Chapter 2

Nutrition for the Athlete

You’re on your way to the gym, and you’re feeling a little hungry. What should you grab on your way out?

You’re on your way back from the gym, and now you’re really hungry. What should you eat this time?

And why do you always feel like it’s time for your next meal? Where does all that food go, anyway?

Chemically speaking, we need food primarily for building blocks, chemical reactants, and energy. The essential nutrients required to maintain life include carbohydrates, proteins, and lipids (the macronutrients), vitamins and minerals (the micronutrients), and water. Our food also has components besides the essential nutrients, sometimes found naturally and sometimes added during processing.

We begin this chapter with a general introduction to the current beliefs about good nutrition and then move onto the molecules within food and their effects on human health. We finish by considering some of the principles surrounding the quest for energy balance and weight control.

Food Guide Pyramids

The First Food Pyramid

The keywords for good nutrition and health are adequacy, moderation, balance, and variety. In other words, a good diet has adequate amounts of the essential nutrients, is moderate in unhealthy components, is balanced in both the kinds of food and the amounts of energy consumed relative to that expended, and shows variety with an assortment of choices that differ from day to day.
These basic nutritional principles were summarized in the original Food Guide Pyramid (Figure 1) released by the U. S. Department of Agriculture (USDA) in 1992. This graphic illustrates the recommended daily amounts of each of the five basic food groups, with the foods that should comprise the bulk of a good diet at the base and the foods that should be minimized at the top. A glance at the Pyramid reveals that healthy choices include plenty of grains (cereals, rice, and pasta), vegetables, and fruits. Also recommended are 2-3 servings from the dairy group and 2-3 servings from the protein group (such as meat, poultry, fish, and beans). The tip of the Pyramid contains foods that are not required for good health but are difficult to resist for many of us: the fats, oils, and sweets.

The Healthy Eating Pyramid

A better version of the food pyramid is the Healthy Eating Pyramid, designed by scientists from the Harvard School of Public Health (Figure 2). This graphic has a number of advantages over the original Food Guide Pyramid while retaining the advantage of the shape. The recommended amounts of foods again reflect their position in the pyramid, from base (recommended in relatively large amounts) to top (use sparingly). However, the new design distinguishes between subtypes of some types of foods.
Some fats, particularly many plant oils, are in fact beneficial to health. Whereas the original Pyramid did not distinguish between “good” and “bad” fats, this version does. Plant oils are recommended at most meals in the revised scheme.

Some carbohydrates, particularly those that are highly refined, are unhealthy. The original Pyramid did not distinguish between “good” and “bad” carbohydrates. The new Pyramid places white rice, bread, and pasta at the tip, recommending limited consumption.

Another feature of this alternative guide is the inclusion of vitamin supplements and moderate alcohol consumption, both of which have recently been suggested to have health benefits. Additionally, the Healthy Eating Pyramid is built on a foundation of daily exercise and weight control, both important components of good health closely related to nutrition.

The factors that determine the ultimate effects of food within the body are closely related to its molecular components. In the next sections, we first consider the molecules that comprise the macronutrients, then move on to discuss the importance of water, the micronutrients, and other components of food.
Carbohydrates

Overview

Nutritional dogma is that carbohydrates should comprise the majority of a person’s total caloric intake. To reflect this, both versions of the Food Pyramid emphasize the importance of carbohydrate-rich whole grains, cereals, fruits, and vegetables.

Carbohydrates are rapidly metabolized to release energy for cellular processes, providing about 4 Cal/gram when oxidized. Structurally, carbohydrates come in two different forms: the simple sugars and the complex carbohydrates (Figure 3). Simple sugars include monosaccharides, the basic building blocks of all carbohydrates, and disaccharides, which contain two monosaccharides covalently linked together. Complex carbohydrates are polymers that may contain thousands of monosaccharides linked together.
Simple Sugars

Simple sugars serve to sweeten a wide variety of whole and processed foods. The average American consumes an estimated 31 teaspoons of added sugar per day\(^1\), significantly in excess of the recommended limit of 6 teaspoons for someone on a 1600-Calorie daily diet. America’s sweet tooth has been linked to increases in the incidence of diabetes and heart disease.

Key dietary monosaccharides (Figure 4) include glucose (“blood sugar”), galactose, and fructose (“fruit sugar”). The most important of these in nutritional terms is glucose, the only energy source that the brain can use under normal conditions. Low blood glucose therefore causes such symptoms as headache, lethargy, and impaired reasoning. Other sugars are normally converted to glucose or a glucose derivative during metabolism.

Dietary disaccharides (Table 1) are broken down into their component monosaccharides during digestion. For example, table sugar (sucrose) contains glucose and fructose. Milk sugar (lactose) contains glucose and galactose. An inconvenient genetic disorder in the breakdown of milk sugar is lactose intolerance, which occurs to some degree in the majority of the world’s adults, particularly those from ethnic backgrounds that traditionally consume few dairy products. The enzyme lactase catalyzes the breakdown of lactose down into glucose and galactose. Throughout the ages, infants have relied on their mother’s milk for their nutrients and therefore readily produce this enzyme. As part of the aging process, many adults lose the ability to produce sufficient lactase to digest lactose. Instead, bacteria in the colon ferment the lactose, leading to problems

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\(^1\) Use of Nutitive and Nonnutritive Sweeteners, American Dietetic Association
with intestinal upset, flatulence, and diarrhea. Some dairy products are supplemented with lactase, allowing those who are lactose intolerant to enjoy them nonetheless.

Simple sugars in whole foods like milk and fruit are an important source of quick energy. Moreover, these foods also supply other necessary nutrients, such as vitamins and minerals. However, refined sugar, which lacks any other nutrients, represents nutritionally “empty” calories devoid of other benefits. Therefore, processed foods that are high in added sugar but low in other nutrients are the carbohydrates that should be limited in the diet.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Key Disaccharides and Their Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Structure</td>
</tr>
<tr>
<td>Sucrose</td>
<td><img src="image" alt="Sucrose structure" /></td>
</tr>
<tr>
<td>Lactose</td>
<td><img src="image" alt="Lactose structure" /></td>
</tr>
<tr>
<td>Maltose</td>
<td><img src="image" alt="Maltose structure" /></td>
</tr>
</tbody>
</table>
Complex Carbohydrates

Whole grains and other plant products also contain complex carbohydrates, polymers of glucose that should comprise the bulk of the body’s fuel. Relevant to discussions of nutrition are starch, an energy storage molecule of plants, and glycogen, the energy storage molecule of animals (Figure 5).

Starch

After it is consumed, dietary starch is quickly broken down into its component glucose molecules, which are sent out into the bloodstream from the digestive tract and taken up by the tissues as needed. Amounts in excess of that required for immediate use are converted to glycogen or fat for storage.

Glycogen

The human body stores about 400 grams of glycogen in the liver and muscles, corresponding to about 1600 total Calories of energy. Glycogen is the form of stored energy in the body that is the quickest to access and provides a means of buffering blood sugar. When blood sugar drops between meals, the liver pumps out glucose from its glycogen stores to provide the muscles and brain with fuel. Glucose is metabolized to release energy during metabolism, as we will discuss later. We will also see that part of the athletic training effect is an increase in liver and muscle glycogen stores, which are normally depleted after an overnight fast or about two hours of vigorous exercise.
Dietary Fiber

In addition to starch, plants also have large amounts of cellulose, another polymer of glucose. Recall that the orientation of the bond between glucose units is the major difference between starch and cellulose. Humans lack an appropriate enzyme to break these bonds and therefore cannot digest cellulose. Cellulose is a component of dietary fiber, which is composed of complex carbohydrates that pass through our systems undigested.

Dietary fiber can be either water-insoluble, such as cellulose, or water-soluble, such as the plant product pectin. The principle determinant of water-solubility is how well the chains interact with each other (through special forces called hydrogen bonds). If the hydrogen-bonding network is extensive, as in cellulose, then water molecules are unable to penetrate the matrix and dissolve the molecules.

Fruits and vegetables are rich in insoluble and soluble fiber, both believed to contribute to their healthful properties. Diets high in fiber can reduce the risk of developing heart disease, hypertension, diabetes, and constipation. The average American consumes only about half of the recommended amount of fiber (for adults, 20-35 grams daily; for children over age 2, an amount equal to their age plus 5 grams). Strategies for increasing fiber intake include consumption of whole fruits instead of juice, replacing processed white rice, bread, and pasta with brown rice and whole-grain products, snacking on raw vegetables and fruit, and substituting legumes for meat two or three times a week.
Glycemic Index

During digestion, dietary carbohydrates are converted to glucose that is released into the bloodstream. The result is increased blood sugar levels after eating. The hormone insulin is secreted in response to high blood sugar levels to trigger uptake of glucose by the tissues.

The rate at which carbohydrate sources are processed to glucose varies widely, with the glycemic index (GI) reflecting how fast a food elevates blood sugar levels (Table 2). Foods with high GI values are broken down quickly and lead to a "spike" in blood sugar concentrations, prompting swift release of insulin, uptake of glucose by the cells, and an ensuing drop in blood sugar that results in fatigue. Foods with low GI values raise blood sugar gradually, triggering a less dramatic insulin response and a gradual uptake of glucose by the tissues. Because of the rapid increase, then drop, in blood sugar, you should avoid eating food with a high glycemic index right before exercise.

Eating excessive amounts of food with high GI values has been linked to increased risks of diabetes, heart disease, obesity, and cancer. The "bad" carbohydrates at the tip of the Healthy Eating Pyramid correspond to foods with high GI values, such as potatoes and white bread. These foods trigger a more rapid increase in blood glucose levels than pure table sugar!

Consumption of high GI foods may be particularly devastating to diabetics, who suffer from either insufficient production of insulin or an impaired response to its effect. The result is prolonged periods of elevated blood sugar levels that can be extremely damaging to tissues, yet cells suffer from an inadequate supply of glucose because they fail to take it up from the bloodstream.

<table>
<thead>
<tr>
<th>Food</th>
<th>GI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baked potato</td>
<td>85</td>
</tr>
<tr>
<td>Corn flakes</td>
<td>84</td>
</tr>
<tr>
<td>White bread</td>
<td>70</td>
</tr>
<tr>
<td>Table sugar</td>
<td>65</td>
</tr>
<tr>
<td>Popcorn</td>
<td>55</td>
</tr>
<tr>
<td>Maple syrup</td>
<td>54</td>
</tr>
<tr>
<td>Breakfast oatmeal</td>
<td>51</td>
</tr>
<tr>
<td>Apple juice</td>
<td>41</td>
</tr>
<tr>
<td>Apple</td>
<td>36</td>
</tr>
<tr>
<td>Green beans</td>
<td>30</td>
</tr>
<tr>
<td>Grapefruit</td>
<td>25</td>
</tr>
</tbody>
</table>

Insulin is the hormone that signals cells to take up glucose, thereby regulating blood sugar levels.
Foods containing complex carbohydrates have lower GI values, meaning that they release glucose more slowly. Such foods include legumes, whole fruits, oats, bran, and whole-grain cereals, all of which have high fiber contents that slow breakdown. These are excellent choices to fuel a workout.

**Proteins**

**Essential Amino Acids**

Dairy products, meats, and legumes are all rich in dietary protein. Proteins are polymers of amino acids. Upon digestion, dietary proteins are broken down into the component amino acids, which can be classified as essential and non-essential. However, these terms are somewhat misleading because all of the amino acids are needed in order to repair, build, and maintain bodily proteins involved in structure (e.g., muscles), immunity (antibodies), and catalysis (enzymes). Essential amino acids are those that the body cannot make itself from simpler molecules and must therefore be obtained in the diet (Table 3).

**Proteins** primarily provide amino acid building blocks to make new proteins.

<table>
<thead>
<tr>
<th>Essential Amino Acids in Humans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Histidine</td>
</tr>
<tr>
<td>Lysine</td>
</tr>
<tr>
<td>Threonine</td>
</tr>
<tr>
<td>Arginine (only in children undergoing rapid growth)</td>
</tr>
</tbody>
</table>

TABLE 3
Complete Proteins

A food that contains all of the essential amino acids is considered to be a complete protein. Most animal sources of proteins are complete, with the notable exception of gelatin. Most plant proteins are incomplete, lacking one or more of the essential amino acids. Combining different plant proteins is the best way to ensure adequate amounts of all essential amino acids. For example, beans are low in the essential amino acid methionine, while rice lacks adequate lysine and threonine. Together, beans and rice provide all of the essential amino acids in sufficient amounts for good health (Figure 6). Another classic favorite, the peanut butter sandwich, combines a cereal grain (often low on tryptophan and lysine) with a legume (low on methionine) to achieve a complete set of the essential amino acids. Notable exceptions are soybeans and quinoa, both of which are plant products that are complete proteins. Because ingestion of incomplete protein sources can lead to malnutrition even with a sufficient caloric intake, vegetarians need to be vigilant that they combine complementary proteins appropriately to obtain enough of the essential amino acids over the course of the day.

Role of Dietary Protein

The principal function of protein in the diet is for the amino acid building blocks necessary to make new proteins in the body. When you eat more protein than is needed to make new proteins, the carbon skeletons of the amino acids can be burned for energy, releasing about 4 Cal/gram. However, the remaining nitrogen (as the toxic compound ammonia) must then be converted to urea (Figure 7) in the liver for excretion in the urine. Because removal of excess quantities of nitrogen is fairly stressful on both the liver and kidneys, too much of a good thing can be harmful in the case of dietary protein.
Protein Recommendations

Because the body has no stores of expendable protein, it should be consumed daily. The current recommendation is that most adults need about 0.8 grams of protein for every kilogram of body mass per day (so in the range of about 60 grams, depending on your mass). Athletes and individuals who are growing rapidly or have other increased metabolic demands usually need slightly more. For example, children need up to 2 grams of protein daily per kilogram of body mass, while teenagers need up to 1.2 grams. Protein contents for some common foods can be found in Table 4.

<table>
<thead>
<tr>
<th>Food</th>
<th>Portion</th>
<th>Protein (g)</th>
<th>% of Daily Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean hamburger</td>
<td>6 oz</td>
<td>49</td>
<td>88</td>
</tr>
<tr>
<td>Roasted chicken</td>
<td>6 oz</td>
<td>43</td>
<td>77</td>
</tr>
<tr>
<td>Fish</td>
<td>6 oz</td>
<td>41</td>
<td>73</td>
</tr>
<tr>
<td>Cottage cheese</td>
<td>1 cup</td>
<td>28</td>
<td>50</td>
</tr>
<tr>
<td>Low-fat yogurt</td>
<td>8 oz</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td>Tofu</td>
<td>1/2 cup</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>Whole milk</td>
<td>1 cup</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Kidney beans</td>
<td>1/2 cup</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Peanut butter</td>
<td>2 Tbsp</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Whole-wheat bread</td>
<td>2 slices</td>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>

*a For an average 70-kg male.

Lipids: Cholesterol, Fats, and Oils

Overview of Dietary Lipids

The tip of the original Food Guide Pyramid contains foods rich in lipids. While lipids are certainly valuable forms of energy, modern diets often contain too much of the wrong types of lipids. The two major classes of dietary lipids are cholesterol and triglycerides, more commonly known as fats and oils.
Cholesterol

Overview of Lipoprotein Complexes

Cholesterol, an important component of animal membranes and precursor to the steroid hormones, is obtained both in the diet and by synthesis in the liver. Because it is a hydrophobic molecule that is normally fairly water-insoluble, cholesterol is transported through the bloodstream to the tissues in structures called lipoprotein complexes (Figure 8). Lipoprotein complexes act to dissolve the nonpolar compound cholesterol in the aqueous environment of the bloodstream, a lot like soaps dissolve greasy dirt so that you wash it away.

Cholesterol and Health

Since the 1960’s scientists have realized that elevated cholesterol in the bloodstream can lead to heart disease. Cholesterol can clog up arteries, a condition known as atherosclerosis (Figure 9). When the coronary arteries become blocked, the heart muscle may not receive sufficient oxygen and nutrients to function properly. Angina, or chest pain, and heart attack can be the result.

Figure 8. Lipoprotein complexes contain a nonpolar core of triglycerides and chemically modified cholesterol packaged in a membrane-like structure of phospholipids and cholesterol. An outer lipoprotein “wrapper” increases water-solubility by presenting a polar face to the outside of the structure.
There are actually different types of lipoprotein complexes that carry cholesterol in different directions. Low-density lipoprotein complexes (LDL), the ones that can clog up arteries, transport cholesterol from the liver to the tissues. High-density lipoproteins (HDL) act as "cholesterol scavengers", scouring artery walls and transporting cholesterol to the liver for excretion. High levels of LDL, often called "bad" cholesterol, increase the risk of atherosclerosis, while high levels of HDL, the "good" cholesterol, decrease the risk. Fasting blood tests that report both LDL and HDL levels are the most informative, with low LDL levels and high HDL levels the healthiest scenario. Current recommendations of the Centers for Disease Control and Prevention (CDC) are the following:

- Total cholesterol less than 200 milligrams per deciliter;
- HDL greater than 40 milligrams per deciliter;
- LDL less than 100 milligrams per deciliter.

Strategies for increasing the amount of HDL, and thereby decreasing the risk of heart attack, include aerobic exercise, moderate alcohol consumption (the equivalent of about one glass of beer or wine daily), diets high in unsaturated fats and fiber, reduction of excess weight, and not smoking. Drug therapy can also be used when lifestyle changes alone are not sufficient.

Estrogen also raises HDL levels, a fact that may relate to the decreased incidence of heart attack in women relative to men. For this reason post-menopausal hormone replacement therapy (HRT) has long been recommended to decrease the risk of heart attack. However, recent evidence suggests that HRT does not confer protection against cardiac disease. On the contrary, recent
studies have linked this practice to increased risks of a number of chronic
diseases, causing many post-menopausal women to rethink the use of HRT.

The French Paradox

Diet can certainly play a role in blood cholesterol levels. Animal fats contain not
only cholesterol but also saturated fats, the molecules from which cholesterol is
made in the body. Therefore, decreasing the amount of dietary animal fats is
another strategy for lowering cholesterol. However, high fat diets do not
necessarily mean increased risk of heart attack, as illustrated by the "French
Paradox" reported in 1992. While the traditional French diet is rich in animal
fats, the French rate of heart attack is about 40% that of Americans. The authors
of the study attributed this decreased risk of heart attack to the French passion
for red wine.

Much of the protective effect of red wine has since been attributed to the
molecule resveratrol (Figure 10), found in grape canes, leaves, and skin. Resveratrol
is an example of a phytochemical, a natural compound found in plant sources that
has disease-preventing properties. Thousands of different phytochemicals exist
that are thought to protect against heart disease, cancer, and diabetes. The
molecular basis for how many of these compounds exert their effect remains
unclear, but many are antioxidants that protect the plants themselves from the
reactive oxygen species produced in an oxygen atmosphere.

Because moderate alcohol consumption appears to reduce the risk of coronary
heart disease by 20-40%, the ethanol in red wine is also likely to contribute to its

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Figure 10. Red wine and grape juice are good sources of the phytochemical
resveratrol, which appears to lower the risk of heart disease. This compound is
also found in the roots of Polygonum cuspidatum, a principal component of
traditional Japanese and Chinese heart medicines.

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healthful effects. Alcohol not only appears to increase the amount of HDL, but it also decreases the amount of a key blood clotting agent, reducing the chance of a blood clot in the arteries, a major cause of heart attack and stroke.

**Triglycerides**

Besides cholesterol, the other major dietary lipids are the triglycerides, composed of a molecule of glycerol linked to three fatty acids. The fatty acid components of a triglyceride can either be saturated (containing no carbon-carbon double bonds) or unsaturated (containing one or more carbon-carbon double bonds; Figure 11).

![Figure 11](image)

Figure 11. Fatty acids can be either *saturated*, containing no double bonds, or *unsaturated*, containing one (monounsaturated) or more (polyunsaturated) double bonds. In the molecular cartoons, black is carbon; blue is hydrogen. Unsaturated fats are nutritionally superior to saturated ones. While foods generally have mixtures of fats, some representative foods with relatively high proportions of the respective types of fats are indicated.
Triglycerides that are solids tend to have saturated fatty acid components, whereas liquid oils tend to have unsaturated fatty acid components. For example, bacon fat, containing primarily saturated fatty acids, is a solid at room temperature, whereas safflower oil, rich in unsaturated fatty acids, is a liquid. It has long been recognized that the unsaturated fats in many plant sources are more healthful than the saturated fats in animal sources.

Triglycerides are efficient energy storage molecules because they are highly reduced, releasing about 9 Cal/gram upon oxidation (more than twice the energy of carbohydrates and proteins). The body’s fat stores are essential to meet its energy needs, particularly during the periods of famine that humans have traditionally experienced in times past. More common in modern society, however, is the problem of excess fat leading to poor health.

Traditionally, it has been recommended that dietary fats be limited to about 30% of total daily calories for good health. However, the new Healthy Eating Pyramid places plant oils near the base, suggesting consumption “at most meals.” This recommendation follows growing evidence suggesting that while some lipids increase the risk for certain diseases (the “bad” fats), others are actually essential for good health (the “good” fats) as we consider in the next sections.

The “Bad” Fats

Saturated Fats

Saturated fats, common in foods from animal sources, increase LDL. In fact, dietary saturated fats have been shown to increase blood cholesterol levels more than dietary cholesterol alone. Perhaps not surprisingly then, diets high in saturated fats have been linked to increased rates of heart disease.

The Healthy Eating Pyramid places red meat and butter, high in saturated fats, at the tip. Substitution of fish, poultry, and eggs as alternative protein sources is recommended for good health. Although eggs have long been stigmatized because they are relatively high in cholesterol, recent studies have shown that individuals with normal blood cholesterol levels can eat a daily egg without significantly raising their LDL levels. Eggs are also a rich source of many other nutrients, including many vitamins and minerals.
Trans Fats

The link between saturated animal fats and heart disease suggests that unsaturated plant fats could be a healthy alternative. However, few consumers care to pour vegetable oil on their morning toast. About a century ago, pioneers in the edible oil industry developed processes to extract plant oils and make them firmer through a process called hydrogenation. Hydrogenation of some of the carbon-carbon double bonds in polyunsaturated fats results in a spreadable solid that might be expected to retain some of the healthful properties of unsaturated fats.

Unfortunately for millions of consumers, partial hydrogenation of polyunsaturated fats produces isomers not commonly found in nature, the trans fatty acids (Figure 12). Trans fats are widespread in commercially prepared baked goods, snack foods, and margarine. Because trans fats have been found to decrease HDL levels while increasing LDL levels, margarine is no longer considered a healthy alternative to butter. In fact, one study found that women who consumed just 4 teaspoons of stick margarine daily had a 50% greater risk of heart disease than women who rarely ate margarine.

Dietary Recommendations

Current recommendations are to limit both saturated and trans fats, replacing them with the “good” fats discussed below. It has been difficult for consumers to identify sources of trans fats since they have not been listed on product labels. However, a new mandate by the Food and Drug Administration (FDA) requires that trans fats be listed on product labels. The FDA estimates that by providing

Figure 12. Double bonds that occur naturally in fats are of the cis configuration (left), leading to a kink in the structure, poor packing of the chains, and a more liquid consistency. During the hydrogenation process to solidify liquid oils, some unhealthful trans unsaturated fats (right) are created.
consumers with the information needed to make healthier food choices, hundreds of heart-related deaths may be prevented each year.

The “Good” Fats

Unsaturated Fats

The unsaturated fats common in plant oils lower LDL levels and raise HDL levels. Therefore, fats that are liquids at room temperature are generally healthier components of the diet than solids or semi-solids. Coconut oil, high in saturated fats, is a notable exception.

Some good fats are called essential fats because the body cannot synthesize them, necessitating their intake in the diet. Two of these are linoleic acid and linolenic acid, both of which have eighteen carbon chains and multiple double bonds (Figure 13). These essential fatty acids are parent compounds from which the omega-6 and the omega-3 fatty acids are derived, respectively.

Omega-6 Fatty Acids

Natives of Crete have a very low rate of heart disease despite consuming an average of 40% of their calories from fat. The key to this “Crete Paradox” is that their traditional diets contain more than a pound of fruits and vegetables daily, many of which are rich in omega-6 essential fats. About 1 teaspoon of most vegetable sources of polyunsaturated fats like flaxseed, safflower, or borage oil can meet the daily requirement for the healthful omega-6 fats (Figure 14).

Omega-3 Fatty Acids

Just like the people of Crete and France, the Greenland Inuit population has

![Figure 13. Linoleic acid and linolenic acid are polyunsaturated fatty acids that must be obtained in the diet. Omega-6 and omega-3 fatty acids, respectively, are derived from these essential fatty acids (named according to the positions of the first double bond from the left).](image)
much lower incidences of heart disease than would be predicted from their high fat diet. Indeed, heart disease is so rare that there is no word in the Inuit language to describe it. The "Inuit Paradox" was first observed during World War II by the British nutritional researcher Hugh Sinclair, who later experimented on himself by consuming only seal and fish for 100 days and studying the effects. In 1970, Danish scientists studying the Inuits reported that a diet rich in certain cold-water fish could have a profound effect on people with high levels of "bad" cholesterol. These fish oils have high levels of essential omega-3 fatty acids, also found in certain seed oils like flaxseed and linseed as well as walnuts.

Polyunsaturated Fats and Health

The importance of certain dietary fats is not only for prevention of heart disease but also reduces the risk of certain forms of cancer. Moreover, essential fatty acids are precursors to a variety of other vital molecules, such as the prostaglandins, signaling molecules that play a role in the inflammation response.

Current recommendations are that at least 90% of the total daily intake of fat is derived from healthful unsaturated fats. Replacing butter, margarine, and cream cheese with avocado, cooking with unsaturated vegetable oils, and substituting fish for red meat regularly are some ways to accomplish this. Being aware of the specific types of fats present in many foods is the first step in choosing wisely (Table 5).

<table>
<thead>
<tr>
<th>Food</th>
<th>% Saturated</th>
<th>% Monounsaturated</th>
<th>% Polyunsaturated</th>
<th>% Trans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canola oil</td>
<td>7</td>
<td>58</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>Corn oil</td>
<td>13</td>
<td>24</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>Olive oil</td>
<td>13</td>
<td>72</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Coconut oil</td>
<td>87</td>
<td>6</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Shortening</td>
<td>22</td>
<td>29</td>
<td>29</td>
<td>18</td>
</tr>
<tr>
<td>Butter</td>
<td>62</td>
<td>27</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Stick margarine</td>
<td>18</td>
<td>2</td>
<td>29</td>
<td>23</td>
</tr>
<tr>
<td>Tub margarine</td>
<td>17</td>
<td>24</td>
<td>49</td>
<td>8</td>
</tr>
</tbody>
</table>

Source: www.hsph.harvard.edu/nutritionsource/fats.html.
Water

Roles of Water in Living Organisms

Carbohydrates, proteins, and lipids are macronutrients that contain stored chemical energy released during metabolism. Other important molecules are required in the diet for reasons other than energy production, including water. Water comprises about 60% of total body mass, serving many important roles in biological systems, including temperature regulation, lubrication, delivery of essential molecules to cells, and removal of wastes from the body. Water is also a reactant in many of the chemical reactions of metabolism and is lost in perspiration, urine and feces, and in air exhaled from the lungs. While most humans can survive without food for two or more months, lack of water can be lethal in just a few days.

Metabolic Water

Water is actually produced to some extent during metabolism. For example, complete oxidation of glucose ($C_6H_{12}O_6$) can be written as follows:

$$C_6H_{12}O_6 + 6 O_2 \rightarrow 6 CO_2 + 6 H_2O$$

The water produced in the oxidation of carbohydrates, proteins, and fats is called “metabolic water” and accounts for about 10% of the water needs of humans. Some animals, including many ocean and desert mammals, can fulfill virtually all their water needs through metabolic water.

Water Dietary Requirements

For humans, daily consumption of about 1 liter of water for every 1,000 Cal of energy expended is a good rule of thumb. This corresponds to about 8-12 glasses of water, although needs vary by level of activity, size, age, and climate. The average American consumes less than 5 glasses of water daily, suggesting that many of us are dehydrated. Moreover, many popular beverages, including those that contain caffeine or alcohol, are diuretics, causing an increased output of urine and often leading to a net loss of water upon consumption. By the time thirst signals the need for fluids, severe dehydration may have already set in, so it is important to drink regularly throughout the day. The simplest way to gauge hydration is through the urine, which should be colorless or only lightly colored.

Athletes have an increased need for fluids to replace those lost by sweating, which helps dissipate extra heat produced during metabolism. Plain water is a better option before exercise to avoid the “rebound effect”- a spike and
subsequent drop in blood sugar following insulin release. However, because insulin is generally not secreted during vigorous exercise, sports drinks are a good option particularly for activities of more than an hour's duration. The additional carbohydrates appear to improve stamina, and the minerals replace those lost to sweating.

Dehydration can result in heat exhaustion, particularly when exercise in hot weather leads to electrolyte imbalance because of excessive sweating. Some of the warning signs include muscle cramps, dizziness, cold and clammy skin, lightheadedness, confusion, nausea, headache, and high body temperature. Rehydration then becomes a priority to avoid symptoms of heat stroke, which can be fatal.

Vitamins
Overview of Vitamins

Our first class of micronutrients is the vitamins, essential organic molecules that generally must be obtained in the diet. As early as 1753, it was recognized that nutritional deficiencies could lead to specific diseases when the Scottish doctor James Lind (1716-1794) published A Treatise of the Scurvy (Figure 15). Dr. Lind experimented with the diets of British sailors suffering from "putrid gums" and general weakness, verifying that oranges and lemons could restore good health, as practiced by the Dutch for hundreds of years. Lind's recommendation was rejected by higher-ups initially because of the expense and storage difficulties of fresh citrus fruits. Ironically, forty-two years later, after Lind's death, West Indian limes were added to the traditional shipboard diet of British sailors (hence the term "limey"), and the incidence of scurvy decreased dramatically.
The term *vitamine* ("vital amines") was originally proposed to describe all molecules essential to prevent such diseases as scurvy. When it was discovered that not all these molecules are amines, the term was modified slightly to "vitamin." Many enzymes require the presence of a particular vitamin to catalyze the chemical reactions involved in normal growth and metabolism.

The hydrocarbon skeletons of all vitamins can be classified as either fat-soluble or water-soluble. The fat-soluble vitamins are relatively nonpolar and are therefore stored in fat tissue. Because they accumulate in the body, it is possible to overdose on the fat-soluble vitamins. Most fat-soluble vitamins can be obtained in oily foods like fish and meat. The water-soluble vitamins must be obtained in the diet regularly because excess amounts are flushed out in the urine. Fruits and vegetables are good sources of many of the water-soluble vitamins.

**Fat-Soluble Vitamins**

There are four fat-soluble vitamins: A, D, E, and K (Table 6).

- **Vitamin A** can either be obtained in the diet directly or be made in the body from beta-carotene, the orange pigment in carrots. Vitamin A's role in vision is the origin of the belief that carrots are good for eyesight. Polar bear liver contains such high levels that about a pound can lead to a toxic overdose of vitamin A, as demonstrated by some unfortunate arctic explorers. Eating large quantities of carrots does not produce toxicity because only the necessary amount is made from beta-carotene. However, it may lead to orange-tinted skin as the nonpolar beta-carotene is also stored in fatty tissue.

- **Vitamin D** is made from cholesterol when the skin is exposed to sunlight, with about 15 minutes of daily exposure of hands and face providing enough of a dose in most people. Those who live in northern climates, stay inside most of the time, or wear sunscreen may be deficient in vitamin D. Because of its vital role in absorption of the calcium needed for bones and teeth, milk is often supplemented with this vitamin. Children with vitamin D deficiency may develop rickets, a bone disorder that results in bent legs. Deficient adults may experience bone softening and pain, with progressive weakening as a result. There has been a resurgence in rickets in the U. S. during the last decade, attributed both to decreases in exposure to sunshine and in milk consumption.
• **Vitamin E** is a powerful antioxidant, protecting cells constantly exposed to high oxygen concentrations from damage by reactive oxygen species. The antioxidant activity of Vitamin E has been implicated in protection against heart disease, strokes, cancer, and senility.

• **Vitamin K** is made in limited amounts by the action of intestinal bacteria, but the rest must be obtained in the diet. Newborn infants are at risk for deficiency because nonpolar molecules cross the placenta relatively poorly and breast milk is low in vitamin K. Because of the risk of gastrointestinal tract and intracranial bleeding due to vitamin K deficiency, standard practice is to give newborns an injection of Vitamin K shortly after birth.

#### Table 6: Fat-Soluble Vitamins

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Sources</th>
<th>Adult RDA&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Fish, liver, eggs, dark green leafy vegetables, yellow-orange fruits and vegetables</td>
<td>800 µg&lt;sup&gt;b&lt;/sup&gt; (women) 1000 µg (men)</td>
<td>Vision</td>
</tr>
<tr>
<td>D</td>
<td>Eggs, fish, liver, fortified milk</td>
<td>5 µg 10 µg (50 years old+) 15 µg (70 years old+)</td>
<td>Calcium absorption (for strong bones and teeth)</td>
</tr>
<tr>
<td>E</td>
<td>Almonds, green leafy vegetables, wheat germ, whole grains</td>
<td>15 mg&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Antioxidant</td>
</tr>
<tr>
<td>K</td>
<td>Green leafy vegetables, cabbage</td>
<td>65 µg (women) 80 µg (men)</td>
<td>Blood clotting</td>
</tr>
</tbody>
</table>

<sup>a</sup>Recommended Daily Allowance; <sup>b</sup>Micrograms; <sup>c</sup>Milligrams

#### Water-Soluble Vitamins

There are nine water-soluble vitamins: eight B complex vitamins and vitamin C (Table 7). The B complex vitamins are grouped together because they all act in energy-producing pathways of metabolism and are found in similar types of foods. Depletion of the water-soluble vitamins may result in as little as two weeks if they are not regularly supplied.

• **Vitamin B1** (thiamine) is required for carbohydrate metabolism. Its deficiency leads to the disease *beriberi* (Sinhalese for “extreme weakness”; Figure 16), which became endemic to parts of Asia following the introduction of polished rice, which strips out the vitamin B1 with the discarded hulls. Paralysis of the lower extremities and other neurological disturbances accompany this disorder. The Dutch scientist Christiaan Eijkman (1858-1930), working in
Java, observed similar symptoms in laboratory chickens kept on a diet of white rice. Changing the diet to one of brown rice cured the chickens, which Eijkman then tried on his human patients with equal success. He was awarded the 1929 Nobel Prize in Physiology or Medicine.

- **Vitamins B2** (riboflavin), **B3** (niacin), **B5** (pantothenic acid), **B6** (pyridoxine), and **B12** (biotin) are essential in the oxidation of carbohydrates, fats, and proteins. Body builders and athletes who consume raw eggs are at risk for developing biotin deficiency since eggs contain avidin, a small protein that binds extremely tightly to biotin and prevents its absorption. Cooking eggs destroys avidin structure so that it releases biotin.

- **Vitamin B9** (folic acid) is crucial in fetal development and so pregnant women or those wishing to become pregnant are advised to ensure that they have sufficient levels. Sufficient folic acid is estimated to achieve prevention of 50-70% of neural tube defects (such as spinal bifida, when the fetus's spine fails to close properly).

- **Vitamin B12** (cobalamin) is a cobalt-containing molecule essential for the manufacture of red blood cells and energy production. Intrinsic factor, a protein produced by the stomach, normally helps to absorb Vitamin B12 from dietary sources. Individuals lacking intrinsic factor may be deficient in this vitamin as can those on strict vegan diets—plants do not make vitamin B12. In fact, many vegetarians of the animal world, like rabbits, eat their own feces to obtain Vitamin B12 made by intestinal bacteria.

  B12 deficiency may result in pernicious anemia, which is fairly common in the elderly (about 2% of those over the age of 60) and results in symptoms of dementia similar to Alzheimer's Disease. Pernicious anemia was first recognized in the nineteenth century and was almost always fatal, with an average survival rate of one to three years. In 1926, two Boston physicians,
Dr. George Minot and Dr. William Murphy, discovered that addition of raw liver to the diet could cure pernicious anemia. The high amounts of vitamin B12 in liver are able to overcome the deficiency in intrinsic factor. This discovery saved many lives (Figure 17), and Minot and Murphy were awarded the 1934 Nobel Prize in Physiology or Medicine.

- **Vitamin C** is necessary for the production of many essential biological molecules, including the collagen of connective tissue, and plays a vital role in wound healing. Its antioxidant properties also suggest that it may reduce the risk of heart disease and some cancers. Deficiencies are common in individuals with eating disorders, who may suffer symptoms similar to those of scurvy.

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Sources</th>
<th>Adult RDA</th>
<th>Normal Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiamine (B₁)</td>
<td>Pork, liver, whole grains,</td>
<td>1.1 mg (women)</td>
<td>Carbohydrate metabolism</td>
</tr>
<tr>
<td></td>
<td>beans, nuts</td>
<td>1.2 mg (men)</td>
<td></td>
</tr>
<tr>
<td>Riboflavin (B₂)</td>
<td>Dairy products, whole grains</td>
<td>1.1 mg (women)</td>
<td>Nutrient oxidation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.3 mg (men)</td>
<td></td>
</tr>
<tr>
<td>Niacin (B₃)</td>
<td>Meat, milk, eggs, nuts, poultry, whole grains</td>
<td>14 mg (women)</td>
<td>Nutrient oxidation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16 mg (men)</td>
<td></td>
</tr>
<tr>
<td>Pantothenic acid (B₅)</td>
<td>Whole grains, meat, vegetables</td>
<td>5 mg</td>
<td>Nutrient oxidation</td>
</tr>
<tr>
<td>Pyrodoxine (B₆)</td>
<td>Meat, fish, poultry, beans, grains, oranges</td>
<td>1.5 mg (women)</td>
<td>Protein metabolism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.7 mg (men)</td>
<td></td>
</tr>
<tr>
<td>Biotin (H)</td>
<td>Eggs, milk, cereal</td>
<td>30 mg</td>
<td>Nutrient oxidation</td>
</tr>
<tr>
<td>Folic Acid (B₉)</td>
<td>Green leafy vegetables</td>
<td>400 μg</td>
<td>Red blood cell formation, prevention of spina bifida</td>
</tr>
<tr>
<td>Vitamin B₁₂</td>
<td>Animal products</td>
<td>2.4 mg</td>
<td>Red blood cell formation, nerve cell maintenance</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>Citrus fruits</td>
<td>75 mg (women)</td>
<td>Antioxidant, collagen formation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90 mg (men)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>+35 mg for smokers</td>
<td></td>
</tr>
</tbody>
</table>
Dietary Recommendations

Traditional nutritional dogma has long been that those with a well-balanced diet have no need to take a daily multivitamin, but more recently this has been called into question. Minimum daily requirements have been set at levels necessary to prevent diseases such as scurvy, but there is some evidence that higher levels may prevent serious chronic diseases like cancer, osteoporosis, and heart disease. It is likely that the recommended daily allowances will increase following further studies of many vitamins. In particular, the antioxidants (vitamin C, E, and the vitamin A precursor beta-carotene) that confer protection against damage by reactive oxygen species are being extensively studied for their possible roles in prevention of cancer, cataracts, heart disease, Alzheimer's, and other chronic ailments.

Minerals

Macrominerals versus Trace Minerals

Minerals are essential non-organic (inorganic) substances required by living organisms. Macrominerals (Table 8) are found in the human body in fairly large amounts (more than five grams). An example is calcium, about two pounds of which is present in the average human, mostly tied up in bones (Figure 18). Trace minerals are found in the human body in amounts of less than five grams. Most serve as necessary components of certain proteins and enzymes. Recommended daily allowances have been established for the more abundant trace minerals (Table 9).

Mineral Requirements

Requirements for many essential minerals change during development, generally increasing with age and metabolic demands. “Extreme” situations such as high-intensity exercise, pregnancy, and lactation may increase need. The most common mineral deficiencies are of calcium and iron, which are also two of the most important minerals for the athlete. Calcium has a relatively large daily requirement of about 1,000 mg, but the average adult consumes...
only about half this. The major consequence of calcium deficiency is weakening of the bones, which increases the risk of stress fractures in runners and other athletes. You can easily avoid a calcium deficiency by consuming three servings of dairy foods per day. (An 8-ounce glass of milk equals one serving.)

The recommended daily iron intake is 10 mg per day for men and 15 mg for premenopausal women. Due to iron losses during menstruation, women need more iron than men, but because they eat fewer calories, women generally obtain less dietary iron than men, often failing to meet their needs. Since iron is essential to the formation of red blood cells, iron deficiency often results in anemia, characterized by chronic fatigue. There is evidence that anemia is more common among endurance athletes, and especially runners, than among the general population, possibly due to iron losses incurred through sweating and other exercise-related mechanisms. Iron deficiency is easily avoided through adequate intake of iron-rich foods including tuna, chicken, beef, soybeans, quinoa, and dark green leafy vegetables.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Sources</th>
<th>Adult RDA</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>Dairy products</td>
<td>1200 mg (19-24 yrs)</td>
<td>Component of bones and teeth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>800 mg (25 yrs+)</td>
<td></td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Meat, dairy, beans</td>
<td>1200 mg (19-24 yrs)</td>
<td>Component of nucleic acids, bones, and teeth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>800 mg (25 yrs+)</td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td>Fruit, milk</td>
<td>2 g (estimated)</td>
<td>Nerve signaling</td>
</tr>
<tr>
<td>Sulfur</td>
<td>All proteins</td>
<td>None</td>
<td>Component of proteins</td>
</tr>
<tr>
<td>Sodium</td>
<td>Table salt</td>
<td>500 mg (estimated)</td>
<td>Nerve signaling</td>
</tr>
<tr>
<td>Chloride</td>
<td>Table salt</td>
<td>750 mg (estimated)</td>
<td>Charge balance</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Vegetables, grains</td>
<td>350 mg (men)</td>
<td>Component of bones, vital to many enzymes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>280 mg (women)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Sources</th>
<th>Adult RDA</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>Meat, whole grains, legumes, green leafy vegetables</td>
<td>15 mg (women) 10 mg (men)</td>
<td>Oxygen transport</td>
</tr>
<tr>
<td>Zinc</td>
<td>Seafood, meat, nuts, legumes</td>
<td>12 mg (women) 15 mg (men)</td>
<td>Nutrient metabolism</td>
</tr>
<tr>
<td>Iodine</td>
<td>Iodized salt</td>
<td>150 mg</td>
<td>Thyroid gland function (metabolism)</td>
</tr>
<tr>
<td>Selenium</td>
<td>Grains, Brazil nuts, meat</td>
<td>55 mg (women) 70 mg (men)</td>
<td>Antioxidant activity</td>
</tr>
</tbody>
</table>
Reading Labels on Food Packages

The Nutrition Education and Labeling Act of 1990 brought about reforms in product labeling of processed foods that allow a knowledgeable consumer to make healthy choices. Figure 19 shows a sample label for macaroni and cheese, which is chock-full of useful information.

- The **Serving Size** should be noted because all subsequent information relates to this. A particular product may appear enticing because it contains only a few Calories. However, if the serving size is extremely small, a realistic portion might provide far more Calories than expected.

- Total **Calories** are followed by the number of **Calories from Fat**. In this example, almost half of the Calories are from fat.

- We can also independently calculate total Calories from the grams of each of the major nutrients given on the label. We saw above that fats are oxidized to release 9 Cal per gram; carbohydrates, 4 Cal per gram; and proteins, 4 Cal per gram. We can use the amounts on the food label to calculate how many Calories are in a serving of our sample product:

  - 12 grams fat x 9 Cal = 108 Cal from fat
  - 31 grams carbs x 4 Cal = 124 Cal from carbs
  - 5 grams protein x 4 Cal = 20 Cal from protein

\[
\begin{align*}
108 \text{ Cal} + 124 \text{ Cal} + 20 \text{ Cal} &= 252 \text{ Cal Total}
\end{align*}
\]
• Perhaps more important than the Total Fat is the breakdown that lists the amounts of the “bad” kinds, Saturated Fat, Trans Fat, and Cholesterol.

• Carbohydrate content is often listed as Total Carbohydrate, Dietary Fiber, and Sugars. Recall that not all carbohydrates are created equal, and that complex carbohydrates and fiber are often considered to be superior to simple sugars. It may be helpful to check the list of ingredients for added sugar, which may be disguised as high fructose corn syrup, dextrose, or corn syrup.

• Vitamins and minerals are also listed as the percentage of the FDA’s recommended daily allowance.

• Percent Daily Value is based on the Recommended Daily Allowance for a person on a 2,000-Calorie diet. Keep in mind that your own energy requirements may differ from this “average”, depending on such factors as your age and lifestyle.

An important point to keep in mind when consuming processed food is that many of the most valuable nutrients are most abundant in unrefined, whole foods such as fruits, vegetables, and whole grains. Processing generally increases the glycemic index, removes nutrients, and sometimes adds undesirable trans fats. A good variety of whole foods generally provides the essential ingredients for optimal health.

Weight Control
Health experts agree that obesity contributes to thousands of deaths in the United States each year. In general, maintaining a healthy weight requires both good dietary habits and regular physical activity. In this section, we discuss weight control and its relationship to nutrition and exercise.

Energy Balance
When more chemical energy, in the form of carbohydrates, proteins, or lipids, is consumed in the diet than is expended, the excess is stored as body fat. Why then does it often seem that different people...
who consume the same amount of food have very different physiques? Although scientists do not completely understand this puzzle, it is known that metabolic efficiencies not only vary across individuals but also have the potential to change within an individual. Additionally, energy expenditure varies widely between individuals and with the level of activity.

To maintain energy balance and body weight, “energy in” must be equivalent to “energy out”. “Energy in” can be calculated from the amounts of carbohydrates, proteins, and fats in the various foods consumed, as we saw in the previous section. “Energy out” is more difficult to measure and includes the following:

- **basal metabolism**, the energy expended to sustain life processes, including respiration, circulation, nerve function, and maintenance of body temperature
- **physical activity**, the energy expended through voluntary activities such as walking and running
- **thermogenesis**, the increased release of heat after consuming a meal

The partitioning of energy expenditure between these three categories varies with the level of physical activity (Figure 20). Furthermore, all three types of energy expenditure increase during exercise. Increases in basal metabolism and thermogenesis appear to persist in those who exercise regularly even when they are not exercising.

Remarkably, body weight tends to remain somewhat constant over time, even with daily fluctuations in dietary choices and level of activity. It appears that internal mechanisms regulate feeding and energy expenditure so that most individuals maintain their weight within a fairly narrow range.

One of the first studies to illustrate this principle was in 1902 when R. O. Neumann varied his own food intake widely for a course of two years but...
found that his weight remained stable. In another study, volunteers at a state prison were asked to eat as much as possible for six months. The participants responded admirably, increasing their consumption by 75 percent on average (up to 10,000 Calories daily). While some put on a few pounds during the first few weeks of the study, body mass soon stabilized. Even participants estimated to consume four times their daily output of energy displayed weight gains of only about 25 percent. Individuals also varied dramatically in their responses to these extra Calories, with some putting on negligible amounts of weight in response to overeating and others gaining considerably more. Somehow an individual’s metabolism must adjust to compensate for differences in Calories consumed.

The Thrifty Gene Hypothesis

The fact that some people tend to gain weight easily while others do not has been attributed to a so-called “thrifty” gene, first proposed by geneticist James Neel in 1962. Neel’s hypothesis was that populations living under extreme conditions would have been likely to experience alternating periods of feast and famine for thousands of years. Selection of a “thrifty” gene would have allowed them to store fat in times of plenty to ensure against starvation during lean times. While it is unlikely that a single gene is responsible for total regulation of body weight, almost certainly a number of hereditary factors (i.e., genes) contribute to establishment of the basal metabolic rate. Decreasing the energy needed to maintain the resting state would certainly have been helpful during periods of famine, but the high-calorie, low activity lifestyle adopted by most members of Western civilization turns this former benefit into a significant risk factor for obesity.

Leptin, the Weight-Control Hormone

One of the breakthroughs in explaining the relative constancy of body weight was the 1994 discovery of the protein leptin (from the Greek leptos, for “thin”). Leptin is a peptide hormone that mediates body weight, metabolism, and reproduction. Rats genetically engineered to be deficient in leptin become obese (Figure 21), but injection with the hormone results fat just “melting away.”

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3 Neumann, R. O. (1902) Archiv. Hugiene 45, 1-87
Leptin, which is released by fat cells, appears to trigger appetite suppression by binding to receptors in the hypothalamus. It appears both to signal that fat reserves are sufficient and to trigger increased expenditure of energy, suggesting that increasing the amount of leptin in humans could be a painless weight-loss remedy. However, obese humans have been found to contain normal amounts of leptin, with some exceptions, and therefore generally do not benefit from treatment with this hormone.

The original function of leptin may have been to regulate the starvation response. During times of limited food availability, the levels of this hormone drop, providing a message to decrease energy expenditure and to mobilize stored fuel reserves. Thus, “thrifty” genes may lead to leptin resistance and increased storage of fat. As a sensor of energy balance, leptin also responds to exercise, with changes in its levels affecting both fuel mobilization and energy expenditure.

**Thermogenesis**

Part of the increased energy expenditure triggered by leptin is attributed to thermogenesis, in which the energy within fuel molecules is simply dissipated as heat rather than used to do work. Infants and small children have relatively high proportions of tissue designed for thermogenesis, accounting for the fact that they often feel like raging furnaces. They literally burn much of their food instead of capturing its energy. Exercise also appears to induce thermogenesis, with increases in fuel burning both during exercise and in the period immediately following.

**Dieting versus Exercise**

Although an estimated 45% of women and 30% of men in the U. S. are trying to lose weight at any given time, we appear to be in a “super sized” epidemic. Americans are getting heavier and heavier (Figure 22). While the types of foods consumed appear to be related to the problem of obesity, another factor is that simply cutting back on “energy in” through dieting is generally not an effective way to maintain energy balance. Limiting food intake generally causes a decrease in both basal metabolism and thermogenesis as the body adapts to fewer calories. In
fact, after a few days of fasting, basal metabolism may drop to 65% of its original level. Therefore, “energy in” is closely tied to the “energy out” component of the energy balance equation.

Physical activity can play a key role in achieving energy balance, and thus weight control, through the following pathways to increased energy expenditure:

- Muscle motion during physical activity uses more energy than inactivity. This energy comes from the metabolism of the body’s fuels, decreasing the amount of fuel stored as fat.

- Muscle tissue requires more fuel than fat tissue to maintain. That is, increased muscle mass increases the body’s basal metabolic rate, resulting in increased energy expenditure even in the resting state.

- Exercise promotes thermogenesis, resulting in increased dissipation of stored chemical energy as heat both during and after physical activity.

In these multiple ways, exercise offers many advantages to the weight-conscious individual over simply eating fewer calories. Restricting caloric intake alone may lead to more immediate weight loss than exercise alone, but the dieter is not likely to continue to lose weight as rapidly in the long term.

Some Answers

“You’re on your way to the gym, and you’re feeling a little hungry. What should you grab on your way out?”

Be mindful of the glycemic index value of any food you grab. Avoid highly processed foods that are high in sugar. (A candy bar is not a great choice, no
matter what TV ads tell you.) You want to avoid a sudden spike in blood sugar just before exercise, because your blood sugar will drop rapidly, leaving you feeling weak. Good choices would be a piece of fruit, some nuts or trail mix, or an energy bar. You can never eat enough fruit! And don’t forget your water bottle!

“You’re on your way back from the gym, and now you’re really hungry. What should you eat this time?”

Now you do want to increase your blood sugar fairly rapidly, as well as re-build your muscles. Combining protein with carbohydrate within 30 minutes after exercise nearly doubles the insulin response, which results in more stored glycogen later. The optimal carbohydrate to protein ratio for this effect is 4:1 (four grams of carbohydrate for every one gram of protein). You can buy fancy sports drinks with this ratio, which would also replace some of the fluid you’ve lost during exercise. You can also go with good old-fashioned chocolate milk!

And why do you always feel like it’s time for your next meal? Where does all that food go, anyway?

You burned it all up! Besides the calories burned during exercise, your basal metabolic rate is higher than average if you’re an athlete, and you are losing more energy through thermogenesis. The bottom line is that it probably IS time for your next meal! Think about adding one of the Mayo Clinic’s Top Ten Healthy Foods to your plate (Figure 23), and enjoy!

1. **Almonds** — for fiber, riboflavin, magnesium, iron and calcium (they actually have the most calcium of all nuts)
2. **Apples** — for pectin and vitamin C
3. **Blueberries** — for phytonutrients and a low-calorie source of fiber
4. **Broccoli** — for calcium, potassium, folate, fiber and phytonutrients
5. **Red beans** — for a low-calorie source of protein
6. **Salmon** — for omega-3 fatty acids
7. **Spinach** — for vitamins A, B and C as well as magnesium
8. **Sweet potatoes** — for a fat-free, low-calorie source of beta carotene
9. **Vegetable juice** — for an easy way to include vegetables in your diet (if you’re thinking V8, I don’t like this—watch out for sodium)
10. **Wheat germ** — for a concentrated source of niacin, thiamin, riboflavin, vitamin E, folate, magnesium, phosphorus, potassium, iron and zinc

Figure 23. The Mayo Clinic’s "superfoods."