
<td>86%</td>
<td>29%</td>
</tr>
<tr>
<td>Iron</td>
<td>90%</td>
<td>138%</td>
<td>138%</td>
</tr>
<tr>
<td>Zinc</td>
<td>97%</td>
<td></td>
<td>40%</td>
</tr>
<tr>
<td>Folate</td>
<td>75%</td>
<td>250%</td>
<td>250%</td>
</tr>
<tr>
<td>Thiamine</td>
<td>146%</td>
<td>146%</td>
<td>187%</td>
</tr>
<tr>
<td>Niacin</td>
<td>92%</td>
<td></td>
<td>88%</td>
</tr>
</tbody>
</table>

**Figure 4.14** Nutrients and fibre in three kinds of bread. The percentages of each nutrient reported for whole-wheat and enriched white bread indicate the amount they contain as compared to the amount contained in whole-grain bread. For example, enriched white bread contains only 29% of the fibre found in whole-grain bread but 250% of the folate because of fortification.


In addition to stripping a grain of its fibre, the refining process reduces many of the grain’s original nutrients. To make up for some of the lost nutrients, manufacturers sometimes enrich the product. **Enriched foods** are foods in which nutrients that were lost during processing have been added back so the food meets a specified standard. Notice that the terms *enriched* and *fortified* are not synonymous: **fortified foods** have nutrients added that did not originally exist in the food (or existed in insignificant amounts). For example, some breakfast cereals have been fortified with iron, a mineral that is not present in cereals naturally. **Figure 4.14** compares the nutrients and fibre in whole-grain bread versus whole-wheat and enriched white breads.

**We Need at Least 25 Grams of Fibre Daily**

How much fibre do we need? The Adequate Intake for fibre is 25 g per day for women and 38 g per day for men, or 14 g of fibre for every 1000 kcal per day that a person eats. Most people in Canada eat between 13 to 22 g of fibre each day. Although fibre supplements are available, it is best to get fibre from food because foods contain additional nutrients such as vitamins and minerals.

As recommended in *Eating Well with Canada’s Food Guide*, eating at least half of your grain products as whole grains and eating the suggested number of vegetables and fruit each day will ensure that you get enough fibre-rich carbohydrate foods in your diet. **Figure 4.15** lists some common foods and their fibre content. You can use this information to design a diet that includes adequate fibre.

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**enriched foods** Foods in which nutrients that were lost during processing have been added back so the food meets a specified standard.

**fortified foods** Foods in which nutrients are added that did not originally exist in the food or existed in insignificant amounts.
Chapter 4 Carbohydrates: Plant-Derived Energy Nutrients

Figure 4.15 Fibre content of common foods. Notes: The Adequate Intake for fibre is 25 g per day for women and 38 g per day for men. The serving sizes shown are those recommended by *Eating Well with Canada’s Food Guide*. Data from: The Canadian Nutrient File. Health Canada, 2012. Reproduced with the permission of the Minister of Health, 2012.

It is important to drink plenty of fluid as you increase your fibre intake, as fibre binds with water to soften stools. Inadequate fluid intake with a high-fibre diet can actually result in hard, dry stools that are difficult to pass through the colon. At least 3L of fluid each day are commonly recommended.

Can you eat too much fibre? Excessive fibre consumption can lead to problems such as intestinal gas, bloating, and constipation. Because fibre binds with water, it causes the body to eliminate more water in the feces, so a very-high-fibre diet could result in dehydration. Fibre also binds with minerals, so a high-fibre diet can reduce our absorption of important nutrients such as iron, zinc, and calcium. However, mineral binding does not seem to be a problem when mineral intake is adequate. In children, some older adults, the chronically ill,
and other at-risk populations, extreme fibre intake can even lead to malnutrition—they feel full before they have eaten enough to provide adequate energy and nutrients. So whereas some societies are accustomed to a very-high-fibre diet, most people in Canada find it difficult to tolerate more than 50 g of fibre per day.

Choosing Complex Carbohydrates

Figure 4.16 compares the food and fibre content of two diets, one high in complex, fibre-rich carbohydrates and the other high in simple carbohydrates. Here are some hints for selecting healthy carbohydrate sources:

- Select breads and cereals that are made with whole grains such as wheat, oats, barley, and rye (make sure the label says "whole" before the word grain). Choose foods that have at least 2 or 3 g of fibre per serving.
- Buy fresh fruits and vegetables whenever possible. When appropriate, eat foods such as potatoes, apples, and pears with the skin left on, as much of the fibre and nutrients are located in the skin.
- Frozen vegetables and fruits can be a healthy alternative when fresh produce is not available. Check frozen selections to make sure there is no extra sugar or salt added.
- Be careful when buying canned fruits and vegetables, as many are high in sodium and added sugar. Foods that are packed in their own juice are healthier than those packed in syrup.
- Eat legumes frequently, every day if possible. Canned or fresh beans, peas, and lentils are excellent sources of fibre-rich carbohydrates, vitamins, and minerals. Add them to soups, casseroles, and other recipes—it is an easy way to eat more of them. Rinse canned beans to remove extra salt or choose low-sodium alternatives.

Try the Nutrition Label Activity below to learn how to recognize various carbohydrates on food labels. Armed with this knowledge, you are now ready to make healthier food choices.

RECAP

The Adequate Intake for fibre is 25 g per day for women and 38 g per day for men. Most Canadians only eat half of the fibre they need each day. Foods high in fibre and complex carbohydrates include whole grains and cereals, fruits, and vegetables. The more processed the food, the fewer fibre-rich carbohydrates it contains.
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High Complex Carbohydrate Diet

Breakfast:
- 40 g Cheerios
- 250 mL skim milk
- 2 slices whole-wheat toast with 15 mL light margarine
- 1 medium banana
- 250 mL fresh orange juice

Lunch:
- 250 mL low-fat blueberry yogourt
- Tuna sandwich (2 slices whole-wheat bread; 63 mL tuna packed in water, drained; 5 mL Dijon mustard; 10 mL low-calorie mayonnaise)
- 2 carrots, raw, with peel
- 250 mL raw cauliflower
- 15 mL peppercorn ranch salad dressing (for dipping vegetables)

Snack:
- 750 mL cups non-fat popcorn

Dinner:
- ½ chicken breast roasted
- 250 mL brown rice, cooked
- 250 mL cooked broccoli
- Spinach salad (250 mL chopped spinach, 1 whole egg white, 2 slices turkey bacon, 3 cherry tomatoes, and 30 mL creamy bacon salad dressing)
- 2 baked apples (no added sugar)

Nutrient Analysis:
- 2034 kcal
- 54% of energy from carbohydrates
- 27% of energy from fat
- 19% of energy from protein
- 32.6 grams of dietary fibre

High Simple Carbohydrate Diet

Breakfast:
- 40 g Fruit Loops cereal
- 250 mL skim milk
- 2 slices white bread toasted, with 15 mL light margarine
- 250 mL fresh orange juice

Lunch:
- McDonald’s Quarter Pounder—1 sandwich
- 1 large order French fries
- 500 mL cola beverage
- 30 jelly beans

Snack:
- 1 cinnamon raisin bagel (9 cm diameter)
- 30 mL cream cheese
- 250 mL low-fat strawberry yogourt

Snack:
- 750 mL cups non-fat popcorn

Dinner:
- 1 whole chicken breast, roasted
- 500 mL mixed green salad
- 30 mL ranch salad dressing
- 1 serving macaroni and cheese
- 375 mL cola beverage
- Cheesecake (1/9 of cake)

Late Night Snack:
- 500 mL gelatin dessert (cherry flavoured)
- 3 raspberry oatmeal no-fat cookies

Nutrient Analysis:
- 3956 kcal
- 62% of energy from carbohydrates
- 24% of energy from fat
- 14% of energy from protein
- 11.2 grams of dietary fibre

Figure 4.16  Comparison of two high-carbohydrate diets. (Note: Diets were analyzed using eaTracker (Dieticians of Canada).)
What’s the Story on Alternative Sweeteners?

Most of us love sweets but want to avoid the extra kilocalories and tooth decay that go along with eating simple sugars. Remember that all carbohydrates, whether simple or complex, contain 4 kcal of energy per gram. Because sweeteners such as sucrose, fructose, honey, and brown sugar contribute energy, they are called nutritive sweeteners.

Other nutritive sweeteners include the sugar alcohols such as mannitol, sorbitol, isomalt, and xylitol. Popular in sugar-free gums, mints, and diabetic candies, sugar alcohols are less sweet than sucrose (Figure 4.18). Foods with sugar alcohols have health benefits that foods made with sugars do not have, such as a reduced glycemic response and decreased risk of dental caries. Also, because sugar alcohols are absorbed slowly and incompletely from the intestine, they provide less energy than sugar, usually only 2 to 3 kcal of energy per gram. However, because they are not completely absorbed from the intestine, they can attract water into the large intestine and cause diarrhea.
Alternative Sweeteners Are Non-Nutritive

A number of other products have been developed to sweeten foods without promoting tooth decay and weight gain. As these products provide little or no energy, they are called non-nutritive, or alternative sweeteners.

Limited Use of Alternative Sweeteners Is Not Harmful

Contrary to popular belief, alternative sweeteners have been determined as safe for adults, children, and individuals with diabetes. Women who are pregnant should discuss the use of alternative sweeteners with their healthcare provider. In general, it appears safe for most pregnant women to consume alternative sweeteners in amounts within Health Canada guidelines. The Acceptable Daily Intake (ADI) is an estimate made by Health Canada of the amount of a sweetener that someone can consume each day over a lifetime without adverse effects. The estimates are based on studies conducted on laboratory animals, and they include a 100-fold safety factor. It is important to emphasize that actual intake by humans is typically well below the ADI.

In recent years, concerns have been raised about the increased ingestion of artificial sweeteners and their effects on appetite and food intake. The number of food products containing non-caloric artificial sweeteners has risen dramatically over the past decade and there is increasing evidence that this might be a contributing factor in the epidemic of obesity in North America. However, additional research is needed to determine the mechanisms by which this might occur. In the meantime, it is wise to limit your intake of foods containing artificial sweeteners to ensure that more nutrient-dense foods are not excluded from your diet.

Saccharin

Discovered in the late 1800s, saccharin is about 300 times sweeter than sucrose (see Figure 4.18). Evidence to suggest that saccharin may cause bladder tumours in rats surfaced in the 1970s; however, more than 20 years of scientific research has shown that saccharin is not related to bladder cancer in humans. Health Canada’s scientists have thoroughly reviewed the available evidence and have determined that saccharin is safe for consumption at levels well below the ADI. However, it is recommended to use saccharin in moderation.

Figure 4.18 Relative sweetness of alternative sweeteners as compared to sucrose.
(Data adapted from: Food Safety Network. 2012. Sweeteners. Available at www.uoguelph.ca/foodsafetynetwork/sweeteners (accessed March 6, 2012).)
the scientific information available and as a result are considering relisting saccharin in the Canadian Food and Drug Regulations to allow its use in certain foods.

**Acesulfame-K**

*Acesulfame-K* (or acesulfame potassium) is marketed under the names Sunette and Sweet One. It is a kilocalorie-free sweetener that is approximately 200 times sweeter than sugar. It is used to sweeten gums, candies, beverages, instant tea, coffee, gelatins, and puddings. The taste of acesulfame-K does not change when it is heated, so it can be used in cooking. The body does not metabolize acesulfame-K, so it is excreted unchanged by the kidneys. The ADI for acesulfame-K is 15 mg per kg body weight per day. For example, the ADI for an adult weighing 68 kg would be 1020 mg.

**Aspartame**

*Aspartame*, also called Equal or NutraSweet, is one of the most popular alternative sweeteners currently found in foods and beverages. Aspartame is composed of two amino acids: phenylalanine and aspartic acid. When these amino acids are separate, one is bitter and the other has no flavour—but joined together, they make a substance that is 200 times sweeter than sucrose. Although aspartame contains 4 kcal of energy per gram, it is so sweet that only small amounts are necessary. Consequently, it ends up contributing little or no energy. Because aspartame is made from amino acids, its taste is destroyed with heat because the dipeptide bonds that bind the two amino acids are destroyed when heated (see Chapter 6); thus, it cannot be used in cooking.

A significant amount of research has been done to test the safety of aspartame. Although a number of false claims have been published, especially on the internet, there is no scientific evidence to support the claim that aspartame causes brain tumours, Alzheimer’s disease, or nerve disorders.

The ADI for aspartame is 40 mg per kg body weight per day. For example, the ADI for an adult weighing 68 kg would be 2720 mg. Table 4.3 shows how many servings of aspartame-sweetened foods would have to be consumed to exceed the ADI. Although eating less than the ADI is considered safe, note that children who consume many powdered drinks, diet sodas, and other aspartame-flavoured products could potentially exceed this amount. Drinks sweetened with aspartame are extremely popular among children and teenagers, but they are very low in nutritional value and should not replace healthier beverages such as milk, water, and 100% fruit juice.

There are some people who should not consume aspartame at all: those with the disease *phenylketonuria (PKU)*. This is a genetic disorder that prevents the breakdown of the amino acid phenylalanine. Because the person with PKU cannot metabolize phenylalanine, it builds up to toxic levels in the tissues of the body and causes irreversible brain damage. In Canada, all newborn babies are tested for PKU; those who have it are placed on a phenylalanine-limited diet. Some foods that are common sources of protein and other nutrients for many growing children, such as meats and milk, contain phenylalanine. Thus, it is critical that children with PKU not waste what little phenylalanine they can consume on nutrient-poor products sweetened with aspartame.

**Table 4.3** The Amount of Food That a 22.7 kg Child and a 68 kg Adult Would Have to Consume Daily to Exceed the ADI for Aspartame

<table>
<thead>
<tr>
<th>Food</th>
<th>22.7 kg Child</th>
<th>68 kg Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>375 mL carbonated soft drink</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>125 mL gelatin dessert</td>
<td>14</td>
<td>42</td>
</tr>
<tr>
<td>Packets of tabletop sweetener</td>
<td>32</td>
<td>97</td>
</tr>
</tbody>
</table>

Sucralose
Sucralose is a high-intensity sweetener marketed under the name Splenda. It is made from sucrose, but chlorine atoms are substituted for the hydrogen and oxygen normally found in sucrose, and it passes through the digestive tract unchanged, without contributing any energy. It is 600 times sweeter than sucrose and is stable when heated, so it can be used in cooking. It has been approved for use in many foods, including chewing gum, salad dressings, beverages, gelatin and pudding products, canned fruits, frozen dairy desserts, and baked goods. Safety studies have not shown sucralose to cause cancer or to have other adverse health effects. The ADI for sucralose is 9 mg per kg body weight per day. For example, the ADI of sucralose for an adult weighing 68 kg would be 612 mg.

Stevia
The stevia plant is native to South and Central America and sweeteners derived from this plant are up to 300 times sweeter than sucrose. Health Canada has not approved the use of stevia or its extracts for use as an additive in food because of insufficient evidence regarding its safety. However, it does allow for the use of these sweeteners as non-medicinal ingredients in natural health products.

What Disorders Are Related to Carbohydrate Metabolism?
Health conditions that affect the body’s ability to absorb and/or use carbohydrates include diabetes, hypoglycemia, and lactose intolerance.

Diabetes: Impaired Regulation of Glucose
Hyperglycemia is the term referring to higher-than-normal levels of blood glucose. Diabetes is a chronic disease in which the body can no longer regulate blood glucose within normal limits, and consequently blood glucose levels become dangerously high. It is imperative to detect and treat the disease as soon as possible because excessive fluctuations in glucose injure tissues throughout the body. As we noted at the beginning of this chapter, if not controlled, diabetes can lead to blindness, seizures, kidney failure, nerve disease, amputations, stroke, and heart disease. Uncontrolled diabetes can also lead to ketoacidosis, which may result in coma and death. Diabetes is the sixth leading cause of death in Canada. Approximately 6% of Canadians aged 12 years or older have diabetes. It is speculated that many more people have diabetes but do not know it. Diabetes is of particular concern for Canada’s Aboriginal population. Aboriginal people are three to five times more likely to have type 2 diabetes than non-Aboriginal Canadians.

The two main forms of diabetes are type 1 and type 2. Some women develop a third form, gestational diabetes, during pregnancy; we will discuss this in more detail in Chapter 16.

In Type 1 Diabetes, the Body Does Not Produce Enough Insulin
Approximately 10% of people with diabetes have type 1 diabetes, in which the beta cells of the pancreas are not able to produce insulin. When people with type 1 diabetes eat a meal and their blood glucose rises, the pancreas is unable to secrete insulin in response.
What Disorders Are Related to Carbohydrate Metabolism?

As a result, blood glucose levels soar, and the body tries to expel the excess glucose by excreting it in the urine. In fact, the medical term for the disease is diabetes mellitus (from the Greek diabainein, “to pass through,” and Latin mellitus, “sweetened with honey”), and frequent urination is one of its warning signs (see Table 4.4 for other symptoms). If blood glucose levels are not controlled, a person with type 1 diabetes will become confused and lethargic and have trouble breathing. This is because the brain is not getting enough glucose to properly function. As discussed earlier, uncontrolled diabetes can lead to ketoacidosis; left untreated, the ultimate result is coma and death.

The cause of type 1 diabetes is unknown, but it may be an autoimmune disease. This means that the body’s immune system attacks and destroys its own tissues, in this case the beta cells of the pancreas. Most cases of type 1 diabetes are diagnosed in adolescents around 10 to 14 years of age, although the disease can appear in infants, young children, and adults. Because it has a genetic link, siblings and children of those with type 1 diabetes are at greater risk than the general population.

The only treatment for type 1 diabetes is administration of insulin by injection or pump several times daily. Insulin is a hormone composed of protein, so it would be digested in the intestine if taken as a pill. Individuals with type 1 diabetes must also monitor their blood glucose levels closely to ensure that they remain within a healthy range (Figure 4.19). The Highlight box below describes how one young man with type 1 diabetes stays healthy.

### Table 4.4 Signs and Symptoms of Diabetes

<table>
<thead>
<tr>
<th>Symptom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unusual thirst</td>
</tr>
<tr>
<td>Frequent urination</td>
</tr>
<tr>
<td>Weight change (gain or loss)</td>
</tr>
<tr>
<td>Extreme fatigue or lack of energy</td>
</tr>
<tr>
<td>Blurred vision</td>
</tr>
<tr>
<td>Frequent or recurring infections</td>
</tr>
<tr>
<td>Cuts and bruises that are slow to heal</td>
</tr>
<tr>
<td>Tingling or numbness in the hands and feet</td>
</tr>
<tr>
<td>Trouble getting or maintaining an erection</td>
</tr>
</tbody>
</table>

Note: The Canadian Diabetes Association does not separate the signs and symptoms of type 1 and type 2 diabetes. Many people who have type 2 diabetes may display no symptoms.

Data from: Reprinted with permission from the Canadian Diabetes Association (diabetes.ca).

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### HIGHLIGHT

**Living with Diabetes**

Vincent is a young man who was diagnosed with type 1 diabetes when he was 10 years old. At first, Vincent and his family were frightened by the disease and found it difficult to adapt their lifestyles to provide a safe and health-promoting environment for Vincent. For example, Vincent’s mother felt frustrated because her son could no longer eat the cakes, pies, and other sweets she had always enjoyed baking for her family, and his sister found herself watching over her brother’s meals and snacks, running to her parents whenever she feared that he was about to eat something that would harm him. Within a few months, though, Vincent’s mother learned to adapt her recipes and cooking
In Type 2 Diabetes, Cells Become Less Responsive to Insulin

In type 2 diabetes, body cells become resistant (less responsive) to insulin. This type of diabetes develops progressively, meaning that the biological changes resulting in the disease occur over a long period of time.

Obesity is the most common trigger for a cascade of changes that eventually results in the disorder. Specifically, the cells of many obese people are less responsive to insulin, exhibiting a condition called insulin insensitivity (or insulin resistance). The pancreas attempts to compensate for this insensitivity by secreting more insulin. At first, the increased secretion of insulin is sufficient to maintain normal blood glucose levels. However, over time, a person who is insulin insensitive will have to circulate very high levels of insulin to use glucose for energy. The cycle continues and eventually the excessive insulin production becomes insufficient for preventing the rise in blood glucose. The resulting condition is referred to as impaired glucose tolerance, meaning glucose levels are higher than normal but not high enough to lead to a diagnosis of type 2 diabetes. Some health techniques to produce a variety of foods that Vincent could enjoy, and the entire family learned to allow Vincent the responsibility for his food choices and his health.

Vincent is now a college student and has been living with diabetes for nine years, but what he still hates most about the disease is that food is always a major issue. Vincent is smart and a good student, but if his blood glucose declines, he has trouble concentrating. He has to eat three nutritious meals a day on a regular schedule and needs to limit his snacks unless his blood sugar is low. When his friends eat candy, chips, or other snacks, he can’t join them. In general, he knows these dietary changes are very healthy, but sometimes he wishes he could eat like all of his friends. On the other hand, he cannot skip a meal, even if he isn’t hungry. It is also important for Vincent to stay on a regular schedule for exercise and sleep.

Vincent must test his blood sugar many times each day. He has to prick his fingers to do this, and they get tender and develop calluses. During his first few years with diabetes, he had to give himself two to four shots of insulin each day. He learned to measure the insulin into a syringe, and he had to monitor where the shots were injected because each insulin shot should be given in a different place on his body to avoid damaging the skin and underlying tissue. Technological advances now offer easier alternatives than a needle and syringe. Vincent uses an insulin infusion pump, which looks like a small pager and delivers insulin into the body through a long, thin tube in very small amounts throughout the day. One of Vincent’s friends also has diabetes but can’t use a pump; instead, he uses an insulin pen, which includes a needle and a cartridge of insulin. Now that Vincent uses the insulin pump, he can choose to eat more of the foods he loves and deliver his insulin accordingly.

Although diabetes is challenging, it does not prevent Vincent from playing soccer and basketball almost every day. In fact, he knows that people with diabetes should be active. As long as he takes his insulin regularly, keeps an eye on his blood sugar, drinks plenty of water, and eats when he should, he knows that he can play sports and do most of the things he wants to do. There are numerous professional and Olympic athletes and other famous people who have diabetes, showing that this disease should not prevent Vincent from leading a healthy life and realizing his dreams.

Currently, there is no cure for type 1 diabetes. However, there are many new treatments and potential cures being researched, such as devices that measure blood glucose without pricking the finger. Some of them can read glucose levels through the skin, and others insert a small needle into the body to monitor glucose continually. Tests are also being conducted on insulin nasal sprays and inhalers. Advances in genetic engineering may soon make it possible to transplant healthy beta cells into the pancreas of virtually anyone with type 1 diabetes, so that the normal cells will secrete insulin. Vincent looks forward to seeing major changes in the treatment of diabetes in the next few years.
professionals refer to this condition as pre-diabetes, as people with impaired glucose tolerance are more likely to get type 2 diabetes than people with normal fasting glucose levels. Eventually the pancreas becomes incapable of secreting these excessive amounts of insulin, and the beta cells stop producing the hormone altogether. Thus, blood glucose levels may be elevated in a person with type 2 diabetes (1) because of insulin insensitivity, (2) because the pancreas can no longer secrete enough insulin, or (3) because the pancreas has entirely stopped insulin production.

Many factors can cause type 2 diabetes. Genetics plays a role, so relatives of people with type 2 diabetes are at increased risk. Obesity and physical inactivity also increase the risk. A cluster of risk factors referred to as the metabolic syndrome is also known to increase the risk for type 2 diabetes. The criteria for metabolic syndrome include having a waist circumference $\geq 88$ cm (or 35 in.) for women and $\geq 102$ cm (or 40 in.) for men, elevated blood pressure, and unhealthy levels of certain blood lipids and blood glucose. Increased age is another risk factor: Most cases of type 2 diabetes develop after age 45.

Once commonly known as adult-onset diabetes, type 2 diabetes in children was virtually unheard of until recently. Unfortunately, the disease is increasing dramatically among children and adolescents, posing serious health consequences for them and their future children.

Type 2 diabetes can be treated in a variety of ways. Weight loss, healthy eating patterns, and regular exercise can control symptoms in some people. More severe cases may require oral medications. These drugs work in either of two ways: they improve body cells’ sensitivity to insulin or reduce the amount of glucose the liver produces. If a person with type 2 diabetes can no longer secrete enough insulin, the patient must take daily injections of insulin just like people with type 1 diabetes.

**Lifestyle Choices Can Help Control or Prevent Diabetes**

Type 2 diabetes is thought to have become an epidemic in Canada. Many factors have contributed to this, including poor eating habits, sedentary lifestyles, increased prevalence of obesity, and an aging population. Underlying these risk factors are a multitude of socio-economic factors that limit individuals’ access to safe, nutritious, and culturally acceptable foods and increase their risk of developing type 2 diabetes. Addressing these root causes of poor health through a population health approach is the major goal of the Integrated Pan-Canadian Healthy Living Strategy discussed in Chapter 1. But what can individuals do to control or prevent diabetes? We can’t control our age, but we can adopt a healthy diet, increase our physical activity, and maintain a healthy body weight.

In general, people with diabetes should follow many of the same dietary guidelines recommended for those without diabetes. One difference is that people with diabetes may need to eat less carbohydrate and slightly more fat or protein to help regulate their blood glucose levels. Carbohydrates are still an important part of the diet, but their intake may need to be reduced. Precise nutritional recommendations vary according to each individual’s responses to foods. In addition, people with diabetes should avoid alcoholic beverages, which can cause hypoglycemia. The symptoms of alcohol intoxication and hypoglycemia are very similar. The person with diabetes and his or her companions may confuse these conditions; this can result in a potentially life-threatening situation.

Moderate daily exercise may prevent the onset of type 2 diabetes more effectively than dietary changes alone. See Chapter 15 for examples of moderate exercise programs. Exercise will also assist in weight loss, and studies show that losing only 5% to 10% of body weight can reduce or eliminate the symptoms of type 2 diabetes.

In summary, by eating a healthy diet, staying active, and maintaining a healthy body weight, you should be able to keep your risk for diabetes low.
Hypoglycemia: Low Blood Glucose

In hypoglycemia, fasting blood sugar falls to lower-than-normal levels (Figure 4.20). One cause of hypoglycemia is excessive production of insulin, which lowers blood glucose too far. People with diabetes can develop hypoglycemia if they inject too much insulin or if they do not eat enough food between meals.
What Disorders Are Related to Carbohydrate Metabolism?

They exercise and fail to eat enough carbohydrates. Two types of hypoglycemia can develop in people who do not have diabetes: reactive and fasting.

**Reactive hypoglycemia** occurs when the pancreas secretes too much insulin after a high-carbohydrate meal. The symptoms of reactive hypoglycemia usually appear about 1 to 4 hours after the meal and include nervousness, shakiness, anxiety, sweating, irritability, headache, weakness, and rapid or irregular heartbeat. Although many people experience these symptoms from time to time, they are rarely caused by true hypoglycemia. A person diagnosed with reactive hypoglycemia must eat smaller meals more frequently to level out blood insulin and glucose levels.

**Fasting hypoglycemia** occurs when the body continues to produce too much insulin, even when someone has not eaten. This condition is usually secondary to another disorder such as cancer, liver infection, alcohol-induced liver disease, or a tumour in the pancreas. Its symptoms are similar to those of reactive hypoglycemia but occur more than four hours after a meal.

**Hypoglycemia** refers to lower-than-normal blood glucose levels. Reactive hypoglycemia occurs when the pancreas secretes too much insulin after a high-carbohydrate meal. Fasting hypoglycemia occurs when the body continues to produce too much insulin even when someone has not eaten.

**Lactose Intolerance: Inability to Digest Lactose**

Sometimes our bodies do not produce enough of the enzymes necessary to break down certain carbohydrates before they reach the colon. A common example is **lactose intolerance**, in which the body does not produce sufficient amounts of the enzyme lactase in the small intestine and therefore cannot digest foods containing lactose.

Lactose intolerance should not be confused with a milk allergy. People who are allergic to milk experience an immune reaction to the proteins found in cow’s milk. Symptoms of milk allergy include skin reactions such as hives and rashes; intestinal distress such as nausea, vomiting, cramping, and diarrhea; and respiratory symptoms such as wheezing, runny nose, and itchy and watery eyes. In severe cases, anaphylactic shock can occur. In contrast, symptoms of lactose intolerance are limited to the GI tract and include intestinal gas, bloating, cramping, nausea, diarrhea, and discomfort. These symptoms resolve spontaneously within a few hours.
Although some infants are born with lactose intolerance, it is more common to see lactase enzyme activity decrease after two years of age. In fact, it is estimated that up to 70% of the world’s adult population will lose some ability to digest lactose as they age.

Not everyone experiences lactose intolerance to the same extent. Some people can digest small amounts of dairy products, whereas others cannot tolerate any. Suarez and colleagues found that many people who reported being lactose intolerant were able to consume multiple small servings of dairy products without symptoms, which enabled them to meet their calcium requirements. Thus, it is not necessary for everyone with lactose intolerance to avoid all dairy products; they may simply need to eat smaller amounts and experiment to find foods that do not cause intestinal distress.

People with lactose intolerance need to find foods that can supply enough calcium for normal growth, development, and maintenance of bones. Many can tolerate specially formulated milk products that are low in lactose, whereas others take pills or use drops that contain the lactase enzyme when they eat dairy products. Calcium-fortified soy milk and orange juice are excellent substitutes for cow’s milk. Many lactose-intolerant people can also digest yogurt and aged cheese, as the bacteria or moulds used to ferment these products break down the lactose during processing.

How can you tell if you are lactose intolerant? Many people discover that they have problems digesting dairy products by trial and error. But because intestinal gas, bloating, and diarrhea may indicate other health problems, you should consult a physician to determine the cause.

Tests for lactose intolerance include drinking a lactose-rich liquid and testing blood glucose levels over a 2-hour period. If you do not produce the normal amount of glucose, you will be unable to digest the lactose present. Another test involves measuring hydrogen levels in the breath, as lactose-intolerant people breathe out more hydrogen when they drink a beverage that contains lactose.

Lactose intolerance results from the inability to digest lactose due to insufficient amounts of the enzyme lactase. Symptoms include intestinal gas, bloating, cramping, diarrhea, and nausea. The extent of lactose intolerance varies from mild to severe.

**SEE FOR YOURSELF**

**Are You at Risk?**

- I have a parent, brother, or sister with diabetes.
- I am a member of a high-risk group (Aboriginal, Hispanic, South Asian, Asian, or African descent).
- I have health complications that are associated with diabetes.
- I gave birth to a baby that weighed over 4 kg (9 lb) at birth.
- I had gestational diabetes.
- I have been told I have impaired glucose tolerance or impaired fasting glucose.
- I have high blood pressure.
- I have high cholesterol or other fats in my blood.
- I am overweight (especially if I carry most of my weight around my middle).
- I have been diagnosed with polycystic ovary syndrome, acanthosis nigricans, or schizophrenia.

*Data from: Reprinted with permission from the Canadian Diabetes Association (diabetes.ca).*
Chapter Review

Test Yourself

1. T Our brains rely almost exclusively on glucose for energy, and our body tissues utilize glucose for energy both at rest and during exercise.

2. F At 4 kcal/g, carbohydrates have less than half the energy of a gram of fat. Eating a high-carbohydrate diet will not cause people to gain body fat unless their total diet contains more energy (or kcal) than they expend. In fact, eating a diet high in complex, fibre-rich carbohydrates is associated with a lower risk for obesity.

3. F Although specific estimates are not yet available, significantly higher rates of type 2 diabetes are now being reported in children and adolescents; these higher rates are attributed to increasing obesity rates in young people.

4. F There is no evidence that diets high in sugar cause hyperactivity in children.

5. T Contrary to recent reports claiming harmful consequences related to consumption of alternative sweeteners, major health agencies have determined that these products are safe for most of us to consume in limited quantities.

Summary

- Carbohydrates contain carbon, hydrogen, and oxygen. Plants make the carbohydrate glucose during photosynthesis.
- Simple sugars include monosaccharides and disaccharides. The three primary monosaccharides are glucose, fructose, and galactose.
- Two monosaccharides joined together are called disaccharides. Glucose and fructose join to make sucrose; glucose and glucose join to make maltose; and glucose and galactose join to make lactose.
- The two monosaccharides that compose a disaccharide are attached by a bond between an oxygen atom and one carbon atom on each of the monosaccharides. There are two forms of this bond: alpha bonds are easily digestible by humans, whereas beta bonds are very difficult to digest.
- Oligosaccharides are complex carbohydrates that contain 3 to 10 monosaccharides.
- Polysaccharides are complex carbohydrates that typically contain hundreds to thousands of monosaccharides. The three types of polysaccharides are starches, glycogen, and fibre.
- Starches are the storage form of glucose in plants.
- Glycogen is the storage form of glucose in humans. Glycogen is stored in the liver and in muscles.
- Dietary fibre is the non-digestible parts of plants, whereas functional fibre is a non-digestible form of carbohydrate extracted from plants or manufactured in the laboratory. Fibre may reduce the risk of many diseases and digestive illnesses.
- Carbohydrate digestion starts in the mouth, where chewing and an enzyme called salivary amylase start breaking down the carbohydrates in food.
- Digestion continues in the small intestine. Specific enzymes are secreted to break starches into smaller mono- and disaccharides. As disaccharides pass through the intestinal cells, they are digested into monosaccharides.
- Glucose and other monosaccharides are absorbed into the bloodstream and travel to the liver, where all non-glucose molecules are converted to glucose.
- Glucose is transported in the bloodstream to the cells, where it is either used for energy, stored in the liver or muscle as glycogen, or converted to fat and stored in adipose tissue.
- Insulin is secreted when blood glucose increases sufficiently, and it assists with the transport of glucose into cells thereby lowering blood glucose levels.
• Glucagon, epinephrine, norepinephrine, cortisol, and growth hormone are secreted when blood glucose levels are low, and they assist with the conversion of glycogen to glucose, with gluconeogenesis, and with reducing the use of glucose by muscles and other organs therefore increasing blood glucose levels.

• The glycemic index and the glycemic load are values that indicate how much a food increases glucose levels. High-glycemic foods can trigger detrimental increases in blood glucose for people with diabetes.

• All cells can use glucose for energy. The red blood cells, brain, and central nervous system prefer to use glucose exclusively.

• Using glucose for energy helps spare body proteins, and glucose is an important fuel for the body during exercise.

• Fibre helps us maintain the healthy elimination of waste products. Eating adequate fibre may reduce the risk of colon cancer, type 2 diabetes, obesity, heart disease, hemorrhoids, and diverticulosis.

• The Acceptable Macronutrient Distribution Range for carbohydrate is 45% to 65% of total energy intake. Our diets should contain less than 25% of total energy from simple sugars.

• High added-sugar intake can cause tooth decay, elevate triglyceride and low-density lipoprotein levels in the blood, and contribute to obesity. It does not appear to cause hyperactivity in children.

• The Adequate Intake for fibre is 25 g per day for women and 38 g per day for men, or 14 g of fibre for every 1000 kcal of energy consumed.

• Foods high in fibre-rich carbohydrates include whole grains and cereals, fruits, and vegetables. Eating 6 to 8 servings of grains products (at least half of which are whole grains) and 7 to 10 servings of fruits and vegetables helps ensure that you meet your fibre-rich carbohydrate goals.

• Alternative sweeteners are added to some foods because they sweeten foods without promoting tooth decay and add little or no calories to foods.

• All alternative sweeteners approved for use in Canada are believed to be safe when eaten at levels at or below the Acceptable Daily Intake levels defined by Health Canada.

• Diabetes is caused by insufficient insulin or by the cells becoming resistant or insensitive to insulin. It causes dangerously high blood glucose levels. The two primary types of diabetes are type 1 and type 2.

• A lower-than-normal blood glucose level is defined as hypoglycemia. There are two types: reactive and fasting. Reactive hypoglycemia occurs when too much insulin is secreted after a high-carbohydrate meal; fasting hypoglycemia occurs when blood glucose drops even though no food has been eaten.

• Lactose intolerance results from an insufficient amount of the lactase enzyme. Symptoms include intestinal gas, bloating, cramping, diarrhea, and discomfort.

1. The glycemic index rates
   a. the acceptable amount of alternative sweeteners to consume in one day.
   b. the potential of foods to raise blood glucose and insulin levels.
   c. the risk of a given food for causing diabetes.
   d. the ratio of soluble to insoluble fibre in a complex carbohydrate.

2. Carbohydrates contain
   a. carbon, nitrogen, and water.
   b. carbonic acid and a sugar alcohol.
   c. hydrated sugar.
   d. carbon, hydrogen, and oxygen.

3. The most common source of added sugar in the Canadian diet is
   a. table sugar.
   b. white flour.
   c. alcohol.
   d. sweetened soft drinks.

4. Glucose, fructose, and galactose are
   a. monosaccharides.
   b. disaccharides.
   c. polysaccharides.
   d. complex carbohydrates.

5. Aspartame should not be consumed by people who have
   a. phenylketonuria.
   b. type 1 diabetes.
   c. lactose intolerance.
   d. diverticulosis.

6. Compare and contrast soluble fibres with insoluble fibres.

7. What is the difference between the glycemic index and the glycemic load?

8. Describe the role of insulin in regulating blood glucose levels.

9. Identify at least four ways in which fibre helps us maintain a healthy digestive system.

10. Your niece, Lilly, is 6 years old and is learning about Eating Well with Canada’s Food Guide in her Grade 1 class. She
points out the grain products group and proudly lists her favourite food choices from this group: "saltine crackers, pancakes, cinnamon toast, and spaghetti." Explain to Lilly, in words she can understand, the difference between fibre-rich carbohydrates and highly processed carbohydrates and why fibre-rich carbohydrates are healthier food choices.

11. When Kenton returns from his doctor’s appointment with the news that he has been diagnosed with type 2 diabetes and must lose weight, his wife looks skeptical. "I thought that diabetes runs in families," she says. "No one in your family has diabetes, and your whole family is overweight! So how come your doctor thinks losing weight will solve your problems?" Defend the statement that obesity can trigger type 2 diabetes.

12. Create a table listing the molecular composition and food sources of each of the following carbohydrates: glucose, fructose, lactose, and sucrose.

Web Links

www.dietitians.ca
Dietitians of Canada
Visit this site to learn more about high- and low-carbohydrate diets, and discover resources for general healthy eating.

www.diabetes.ca
Canadian Diabetes Association
Find out more about risk factors for developing diabetes and the nutritional needs of people living with diabetes.

www.cda-adc.ca
Canadian Dental Association
Go to this site to learn more about dental caries and oral health.

Canadian Health Program for First Nations, Inuit and Aboriginal Health

Learn more about the incidence of diabetes in Aboriginal populations and about culturally appropriate prevention and health promotion initiatives.

Health Canada
Here you can find a summary of dietary recommendations for the Canadian public, which includes recommendations for carbohydrate intake.

www.heartandstroke.com
Heart and Stroke Foundation
Read the position statement of the Heart and Stroke Foundation on low-carbohydrate diets and heart disease and stroke.

MasteringNutrition*

www.masteringnutrition.pearson.com
Assignments
Animations: Carbohydrate Absorption • Carbohydrate Digestion • Diverticulosis & Fibre • Hormonal Control of Blood Glucose • Alcohol Absorption
Study Area
Video: Understanding Carbohydrates • Practice Tests • Diet Analysis • eText

References

References


Almost every day in the news we see headlines about obesity: “More Canadians Overweight!” “The Fattening of North America,” “Obesity is a National Epidemic.” Over the past 25 years, obesity rates have increased dramatically in Canada. It has become public health enemy number one, as many chronic diseases such as type 2 diabetes, heart disease, high blood pressure, and arthritis go hand in hand with obesity.

Of particular concern are the rising obesity rates in children. The results of the 2004 Canadian Community Health Survey (CCHS) indicate that the prevalence of obesity is 6.3% in young children aged 2 to 5 years, 8.0% in children aged 6 to 11 years, and 9.4% in adolescents aged 12 to 17 years. This is a 250% increase in obesity rates since the late 1970s and translates into about half a million children and youth.

Why should we concern ourselves with fighting obesity in children? First, it is well established that the treatment of existing obesity is extremely challenging, and our greatest hope of combating this disease is through prevention. Most agree that prevention should start with children at a very early age. Second, there is a tendency for obese children to remain obese as adults, suffering all of the health problems that accompany this disease. Young children are now experiencing type 2 diabetes, high blood pressure, and high cholesterol at increasingly younger ages, only compounding the devastating effects of these illnesses as they get older. We have reached the point at which serious action must be taken immediately to curb this growing crisis.

How can we prevent obesity? This is a difficult question to answer. One way is to better understand the factors that contribute to obesity, and then take actions to alter these factors. We know of many factors that contribute to overweight and obesity. These include genetic influences, lack of adequate physical activity, and eating foods that are high in fat, added sugar, and energy. While it is easy to blame our genetics, they cannot be held entirely responsible for the rapid rise in obesity that has occurred over the past 25 years. Our genetic makeup takes thousands of years to change; thus, humans who lived 50 or 100 years ago have essentially the same genetic makeup as humans who live now. The fact that obesity rates have risen so dramatically in recent years indicates that we need to look more closely at how changes in our lifestyle and environment over this same period have contributed to obesity.

One factor that has been the topic of much discussion and debate in recent years is the contribution of added sugars, particularly in the form of high-fructose corn syrup (HFCS) to overweight and obesity. Researchers in the United States have linked the increased use and consumption of HFCS in beverages and foods with the rising rates of obesity since the 1970s, when HFCS was first developed and marketed (see Figure 4a). HFCS use in Canada is not tracked separately from total sweeteners and appears on food labels as the generic term “glucose/fructose.” Consequently, similar correlations can’t be examined. However, it is known that HFCS provides about 95% of the caloric sweeteners used by the Canadian soft drink industry, which is on par with the 100% usage in the United States.

How significant a problem is soft drink consumption in children? Studies from the United States show that girls and boys ages 6 to 11 years drank about twice as many soft drinks in 1998 as compared to 1977, and consumption of milk over this same time period dropped by about 30%. Equally alarming is the finding that one-fourth of a group of adolescents studied were heavy consumers of sugared soft drinks, drinking at least 770 mL of soft drinks each day. In Canada, boys aged 14–18 years consume on average 359 mL of sweetened soft drinks daily, roughly equivalent to one 355 mL can. This intake is equivalent to almost 150 extra calories! So, it’s not surprising that researchers have shown that for each extra sugared soft drink that children consume each day, the risk of obesity increases by 60%. A recent pilot intervention study found that replacing sweetened soft drinks with non-caloric beverages in the diets of 13- to 18-year-old adolescents resulted in a significant decrease in body mass index in the adolescents who were the most overweight when starting the study.

All of this alarming information has led to dramatic changes in the availability of soft drinks in schools and at school-sponsored events. Most provinces in Canada have school food and nutrition policies that limit the sale of
et al. speculated that HFCS could lead to lower circulating levels of both insulin and leptin, resulting in an increase in appetite and food intake, excessive energy intake, and thus increased obesity. At the same time, HFCS could contribute to obesity because people consume significant amounts of excess energy in the form of HFCS-sweetened soft drinks and foods. Consumption of fructose has also been reported to increase the production of triglycerides in the blood significantly more than glucose and, in animals, can lead to insulin resistance and impaired glucose regulation—factors that can lead to weight gain and type 2 diabetes. However, these studies have been criticized for using pure fructose and pure glucose at much higher concentrations than would be found in the American diet, and equating the metabolism of fructose with HFCS. Further, many of these early studies were in vitro (in test tubes) or laboratory feeding studies.

More specifically, it has been suggested that the consumption of sweetened soft drinks is more likely to cause weight gain than consumption of sugary foods. Some researchers believe that liquid calories are less satiating than calories from solid foods, possibly because of the higher water content. However, other researchers have shown that solid foods are more satiating.

Although the evidence pinpointing HFCS as a major contributor to the obesity epidemic originally appeared strong, a growing number of researchers disagree with these speculations about HFCS. It has been proposed that HFCS could lead to lower circulating levels of both insulin and leptin, resulting in an increase in appetite and food intake, excessive energy intake, and thus increased obesity. At the same time, HFCS could contribute to obesity because people consume significant amounts of excess energy in the form of HFCS-sweetened soft drinks and foods. Consumption of fructose has also been reported to increase the production of triglycerides in the blood significantly more than glucose and, in animals, can lead to insulin resistance and impaired glucose regulation—factors that can lead to weight gain and type 2 diabetes. However, these studies have been criticized for using pure fructose and pure glucose at much higher concentrations than would be found in the American diet, and equating the metabolism of fructose with HFCS. Further, many of these early studies were in vitro (in test tubes) or laboratory feeding studies.

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that soft drinks would have contributed to the obesity epidemic no matter whether the sweetener was sucrose or fructose, and that their contribution to obesity arises from the increased consumption resulting from massive increases in advertising, substantial increases in serving sizes of soft drinks, and virtually unlimited access to soft drinks throughout our everyday lives.60

Forshee and colleagues conducted a search of the literature related to HFCS and weight gain and found that few studies directly explored the relationship between HFCS, body weight, and BMI.61 The only evidence linking HFCS consumption and rising BMI rates was ecological data. A recent study has also indicated that though four weeks of increased fructose consumption in humans does cause an increased production of triglycerides as previously stated, it does not cause weight gain or increased resistance to insulin.61 Thus, it may be that animals respond differently than humans to diets high in fructose. Other researchers argue that the timing of sugar administration influences satiety, not the chemical structure.63 Therefore, it is entirely possible that the obesity epidemic has resulted from increased consumption of energy (predominantly in the form of sweetened soft drinks and other high-energy foods) and a reduction in physical activity levels, and HFCS has nothing to do with this epidemic. Evidence to support this supposition stems from the fact that obesity rates are rising around the world, and many of the countries experiencing this epidemic do not use HFCS as a sweetener.

There is also little evidence that HFCS is less satiating than other dietary sweeteners.64 Monsivais and colleagues gave commercially available cola beverages, sweetened with sucrose, HFCS 42, or HFCS 55 to 37 volunteers to determine the relative effects on hunger, satiety, and energy intakes at the next meal.62 They found no significant differences between the sucrose and HFCS-sweetened beverages.

Clearly, this issue is extremely complex. It has been suggested that more research needs to be done in humans before we can fully understand how HFCS contributes to our diet, and whether its consumption adversely affects our health.36,55

Using the Evidence

1. After reading this, do you think HFCS is a major contributor to the obesity epidemic?
2. Should HFCS be banned from our food supply? Please justify.
3. Should soft drink companies be encouraged to replace HFCS with sucrose or some other form of caloric sweetener?
4. Should reducing soft drink consumption be up to individuals, or should it be mandatory for those at high risk for obesity?
5. Should families, schools, and our government play a central role in controlling the types of foods and beverages offered to young people throughout their day?