# Carbohydrates

Carbohydrates are often referred to as sugars and starches, or as simple and complex carbohydrates. Examples of starches include grains, corn, rice, barley, vegetables, beans, and wheat, whereas examples of sugars include sweets (candy), sugar (cane sugar), fruit, and milk. Except for lactose (milk sugar) and glycogen (the storage form of carbohydrates in the body), all carbohydrates are plant-derived. Collectively, they are considered the body’s primary fuel source, yet are often labelled as the cause of weight gain. Carbohydrates frequently take a back seat to protein following exercise by those who fail to recognise the importance of this nutrient. Blame for these belief systems can be attributed to misinformation or even misunderstandings.

Although carbohydrates are not considered essential for survival, considering how the body can synthesise the amounts of glucose needed to survive from non-carbohydrate sources, they are generally needed in specific quantities to optimise health and performance. Subsequently, it is important for nutrition coaches to understand the importance of carbohydrates and how they function within the body.

| **Type** | **Examples** |
| --- | --- |
| Starches | Grains, corn, rice, barley, vegetables, beans, and wheat |
| Sugars | Sweets (candy), sugar (cane sugar), fruit, and milk |

## Carbohydrate structure

Although the terms starches and sugars may resonate with the public, practitioners often refer to carbohydrates by their scientific classifications: monosaccharides or single sugar units, disaccharides or paired sugar units, and polysaccharides, which represent longer sugar unit chains. It is the monosaccharides and disaccharides that are collectively known as simple sugars to many.

A smaller subgroup, called oligosaccharides, also exists, containing 3 to 10 sugar units. Polysaccharides and oligosaccharides are known as complex carbohydrates. As humans, we consume all these different forms of carbohydrates. However, our digestive process breaks down our digestible complex carbohydrates to their building blocks: the monosaccharides that are then absorbed into the body. Once absorbed, carbohydrates can be used immediately as a source of fuel or can be stored as glycogen in specific cells. In fact, the largest storage depots for carbohydrates (glycogen) are the muscle and liver cells.

### Monosaccharides

This group of carbohydrates represents single-sugar units and the only absorbable form of carbohydrates. Glucose (sometimes also referred to as dextrin or dextrose), fructose, and galactose represent the three nutritionally important monosaccharides to humans. They are each composed of carbon, hydrogen, and oxygen. Subsequently, they are called hydrocarbons and they have the same molecular structure of C6H12O6. Although assembled with the same number of elements, the orientation of these elements within the molecule renders them uniquely different. Notice the difference in the molecular structure of fructose in comparison to glucose and galactose, which are both similar. This difference helps explain why fructose and glucose are absorbed and function differently in the body. While glucose and fructose are found in many food sources, galactose is only present in dairy products, forming part of the milk-sugar lactose.

d for Thought

Carbohydrates contain the elements carbon, hydrogen, and oxygen. Hydrogen and oxygen form water (H2O), hence the term *hydrate*, which then combines with the carbon atoms (or, if viewed differently, the water molecule hydrates the carbon).

### Disaccharides

Like monosaccharides, disaccharides are also categorised as simple sugars. However, disaccharides are comprised of three nutritionally important molecules: sucrose, lactose, and maltose.

* Sucrose is comprised of one glucose molecule joined with one fructose molecule. Examples include cane sugar, brown sugar, and date sugar. Sucrose contributes as a primary sugar in most fruits.
* Lactose is comprised of one glucose molecule joined with one galactose molecule. It is only found in dairy products.
* Maltose is comprised of two glucose molecules. Examples include corn syrup, brown rice syrup, and black treacle

**Added sugars**

Naturally occurring sugars, such as those found in fruit or milk, are generally considered healthier options because the foods that contain natural sugars also include other important nutrients like vitamins and fibre. Added sugars are those not naturally occurring in food groups and include syrups and other caloric sweeteners found in sweets and sweetened beverages (soft drinks). Added sugars are sugars that are added to foods or food products, not sugars that are naturally contained in the food.

Added sugars include regular (cane) sugar, brown sugar, coconut nectar, date sugar, turbinado, raw sugar cane, and many other aliases for sugar itself. All added sugars, regardless of their source, are either monosaccharides or disaccharides that contain glucose, fructose, or galactose.

|  |  |
| --- | --- |
| Raw, brown, and white sugar (sucrose)  Corn sweetener and syrups  Malt syrup  Turbinado sugar  Rice syrup  Date sugar  Glucose  Fructose  Lactose  Maltose | Honey  High fructose corn syrup  Invert sugar  Trehalose  Maple sugar or syrup  Caramel  Agave sugar  Dextrose  Dextrin  Molasses |

Elevated levels of insulin in circulation may desensitise the body’s insulin receptors embedded within the membranes of a cell. This can advance the likelihood of developing insulin resistance, which reduces the body’s effectiveness of moving glucose out of the blood and into cells. In turn, this might increase the potential for moving toward the onset of conditions that lead to diabetes and prediabetes (early-stage diabetes). Effective ways to preserve insulin sensitivity include managing sugar and total carbohydrate intakes and remaining physically active. A regular regimen of activity helps resensitise these insulin receptors.

### Oligosaccharides

This small and less-frequently discussed group of polymer saccharides falls under the label of complex carbohydrates, but generally contains between only 3 and 10 sugar units. These partially-digestible polymers are found in legumes (e.g., peas, lentils, or beans) and plant sources; contain glucose, fructose, and/or galactose; and are touted for health-promoting benefits. Oligosaccharides are largely resistant to digestion because the human digestive tract lacks the necessary enzymes that can chemically break down many of these structures. This allows them to pass to the large intestine where intestinal bacteria act on them.

In fact, certain enzymes derived from intestinal bacteria may produce oligosaccharides from ingested starches and sugars. They essentially serve as food for our large intestinal bacteria and are also referred to as prebiotics. This category includes fructo-oligosaccharides (FOS), galacto-oligosaccharides (GOS) and inulin, which is extracted from chicory root. Sources of FOS include Jerusalem artichoke, leeks, onions, and asparagus, while examples of GOS are soybeans and human breast milk, which can support a healthy immune system in infants. Raffinose, stachyose, and verbascose, all found in beans, peas, and other vegetable sources, contain these three monosaccharides in the chemical structure.

| **Category** | **Examples** |
| --- | --- |
| Fructo-oligosaccharides | Jerusalem artichoke, leeks, onions, and asparagus |
| Galacto-oligosaccharides | Soybeans and human breast milk |
| Inulin | Chicory root, sugar beets, leeks, asparagus, and banana |

### Polysaccharides

Polysaccharides are also complex carbohydrates and comprise starches, fibres and glycogen. Each contain long-chain glucose structures of more than 10 units, but they can be as large as several thousand units (e.g., glycogen molecule). Polysaccharide chains are arranged as straight-chain structures called amylose, branched-chain structures called amylopectin, and as a block structure called fibre. Both amylose and amylopectin are digestible and make up approximately 20% and 80% of the digestible starches found in vegetables, grains, pasta, rice, and beans, respectively. Because enzymes digest from open ends of a structure, amylopectin will digest to the absorbable monosaccharide form of glucose faster than amylose. This raises the question to the implications of complex carbohydrates containing more amylopectin versus amylose.

Greater levels of amylopectin result in a faster and a greater spike in blood sugar than a similar compound with more amylose. Not only does this have repercussions with respect to changes in blood sugar, but it explains why not all complex carbohydrates rate low on the glycaemic index (GI). Interestingly, because fibre has no open ends, it cannot be digested in the human intestine by digestive enzymes.

**Fibre**

Although fibre represents most of the indigestible portions of plant food, it is not a single compound. It is a group of compounds that share similar characteristics and are generally classified as either soluble or insoluble. Examples of soluble fibre include pectins, gums and mucilages that originate from the inside of the plant cell. They are called soluble because they either dissolve or swell when placed in water and most can be digested by the bacteria living within the large intestine. Therefore, they are also sometimes called fermentable.

Soluble fibres are found in oat bran, oatmeal, beans, fruits (e.g., apples or pears) and vegetables (e.g., artichoke, leeks, or sweet potatoes), as well as in many commercial products like salad dressings, jams, and jellies. They offer several benefits that include the following:

* Weight loss — It can delay gastric emptying (from the stomach) and it promotes an overall feeling of fullness, thereby potentially reducing caloric intake.
* Reducing risk for cardiovascular disease — It can bind to cholesterol particles. It can prevent its absorption and help remove this compound from the body.
* Bowel movement and intestinal health — It attracts water and it promotes bulk to the stool, which can safeguard against constipation.
* Diabetes protection — This carbohydrate is not absorbed. It can, therefore, reduce potential blood sugar spikes.
* Improved absorption of foods — It slows the movement of food through the small intestine. It can enhance nutrient absorption.

Insoluble fibre (water insoluble) forms the structural parts of plants and include compounds like cellulose, hemicellulose and lignin, and is often found in the outermost portion of grains, vegetables, fruits and seeds (e.g. whole-grain wheat, celery, brown rice, quinoa, apple peels or broccoli). They are called insoluble or non-fermentable because they do not dissolve in water and are not easily digested by intestinal bacteria. When many of these compounds have their outermost portions removed, this is what produces a processed starch (e.g., whole-wheat kernel to white bread or brown rice to white rice).

Like the soluble fibres, insoluble fibre also provides many health benefits that include the following:

* Digestive health — It adds bulk and draws water into the GI tract. It improves regularity in the large intestine to avoid constipation and other bowel-related health problems (e.g. haemorrhoids).
* Reduces risk of cancer—It improves movement through the large intestine. It reduces the risk of colon cancer and other large intestinal diseases (e.g. diverticulosis).
* Weight loss — By delaying gastric emptying (from the stomach), it promotes an overall feeling of fullness, reducing caloric intake.

If a food is listed as a good source of fibre, it may contain insoluble fibre, soluble fibre, or both. See Table: Soluble and Insoluble Fibres for examples of soluble and insoluble fibre foods sources and potential health benefits.

| **Fibre Type** | **Food Sources** | **Health Benefits** |
| --- | --- | --- |
| Soluble | Oat bran  Oatmeal  Beans  Apples  Pears  Certain vegetables (e.g., artichoke, leeks, or sweet potatoes) | Lower total LDL cholesterol (may decrease risk of heart disease)  Possible weight loss  Improved bowel movement and intestinal health  Potential diabetes protection  Improved food absorption |
| Insoluble | Whole-grain wheat  Celery  Brown rice  Quinoa  Apple peels  Broccoli | Enhanced digestive health  Reduced risk of cancer  Possible weight loss |

In their natural growing state, whole grains consist of the entire seed, known as a kernel. The kernel consists of three parts: the bran, germ, and endosperm. The bran is the outermost layer of the kernel and is designed to protect the kernel from the environment. It contains B vitamins, antioxidants, and fibre. The germ is the embryo of the kernel and contains B vitamins, minerals, some protein, and healthy fats. The endosperm is the largest portion of the kernel. It contains starchy carbohydrates, some protein, and small amounts of vitamins and minerals. During most refining processes, the bran and germ are removed from the kernel. As such, much of the fibre and nutrients are lost. Examples of this process including removing the outer layer of a whole-grain kernel to convert brown rice to white rice.

Functional fibre is a compound derived from isolated, indigestible carbohydrates to supposedly provide some of the physiological benefits that naturally occurring fibres provide to humans. These commercially available and man-made compounds like polydextrose and inulin are popular in many foods, but whether they offer the same health-promoting benefits as natural fibre remains to be determined.

**Glycogen**

Glycogen is the storage molecule of glucose in animals, similar to how starch is the storage form of carbohydrates in plants. It is a large molecule with a pinwheel orientation centered around a protein core (glycogenin), and it can range from 100 to over 30,000 glucose units. It is important to note that there is no fructose in glycogen; only glucose molecules are used to form glycogen. It has a highly branched structure, which allows enzymes to rapidly break the molecule apart as needed during glycogenolysis. The formation of glycogen (glycogenesis) occurs under action of glycogen synthase, an enzyme that is most active immediately after meals and after exercise.

Although muscle tissue contains significantly more stored glycogen than the liver, this glycogen is not available to help preserve blood glucose during times when blood sugar levels decrease. This is because muscles cells, unlike liver cells, lack a specific enzyme called glucose 6-phosphatase, which helps create a free glucose molecule from glucose 6-phosphate, a compound that is formed when stored glycogen is broken down for energy.

Carbohydrates are found in three distinct locations within the body. A small amount of glucose located in the blood is needed for distribution to all parts of the body (e.g., brain and central nervous system, which both prefer glucose as a fuel). A moderate amount of glycogen is stored in the liver, which is needed to preserve blood sugar. Lastly, large quantities of glycogen are stored in muscle tissue, which serve to fuel muscular work. What about the heart and other organs? An important distinguishing factor between liver and muscle glycogen is the fact that the liver is the only organ that can release glucose into the blood. Once glycogen is formed in a muscle cell, it is trapped and cannot be released into circulation. This concept has important implication in normal metabolism, fasting states, and during exercise.

Normal carbohydrate storage in muscle cells is approximately 15 grams per kilogram (6.8 g/lb.) of muscle tissue. Considering how muscle comprises approximately 30% of a woman's mass and close to 40% of a man's mass, this averages somewhere between 250 and 600 grams (1,000 to 2,400 kcal) in muscle tissue. Liver cells store approximately 50 grams per kilogram (22.7g/lb.) of tissue, and, considering how the liver weighs approximately 1.5 to 2.5 kg, this totals about 75 to 125 grams (300 to 500 kcal).

By comparison, blood glucose stores are small, ranging between 3 to 5 grams in a small adult, to about 10 to 15 grams in a very-large male. The average adult stores around 2,000 to 2,500 kcal, whereas an endurance athlete can expand their storage capacity to over 3,000 kcal. It is estimated that an average adult will burn about 100 kcal/mile (1.6 km); therefore, the amount of glycogen stores in the body would cover about 20 miles (32 km).

### Summary of carbohydrate classifications

Carbohydrates follow a sequential classification system derived from the number of sugar units contained within the structure or chain. Although humans may ingest a variety of different carbohydrates (e.g., starches and sugars), the digestive process breaks them down into their individual building blocks (called monosaccharides), which represent the only absorbable form of carbohydrates to the body.

### Carbohydrate roles within the body

The primary role of dietary carbohydrates is to provide energy for the body. Any excess carbohydrates not used for immediate energy production can be stored as glycogen within the muscle and liver. Because the liver is capable of releasing glucose into circulation, it helps regulate blood glucose and insulin metabolism, which helps avoid or manage diseases like diabetes and metabolic syndrome. Should there be additional carbohydrates, it is possible for this excess (i.e. beyond what the body can store as glycogen) to be converted to fats called triglycerides. Given this effect, carbohydrates could play a minor role in indirectly regulating some fat production. Furthermore, balanced levels of glucose and insulin also assist with regulating circulating levels of other hormones like testosterone and the thyroid hormones.

“The presence of adequate amounts of carbohydrates can spare the body’s need to catabolise (break down) muscle tissue.”

The physiological pathway of fat metabolism involves a carbohydrate by-product for complete metabolism. When insufficient quantities of this specific carbohydrate byproduct exist, the partially degraded fat fragments are converted to ketones and metabolized differently. In situations of inadequate carbohydrates, the body can produce glucose from certain non-carbohydrate sources, including specific amino acids (via gluconeogenesis) that are almost exclusively derived from muscle tissue. Therefore, the presence of adequate amounts of carbohydrates can spare the body’s need to catabolise (break down) muscle tissue. The body can also make glucose from fatty acids, if needed, particularly when consuming a high-fat, very-low carbohydrate diet. Remember, the brain requires glucose to function and will ultimately do whatever is needed to function; in this case, it makes glucose from non-glucose sources.

Lastly, as mentioned earlier, soluble and insoluble fibres provide many health benefits ranging from enhanced rates of weight loss and reduced cholesterol, to enhanced digestive health and reduced risks of developing cancer.

**Carbohydrate digestion and absorption**

Carbohydrate digestion begins in the mouth because of salivary amylase, an enzyme released by the salivary glands. Salivary amylase starts the digestive process by cleaving large-chain polysaccharides into smaller segments. The physical process of chewing food and adding fluid volume (i.e., saliva) to solid food facilitates digestion by increasing its surface area. In simpler terms, an individual’s own saliva along with chewing helps break down carbohydrates. It also facilities the action of swallowing food to pass it to the stomach. This small, rounded mass of food that is swallowed is known as bolus.

In the stomach, food mixes with gastric juices and the high acidity of stomach contents continue the digestive process. However, on leaving the stomach and entering the duodenum of the small intestine, this chyme is neutralised by sodium bicarbonate released from the pancreas, so that pancreatic amylase can continue the digestion of carbohydrates in the jejunum.

In the jejunum, the digestible carbohydrates are further broken down to disaccharide and monosaccharide forms, which then move to the latter portion of the small intestine, the ileum, where most carbohydrates absorption occurs. While the monosaccharides are in their absorbable form, the disaccharides still need to undergo further digestion to single sugar units, which takes place within the brush border of the intestinal wall. The walls of the small intestine contain many finger-like projections called villi, each with even smaller projections called microvilli that collectively increase the region’s surface area to enhance nutrient absorption. The absorptive cells within the brush border release specific enzymes to digest any remaining disaccharides to their monosaccharide form.

Some individuals are lactose intolerant, implying that they are unable to digest lactose, or milk sugar, due to a lactase deficiency or insufficiency. Because of the body’s inability to digest lactose, the intestinal bacteria digest this carbohydrate, resulting in bloating, diarrhoea, gas, nausea, and pain in the abdomen. A primary cause of lactose intolerance is genetic inheritance. In some individuals, the small intestine begins to make less lactase after infancy and continues to decrease with age, a condition called lactase non-persistence. Symptoms associated with this lactose intolerance may not begin until later in childhood, the teenage years, or even until adulthood. Individuals who are lactose intolerant can opt to avoid dairy products, consume lactose-free dairy products, or take a tablet containing the lactase enzyme before ingesting any dairy.

Once all digestion is complete, the monosaccharides are then absorbed by the absorptive cells into the intestinal wall. Glucose and galactose, however, are absorbed via a different process than fructose. This process results in glucose and galactose being absorbed into the body at a faster rate than fructose.

Once absorbed, all monosaccharides enter the hepatic portal vein for transportation to the liver. Priority number one for carbohydrates is to serve as an immediate fuel, so glucose or fructose can be used by the liver or pass into circulation for delivery to any target cell. Because galactose only contributes marginally to overall carbohydrate intake, it will not be discussed. Glucose feeds directly into the energy pathways, while only about 35 to 45% of the absorbed fructose is oxidised in the energy pathways.

When the immediate fuel needs are met, priority two for the surplus of carbohydrates (i.e., glucose or fructose) is to replenish liver and muscle glycogen. Glucose molecules combine to build larger glycogen chains, whereas approximately 40 to 50% of the fructose taken into the cell becomes converted to glucose for glycogen synthesis. Interestingly, while the body’s absorbed fructose is either oxidised or converted to glucose, the balance is converted to either lactate (about 30%) or to triglycerides (fats) (<1%). While the conversion to triglycerides is small, it has raised health concerns, especially with the liver. A prevailing belief involving fructose accumulation in the liver is its conversion to fat that becomes stored within this organ. A significant collection of fats in the liver can damage liver cells, much like what happens with the disease cirrhosis.

This disease is called non-alcoholic fatty liver disease (NAFLD), a condition demonstrating greater significance in inactive people who consume large amounts of fructose (and overall energy) in their diet. Fructose intakes need to be consumed in quantities over 100 grams (3.5 ounces) a day for there to be any measurable detriment to human health. In juxtaposition to this, the average American consumes roughly 55 grams (1.94 ounces) of fructose per day, so just under half of what is considered a problematic intake. So, all the data points toward excess energy intake, not fructose per se, are the leading cause of NAFLD.

### Hormonal regulation of glucose

Two primary hormones, insulin and glucagon, are responsible for preserving blood glucose.

* Insulin is a hormone released from the pancreas. Although insulin has many important physiological roles in the body with respect to carbohydrates, it serves to lower blood sugar levels and prevent hyperglycaemia by facilitating glucose uptake into the liver, muscle and fat cells (for lipogenesis or fat building). In other words, insulin escorts glucose in the blood to the liver, muscle, and fat cells. In the liver cell, it inhibits the release of glucose into circulation. In cells, it promotes glycogenesis and inhibits gluconeogenesis. It is also involved in amino acids and fatty acid uptake into cells.
* Glucagon is a hormone also released from the pancreas. Its functions are essentially the opposite of insulin. It serves to raise blood sugar levels during periods of hypoglycaemia by facilitating glucose release from the liver into circulation. In other words, glucagon is the hormone responsible for telling the liver to release glucose into the bloodstream. It promotes glycogenolysis and gluconeogenesis, and it also inhibits lipogenesis.

**At rest**

The mechanism by which insulin works to move glucose into a cell involves a secondary messenger because insulin cannot physically enter a cell. Insulin is protein based and cell membranes are fat-based, essentially repelling anything that is water soluble, like protein. Therefore, insulin, acting like a key, binds to specialised receptors, acting like locks that are embedded within the cell membrane. This hormone-receptor complex activates pathways inside the cell (i.e., secondary messengers) that open special channels to allow for the entry of glucose into the cell. This functionality, however, is largely dependent on the availability of adequate amounts of insulin and the sensitivity of the receptors to recognise insulin.

In a healthy body, glucose in circulation enters the pancreas and stimulates those beta-cells to release insulin. Once in circulation, insulin will push excess glucose into cells and restore normal blood sugar levels. The liver (primarily) and kidneys collectively start to absorb insulin out of circulation and break it down to stop blood sugar levels from dropping too low. Anytime an individual enters states of hypoglycaemia, glucagon is released from the pancreas and travels to the liver, where it releases stored glycogen to restore normal blood sugar levels.

Insulin production is dependent on the biological status of those beta-cells in the pancreas. In some individuals, these cells may stop producing insulin, perhaps due to some genetic variant or an autoimmune response. In this case, the individual relies on exogenous insulin from a pump or injection, and is diagnosed with Type 1 diabetes. Insulin’s ability to function at the cellular level depends on the receptors ability to recognise the hormone (i.e., receptor sensitivity). A physically inactive lifestyle, coupled with overconsumption of energy (e.g., too many calories), can ultimately decrease receptor sensitivity to insulin, leading to insulin resistance, and, ultimately, Type 2 diabetes. In fact, Type 2 diabetes represents about 90% of all diabetes cases throughout the world.

Two of the most important therapeutic modalities for Type 2 diabetics are weight loss, if necessary, and regular participation in physical activity because it resensitises the cell receptors. In fact, weight loss equivalent to 10% of overall body weight is enough to substantially reduce the risk of developing Type 2 diabetes, and among people with Type 2 diabetes, similar weight loss dramatically improves the disease.

**During exercise**

During exercise, hormonal regulation of blood sugar becomes a little more complex. The presence of exercising hormones like norepinephrine and epinephrine (adrenaline) in circulation bind to receptors in the pancreas to inhibit much of the production of insulin. This occurs because exercise is a catabolic event that relies on the release of stored energy to use for work, and insulin is an anabolic hormone that normally functions to build energy stores and prevents their breakdown or release. In other words, exercise and circulating insulin are not events that can or should happen simultaneously.

If insulin is suppressed during exercise, yet needed to move glucose into cells, then why do individuals ingest carbohydrates (e.g., drinks or food) during exercise?

As discussed, certain cells like muscle, liver, and fat cells rely on that insulin-mediated glucose uptake (IMGU) pathway for moving nutrients into the cell during resting conditions, but when insulin production and release is suppressed (i.e., during exercise), these cells rely on a second, non-insulin mediated glucose uptake (NIMGU) pathway to help move glucose into the cell. During exercise, this pathway can increase glucose uptake rates into the cell significantly (i.e., more than the IMGU pathway), which can lower blood sugar levels if it is not carefully managed.

During exercise, epinephrine, norepinephrine and glucagon levels all increase to stimulate glycogenolysis and glucose release from the liver into the blood. But accelerated glucose uptake into muscle cells can pose a major problem if blood glucose levels drop too much. Remember, red blood cells can only use glucose as a fuel and they rely exclusively on blood glucose as that fuel. Cortisol is tasked with preserving both blood sugar and liver glycogen, considering how the liver is the only organ that can release glucose into circulation. Under scenarios of prolonged exercise, glycogen depletion, or carbohydrate or caloric restriction, cortisol levels elevate to preserve liver glycogen, which, in turn, preserves blood sugar. Cortisol stimulates lipolysis to slow carbohydrate utilisation rates, but it also strives to produce much-needed glucose via gluconeogenesis. It derives its substrate for conversion from various sources, but primarily from amino acids that originated as muscle tissue, or from protein food sources, if they are ingested around the same time the glucose manufacture occurs (e.g., during exercise).

### Glycaemic index

It was previously discussed how excessive energy intake can elevate insulin, which can desensitise insulin receptors embedded within the cell membranes, and how this advances the potential for insulin resistance, pre-diabetes, or perhaps even Type 2 diabetes. But, do all carbohydrates exact the same toll on the body by virtue of their insulin response? The answer is no. To help understand the uniquely different effects of each carbohydrate source, one needs to understand the concept of glycaemic index.

The glycaemic index (GI score) is a relative ranking of a food’s effect on blood glucose (blood sugar) 2 hours after the consumption of that food. The scoring index assigns a value of 100 to represent glucose, the reference food for this ranking system. A score of 50 would essentially reflect a food that elevates blood sugar at half the rate of glucose. Low GI foods are classified as foods with scores under 55, medium GI foods are classified as foods with scores between 56 and 69, and high GI foods are classified as foods with scores above 69. There are some key observations to note:

* Not all simple sugars have high GI scores (e.g. fructose or sucrose). Fructose is absorbed more slowly and needs conversion to glucose in the liver. This subsequently lowers its GI score.
* Not all complex carbohydrates have low GI scores (e.g. instant rice, instant mashed potatoes or cornflakes). Removing fibre can increase a food’s GI score.

| **Food** | **GI Score** | **Food** | **GI Score** |
| --- | --- | --- | --- |
| Glucose | 100 | Hamburger bun | 61 |
| Baguette (white, plain) | 95 | Raisin Bran® cereal | 61 |
| Hard Candy | 90–100 | Sweet potato | 60 |
| Baby carrots | 92 | Honey | 55 |
| Rice (instant) | 91 | Snickers® Bar | 55 |
| Gatorade® (U.S. formula) | 89 | Oatmeal (steel cut) | 55 |
| Potato (instant, mashed) | 87 | Tortilla (corn) | 52 |
| Pretzels | 83 | Quinoa | 53 |
| White potato (boiled) | 82 | Orange juice, Oranges | 50 |
| Cornflakes cereal | 81 | Brown rice (steamed) | 50–55 |
| Oatmeal (instant) | 79 | Banana | 30–55 |
| Donut (plain) | 75 | Carrots | 47 |
| French fries | 75 | Sponge cake (plain) | 46 |
| Graham crackers | 74 | Chicken nuggets (frozen) | 46 |
| Soda crackers | 74 | Peach | 42 |
| Cream of Wheat® (instant) | 74 | Spaghetti | 42 |
| Corn chips | 72 | Apple juice | 41 |
| White rice (boiled) | 72 | Baked beans | 40 |
| Saltine crackers | 70 | Strawberries | 40 |
| White bread | 70 | Apple | 36 |
| Watermelon | 70-80 | Kidney beans | 34 |
| Bread (whole wheat) | 69 | Milk (all varieties) | 31 |
| Special K® cereal (U.S. formula) | 69 | Tortilla (wheat) | 30 |
| Popcorn (microwave) | 65 | Grapefruit | 25 |
| Sucrose (sugar) | 65 | Fructose | 18 |
| Macaroni and cheese | 64 | Peanuts | 13 |
| White rice | 64 | Agave | 11 |
| Raisins | 64 | Hummus | 6 |
| Cola | 63 | Sugar alcohols (non-caloric sweetener) | 3 |

As illustrated, the GI score ranking is not as simple as distinguishing simple from complex carbohydrates. Many factors can affect a food’s GI score. Examples include the following:

* Monosaccharide form — glucose versus fructose
* Polysaccharide form — amylopectin versus amylose
* Food form (liquid versus solid) — Foods leaving the stomach generally have a semi-liquid, gooey consistency (e.g. like cream of wheat). Solid foods will, therefore, remain in the stomach longer until they reach that consistency. However, semi-liquid (smoothies or pulp) or liquid forms of food (juicing) empty the stomach much faster.
* Degree of processing and cooking — This alters GI scores in both directions. Separating nutrients from fibre during cooking (boiling) can raise GI scores while making starch more resistant via repeated heating or cooking can lower GI scores (e.g., reheating pizza where it becomes rubber-like).
* Presence of other nutrients (e.g. fibre, protein or fats) — This slows gastric emptying and digestion, which lower the food’s GI score.
* Human variability in digestion and absorption

All being said, there are many limitations to implementing GI in practice because most people rarely eat many of these foods alone and instead enjoy a mixed meal (e.g., peanut on bread or milk with oats). Furthermore, considering how GI demonstrates varied responses among people, and how it has limited clinical applicability as a stand-alone score for a single food, it should be used with caution.

Another consideration overlooked with GI scores relates to the quantity of a carbohydrate food consumed, which can influence blood sugar responses. While GI scores rank the effect of a carbohydrate sample on raising blood glucose, glycaemic load (GL) also considers the quantity of the food consumed. Because both GI and the amount of the carbohydrates consumed influence overall blood sugar responses, consideration of their collective impact should theoretically provide a better estimate of how much insulin might be needed to correct a blood sugar response.

As an example, examine baby carrots, which have a GI score of approximately 92 versus corn which has a GI score of approximately 60. If examined alone, logic dictates that carrots would require more insulin to correct. However, if only six grams of carrots were eaten, but 20 grams of corn was eaten, the amount of insulin needed for corn might be greater. A method for calculating GL exists, but there is no universal consensus among experts on the validity and significance of calculating numerical GL scores.

Recent evidence has also come out to suggest that both the GI and GL may not be overly reliable. In a recent study, it was demonstrated that each person has a substantially different response to the same foods. For example, in this study, giving two different people a slice of bread yielded completely different glycaemic responses. One person had a very large spike in blood glucose, while the other person had virtually no spike in blood glucose. The same thing occurred when they fed different people ice cream (Zeevi et al., 2015). This suggests that while GI and GL may help us better understand foods, they may not be overly robust tools to use for every client.

### Current versus recommended intakes

The recommended dietary allowance (RDA) for carbohydrates for adults aged 19 years and older is set at 130 grams per day (U.S. Department of Health and Human Services, U.S. Department of Agriculture, 2015). Generally, this is considered the minimum amount needed to maintain normal metabolism and utilisation of fuels. However, the Acceptable Macronutrient Distribution Range (AMDR) for carbohydrates is set at 45 to 65% of the total caloric intake daily, which might be at least double the RDA.

This means that if a person was consuming 2,400 calories daily, carbohydrates should represent 1,080 to 1,560 calories of that total (45 to 65%). Considering how four calories equals one gram of carbohydrates, this would amount to 270 to 390 grams a day, values that far exceed the minimal RDA. This demonstrates the confusion with having and following multiple guidelines, because 130 grams and over 270 grams represent a significant differential in calories.

**Current intakes**

Although the average intake of carbohydrates in the American diet represents approximately 47.4% and 49.6% of total calories for men and women, respectively, it is the absolute or total amount of food ingested that is too high, representing a surplus of calories in our diets. One could also argue that perhaps the choice of carbohydrates many consume are less than desirable. One major concern is the excessive amount of sugar consumed, which is approximated by the United States Department of Agriculture (USDA) to be between 150 to 170 pounds of refined sugars per adult per year, an estimate that has increased by 39% since 1950. This is equivalent to approximately 1,800 cans of 12 oz. (355 mL) of soft drink per year. In fact, the United States consumes more sugar than any other country in the world. The largest sources of sugar intake represent those found in beverages, excluding milk and juices, and snacks and sweets.

When examining sugar intake and the current dietary guidelines, it is important to first distinguish total sugar from added sugar. Added sugars represent all sugars derived from food sources that *exclude* those sugars found naturally in fruits and dairy. Although these naturally occurring sugars represent healthier options given the presence of the other nutrients (e.g., vitamins and minerals), excessive intake of these foods can also increase the risk for diabetes in the same manner as added sugars (Imamura et al., 2015).

The World Health Organisation (WHO) issued a guideline in 2015 recommending that adults and children reduce their daily intake of added sugar to under 10% of total kcal. WHO also suggested that additional benefits are attained by further reducing that intake to under 5% or about 25 grams / 0.88 ounces (6 teaspoons).

The following tables list the quantities of sugar between various beverages and juices; between juices, blended fruits, and juicing; and between sweets and food bars. Consider how similar the quantities of sugar between each are, although perceptions of one versus the other are hugely different (i.e., healthy versus unhealthy). Furthermore, examine the caloric density differences between a 12-ounce serving of fresh juice, blended fruit, and juicing. Juicing simply adds a greater density of sugar because of the quantity of fruits and/or vegetables needed to make juice (1 piece of fruit = 4 oz of juice or about 120 mL) eliminates the fibre.

| **12 oz. (355 mL) Serving** | **Kcal** | **Sugar** |
| --- | --- | --- |
| Coke® | 140 | 39g |
| Pepsi® | 150 | 41g |
| Minute Maid® (apple juice) | 170 | 39g |

| **12 oz. (355 mL) Serving** | **Kcal** | **Sugar** |
| --- | --- | --- |
| Fresh Juice (with pulp) | 180 | 45g |
| Blended Juice | 215 | 54g |
| Juicer | 250 | 64g |

How would you address the following scenarios?

1. A client believes that by purchasing brown sugar rather than white sugar, she is making a healthier choice, although it is 15% more expensive.
2. She decides to substitute fruit-flavoured beverages in place of regular sodas to improve her health, although both contain about 40 grams of sugar per serving.
3. She needs to fuel her muscles as quickly as possible and is undecided between a product with high amounts of fructose versus one with high amounts of glucose. Which might replenish her energy faster?

Talking Points

1. Recall that your body does not know, nor care about the source of sugar. Brown sugar and white sugar are both added sugar.
2. Recall that while fruit juice may have small amounts of nutrition (e.g. fibre, vitamins and minerals), fruit-flavoured beverages generally do not. These products are not drastically different and there are better choices to hydrate.
3. Recall that glucose is absorbed earlier and faster into the body.