

Carbohydrates - 1

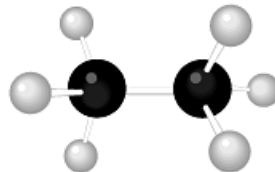
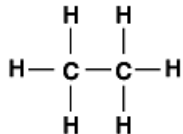
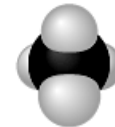
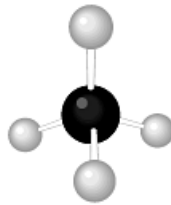
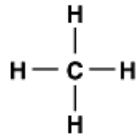
Our more-detailed discussions of nutrients needed for our bodies will focus on the following:

- The chemical structure(s) of the nutrients required
- Amounts of nutrients required
- Good food choices for specific nutrients

Recall that all major nutrients except minerals and water are **organic** (composed of carbon and hydrogen) To best understand the structure of these nutrients it is useful to have a brief introduction to the chemistry of carbon - which will explain why many of our major nutrients can so readily be inter-converted. For more detail than is provided in class, particularly for molecular structure, turn to Appendix C of your textbook. Some basic chemistry concepts can be found in Appendix B.

Carbon Characteristics

- Carbon is one of the atoms (elements) that forms covalent bonds (joins with other atoms) to become stable. Each carbon atom makes **4 bonds**
- Carbon may make bonds with other carbon atoms forming chains, branching chains or rings of linked carbon atoms.
- Carbon may also bond to different kinds of atoms, most notably hydrogen. In fact, the basic carbon compound is a **hydrocarbon**, formed from carbon and hydrogen.



Most hydrocarbons have very similar properties - for example the C-H bond is **energy rich**; make good fuels (methane, propane, butane, methanol, alcohol)

The major compounds (carbohydrates, lipids and proteins) of living organisms are modifications of hydrocarbons - the modifications are called **functional groups**, because they confer the unique properties of the compound. As we look at our major nutrients: carbohydrates, lipids and proteins, you will identify their hydrocarbon backbones and note the functional groups that uniquely identify each type of compound.

Carbohydrates

We can now turn our attention to the first of the major nutrients: the carbohydrates.

Carbohydrate Function

Carbohydrate is the primary **fuel** source for our cells. Billions of glucose molecules are used by our cells each minute, along with fatty acid fragments that help fuel our muscle and tissue activity. It's good to remember that glucose, a carbohydrate, is the preferred fuel molecule for a number of reasons.

- Protein is often more expensive plus the amino portion is not fuel, and must be excreted as the osmotically active (and toxic) urea.
- Fats are very energy rich but less efficient as fuel, and the brain has restrictions that prevent brain and nervous system cells from using fats for fuel.
- Alcohol is metabolized in much the same way as fat plus it's toxic. To some extent alcohol decreases available energy because of its action on the energy carrier NAD⁺.

Why carbohydrates?

Probably evolution

- Carbohydrates are the fuel storage and structural molecules of plants. Cellulose, the structural component of plant cell walls, is the most abundant organic molecule on earth. (Of course cellulose is non-digestible, so isn't fuel, but it's a nice statistic.) Starch is the primary fuel storage molecules of plants.
- Glucose is the immediate product of **photosynthesis**; other organic compounds are manufactured in plants from photosynthetic derivatives.
- We have a handy source of carbohydrates from plants. Carbohydrates are readily available from seeds and fruits, and vegetative storage structures of plants such as roots, bulbs and corms. Of course, for the plant these are reserves to carry them through dormancy or give their next generation a head start – but that is from the plant's perspective.

It is rare for plants to have much glucose, or any simple sugars – the mature fruit that is designed for dispersal purposes is the major exception. (The fruit attracts dispersal agents to carry seeds to new area). Sugar cane and sugar beet are two other exceptions.

Carbohydrate Structure

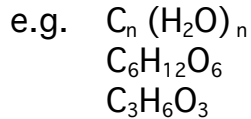
In chemistry, the word carbohydrate is just a general term that indicates their overall composition of carbon and water. There are three groups of carbohydrates to discuss: **simple sugars, complex carbohydrates** and **fiber**. All carbohydrates are composed of one kind of building block, or subunit - the **monosaccharide**. Simple sugars are composed of one or two monosaccharides. The complex carbohydrates and fiber are polysaccharides, many monosaccharides bonded together.

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All monosaccharides share a common "structure". Monosaccharides contain:

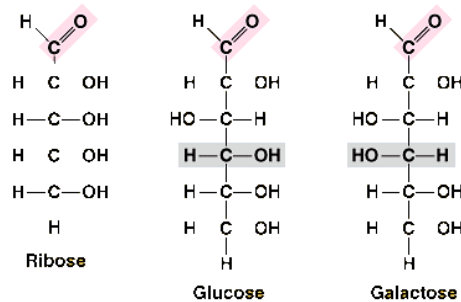
- Carbon
- Hydrogen
- Oxygen

The ratio of atoms in a monosaccharide is: (CH_2O)



The functional groups of monosaccharides are:

- $-\text{OH}$ Hydroxyl
- $=\text{O}$ Carbonyl

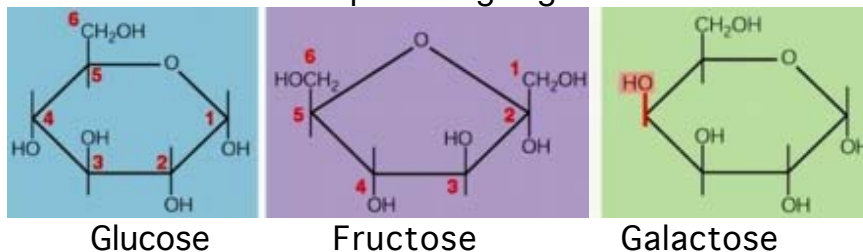


By convention, monosaccharides and all carbohydrate names end in "-ose". Recall that the enzymes have the "-ase" suffix, and are usually named after the substance they digest.

Simple Sugars: Monosaccharides and Disaccharides

Monosaccharides

- The three common monosaccharides are: **glucose**, **fructose** and **galactose**, all forms of the hexose $\text{C}_6\text{H}_{12}\text{O}_6$. Molecules that have the same number and kinds of atoms are called isomers. Glucose, galactose and fructose are isomers.
- **Glucose** is formed in photosynthesis and virtually all carbohydrates that are digested are digested into or converted into glucose for circulation to our cells and tissues. However, glucose is rarely stored in plant tissues or in our cells.
- **Fructose** is found in some fruits and in honey, produced from nectar (which is primarily the disaccharide, sucrose), and is very sweet to our taste buds.
- **Galactose** is a constituent of the disaccharide lactose, and not found as a free monosaccharide except during digestion.



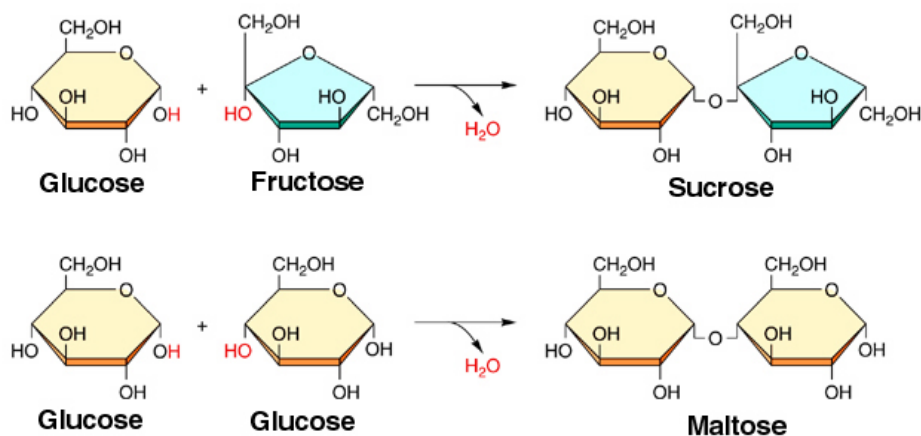
- We also have some 5-carbon monosaccharides (ribose, xylose)

Disaccharides

- Disaccharides are 2 monosaccharides joined by a **dehydration synthesis**, or **condensation**, which is the removal of a water molecule to join molecules together.

Recall that **condensation** and **hydrolysis**, which involve adding or removing water molecules, are common chemical reactions in cells and tissues. Polymers are formed from their subunits by **dehydration synthesis**, removing molecules of water (a hydrogen (H-) from one subunit and the hydroxyl (-OH) from the second subunit) to join the subunits together. When larger molecules are broken down, such as in digestion, water molecules are added in to break the macromolecules into their subunits, a process called **hydrolysis**.

- The common disaccharides are **sucrose** (glucose + fructose), **lactose** (glucose + galactose) and **maltose** (glucose + glucose).
 - Lactose**, the only animal sugar, is found in mammalian milk.
 - Maltose** is a breakdown product of the polysaccharide, starch. Maltose is formed when seeds germinate and convert their stored starch into fuel molecules for germination. It is also produced during digestion and during fermentations that ultimately produce alcohol.
 - Sucrose** is the common sugar stored in plants, primarily in fruits, but also in some vegetables. Sucrose is also the refined product of sugar beets and sugar cane, and the sole legal "sugar".
- During the condensation to form disaccharides the two monosaccharide molecules are joined by a C—O—C bond (called a glycosidic bond in chemistry).



Sugar Consumption

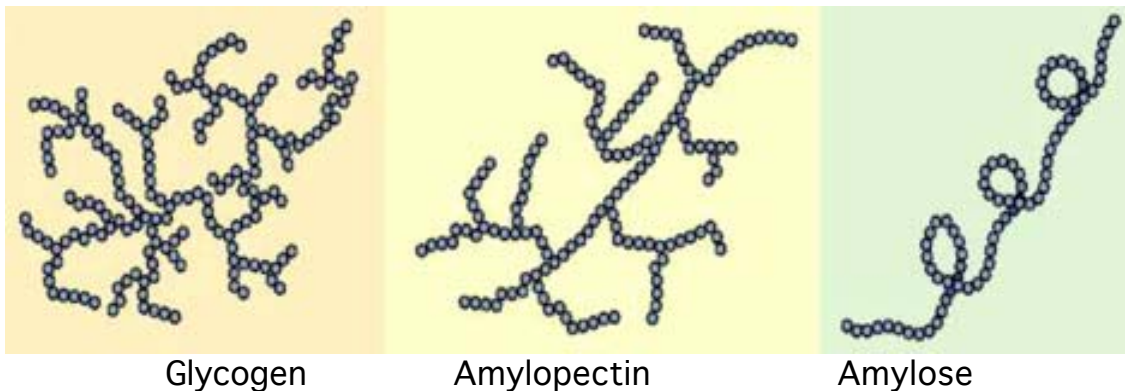
Recall that our nutritional guidelines recommend no more than 10% of our total calories come from sugars. We consume about 25% of our calories today in the form of sugars. **We will come back to the uses of sugars, sugar problems in our diets and where sugars are found in foods later.**

Oligosaccharides

Some plants produce small chain carbohydrates of 3 – 10 glucose units. These oligosaccharides are not digestible by humans but many can be digested by our intestinal bacteria and their by-products are a major source of intestinal gas.

Complex carbohydrates

- The complex carbohydrates include the digestible polysaccharides. Polysaccharides are formed by joining several monosaccharides, each to the next by a dehydration synthesis. The common digestible polysaccharides are:
 - Starch (α 1-4 linkages of glucose)
 - Glycogen
- Both starch and glycogen are polysaccharides of glucose. Starch is a very long coiled, unbranched (amylose) or branching (amylopectin) chain, with about 1000 glucose molecules in any branch. Glycogen branches frequently (about every 10 or so glucose units) and is more easily broken down.



Complex Carbohydrates in the Diet

Historically, as nations gain wealth by "development", diets are altered from grains-based to consuming more animal products, sweets, and other refined goods, a trend which may not be healthy.

The complex carbohydrates (starches) are the foundation of our diets, ideally providing about 60% of our calories. Complex carbohydrates are found in grains, legumes and vegetables. Because complex carbohydrates found in whole foods take longer to digest, they are absorbed at a more uniform rate, minimizing negative effects on blood glucose levels. Our food choices for complex carbohydrates can also provide fiber, which we will discuss soon.

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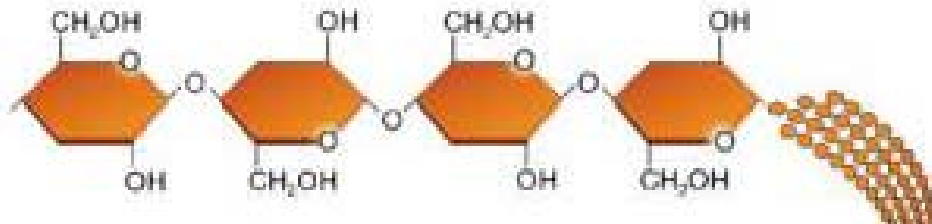
However, as we discussed in our nutrition guidelines, our choices should emphasize whole grains, legumes and vegetables, not processed grain products and sweets. In the United States, the vast majority of our complex carbohydrate consumption is in the form of processed grain foods, and some of the nutrients are lost in processing, along with fiber and possibly phytochemicals.

Diets high in complex carbohydrates (assuming we make healthy choices) can lower our risk for **heart disease**, some **cancers** (if the choices include vegetables rich in pigments – phytochemicals), **diabetes**, and promote **intestinal health**. Diets rich in whole grains and vegetables are also important in long-term **weight control**. We often eat less total food when the foods we eat are high in fiber.

Lots of variation is good with carbohydrates, since good food choices also provide important vitamins, minerals and fiber. Eat those vegetables! Eat legumes! Eat whole grains!

Fiber

- Fiber includes the non digestible (for humans) structural carbohydrates of plants. Fiber can be soluble or non-soluble. Both soluble and non-soluble fiber are important in the diet. The most common fiber is cellulose.
 - Cellulose is comprised of long chains of glucose (β 1-4 linkages)



- Cellulose is for most living organisms, non-digestible. Few organisms have the enzyme needed to break down cellulose. Cellulose and related compounds form most of what we call **fiber**.
- There are several related fibers
 - **Hemicelluloses** are a mixture of branching chains of a number of monosaccharides, none of which we digest.
 - **Pectins** are chemically a calcium-carbohydrate compound (calcium pectate is the most common). Pectins form the middle lamella layer between cells of plants and literally glue the cells to each other. Pectin is water soluble and forms a gel texture when heated.

As a side note, pectins help maintain the texture of fresh fruits and vegetables. The middle lamella layer breaks down in heat, which helps explain why cooked apples become applesauce. Commercial pectins are used to glue juices into jams and jellies.

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- **Gums** and **mucilages** are similar soluble modified carbohydrates that protect plants from damaging injuries. Some plants produce lots of these substances. Some protists, notably brown and red algae also produce gums or mucilages. Gum Arabic, carrageen and guar are substances used to stabilize and texturize many foods.
- **Lignin** is a very tough "fiber" used in secondary walls of plants to provide strength. Wood has lots of lignin, as do the true fiber cells of plants. (In botany, fiber is one of the plant tissue types, elongated cells of the tissue, sclerenchyma. The gritty texture of pears comes from another type of sclerenchyma, the sclerid. Lignins are phenolic compounds. We eat few foods that contain lignin – it's too tough.

The Value of Fiber in the Diet

Where do we find dietary Fiber?

Fiber is found in all **unprocessed** plants. All plant cells have cell walls produced exterior to their plasma membrane. The wall provides shape, strength and protection. Walls are made of cellulose and related materials. Generally tougher plant foods have more fiber (more protection) because their cells have multiple cell wall layers for strength and support. No fiber is found in animal tissues.

Good Sources of Fiber

We need about 25 – 40 grams of fiber a day. Most of us get about half that amount at best. Most fruits, veggies and whole grains have about 2 gm/serving. Legumes are high fiber foods with about 8 gm/servings.

- Whole fruits are often good sources for pectins but have less total fiber than grains
- Legumes are excellent sources of soluble fibers (pectins) as well as insoluble fiber
- Most vegetables have a high cellulose content (insoluble fiber)
- Whole grains, especially wheat and corn, have much cellulose and hemicellulose. Oats are a good source of soluble fiber. (So is okra.)
- Nuts are also good fiber sources

Why Consume Fiber?

- Fiber affects water absorption (cellulose sponges?)
- Fiber affects some mineral absorption, especially cellulose fiber
- Fiber adds bulk and helps make you feel fuller sooner (**satiety value**) (Some low calorie breads literally add cellulose so the slice is the familiar size.) A high fiber diet can be valuable for weight control because literally you eat less. Plus whole foods high in fiber are rarely high in fat or in total calories. Nuts are an exception. They are idiotically high in fat.
- Fiber promotes optimal intestinal motility. Fiber attracts water, softens feces (prevents constipation) and motility helps to prevent intestinal irritations like bacterial infections of the appendix.

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- Fiber stimulates muscles of intestine so minimizes diverticulosis, a weakening in the intestine that can lead to diverticulitis, an inflammation of little pouches formed in the intestinal lining.
- Fiber minimizes intestinal exposure to potentially harmful chemicals and may be a factor in lowering risk of colon cancer.
- Soluble fiber, such as pectins and gums, helps lower cholesterol and triglyceride levels in body. Bran fibers, except oats and barley, do not contain soluble fiber. Legumes are good sources of soluble fiber. (15 gm pectin/day in some patients helped a 10% decrease in blood cholesterol)
- Fiber helps control type II diabetes by reducing the rate of glucose absorption. But the real benefit may just be an improved diet, not the fiber per se!

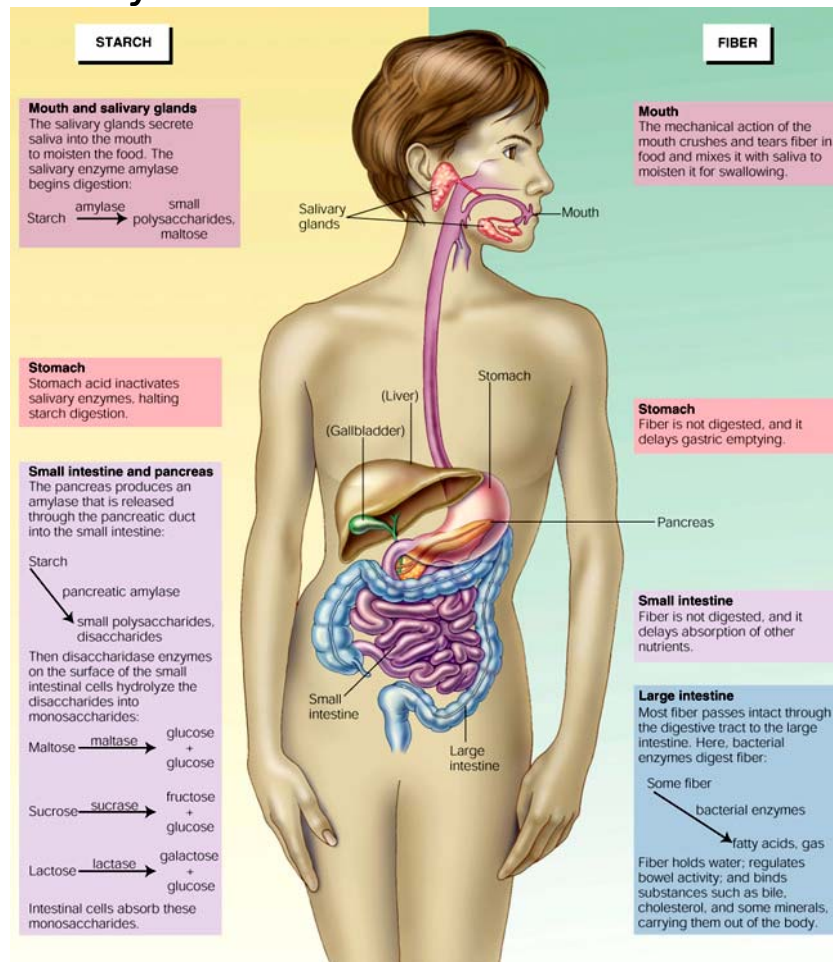
Fiber Cautions

- Fiber can interfere with the absorption of some medications.
- Fiber can reduce digestion and absorption by increasing the rate of passage through digestive tract.
- Fiber is rough. It can be hard on the mucosa of digestive tract.
- Whole grains contain phytic acid, which may chelate some minerals (calcium, iron, magnesium and zinc) (One has to consume lots and lots of whole grains to have a negative effect on mineral absorption, but this is one reason to be certain that your mineral intake is adequate.)
- A high-fiber diet may promote intestinal discomfort since the colon bacteria may enjoy the meal provided and produce lots of gases.
- Whole grains are high in phosphorus which may cause problems for kidneys.
- Some fiber may inhibit carotene conversion to Vitamin A.
- Fiber can promote dehydration (imbibes water).
- Some people can't eat enough calories when they consume lots of high-fiber, bulky, low calorie foods.

Use of Fiber Supplements

Although fiber supplements, commonly produced from *Psyllium* seed coats, add non-soluble fiber to the diet, whole foods contain many other things too, and a better overall diet promotes health far more than adding a few grams of fiber in a pill or powder added to your orange juice.

Digestion of Carbohydrates



Carbohydrate digestion starts in the oral cavity with the secretion of salivary amylase that hydrolyzes starch to maltose. The chewing of food helps break up fiber. When the food bolus reaches the stomach, amylase is denatured by stomach acid. Although some acid hydrolysis occurs in the stomach, very little carbohydrate digestion occurs. Foods high in fiber increase the time spent in the stomach, which contributes to the feeling of fullness, or satiety.

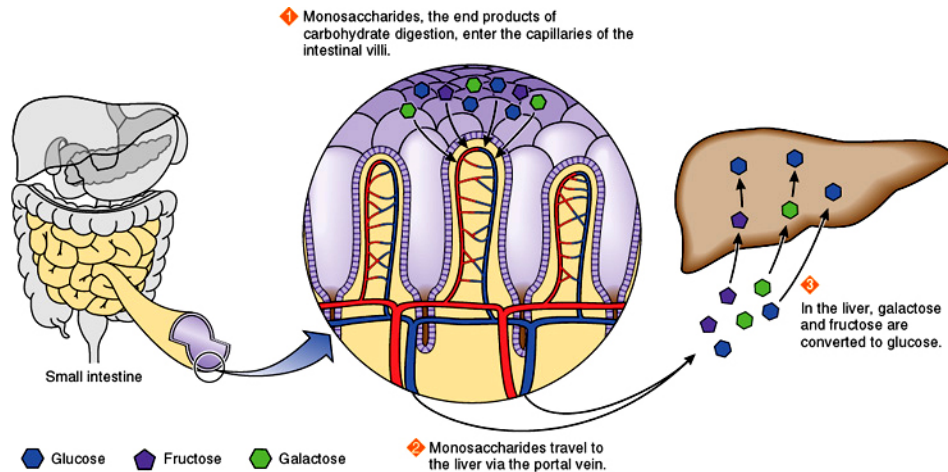
Most enzymatic digestion of carbohydrates occurs in the small intestine. Enzymes secreted by the pancreas and the linings of the small intestine break down starches into maltose (then converted to glucose) and disaccharides into their constituent monosaccharides.

- Pancreatic amylase starch ---> maltose
- Maltase maltose ---> glucose
- Lactase lactose ---> glucose and galactose
- Sucrase sucrose ---> glucose and fructose

Some starches resist digestion and pass into the large intestine where they act much the same way as fiber and are subject to digestion by our intestinal bacteria. Their by-products include a number of gases, water and some small fatty acids. The acids can be absorbed across the colon and transported to the liver.

Absorption of Carbohydrates

Monosaccharides are readily absorbed across the intestinal villi into the capillaries of the intestinal mesentery when they travel to the liver for further processing. In the liver, galactose and fructose are converted to glucose for distribution to cells and tissues. Ultimately, any carbohydrate absorbed is converted to glucose. Fructose is absorbed more slowly than glucose and galactose.



Using Sugars in the Body

As stated, the sugars include the monosaccharides, disaccharides and sugar alcohols. Sugars, mostly sucrose, are naturally found in fruits and in some vegetables. The only sugar produced by animals is lactose. About a quarter of our total calories typically come from sugars, and almost 20% from added sugars.

During the past 15 years, per capita consumption of sugar has risen 28% in the United States. Much of this increase is attributed to a 40% increase in soft drink consumption. Teens now consume twice as much soda as they do milk.

From *Nutrition Action*, December, 2002: "We now produce 152 pounds of added sugars each year for every person in the United States. Soft drinks account for a third of our intake. So-called "fruit" drinks supply another ten percent, while cookies, cakes, and other sweet baked goods contribute 14 percent. Candy, breakfast cereals, and ice cream each chip in about five percent."

Is there anything wrong with this?

Most sugar-containing foods are not nutrient dense. This means that for those of us consuming 20% of our calories from added sugars 80% of our calories must provide all of the other nutrients. With a third of our nation, including children, seriously overweight, or for those whose total calorie intake is low, it's difficult to get a nutrient dense diet with so few calories left after we subtract the sugary foods. And for some, since this is the "average", consumption of sugars is much higher. Someone who can consume 3000 or more calories a day, and makes generally healthy food choices, eating lots of sugar calories is less harmful, but not a good long term habit. Almost all of us, as we age, have to consume fewer calories. The statement that old habits are hard to break applies to sugar, too.

Let's examine sugars

Is there any difference in sugars? Is all sugar, sugar? Are some better? Are some worse?

Sucrose

Sucrose as marketed is a 99.9% pure (better than soap) crystalline disaccharide of glucose – fructose. Sucrose is found naturally in fruits, nectar, and in quantities in sugar cane and sugar beets, from which it is refined to achieve the purity required. Sucrose is probably the purest substance we ingest. It is used in many foods that have added sugars. Its prominence is declining, however, since harvesting and processing cane and beets is more costly than producing sugars from corn.

Other Sucrose forms

Raw sugar

Raw sugar is a coarse crystalline sucrose formed by evaporating cane juice. Impurities (insects, dirt, etc.) must be removed prior to sale.

Turbinado sugar

Turbinado sugar is refined to remove impurities and most of the molasses from cane syrup. The crystals are steam washed to remove impurities.

Brown sugar

Brown sugar is a mixture of sucrose and molasses that is 91-96% sucrose. It is often prepared by adding molasses to refined sucrose.

Molasses

Molasses is the residue from sugar processing contains **iron** from processing. The amounts of iron vary.

Invert sugar

Invertose, or invert sugar is a mixture of glucose and fructose formed by subjecting sucrose to acid and enzymatic hydrolysis - it is sweeter than sucrose and is a liquid. Invert sugar is often used in confections. The liquid is more calorie dense than crystalline sugars.

Honey

Honey is an invert sugar, produced from nectar in the digestive tract of bees. Bees have the enzyme, invertase, that converts the sucrose found in nectar into invertose, or honey. Bees regurgitate (vomit) the honey after partial digestion. Has minute amounts of other substances depending on nectar source. Honey will contain minute quantities of some minerals, and some contaminants, including potentially harmful bacteria. Most honey is pasteurized to destroy bacteria.

Maple sugar

Maple sugar is mostly sucrose obtained by evaporating the sap of maple trees. Several species of maple can be used to obtain the sap. Maple syrup is a dilute liquid form of maple sugar.

Other Sugars

Glucose

Glucose, a natural photosynthetic product, is the end product of carbohydrate digestion. Our cells use glucose for the primary fuel molecule. It is a constituent of all the disaccharides.

Dextrose

Dextrose is the commercial name for glucose. It is often produced by starch hydrolysis using acid, heat or enzymes.

Fructose

Fructose is found naturally in some fruits. Our taste buds detect fructose as "sweeter" than other sugars. Fructose is absorbed more slowly than glucose and is not affected by insulin. The liver converts all fructose into glucose or glycogen. Too much fructose may cause diarrhea.

Levulose

Levulose is the commercial name for fructose.

Corn syrup

Corn syrups is a product of acid or enzymatic hydrolysis of cornstarch. The product is mostly glucose.

High Fructose Corn Syrup

About 10% of the calories the average US person consumes come from high fructose corn syrup. For many, it is closer to 20%. HFCS is corn syrup refined to a mixture of fructose and glucose, much of which is even further modified to a HFCS chemically similar to sucrose; both sucrose and HFCS are composed of one glucose and one fructose molecule.

80 - 90% of HFCS is used by the beverage industry. The rest is used by processed food manufacturers (cereal, bakery and dairy industry). U.S. production of HFCS increased from 2.18 million tons in 1980 to 9.4 million tons in 1999. In 2000 about 5.3% of the total corn crop was used to produce HFCS. (Information from the *Journal of the American Dietetic Association*, "Sugar and sugars: Myths and realities." by Ann M. Coulston and Rachel K. Johnson, March 2002.)

Lactose

Lactose is the sugar found in milk. Lactose is also processed from whey and used in pharmaceuticals as a binder. Lactose is not sweet tasting.

Maltose

Maltose is produced by the digestion of starch into disaccharide units. It is found naturally in germinating grains, and is called malt. Grains, especially barley, are "malted" to produce malt for the brewing industry and for malted milk shakes.

The Sugar Alcohols

- The sugar alcohols include Sorbitol, Mannitol, Maltitol and Xylitol, etc.
- Sugar alcohols are found naturally in fruits or bark (xylitol) or commercially prepared from dextrose or hydrolyzed starch.
- More than 20 – 50g/day may cause diarrhea and cramps – most are not as absorbable by body so provide fewer calories than sugars.

How are sugars different from each other?

Nutrient density

- All sugars lack nutrient density. There is **no** nutritional benefit or detriment to one's choice of sugars in that sense. However, there is an appreciable difference in choice with reference to concentration of sugars in one's serving and what else might be in the food that contains the sugar.
- Whole food sources of sugars are better choices since they are more likely to have dilute sugars and other nutrients in addition to the sugar in the food.
- Foods that have "added sugars" – no matter what kind of added sugar – will be less nutrient dense.

Use in body cells and tissues

- Except for the sugar alcohols, all sugars are converted to glucose for distribution to cells and tissues. There are no differences. They are **all** the same.
- The sole difference in sugars is concentration in food sources. Since sugars require minimal digestion, they are rapidly absorbed, and when concentrated, the sugars hit the liver at rates beyond its ability to immediately regulate forcing more glucose into circulation. (See later)

Calories

- Liquid sugars, such as honey have more calories/teaspoon than crystalline sugars.

Sweetness

- Fructose is 1.2 ---> 1.7 times sweeter than sucrose
- Glucose, mannitol and sorbitol are about 70% as sweet as sucrose
- Xylitol is about as sweet tasting as sucrose
- Maltose and lactose do not taste sweet; they are about 30% as sweet as sucrose

Refined versus "natural"

- Natural means derived from a living organism. It does not mean whole, pure or even organic (a term that means grown without chemically produced pesticides, herbicides or fertilizers).
- All sugars are naturally derived, even high fructose corn syrup.
- Refined means processed in some way from the whole food.
- With reference to sugars:
 - Refined sucrose, by law, is chemically crystalline pure. It is impossible for refined sugar to be harmful. What's "harmful" is how we add amounts of any sugars to foods, rendering them calorie dense and nutrient "undense".
 - The so-called "natural" sugars may have serious contaminants, especially raw honey that may contain *Clostridium botulinum* and other bacteria

Is sugar bad for health - a controversial question

Sugar and dental caries

Sugar intake is correlated to dental caries. The bacteria in our oral cavity convert sugars and starches into acids that promote tooth decay. Sticky sugars are more likely to promote decay since they may cling to the tooth surface giving the bacteria time to act. Bacteria need 20 – 30 minutes to do their damage.

Sugar Intake and Poor Nutrition

Sugar does not cause malnutrition by itself. However, sugar lacks nutrient density so other food choices become more critical relative to the total calories needed when more sugar is consumed. If 25% of our calories are sugars, and those calories are in the form of "added sugars", sedentary and older people in particular need to be very conscientious about their other food choices. And we are not. Unfortunately, our poor nutritional decisions don't catch up with us until later in life. A young person, outwardly healthy, doesn't want to think about what he or she is eating apart from "taste". The result is poor food habits that are difficult to change.

Hyperactivity - Misbehavior

Controlled studies that compare sugar consumption to hyperactivity reveal that there are no differences in the behavior of children when given sugar and when not. This does not dispel myths about sugar intake and behavior, and personal stories abound that relate sugar intake to behavior problems, and not just in children. The best thing to remember is that all of us, including children, need to have healthy diets and a high sugar diet is not promoting health. Children who are undernourished and malnourished may have concentration problems in school and elsewhere. Most of us get "cranky" when hungry.

Sugar and Obesity

Some people consume too many calories because sugar-containing foods are tasty and many are calorie dense, along with also being high in fat. In that sense, there may be some people who are "obese" because they have excessive sweet tooth problems. Most sugar calories are just like any other calories -- all excess calories are converted to fat and stored. It is regrettable that apart from some who have medical metabolic disorders, obesity for most is directly related to consuming more calories than used, no matter what the source of calories.

However, the increasing consumption of high fructose corn syrup (HFCS) (see above) has been linked to the growing rates of obesity and type II diabetes according to the *American Journal of Clinical Nutrition* (2004). Large amounts of HFCS impair blood sugar control and may stimulate appetite.

Lactose intolerance

Lactose intolerance results when the enzyme lactase is not produced, or produced in quantities too low to digest lactose. 70 - 80% of the world's population is affected by lactose intolerance to some extent. Lactose is osmotically active, attracting water resulting in intestinal discomfort and diarrhea. The bacteria in our colon digest the lactose and their by-products add to the intestinal discomfort.

For those who are lactose intolerant, there are ways to consume dairy products that "get around" the lactose problem.

- For many, small amounts of lactose-containing foods can be tolerated without problem. One just avoids large servings of milk products.
- Fermented or processed milk, kefir, yogurt and most cheeses have less lactose. The lactose is fermented in the processing. However, much yogurt has added milk solids that increase the amount of lactose present.
- Some milk, such as Lactaid, has additives that minimize the amount of lactose in the milk. Acidophilus milk has bacteria added that convert the lactose to glucose and galactose. However, they are not active in the cold temperatures used to store milk.
- For those who are seriously lactose intolerant, diet must be restricted.

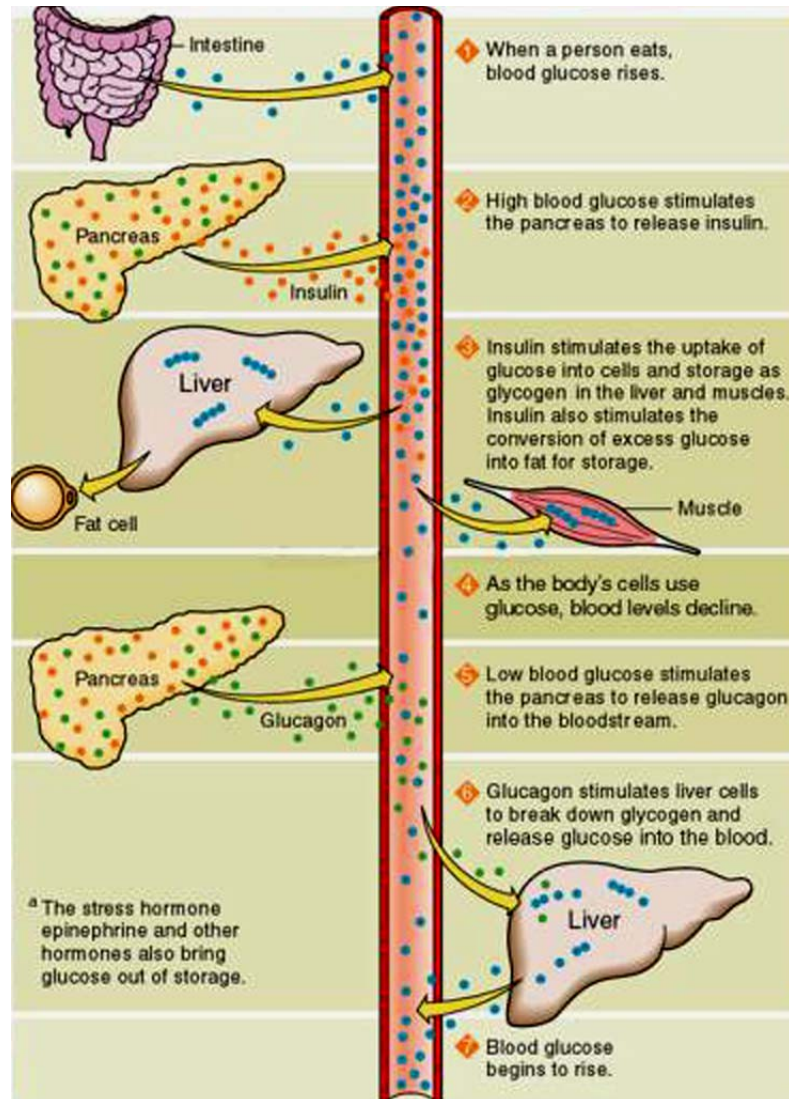
Some people are allergic to proteins found in milk and do not tolerate milk. It is unrelated to lactose intolerance.

Sugar and Blood Glucose Balance

Recall that one of the jobs of the liver is to maintain appropriate levels of glucose in the blood. Simple sugars are rapidly absorbed, so that when taken in a concentrated form they may overload liver/blood glucose levels [short term] with subsequent peaks and valleys in blood sugar as the body compensates. The liver does its job by first, converting glucose to glycogen when too much glucose is in the blood, and converting glycogen to glucose when there is too little glucose.

When there is too much glycogen, excess is converted to fat, as discussed in our first unit. When there is no glycogen, and blood glucose levels are low, amino acids must be converted to pyruvate, which can then be converted to glucose, to supply brain, nervous system cells and red blood cells with glucose. The conversion of amino acids to glucose is known as **gluconeogenesis**, and will use the body's muscle tissue to supply the amino acids. Adipose supplies are mobilized to provide fuel to other cells and tissues when glucose levels are inadequate.

During starvation or fasting, the body's fat reserves are not all converted to fuel fragments. Some combine to form **ketone bodies** that enter circulation at a rapid rate and may accumulate in the blood upsetting the pH balance of blood. This results in a toxic condition called **ketosis**. (Alcoholics are also prone to ketosis, as are some diabetics.)



Blood Glucose out of Balance: Hypoglycemia and Diabetes

Some people have medical conditions in which blood glucose levels can not be maintained at appropriate levels. The two most common are **hypoglycemia** and **diabetes**. Sugar does not cause these conditions; however, the body does not properly regulate blood glucose levels, so that sugar intake and the blood glucose response to foods can be important in controlling the symptoms of these diseases. The blood glucose response to the foods we eat is known as the **glycemic effect**.

Glycemic Index

Everyone has individual variations in "handling" sugars. The rate of digestion and absorption of sugars in foods is known as the **glycemic index**. Foods whose sugars are readily digested and absorbed have a high glycemic index. Foods with slow rates of absorption have a low glycemic index.

Generally foods high in concentrated sugars have a high glycemic index and foods with complex carbohydrates have a lower glycemic index. Unfortunately, this is not always true, and when true for one person may not be in a second. The glycemic effect of any given food measured in a laboratory will be different depending on other foods consumed in the same meal that affect the overall rate of digestion and absorption. Two foods with the same sugar content may have very different glycemic effects, and be different for two different people.

Moderating the rate at which glucose is absorbed from the intestine can be beneficial for those who are insulin resistant or for diabetics, in particular. Some studies indicate that a diet with a low glycemic index improves metabolism of lipids as well as carbohydrates.

Although some books advocate using the glycemic index of foods to determine which foods to include or restrict from one's diet, the rate of digestion and absorption varies so much individually **and** with the other kinds of foods consumed at the same time, the glycemic index is not the most reliable way to monitor one's sugar consumption or a way to choose which foods to eat for optimal health.

It's far better to choose carbohydrate-containing foods that are nutrient dense and fiber-rich to moderate digestion and absorption. Restricting healthy, nutrient dense foods does not promote health or appropriate weight. Consuming foods that are high in sugars that are not nutrient dense, no matter what their glycemic index is not health-promoting and may stimulate some to overeat.

Of most concern to health is that people will (and are) restricting all carbohydrates in the diet rather than choosing healthy carbohydrate containing foods with fiber and nutrients that promote health. This includes learning about foods that promote more rapid absorption of sugars, and including those foods in meals that also contain other foods that affect total rate of digestion.

Hypoglycemia

Moderate hypoglycemia (as well as hyperglycemia) occurs naturally as a result of how the body processes and regulates blood glucose levels. People differ in their sugar sensitivity, and most of us experience occasional reactions to sugar. If the individual reaction is serious, medically supervised dietary remedies are in order.

Fasting hypoglycemia, which occurs when the body's glucose reserves are depleted, may cause headache, fatigue, and confusion. Symptoms are usually alleviated by eating, which will restore the body's sugar levels.

For some people, the low level of glucose in the blood produces symptoms similar to those of an anxiety attack: weakness, sweating, rapid heart rate, hunger and shakiness. In more serious cases, called **reactive hypoglycemia**, the transitions are so uneven that memory, thought processes, and psychomotor activity can be impaired. Reactive hypoglycemia can only be identified through medical testing.

The symptoms experienced in hypoglycemia are common to some other conditions such as:

- Psychological stress shares many of the hypoglycemia symptoms.
- Multiple sclerosis shares many symptoms.
- Other circulatory or respiratory problems that slow glucose delivery to the brain will have similar symptoms.

As a side note, eating lots of concentrated sugars may result in dehydration since glucose is osmotically active and excess levels of glucose can be excreted through the kidney, taking water with it. Headaches are common when dehydrated.

Diabetes

Diabetes, or diabetes mellitus, is a disease in which the pancreas either does not produce adequate (or any) insulin, or the insulin produced is ineffective.

Type I diabetes occurs when the pancreas does not produce insulin. It is most commonly diagnosed in children, and is a life-long disease. There may be a genetic component, along with immune system malfunction, virus infection or toxins contributing to the failure of cells of the pancreas to produce insulin. Insulin must be provided as a treatment, and diabetics must monitor blood glucose levels carefully to balance insulin intake. Insulin is provided by injection.

Type II diabetes results when cells insulin receptors do not recognize insulin, and remain unresponsive to glucose uptake. Type II diabetes used to be considered a disease of older people, but is now showing up in teens and young adults. Obesity is a leading contributor to type II diabetes. Weight control is a major factor in treating type II diabetes.

We will discuss diabetes in our section on diet and health but it doesn't hurt to mention some of the ways in which diabetes can be managed here:

- Eat balanced meals and control the consumption of concentrated sugars
- A diet high in whole grain carbohydrates manages digestion and absorption of glucose to provide a slow, but steady release of glucose into the blood.

Diabetes promotes destruction and blockage of blood vessels that may lead to:

- Circulatory malfunction including stroke and cardiovascular disease
- Blindness
- Kidney disease
- Nerve damage
- Gangrene in tissues with resultant amputations

Sugar Substitutes (Artificial Sweeteners and Sugar Replacers)

Before we leave carbohydrates, many choose to cater to their sweet tooth by choosing foods that do not contain sugar, but instead are "sweetened" with a non-carbohydrate substance, or, in some cases, a sugar alcohol. There are a number of reasons why some people choose to use sugar substitutes. Some diabetics use sugar substitutes as a way to have something sweet without risking glucose imbalance. Some think they will reduce calorie consumption by choosing "sugar-free" foods. Some also think that foods advertised as not containing sugar are healthier, but many of these foods do contain sugar, have as many calories, but the sugar they contain is simply not added sucrose. It's some other added sugar. Some also use sugar-free foods as a way to lower calorie consumption so they can have more calories of other kinds of foods. Some don't even know the food they are choosing is sweetened with a sugar substitute.

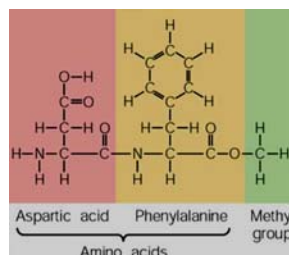
Prior to the 1980's few foods were sweetened with sugar substitutes. One could purchase saccharin tablets or syrup, and for a while the sweetener, cyclamate. But the individual consumer added the **saccharin** or **cyclamate** to foods and beverages. Neither was used in cooking or packaged products to speak of. Some foods were made with fructose rather than sucrose and sold as "sugar-free". Sugarless gum was available that contained sugar alcohols, which do not promote dental caries. Then came **aspartame**. Today we have thousands and thousands of foods that contain the sweetener aspartame, along with foods containing two other sugar substitutes: **acesulfame-K** and **sucralose**. Others are being developed for market.

Let's look at some of our sugar substitutes

Saccharin

- Saccharin is a known carcinogen exempted from the Delaney Act by legislative action. Numerous studies indicated that the amounts ingested are low enough to not promote human cancers, except maybe for heavy smokers who also use saccharin in large amounts.
- Saccharin was removed from the list of carcinogens in 2000 and warnings are no longer required on foods that contain saccharin. The National Cancer Institute still warns of saccharin risks for those who consume more 6 packets of saccharin sweetener daily or 16 ounces on diet beverages containing saccharin.
- The amount of saccharin in use and in food products today is small. It is found in some toothpastes as well.

Aspartame (NutraSweet)



- Aspartame technically is a sugar replacer since it contains calories and is digested. Aspartame is composed of two amino acids: phenylalanine and aspartic acid, along with a bonded methyl group, whose bonded molecular shape triggers our sweet taste buds with about 200 times the intensity of sugar. Very small amounts of aspartame can be used to sweeten foods and beverages, so in reality, it contributes few if any calories or nutrients to our bodies.
- Aspartame is heat and time unstable, limiting its use in products that are cooked.
- Aspartame is found in thousands of products, with diet sodas in the lead.
- We currently consume about 14 pounds per person per year in United States. Adults and children alike consume aspartame-sweetened foods and beverages.
- Those who have the genetic disorder, **phenylketonuria**, cannot tolerate intake of any phenylalanine beyond what is absolutely needed for growth and development. Their diets are so restricted that they cannot afford to consume anything that is not essential. And aspartame-sweetened foods add phenylalanine to their diets without the other critical vitamins and minerals they must consume.
- Reports of headaches from consuming aspartame have been studied but controlled studies have failed to demonstrate this. People who think they are sensitive to aspartame can avoid its use.

Digestion of Aspartame

Aspartame digestion produces the two amino acids, which can be absorbed, plus methyl alcohol. The methyl alcohol is converted to formaldehyde which is oxidized to form CO₂. Many foods contain or produce as digestion products methanol, and use the same pathway to convert the toxic methanol and formaldehyde.

Heat and acid breakdown of aspartame form **diketopiperazine**, but the amounts known to form have been tested and shown not to be harmful. There is also no evidence that aspartame affects neurotransmitter proteins or causes migraine headaches.

Acesulfame potassium or Acesulfame-K (Sunette)

- Acesulfame-K is, like aspartame, 200 times sweeter than sugar. Its structure is similar to saccharin. It is not digested or absorbed.
- Acesulfame-K was approved by the FDA for gum, drink mixes, puddings, non-dairy creamers, etc.
- Although some rats used in tests formed tumors, the FDA ruled that tumors formed were similar to tumors rats normally get in any rat study, and not caused by the test substance.
- It is on the CSPI list of inadequately tested products and they recommend against its use for that reason.

Sucralose (Splenda)

- Sucralose is a sucrose derivative in which three of the -OH groups of the sugar have been replaced with chlorine atoms. It is not digestible because we have no enzymes that recognize the chlorinated molecule.
- Sucralose is about 600 times sweeter than sucrose and exceptionally stable.
- Sucralose passed all animal safety tests and is deemed safe to use. It is one of the few sugar alternatives that *Nutrition Action Newsletter* (2004) "graded" as safe to use.

Stevia

- Stevia is a sweet extract from a tropical shrub. We lack enzymes to digest it. The active substance is stevioside.
- Rats fed large doses of stevia had reduced sperm counts and abnormal cell growth in their testes. Female hamsters produced smaller offspring. Based on these studies and absence of other studies that would counter these results, the FDA prohibited the use of stevia as a food additive. The WHO, European Union and Health Canada also do not permit stevia in foods.
- However, stevia can be, and is, sold as an herbal supplement in the United States. Stevia can be purchased and used by consumers as a "nutrient supplement" to sweeten their food in spite of its being prohibited as a food additive.

Other Sugar Substitutes

Cyclamate

Cyclamate approval was removed by the FDA in 1969 after about 20 years of use because a study showed it was a carcinogen. Although no subsequent studies indicate that cyclamate initiates cancers, it may enhance or promote existing cancers, and the FDA is currently maintaining the ban. Many other countries permit cyclamate as a food additive.

Neotame

Neotame is a synthetic derivative of the same two amino acids as aspartame (aspartic acid and phenylalanine, but the bond joining the two is more stable and not broken down during digestion. Animal studies to date have raised no safety issues. It has not yet been added to foods.

Alitame

Alitame is similar to aspartame but uses the amino acid aspartic acid with alanine, and is heat stable. Alitame does not work alone, but enhances the sweetness of other sweeteners. FDA approval is pending.

Tagatose (Naturose)

Tagatose is a stereoisomer of sucrose made from lactose. We lack enzymes to digest it so it's mostly not absorbed. It can cause bloating and gases if consumed in large amounts because our intestinal bacteria can digest it. It's found in few products, mostly 7-11 slurpees made with Diet Pepsi.

Consuming Sugar Substitutes

All products containing aspartame must have a warning label for phenylketonurics. Food labels must list additives, so other sugar substitutes and sugar replacers will be listed on labels. Often the food has large print advertising that it contains no sugar, but that applies to foods that use any sugar other than sucrose as well.

Aspartame is by far the sweetener of choice. Aspartame was originally approved for a maximum of 50 mg/kgm body weight/day. Small children fed lots of diet sodas and sweets sweetened with aspartame may approach that limit. Few adults could unless they were drinking about 20 diet sodas daily.

Each of us can choose whether to consume foods with sugar substitutes or foods sweetened with natural sugars. In any case, we need to also pay attention to our total calorie consumption and the proportion of calories we consume that are from all sugar sources. Sugar-free does not mean low calorie, and definitely does not mean "good for you".