Human Nutrition

in a Canadian Context

Adapted and abridged version of an open access textbook by the University of Hawai'i at Mãnoa Food Science and Human Nutrition Program: Human Nutrition // CC BY 4.0

Reviewed and Edited by Karine Hamm – Douglas College, Sports Science department – July 2020.

Photo by Mockup Graphics on Unsplash

This book was produced with Pressbooks (https://pressbooks.com) and rendered with Prince.

Preface

This open access textbook was developed as an introductory nutrition resource to introduce basic concepts related to nutrition. It was edited and developed for students from Douglas College enrolled in Topics in Human Nutrition (SPSC 1192). However, this open access textbook may be of interest to other courses interested in teaching nutrition through a Canadian lens. This book is best viewed online using the pressbooks format however, multiple formats (e.g., pdf, epub, mobi) are also made available.

A free textbook is great, but it can be even better with your help. please contact me if you find any errors or typos in the book.

CHAPTER 1. INTRODUCTION TO NUTRITION

Introduction

The foundation comes first, then the building

Image by Jim Hollyer / CC BY 4.0

Learning Objectives

By the end of this chapter, you will be able to:

- Describe basic concepts in nutrition
- Describe factors that affect your nutritional needs
- Describe the purpose and function of nutrition

recommendations

- Describe the components of a healthy diet
- Interpret the Nutrition Labels found on food items
- Describe the purpose and use of the Canada's Food Guide

What is the Science of Nutrition?

Nutrition is the science of food, how food nourishes our bodies and affects our health. It covers the processes related to food consumption, digestion, metabolism and the nutrients found in foods. In nutrition, we uncover how these nutrients affect our bodies and our health. Nutrition also involves studying factors that influence our eating patterns, developing recommendations about the amount of nutrients we should consume daily, maintaining food safety and addressing issues related to food supply.

What are Nutrients?

Food refers to the plants and animals that we consume. The foods we eat contain nutrients. Nutrients are substances required by the body to perform its basic functions. Nutrients must be obtained from our diet, since the human body does not synthesize or produce them. Nutrients have one or more of three basic functions: they provide energy, contribute to body structure, and/or regulate chemical processes in the body.

These basic functions allow us to detect and respond to environmental surroundings, move, excrete wastes, respire (breathe), grow, and reproduce. There are six classes of nutrients required for the body to function and maintain overall health. These are **carbohydrates, lipids, proteins, water, vitamins,** and **minerals**. Foods also contain non-nutrients that may be harmful (such as natural toxins common in plant foods and additives like some dyes and preservatives) or beneficial (such as antioxidants and phytochemicals).

Macronutrients

Nutrients that are needed in large amounts are called macronutrients. There are three classes of macronutrients: **carbohydrates, lipids**, and **proteins**. These can be metabolically processed into cellular energy. The energy from macronutrients comes from their chemical bonds. This chemical energy is converted into cellular energy that is then utilized to perform work, allowing our bodies to conduct their basic functions. A unit of measurement of food energy is the calorie. On nutrition food labels the amount given for "calories" is actually equivalent to each calorie multiplied by one thousand. A kilocalorie (one thousand calories, denoted with a small "c") is synonymous with the "Calorie" (with a capital "C") on nutrition food labels. Water is also a macronutrient in the sense that you require a large amount of it, but unlike the other macronutrients, it does not yield calories.

Carbohydrates

Carbohydrates are molecules composed of carbon, hydrogen, and oxygen. The major food sources of carbohydrates are grains, milk, fruits, and starchy vegetables, like potatoes. Non-starchy vegetables also contain carbohydrates, but in lesser quantities. Carbohydrates are broadly classified into two forms based on their chemical structure: simple carbohydrates, often called simple sugars; and complex carbohydrates.

Simple carbohydrates consist of one or two basic units. Examples of simple sugars include sucrose, the type of sugar you would have in a bowl on the breakfast table, and glucose, the type of sugar that circulates in your blood.

Complex carbohydrates are long chains of simple sugars that can be unbranched or branched. During digestion, the body breaks down digestible complex carbohydrates to simple sugars, mostly glucose. Glucose is then transported to all our cells where it is stored, used to make energy, or used to build macromolecules. Fiber is also a complex carbohydrate, but it cannot be broken down by digestive enzymes in the human intestine. As a result, it passes through the digestive tract undigested unless the bacteria that inhabit the colon or large intestine break it down.

One gram of digestible carbohydrates yields four kilocalories of energy for the cells in the body to perform work. In addition to providing energy and serving as building blocks for bigger macromolecules, carbohydrates are essential for proper functioning of the nervous system, heart, and kidneys. As mentioned, glucose can be stored in the body for future use. In humans, the storage molecule of carbohydrates is called glycogen, and in plants, it is known as starch. Glycogen and starch are complex carbohydrates.

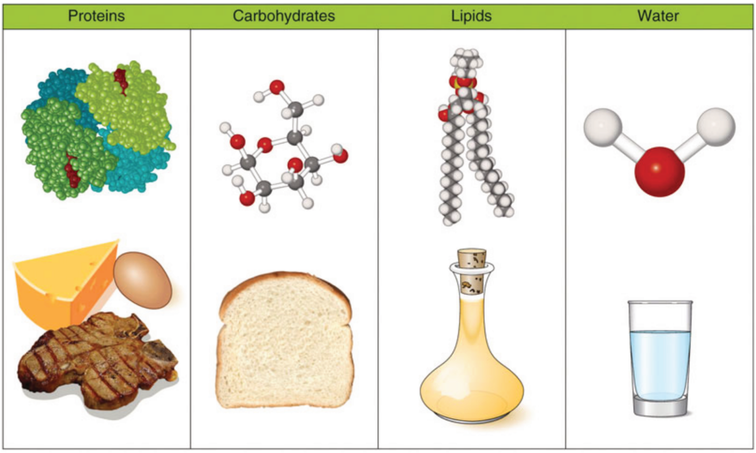
Lipids

Lipids are also a family of molecules composed of carbon, hydrogen, and oxygen, but unlike carbohydrates, they are insoluble in water. Lipids are found predominantly in butter, oils, meats, dairy products, nuts, and seeds, and in many processed foods. The three main types of lipids are triglycerides (triacylglycerols), phospholipids, and sterols. The main job of lipids is to provide or store energy. Lipids provide more energy per gram than carbohydrates (nine kilocalories per gram of lipids versus four kilocalories per gram of carbohydrates). In addition to energy storage, lipids serve as a major component of cell membranes, surround and protect organs (in fat-storing tissues), provide insulation to aid in temperature regulation, and regulate many other functions in the body.

Proteins

Proteins are macromolecules composed of chains of subunits called amino acids. Amino acids are simple subunits composed of carbon, oxygen, hydrogen, and nitrogen. Food sources of proteins include meats, dairy products, seafood, and a variety of different plant-based foods, most notably soy. The word protein comes from a Greek word meaning "of primary importance," which is an apt description of these macronutrients; they are also known colloquially as the "workhorses" of life. Proteins provide four kilocalories of energy per gram; however providing energy is not protein's most important function. Proteins provide structure to bones, muscles and skin, and play a role in conducting most of the chemical reactions that take place in the body. Scientists estimate that greater than one-hundred thousand different proteins exist within the human body. The genetic codes in DNA are basically protein recipes that determine the order in which 20 different amino acids are bound together to make thousands of specific proteins.

Figure 1.1 The Macronutrients: Carbohydrates, Lipids, Protein, and Water



Water

There is one other nutrient that we must have in large quantities: water. Water does not contain carbon, but is composed of two hydrogens and one oxygen per molecule of water. More than 60 percent of your total body weight is water. Without it, nothing could be transported in or out of the body, chemical reactions would not occur, organs would not be cushioned, and body temperature would fluctuate widely. On average, an adult consumes just over two liters of water per day from food and drink combined. Since water is so critical for life's basic processes, the amount of water input and output is supremely important.

Micronutrients

Micronutrients are nutrients required by the body in lesser amounts, but are still essential for carrying out bodily functions. Micronutrients include all the essential minerals and vitamins. There are sixteen essential minerals and thirteen vitamins (See Table 1.1 "Minerals and Their Major Functions" and Table 1.2 "Vitamins and Their Major Functions" for a complete list and their major functions). In contrast to carbohydrates, lipids, and proteins, micronutrients are not sources of energy (calories), but they assist in the process as cofactors or components of enzymes (i.e., coenzymes). Enzymes are proteins that catalyze chemical reactions in the body and are involved in all aspects of body functions from producing energy, to digesting nutrients, to building macromolecules. Micronutrients play many essential roles in the body.

Table 1.1 Minerals and Their Major Functions

Minerals	Major Functions
Macro	
Sodium	Fluid balance, nerve transmission, muscle contraction
Chloride	Fluid balance, stomach acid production
Potassium	Fluid balance, nerve transmission, muscle contraction
Calcium	Bone and teeth health maintenance, nerve transmission, muscle contraction, blood clotting
Phosphorus	Bone and teeth health maintenance, acid-base balance
Magnesium	Protein production, nerve transmission, muscle contraction
Sulfur	Protein production
Trace	
Iron	Carries oxygen, assists in energy production
Zinc	Protein and DNA production, wound healing, growth, immune system function
Iodine	Thyroid hormone production, growth, metabolism
Selenium	Antioxidant
Copper	Coenzyme, iron metabolism
Manganese	Coenzyme
Fluoride	Bone and teeth health maintenance, tooth decay prevention
Chromium	Assists insulin in glucose metabolism
Molybdenum	Coenzyme

Minerals

Minerals are solid inorganic substances that form crystals and are classified depending on how much of them we need. Trace minerals, such as molybdenum, selenium, zinc, iron, and iodine, are only required in a few milligrams or less.

Macrominerals, such as calcium, magnesium, potassium, sodium, and phosphorus, are required in hundreds of milligrams. Many minerals are critical for enzyme function, others are used to maintain fluid balance, build bone tissue, synthesize hormones, transmit nerve impulses, contract and relax muscles, and protect against harmful free radicals in the body that can cause health problems such as cancer.

Vitamins

The thirteen vitamins are categorized as either water-soluble or fat-soluble. The water-soluble vitamins are vitamin C and all the B vitamins, which include thiamine, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, folate and cobalamin. The fat-soluble vitamins are A, D, E, and K. Vitamins are required to perform many functions in the body such as making red blood cells, synthesizing bone tissue, and playing a role in normal vision, nervous system function, and immune system function.

Table 1.2 Vitamins and Their Major Functions

Vitamins	Major Functions
Water-soluble	
Thiamin (B1)	Coenzyme, energy metabolism assistance
Riboflavin (B2)	Coenzyme, energy metabolism assistance
Niacin (B3)	Coenzyme, energy metabolism assistance
Pantothenic acid (B5)	Coenzyme, energy metabolism assistance
Pyridoxine (B6)	Coenzyme, amino acid synthesis assistance
Biotin (B7)	Coenzyme, amino acid and fatty acid metabolism
Folate (B9)	Coenzyme, essential for growth
Cobalamin (B12)	Coenzyme, red blood cell synthesis
C (ascorbic acid)	Collagen synthesis, antioxidant
Fat-soluble	
A	Vision, reproduction, immune system function
D	Bone and teeth health maintenance, immune system function
E	Antioxidant, cell membrane protection
K	Bone and teeth health maintenance, blood clotting

Vitamin deficiencies can cause severe health problems and even death. For example, a deficiency in niacin causes a disease called pellagra, which was common in the early twentieth century in some parts of America. The common signs and symptoms of pellagra are known as the "4D's—diarrhea, dermatitis, dementia, and death." Until scientists found out that better diets relieved the signs and symptoms of pellagra, many people with the disease ended up hospitalized in insane asylums awaiting death. Other vitamins were also found to prevent certain disorders and diseases such as scurvy (vitamin C), night blindness (vitamin A), and rickets (vitamin D).

Table 1.3 Functions of Nutrients

Protein	Necessary for tissue formation, cell reparation, and hormone and enzyme production. It is essential for building strong muscles and a healthy immune system.
Carbohydrates	Provide a ready source of energy for the body and provide structural constituents for the formation of cells.
Fat	Provides stored energy for the body, functions as structural components of cells and also as signaling molecules for proper cellular communication. It provides insulation to vital organs and works to maintain body temperature.
Vitamins	Regulate body processes and promote normal body-system functions.
Minerals	Regulate body processes, are necessary for proper cellular function, and comprise body tissue.
Water	Transports essential nutrients to all body parts, transports waste products for disposal, and aids with body temperature maintenance.

Lifestyles and Nutrition

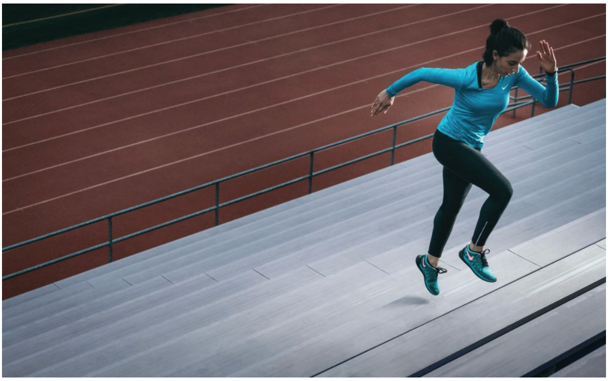


Image by John Towner on unsplash.com / CC0

In addition to nutrition, health is affected by genetics, the environment, life cycle, and lifestyle. One facet of lifestyle is your dietary habits. Recall that we discussed briefly how nutrition affects health. A greater discussion of this will follow in subsequent chapters in this book, as there is an enormous amount of information regarding this aspect of lifestyle. Dietary habits include what a person eats, how much a person eats during a meal, how frequently meals are consumed, and how often a person eats out. Other aspects of lifestyle include physical activity level, recreational drug use, and sleeping patterns, all of which play a role in health and impact nutrition. Following a healthy lifestyle improves your overall health.

Physical Activity

Being physically active is one of the most important steps that Canadians of all ages can take to improve their health. There is strong evidence that increased physical activity decreases the risk of early death, heart disease, stroke, Type 2 diabetes, high blood pressure, and certain cancers; prevents weight gain and falls; and improves cognitive function in the elderly. The Canadian Physical Activity Guidelines are available at the website of The Canadian Society for Exercise Physiology[1].

Recreational Drug Use

Recreational drug use, which includes tobacco-smoking, electronic smoking device use, and alcohol consumption along with narcotic and other illegal drug use, has a large impact on health. Smoking cigarettes can cause lung cancer, eleven other types of cancer, heart disease, and several other disorders or diseases that markedly decrease quality of life and increase mortality.

Staying away from excessive alcohol intake lowers blood pressure, the risk from injury, heart disease, stroke, liver problems, and some types of cancer. While excessive alcohol consumption can be linked to poor health, consuming alcohol in moderation has been found to promote health such as reducing the risk for heart disease and Type 2 diabetes in some people. Drinking in moderation is defined as no more than one drink a day for women and two drinks a day for men.

Illicit and prescription drug abuse are associated with decreased health. The health effects of drug abuse can be far-reaching, including the increased risk of stroke, heart disease, cancer, lung disease, and liver disease.

1. http://www.csep.ca/english/view.asp?x=804

Sleeping Patterns

Inadequate amounts of sleep, or not sleeping well, can also have remarkable effects on a person's health. In fact, sleeping can affect your health just as much as your diet. Scientific studies have shown that insufficient sleep increases the risk for heart disease, Type 2 diabetes, obesity, and depression. Abnormal breathing during sleep, a condition called sleep apnea, is also linked to an increased risk for chronic disease.

Personal Choice: The Challenge of Choosing Foods

There are other factors besides environment and lifestyle that influence the foods you choose to eat. Different foods affect energy level, mood, how much is eaten, how long before you eat again, and if cravings are satisfied. We have talked about some of the physical effects of food on your body, but there are other effects too.

Food regulates your appetite and how you feel. Multiple studies have demonstrated that some high fiber foods and high-protein foods decrease appetite by slowing the digestive process and prolonging the feeling of being full or satiety. The effects of individual foods and nutrients on mood are not backed by consistent scientific evidence, but in general, most studies support that healthier diets are associated with a decrease in depression and improved well-being. To date, science has not been able to track the exact path in the brain that occurs in response to eating a particular food, but it is quite clear that foods, in general, stimulate emotional responses in people. Food also has psychological, cultural, and religious significance, so your personal choices of food affect your mind, as well as your body. The social implications of food have a great deal to do with what people eat, as well as how and when. Special events in individual lives—from birthdays to funerals—are commemorated with equally special foods. Being aware of these forces can help people make healthier food choices—and still honor the traditions and ties they hold dear.

Typically, eating kosher food means a person is Jewish; eating fish on Fridays during Lent means a person is Catholic; fasting during the ninth month of the Islamic calendar means a person is Muslim. On New Year's Day, Japanese take part in an annual tradition of Mochitsuki also known as Mochi pounding in hopes of gaining good fortune over the coming year.

Factors that Drive Food Choices

Along with these influences, a number of other factors affect the dietary choices individuals make, including:

- **Taste, texture, and appearance**. Individuals have a wide range of tastes which influence their food choices, leading some to dislike milk and others to hate raw vegetables. Some foods that are very healthy, such as tofu, may be unappealing at first to many people. However, creative cooks can adapt healthy foods to meet most people's taste.
- **Economics.** Access to fresh fruits and vegetables may be scant, particularly for those who live in economically disadvantaged or remote areas, where cheaper food options are limited to convenience stores and fast food.
- **Early food experiences.** People who were not exposed to different foods as children, or who were forced to swallow every last bite of overcooked vegetables, may make limited food choices as adults.

- **Habits.** It's common to establish eating routines, which can work both for and against optimal health. Habitually grabbing a fast food sandwich for breakfast can seem convenient, but might not offer substantial nutrition. Yet getting in the habit of drinking an ample amount of water each day can yield multiple benefits.
- **Culture.** The culture in which one grows up affects how one sees food in daily life and on special occasions.
- **Geography.** Where a person lives influences food choices. For instance, people who live in Winnipeg may have less access to seafood than those living along the coasts.
- **Advertising.** The media greatly influences food choice by persuading consumers to eat certain foods.
- **Social factors.** Any school lunchroom observer can testify to the impact of peer pressure on eating habits, and this influence lasts through adulthood. People make food choices based on how they see others and want others to see them. For example, individuals who are surrounded by others who consume fast food are more likely to do the same.
- **Health concerns.** Some people have significant food allergies, to peanuts for example, and need to avoid those foods. Others may have developed health issues which require them to follow a low salt diet. In addition, people who have never worried about their weight have a very different approach to eating than those who have long struggled with excess weight.

Food Quality

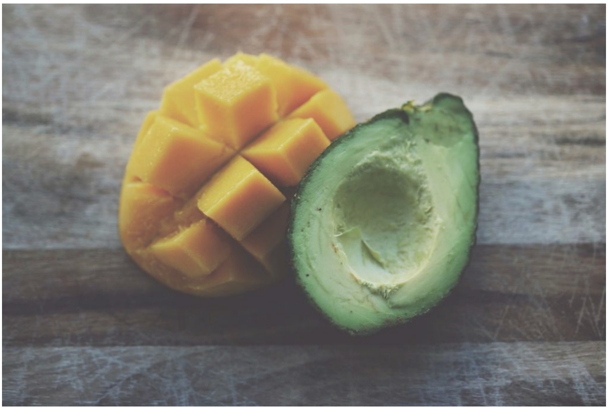


Image by David De Veroli on unsplash.com / CC0

One measurement of food quality is the amount of nutrients it contains relative to the amount of energy it provides. High-quality foods are **nutrient dense**, meaning they contain significant amounts of one or more essential nutrients relative to the amount of calories they provide. Nutrient-dense foods are the opposite of “empty-calorie” foods such as carbonated sugary soft drinks, which provide many calories and very little, if any, other nutrients. Nutrient-dense foods are foods that give the highest amount of nutrients for the least amount of energy (or kilocalories). Food quality is additionally associated with its taste, texture, appearance, microbial content, and how much consumers like it.

Food: A Better Source of Nutrients than Supplements

It is better to get all your micronutrients from the foods you eat as opposed to from supplements. Supplements contain only what is listed on the label, but foods contain many more macronutrients, micronutrients, and other chemicals, like antioxidants, that benefit health. There is no consistent evidence that supplements are better than food in promoting health and preventing disease.

Achieving a Healthy Diet

A **healthy diet** provides the proper combination of energy and nutrients to promote health. Achieving a healthy diet is a matter of balancing the quality and quantity of food that is eaten. There are five key factors that make up a healthful diet:

1. A diet must be **adequate**, by providing sufficient amounts of each essential nutrient, as well as fiber and adequate calories.
2. A **balanced** diet results when you do not consume one nutrient at the expense of another, but rather get appropriate amounts of all nutrients.
3. **Calorie control** is necessary so that the amount of energy you get from the nutrients you consume equals the amount of energy you expend during your day's activities.
4. **Moderation** means not eating to the extremes, neither too much nor too little.
5. **Variety** refers to consuming different foods from within each of the food groups on a regular basis. By eating a variety of foods, you increase your chances of consuming the nutrients required.

A healthy diet is one that favours whole foods. As an alternative to modern processed foods, a healthy diet focuses on "real" fresh whole foods that have been sustaining people for generations. Whole foods supply the needed vitamins, minerals, protein, carbohydrates, fats, and fiber that are essential to good health. Commercially prepared and fast foods are often lacking nutrients and often contain inordinate amounts of sugar, salt, saturated and trans fats, all of which are associated with the development of diseases such as atherosclerosis, heart disease, stroke, cancer, obesity, diabetes, and other illnesses. A balanced diet is a mix of food from the different food groups (vegetables, legumes, fruits, grains, protein foods, and dairy).

Adequacy

An adequate diet is one that favours nutrient-dense foods. Nutrient-dense foods are defined as foods that contain many essential nutrients per calorie. Nutrient-dense foods are the opposite of "empty-calorie" foods, such as sugary carbonated beverages, which are also called "nutrient-poor." Nutrient-dense foods include fruits and vegetables, lean meats, poultry, fish, low-fat dairy products, and whole grains. Choosing more nutrient-dense foods will facilitate weight loss, while simultaneously providing all necessary nutrients.

Balance

Balance the foods in your diet. Achieving balance in your diet entails not consuming one nutrient at the expense of another. For example, calcium is essential for healthy teeth and bones, but too much calcium will interfere with iron absorption. Most foods that are good sources of iron are poor sources of calcium, so in order to get the necessary amounts of calcium and iron from your diet, a proper balance between food choices is critical. Another example is that while sodium is an essential nutrient, excessive intake may contribute to congestive heart failure and chronic kidney disease in some people. Remember, everything must be consumed in the proper amounts.

Moderation

Eat in moderation. Moderation is crucial for optimal health and survival. Eating nutrient-poor foods each night for dinner will lead to health complications. But as part of an otherwise healthful diet and consumed only on a weekly basis, this should not significantly impact overall health. It's important to remember that eating is, in part, about enjoyment and indulging with a spirit of moderation. This fits within a healthy diet.

Monitor food portions. For optimum weight maintenance, it is important to ensure that energy consumed from foods meets the energy expenditures required for body functions and activity. If not, the excess energy contributes to gradual, steady accumulation of stored body fat and weight gain. In order to lose body fat, you need to ensure that more calories are burned than consumed. Likewise, in order to gain weight, calories must be eaten in excess of what is expended daily.

Variety

Variety involves eating different foods from all the food groups. Eating a varied diet helps to ensure that you consume and absorb adequate amounts of all essential nutrients required for health. One of the major drawbacks of a monotonous diet is the risk of consuming too much of some nutrients and not enough of others. Trying new foods can also be a source of pleasure—you never know what foods you might like until you try them.

Developing a healthful diet can be rewarding, but be mindful that all of the principles presented must be followed to derive maximal health benefits. For instance, introducing variety in your diet can still result in the consumption of too many high-calorie, nutrient poor foods and inadequate nutrient intake if you do not also employ moderation and calorie control. Using all of these principles together will promote lasting health benefits.

Understanding Daily Reference Intakes

There are several tools that can help you design a healthy diet. You can get in the habit of reading food labels and rely on the advice of Canada's Food Guide. To better understand food labels and the Nutrition Facts tables, you must be familiar withe the Dietary Reference Intakes (DRI). DRI's are the recommendation levels for specific nutrients and consist of a number of different types of recommendations. The aim of this value is to prevent and reduce the risk of developing chronic disease and promoting optimal health.

Daily Reference Intakes: A Brief Overview

"Dietary Reference Intakes" (DRI) is an umbrella term for four reference values:

- Estimated Average Requirements (EAR)
- Recommended Dietary Allowances (RDA)
- Adequate Intakes (AI)
- Tolerable Upper Intake Levels (UL)

The DRIs are not minimum or maximum nutritional requirements and are not intended to fit everybody. They are to be used as guides only for the majority of the healthy population[1].

The DRIs are dietary standards for healthy people only; they are not appropriate for people who are ill or malnourished, even if they were healthy previously. They identify the amount of nutrient needed to prevent deficiency diseases in healthy individuals, but also consider how much of this nutrient is required to reduce the risk of chronic diseases.

Determining Dietary Reference Intakes

Each DRI value is derived in a different way. See below for an explanation of how each is determined:

1. **Estimated Average Requirements (EAR).** The EAR for a nutrient is determined by a committee of nutrition experts who review the scientific literature to determine a value that meets the requirements of 50 percent of people in their target group within a given life stage and for a particular sex. The requirements of half of the group will fall below the EAR and the other half will be above it. It is important to note that, for each nutrient, a specific bodily function is chosen as the criterion on which to base the EAR. For example, the EAR for calcium is set using a criterion of maximizing bone health. Thus, the EAR for calcium is set at a point that will meet the needs, with

1. Deng S, West BJ, Jensen CJ. A Quantitative Comparison of Phytochemical Components in Global Noni Fruits and Their Commercial Products. Food Chemistry. 2010; 122(1), 267–70. http://www.sciencedirect.com/science/article/pii/S0308814610001111. Accessed December 4, 2017.

respect to bone health, of half of the population. EAR values become the scientific foundation upon which RDA values are set.

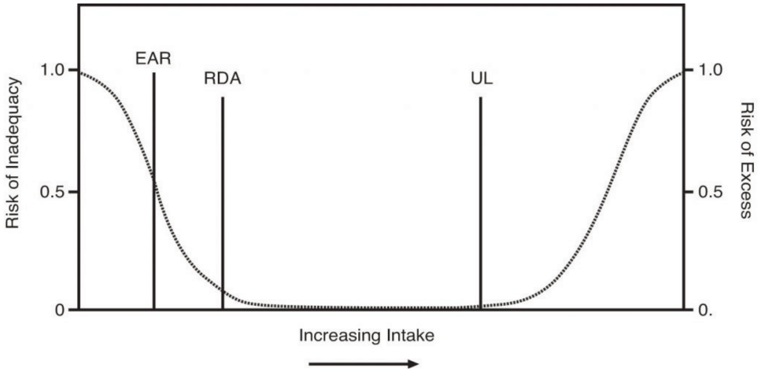
2. **Recommended Daily Allowances (RDA).** Once the EAR of a nutrient has been established, the RDA can be mathematically determined. While the EAR is set at a point that meets the needs of half the population, RDA values are set to meet the needs of the vast majority (97 to 98 percent) of the target healthy population. It is important to note that RDAs are not the same thing as individual nutritional requirements. The actual nutrient needs of a given individual will be different than the RDA. However, since we know that 97 to 98 percent of the population's needs are met by the RDA, we can assume that if a person is consuming the RDA of a given nutrient, they are most likely meeting their nutritional need for that nutrient. The important thing to remember is that the RDA is meant as a recommendation and meeting the RDA means it is very likely that you are meeting your actual requirement for that nutrient.

Understanding the Difference

There is a distinct difference between a requirement and a recommendation. For instance, the DRI for vitamin D is a recommended 600 international units each day. However, in order to find out your true personal requirements for vitamin D, a blood test is necessary. The blood test will provide an accurate reading from which a medical professional can gauge your required daily vitamin D amounts. This may be considerably more or less than the DRI, depending on what your level actually is.

1. **Adequate Intake (AI).** AIs are created for nutrients when there is insufficient consistent scientific evidence to set an EAR for the entire population. As with RDAs, AIs can be used as nutrient-intake goals for a given nutrient. For example, there has not been sufficient scientific research into the particular nutritional requirements for infants. Consequently, all of the DRI values for infants are AIs derived from nutrient values in human breast milk. For older babies and children, AI values are derived from human milk coupled with data on adults. The AI is meant for a healthy target group and is not meant to be sufficient for certain at-risk groups, such as premature infants.
2. **Tolerable Upper Intake Levels (UL).** The UL was established to help distinguish healthful and harmful nutrient intakes. Developed in part as a response to the growing usage of dietary supplements, ULs indicate the highest level of continuous intake of a particular nutrient that may be taken without causing health problems. When a nutrient does not have any known issue if taken in excessive doses, it is not assigned a UL. However, even when a nutrient does not have a UL it is not necessarily safe to consume in large amounts.

Figure 12.1 DRI Graph



This graph illustrates the risks of nutrient inadequacy and nutrient excess as we move from a low intake of a nutrient to a high intake. Starting on the left side of the graph, you can see that when you have a very low intake of a nutrient, your risk of nutrient deficiency is high. As your nutrient intake increases, the chances that you will be deficient in that nutrient decrease. The point at which 50 percent of the population meets their nutrient need is the EAR, and the point at which 97 to 98 percent of the population meets their needs is the RDA. The UL is the highest level at which you can consume a nutrient without it being too much—as nutrient intake increases beyond the UL, the risk of health problems resulting from that nutrient increases.

Source: Dietary Reference Intakes Tables and Application. The National Academies of Science, Engineering, and Medicine. Health and Medicine Division. http://nationalacademies.org/HMD/Activities/Nutrition/SummaryDRIs/DRI-Tables.aspx. Accessed November 22, 2017.

DRIs for Energy and Macronutrients

Estimated Energy Requirement (EER). The EER is the average dietary energy intake that is predicted to maintain energy balance in healthy adults. This value is defined by a person's age, gender, weight, height and level of physical activity that is consistent with good health.

The **Acceptable Macronutrient Distribution Range (AMDR)** is the calculated range of how much energy from carbohydrates, fats, and protein is recommended for a healthy diet adequate of the essential nutrients and is associated with a reduced risk of chronic disease. The ranges listed in Table 1.4 "Acceptable Macronutrient Distribution Ranges (AMDR) For Various Age Groups" allows individuals to personalize their diets taking into consideration that different subgroups in a population often require different requirements. The DRI committee recommends using the midpoint of the AMDRs as an approach to focus on moderation[2].

Table 1.4 Acceptable Macronutrient Distribution Ranges (AMDR) For Various Age Groups

Age Group	Protein (%)	Carbohydrates (%)	Fat (%)
Children (1–3)	5–20	45–65	30–40
Children and Adolescents (4–18)	10–30	45–65	25–35
Adults (>19)	10–35	45–65	20–35

Source: Food and Nutrition Board of the Institute of Medicine. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. http://www.nationalacademies.org/hmd/~/media/Files/Activity%20Files/Nutrition/DRI-Tables/8_Macronutrient%20Summary.pdf?la=en. Published 2002. Accessed November 22, 2017.

2. Dietary Reference Intakes Tables and Application. The National Academies of Science, Engineering, and Medicine. Health and Medicine Division. http://nationalacademies.org/HMD/Activities/Nutrition/SummaryDRIs/DRI-Tables.aspx. Accessed November 22, 2017.

Tips for Using the Dietary Reference Intakes to Plan Your Diet

You can use the DRIs to help assess and plan your diet. Keep in mind when evaluating your nutritional intake that the values established have been devised with an ample safety margin and should be used as guidance for optimal intakes. Also, the values are meant to assess and plan average intake over time; that is, you don't need to meet these recommendations every single day—meeting them on average over several days is sufficient.

Discovering Nutrition Facts

The Labels on Your Food

Understanding the significance of dietary guidelines and how to use DRIs in planning your nutrient intakes can make you better equipped to select the right foods the next time you go to the supermarket.

In Canada, mandatory labeling came into effect in 2005. As a result, all packaged foods sold in Canada must have nutrition labels that accurately reflect the contents of the food products. There are several mandated nutrients and some optional ones that manufacturers or packagers include.

Almost all pre-packaged foods are required to have a Nutrition Facts label. This label reflects scientific information and makes it easier for consumers to make informed food choices. The label must include four components:

1. **Ingredient List:** The ingredients must be listed by their common names, in descending order by weight. Ingredient lists are mandatory on all food labels.
2. **Nutrition Facts Table:** The facts table has a consistent forma and provides information on calories and a core list of 13 ingredients: fat, saturated fat, trans fat, cholesterol, sodium, carbohydrate, fibre, sugars, protein, vitamin A, vitamin C, calcium and iron. Food manufacturers may include other nutrients but they must follow a template. More information on the Nutrition Facts Table in the section below.
3. **Nutrient Content Claims:** These are statements based on

current scientific evidence that can be made when the product meets a certain criteria. Nutrient content claims provide information about the amount of one specific nutrient in a food, such as fiber or fat. Examples of such claims include: “source of omega-3 polyunsaturates” or “25% less sodium”. While nutrient content claims are optional, they must meet government regulations before appearing on a package.

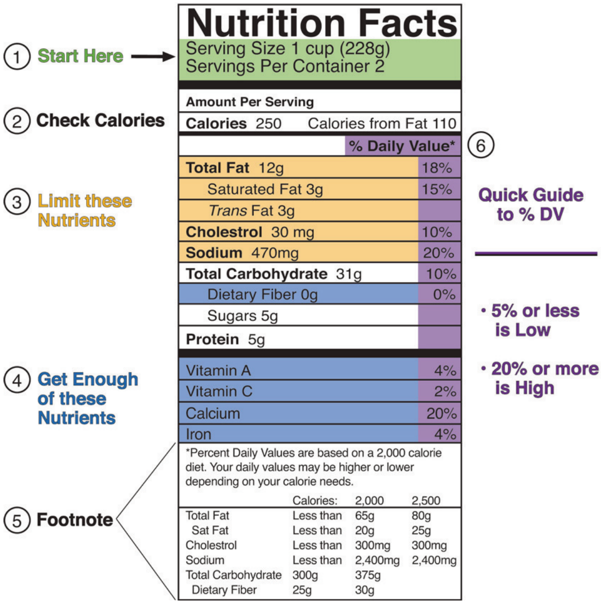
4. **Diet-Related Health Claims:** Health claims are statements that link a food or food component to a reduced risk of a disease or to a condition. To use a specific health claim, the food must meet specific content criteria. For example, to say a food may lower the risk of hypertension, it must be low in sodium and contain at least 350mg of potassium.

Reading the Label

The first part of the Nutrition Facts panel gives you information on the **serving size**. For example, a label on a box of crackers might tell you that twenty crackers equals one serving. All other values listed thereafter, from the calories to the dietary fiber, are based on this one serving. On the panel, the serving size is followed by the number of calories and then a list of selected nutrients. You will also see “Percent Daily Value” on the far right-hand side. This helps you determine if the food is a good source of a particular nutrient or not. The Daily Value (DV) represents the recommended amount of a given nutrient based on the RDI of that nutrient in a 2,000-kilocalorie diet. The percentage of Daily Value (percent DV) represents the proportion of the total daily recommended amount that you will get from one serving of the food. For example, in the older food label in Figure 1.2 “Reading a Nutrition Label,” the percent DV of calcium for one serving of macaroni-and-cheese is 20 percent, which means that one serving of macaroni and cheese provides 20 percent of the daily recommended calcium intake. Since the DV for calcium is 1,000 milligrams, the food producer determined the percent DV for calcium by taking the calcium content in milligrams in each serving, and dividing it by 1,000 milligrams, and then multiplying it by 100 to get it into percentage format. Whether you consume 2,000 calories per day or not you can still use the percent DV as a target reference.

Generally, a percent DV of 5 is considered low and a percent DV of 20 is considered high. This means, as a general rule, for fat, saturated fat, trans fat, cholesterol, or sodium, look for foods with a low percent DV. Alternatively, when concentrating on essential mineral or vitamin intake, look for a high percent DV. To figure out your fat allowance remaining for the day after consuming one serving of macaroni-and-cheese, look at the percent DV for fat, which is 18 percent, and subtract it from 100 percent. To know this amount in grams of fat, read the footnote of the food label to find that the recommended maximum amount of fat grams to consume per day for a 2,000 kilocalories per day diet is 65 grams. Eighteen percent of sixty-five equals about 12 grams. This means that 53 grams of fat are remaining in your fat allowance. Remember, to have a healthy diet the recommendation is to eat less than this amount of fat grams per day, especially if you want to lose weight.

Figure 1.2 Reading a Nutrition Label



A sample label for macaroni and cheese.

Source: How to Understand and Use the Nutrition Facts Panel. FDA. http://www.fda.gov/food/labelingnutrition/consumerinformation/ucm078889.htm#dvs. Updated February 15, 2012. Accessed November 22, 2017.

Of course, this is a lot of information to put on a label and some products are too small to accommodate it all. In the case of small packages, such as small containers of yogurt, candy, or fruit bars, permission has been granted to use an abbreviated version of the Nutrition Facts panel. To learn additional details about all of the information contained within the Nutrition Facts panel, see the following website: https://www.canada.ca/content/dam/canada/health-canada/migration/healthy-canadians/alt/pdf/publications/eating-nutrition/label-etiquetage/fact-fiche-eng.pdf

Figure 1.3 Food Serving Sizes


FOOD SERVING SIZES GET A REALITY CHECK
Serving Size Changes
What's considered a single serving has changed in the decades since the original nutrition label was created. So now serving sizes will be more realistic to reflect how much people typically eat at one time.
CURRENT SERVING SIZE
4 SERVINGS
1 PINT
200 CALORIES
NEW SERVING SIZE
3 SERVINGS
1 PINT
270 CALORIES
Packaging Affects Servings
Package size affects how much people eat and drink. So now, for example, both 12 *and* 20 ounce bottles will equal 1 serving, since people typically drink both sizes in one sitting.
12 OUNCES
120 CALORIES
20 OUNCES
200 CALORIES
1 SERVING PER BOTTLE
FOR EITHER BOTTLE SIZE

Source: https://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm385663.htm

The Nutrition Facts panel provides a wealth of information about the nutritional content of the product. The information also allows shoppers to compare products. Because the serving sizes are included on the label, you can see how much of each nutrient is in each serving to make the comparisons. Knowing how to read the label is important because of the way some foods are presented. For example, a bag of peanuts at the grocery store may seem like a healthy snack to eat on the way to class. But have a look at that label. Does it contain one serving, or multiple servings? Unless you are buying the individual serving packages, chances are the bag you picked up is at least eight servings, if not more.

Nutrient Content Claims on Labels

In addition to mandating nutrients and ingredients that must appear on food labels, any nutrient content claims must meet certain requirements. For example, a manufacturer cannot claim that a food is fat-free or low-fat if it is not, in reality, fat-free or low-fat. Low-fat indicates that the product has three or fewer grams of fat; low salt indicates there are fewer than 140 milligrams of sodium, and low-cholesterol indicates there are fewer than 20 milligrams of cholesterol and two grams of saturated fat. See Table 1.5 “Common Label Terms Defined” for some examples.

Table 1.5 Common Label Terms Defined

Term	Explanation
Lean	Fewer than a set amount of grams of fat for that particular cut of meat
High	Contains more than 20% of the nutrient's DV
Good source	Contains 10 to 19% of nutrient's DV
Light/ lite	Contains ⅓ fewer calories or 50% less fat; if more than half of calories come from fat, then fat content must be reduced by 50% or more
Organic	Contains 95% organic ingredients

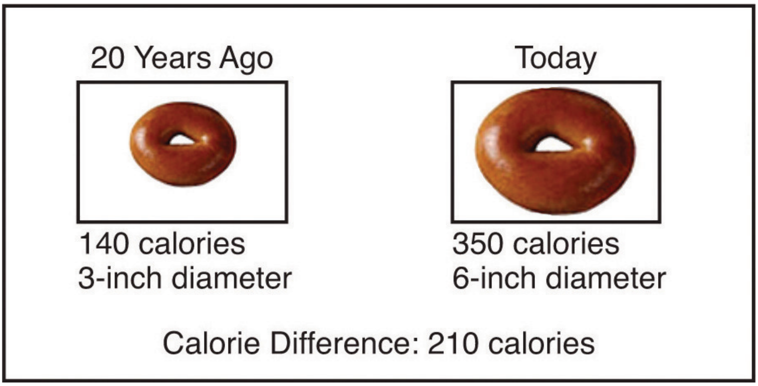
When Enough Is Enough

Estimating Portion Size

Have you ever heard the expression, "Your eyes were bigger than your stomach?" This means that you thought you wanted a lot more food than you could actually eat. Amounts of food can be deceiving to the eye, especially if you have nothing to compare them to. It is very easy to heap a pile of mashed potatoes on your plate, particularly if it is a big plate, and not realize that you have just helped yourself to three portions instead of one.

In many restaurants and eating establishments, portion sizes have increased and consequently the typical meal contains more calories than it used to. In addition, our sedentary lives make it difficult to expend enough calories during normal daily activities. In fact, more than one-third of adults are not physically active at all.

Figure 1.4 A Comparison of Serving Sizes



Source: https://www.nhlbi.nih.gov/health/educational/wecan/portion/documents/PD1.pdf

As food sizes and servings increase it is important to limit the portions of food consumed on a regular basis. Dietitians have come up with some good hints to help people tell how large a portion of food they really have. Some suggest using common items such as a deck of cards while others advocate using your hand as a measuring rule.

Table 1.6 Determining Food Portions

Food Product	Amount	Object Comparison	Hand Comparison
Pasta, rice	½ c.	Tennis ball	Cupped hand
Fresh vegetables	1 c.	Baseball	
Cooked vegetables	½ c.		Cupped hand
Meat, poultry, fish	3 oz.	Deck of cards	Palm of your hand
Milk or other beverages	1 c.	Fist	
Salad dressing	1 Tbsp.	Thumb	
Oil	1 tsp.	Thumb tip	

Everyday Connections

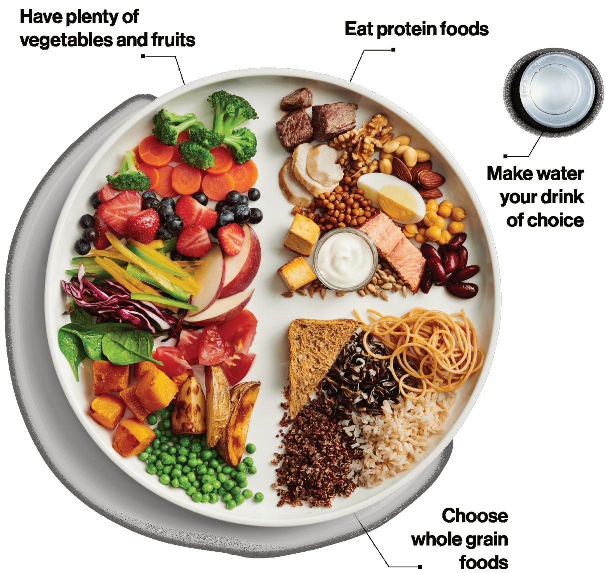
If you wait many hours between meals, there is a good chance you will overeat. To refrain from overeating try consuming small meals at frequent intervals throughout the day as opposed to two or three large meals. Eat until you are satisfied, not until you feel “stuffed.” Eating slowly and savoring your food allows you to both enjoy what you eat and have time to realize that you are full before you get overfull. Your stomach is about the size of your fist but it expands if you eat excessive amounts of food at one sitting. Eating smaller meals will diminish the size of your appetite over time so you will feel satisfied with smaller amounts of food.

Canada's Food Guide

Canada’s first food guide, the Official Food Rules, was developed in 1942 to help prevent nutritional deficiencies and improve the health of Canadians during wartime food rationing. Since that time, it was been transformed many times to adapt to the current situations and demands. The current version recommends the following:

1. Eat plenty of vegetables and fruits, whole grain foods and protein foods. Choose protein foods that come from plants more often. Select mono and poly-unsaturated fats over saturated fats.
2. Limit highly processed foods. Prepare meals with little to no sodium, sugars or saturated fats.
3. Make water your drink of choice.
4. Use food labels
5. Be aware that marketing can influence your choices.

Figure 1.5 Canada’s Food Guide



The guide outlines a set of recommendations to develop healthy eating habits:

1. Be mindful of your eating habits. Take time to eat and notice when you are hungry and full.
2. Cook more often. Plan what you eat, involve others in planning and prepare meals.
3. Enjoy your food. Culture and food traditions can be part of healthy eating.
4. Eat meals with others.

Source: https://food-guide.canada.ca/en/healthy-eating-recommendations/

Units of Measure

In nutrition, there are two systems of commonly used measurements: Metric and US Customary.

The Metric and US Customary System

These are commonly used prefixes for the Metric System:

Micro- (μ)	1/1,000,000th (one millionth)
Milli- (m)	1/1000th (one thousandth)
Centi- (c)	1/100th (one hundredth)
Deci- (d)	1/10th (one tenth)
Kilo- (k)	1000x (one thousand times)

Mass

Metric System	**US Customary System**	**Conversions**
Microgram (μg)	Ounce (oz)	1 oz = 28.35 g
Milligram (mg)	Pound (lb)	1 lb = 16 oz
Gram (g)		1 lb = 454 g
Kilogram (kg)		1 kg = 2.2 lbs

Volume

Metric System	US Customary System	Conversions
Milliliter (mL)	Teaspoon (tsp)	1 tsp = 5 mL
Deciliter (dL)	Tablespoon (tbsp)	1 tbsp = 3 tsp = 15 mL
Liter (L)	Fluid ounce (fl oz)	1 fl oz = 2 tbsp = 30 mL
	Cup (c)	1 c = 8 fl oz = 237 mL
	Pint (pt)	1 pt = 2 c = 16 fl oz
	Quart (qt)	1 qt = 4 c = 32 fl oz = 0.95 L
	Gallon (gal) = 4 qt	1 gal = 4 qt

Length

Metric System	US Customary System	Conversions
Millimeter (mm)	Inch (in)	1 in = 25.4 mm
Centimeter (cm)	Foot (ft)	1 ft= 30.5 cm
Meter (m)	Yard (yd)	1 yd = 0.9 m
Kilometer (km)	Mile (mi)	1 mi = 1.6 km

CHAPTER 2. THE SCIENTIFIC METHOD IN NUTRITION

Research and the Scientific Method

Photo by Jonathon Simcoe on unsplash.com / CC0

Learning Objectives

By the end of this chapter you will be able to:

- Describe the Scientific Method and understand its role in Nutrition.
- Differentiate between lay-literature and peer-

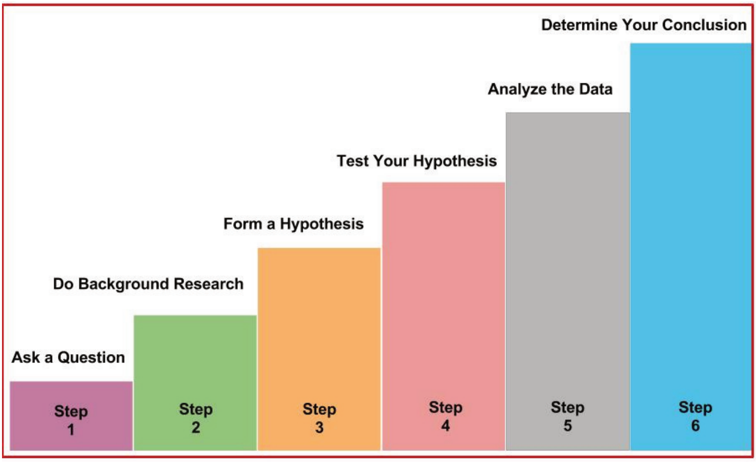
reviewed/scientific literature.

- Search scientific databases to find peer-reviewed articles.
- Differentiate between original studies and review articles.
- Stay organized with literature review matrices when conducting research.
- Properly cite and reference peer-reviewed articles when reporting their information.

Where do you get your nutrition information? The news, articles on social media or word of mouth? Knowing which sources are trustworthy and which are based on scientific fact can be confusing. The best resources are called peer-reviewed or scientific journals. They reside in special databases such as Google Scholar, Pubmed or Medline to name a few. These journals contain articles written by nutritional scientists and reviewed by their peers, experts in their respective fields. The articles are summaries of experiments run (original studies) using the **scientific methods** or summaries of a series of studies on a similar topic (reviews).

Nutritional scientists discover the health effects of food and its nutrients by first making an observation. Once observations are made, they come up with a hypothesis, test their hypothesis, and then interpret the results. After this, they gather additional evidence from multiple sources and finally come up with a conclusion. This organized process of inquiry used in science is called the **scientific method**.

Figure 2.1 Scientific Method Steps



In 1811, French chemist Bernard Courtois was isolating saltpeter for producing gunpowder to be used by Napoleon's army. To carry out this isolation, he burned some seaweed and in the process, observed an intense violet vapor that crystallized when he exposed it to a cold surface. He sent the violet crystals to an expert on gases, Joseph Gay-Lussac, who identified the crystal as a new element. It was named iodine, the Greek word for violet. The following scientific record is some of what took place in order to conclude that iodine is a nutrient.

Observation. Eating seaweed is a cure for goiter, a gross enlargement of the thyroid gland in the neck.

Hypothesis. In 1813, Swiss physician Jean-Francois Coindet hypothesized that the seaweed contained iodine, and that iodine could be used instead of seaweed to treat his patients[1].

1. Zimmerman, M.B. Research on Iodine Deficiency and Goiter in the 19th and Early 20th Centuries. Journal of Nutrition. 2008; 138(11),

Experimental test. Coindet administered iodine tincture orally to his patients with goiter.

Interpret results. Coindet's iodine treatment was successful.

Hypothesis. French chemist Chatin proposed that the low iodine content in food and water in certain areas far away from the ocean was the primary cause of goiter, and renounced the theory that goiter was the result of poor hygiene.

Experimental test. In the late 1860s the program, "The stamping-out of goiter," started with people in several villages in France being given iodine tablets.

Results. The program was effective and 80 percent of goitrous children were cured.

Hypothesis. In 1918, Swiss doctor Bayard proposed iodizing salt as a good way to treat areas endemic with goiter.

Experimental test. Iodized salt was transported by mules to a small village at the base of the Matterhorn where more than 75 percent of school children were goitrous. It was given to families to use for six months.

Results. The iodized salt was beneficial in treating goiter in this remote population.

Experimental test. Physician David Marine conducted the first experiment of treating goiter with iodized salt in America in Akron, Ohio.[2]

Results. This study was conducted on over four-thousand school children, and found that iodized salt prevented goiter.

2060–63. http://jn.nutrition.org/content/138/11/2060.full Accessed September 17, 2017

2. Carpenter, K.J. David Marine and the Problem of Goiter. Journal of Nutrition. 2005; 135(4), 675–80. http://jn.nutrition.org/content/135/4/675.full?sid=d06fdd35-566f -42a2-a3fd- efbe0736b7ba Accessed September 17, 2017.

Conclusions. Seven other studies similar to Marine's were conducted in Italy and Switzerland, which also demonstrated the effectiveness of iodized salt in treating goiter. In 1924, US public health officials initiated the program of iodizing salt and started eliminating the scourge of goiter. Today, more than 70% of American households use iodized salt and many other countries have followed the same public health strategy to reduce the health consequences of iodine deficiency.

Career Connection

What are some of the ways in which you think like a scientist, and use the scientific method in your everyday life? Any decision-making process uses some aspect of the scientific method. Think about some of the major decisions you have made in your life and the research you conducted that supported your decision. For example, what brand of computer do you own? Where is your money invested? What post-secondary institution do you attend?

Evidence-Based Approach to Nutrition

It took more than one hundred years from iodine's discovery as an effective treatment for goiter until public health programs recognized it as such. Although a lengthy process, the scientific method is a productive way to define essential nutrients and determine their ability to promote health and prevent disease. The scientific method is part of the overall evidence-based approach to designing nutritional guidelines[3]. An evidence-based approach to nutrition includes[4]:

- Defining the problem or uncertainty (e.g., the incidence of goiter is lower in people who consume seaweed)
- Formulating it as a question (e.g., Does eating seaweed decrease the risk of goiter?)
- Setting criteria for quality evidence
- Evaluating the body of evidence
- Summarizing the body of evidence and making decisions
- Specifying the strength of the supporting evidence required to make decisions
- Disseminating the findings

The Food and Nutrition Board, under Health Canada, constructs its nutrient recommendations (i.e., Dietary Reference Intakes, or DRI) using an evidence-based approach to nutrition. The entire procedure for setting the DRI is documented and made available to the public.

3. Myers E. Systems for Evaluating Nutrition Research for Nutrition Care Guidelines: Do They Apply to Population Dietary Guidelines? J Am Diet Assoc. 2003; 12(2), 34–41. http://jandonline.org/article/S0002-8223(03)01378-6/abstract. Accessed September 17, 2017.
4. Briss PA, Zara S, et al. Developing an Evidence-Based Guide to Community Preventive Services—Methods. Am J Prev Med. 2000; 18(1S), 35–43. https://www.ncbi.nlm.nih.gov/pubmed/10806978. Accessed September 17, 2017.

Types of Scientific Studies

There are various types of scientific studies on humans that can be used to provide supporting evidence for a particular hypothesis. These include epidemiological studies, interventional clinical trials, and randomized clinical trials. Valuable nutrition knowledge also is obtained from animal studies and cellular and molecular biology research.

Table 2.1 Types of Scientific Studies

Type	Description	Example	Notes
Epidemiological	Observational study of populations around the world and the impact of nutrition on health.	Diets with a high consumption of saturated fat are associated with an increased risk of heart attacks.	Does not determine cause-and-effect relationships.
Intervention Clinical Trials	Scientific investigations where a variable is changed between groups.	Testing the effect of different diets on blood pressure. One group consumes an American diet, group 2 eats a diet rich in fruits and vegetables, and group 3 eats a combination of groups 1 and 2.	If done correctly, it does determine cause-and-effect relationships.
Randomized Clinical Trials	Participants are assigned by chance to separate groups that compare different treatments. Neither the researchers nor the participants can choose which group a participant is assigned.	Testing the effect of calcium supplements on women with osteoporosis. Participants are given a pill daily of a placebo or calcium supplement. Neither the participant nor the researcher know what group the participant is in.	Considered the “gold” standard for scientific studies.

Animal and Cellular Biology	Studies are conducted on animals or on cells.	Testing the effects of a new blood pressure drug on guinea pigs or on the lipid membrane of a cell.	Less expensive than human trials. Study is not on whole humans so it may be not applicable.

Nutrition Assessment

Nutritional assessment is the interpretation of anthropometric, biochemical (laboratory), clinical and dietary data to determine whether a person or groups of people are well nourished or malnourished (overnourished or undernourished).

Nutritional assessment can be done using the ABCD methods. These refer to the following:

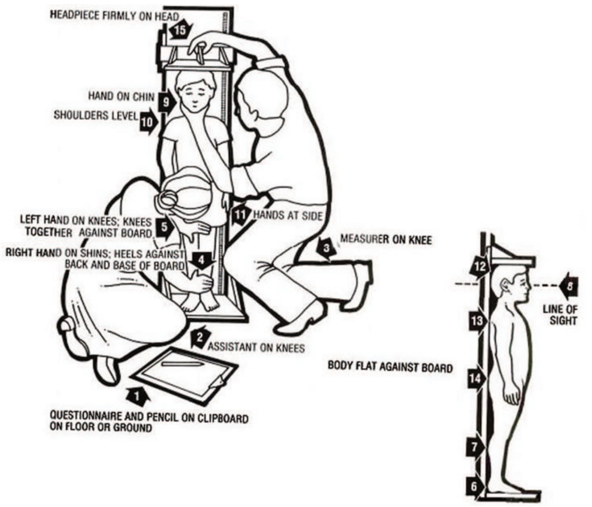
- A. Anthropometry
- B. Biochemical methods
- C. Clinical methods
- D. Dietary methods

Anthropometry methods of assessing nutritional status

The word anthropometry comes from two words: Anthropo means 'human' and metry means 'measurement'. The different measurements taken to assess growth and body composition are presented below.

To assess growth, several different measurements including length, height, weight, head circumference, mid-arm circumference, skin-fold thickness, head/chest ratio, and hip/waist ratio can be used. Height and weight measurements are essential in children to evaluate physical growth. As an additional resource, the NHANES Anthropometry Procedures Manual (revised January 2004) can be viewed here https://www.cdc.gov/nchs/data/nhanes/nhanes_03_04/BM.pdf

Figure 2.2 Measuring Height



(Source: UNICEF, 1986, How to weigh and measure children: assessing the nutrition status of young children)

Biochemical methods of assessing nutritional status

Biochemical or laboratory methods of assessment include measuring a nutrient or its metabolite in the blood, feces, urine or other tissues that have a relationship with the nutrient. An example of this method would be to take blood samples to measure levels of glucose in the body. This method is useful for determining if an individual has diabetes.

Figure 2.3 Measuring Blood Glucose Levels

Image by TesaPhotography / CC0

Clinical methods of assessing nutritional status

In addition to the anthropometric assessments, you can also assess clinical signs and symptoms that might indicate potential specific nutrient deficiency. Special attention are given to organs such as skin, eyes, tongue, ears, mouth, hair, nails, and gums. Clinical methods of assessing nutritional status involve checking signs of deficiency at specific places on the body or asking the patient whether they have any symptoms that might suggest nutrient deficiency.

Dietary methods of assessing nutritional status

Dietary methods of assessment include looking at past or current intakes of nutrients from food by individuals or a group to determine their nutritional status. There are several methods used to do this:

24 hour recall

A trained professional asks the subject to recall all food and drink consumed in the previous 24 hours. This is a quick and easy method. However, it is dependent upon the subject's short-term memory and may not be very accurate.

Food frequency questionnaire

The subject is given a list of foods and asked to indicate intake per day, per week, and per month. This method is inexpensive and easy to administer. It is more accurate than the 24 hour recall.

Food Diary

Food intake is recorded by the subject at the time of eating. This method is reliable but difficult to maintain. Also known as a food journal or food record.

Observed food consumption

This method requires food to be weighed and exactly calculated. It is very accurate but rarely used because it is time-consuming and expensive.

Evolving Science

Science is always moving forward, albeit sometimes slowly. One study is not enough to make a guideline or a recommendation, or cure a disease. Science is a stepwise process that builds on past evidence and finally culminates into a well-accepted conclusion. Unfortunately, not all scientific conclusions are developed in the interest of human health, and some can be biased. Therefore, it is important to know where a scientific study was conducted and who provided the funding, as this can have an impact on the scientific conclusions being made. For example, an air quality study paid for by a tobacco company diminishes its value in the minds of readers as well as a red meat study performed at a laboratory funded by a national beef association.

Nutritional Science Evolution

One of the newest areas in the realm of nutritional science is the scientific discipline of nutritional genetics, also called nutrigenomics. Genes are part of DNA and contain the genetic information that make up all of our traits. Genes are codes for proteins and when they are turned “on” or “off,” they change how the body works. While we know that health is defined as more than just the absence of disease, there are currently very few accurate genetic markers of good health. Rather, there are many more genetic markers for disease. However, science is evolving, and nutritional genetics aims to identify what nutrients to eat to “turn on” healthy genes and “turn off” genes that cause disease.

Using Science and Technology to Change the Future

As science evolves, so does technology. Both can be used to create a healthy diet, optimize health, and prevent disease. Picture yourself not too far into the future: you are wearing a small "dietary watch" that painlessly samples your blood, and downloads the information to your cell phone, which has an app that evaluates the nutrient profile of your blood and then recommends a snack or dinner menu to assure you maintain adequate nutrient levels. What else is not far off? How about another app that provides a shopping list that adheres to all dietary guidelines and is emailed to the central server at your local grocer, who then delivers the food to your home? The food is then stored in your smart fridge which documents your daily diet at home and delivers your weekly dietary assessment to your home computer. At your computer, you can compare your diet with other diets aimed at weight loss, optimal strength training, reduction in risk for specific diseases or any other health goals you may have. You also may delve into the field of nutritional genetics and download your gene expression profiles to a database that analyzes your genes against millions of others.

Nutrition and the Media

A motivational speaker once said, "A smart person believes half of what they read. An intelligent person knows which half to believe." In this age of information, where instant Internet access is just a click away, it is easy to be misled if you do not know where to go for reliable nutrition information.

Using Eyes of Discernment

"New study shows that margarine contributes to arterial plaque."

"Asian study reveals that two cups of coffee per day can have detrimental effects on the nervous system."

How do you react when you read news of this nature? Do you boycott margarine and coffee? When reading nutrition-related claims, articles, websites, or advertisements, always remember that one study does not substantiate a fact. One study neither proves nor disproves anything. Readers who may be looking for complex answers to nutritional dilemmas can quickly misconstrue such statements and be led down a path of misinformation. Listed below are ways that you can develop discerning eyes when reading nutritional news.

1. The scientific study under discussion should be published in a peer reviewed journal, such as the Journal of Nutrition. Question studies that come from less trustworthy sources (such as non peer-reviewed journals or websites) or that are not formally published.
2. The report should disclose the methods used by the researcher(s). Did the study last for three or thirty weeks? Were there ten or one hundred participants? What did the participants actually do? Did the researcher(s) observe the results themselves or did they rely on self reports from program participants?
3. Who were the subjects of this study? Humans or animals? If human, are any traits/characteristics noted? You may realize you have more in common with certain program participants and can use that as a basis to gauge if the study applies to you.
4. Credible reports often disseminate new findings in the context of previous research. A single study on its own gives you very limited information, but if a body of literature supports a finding, it adds to credibility.
5. Peer-reviewed articles deliver a broad perspective and are inclusive of findings of many studies on the exact same subject.
6. When reading such news, ask yourself, “Is this making sense?” Even if coffee does adversely affect the nervous

system, do you drink enough of it to see any negative effects? Remember, if a headline professes a new remedy for a nutrition-related topic, it may well be a research-supported piece of news, but more often than not, it is a sensational story designed to catch the attention of an unsuspecting consumer. Track down the original journal article to see if it really supports the conclusions being drawn in the news report.

When reading information on websites, remember the following criteria for discerning if the site is valid:

1. Who sponsors the website?
2. Are names and credentials disclosed?
3. Is an editorial board identified?
4. Does the site contain links to other credible informational websites?
5. Even better, does it reference peer-reviewed journal articles? If so, do those journal articles actually back up the claims being made on the website?
6. How often is the website updated?
7. Are you being sold something at this website?
8. Does the website charge a fee?

For more information, visit http://www.csuchico.edu/lins/handouts/eval_websites.pdf

Finding Peer-Reviewed Articles

This Chapter is specific to the resources offered at Douglas College but similar resources should be available at your institution. Peer-Reviewed articles are found in specializes databases available at the Library webpage. You can navigate to 'Articles and Databases' and search by subject. You can navigate to the 'Sciences' tab and find the link to **ScienceDirect**. This database will offer journals related to Nutrition. Also available at Douglas College is SportDiscus, Medline, Google Scholar and Academic Search Complete. Once you select the database of your choice, you enter key words in the search bar much like you would with a traditional search engine. You can choose to refine your search by selecting 'full text', 'review article' or 'research article' if needed.

Let's practice. Say you are instructed to research whether Himalayan salt is better for your health than regular table salt for regulating blood pressure. The search words you could enter is 'himalayan salt', 'table salt', 'hypertension', 'black salt' etc… If an article comes up that seems interesting, you can click on the link and read the abstract. The abstract is the first paragraph at the top of the article. It's purpose is to summarize the article in a few hundred words or less. It should give you an idea of whether the article is suitable for your study.

Figure 2.4 Peer-reviewed article

ABN8008
EFFECTS ON BLOOD PRESSURE OF BLACK SALT (HIMALAYAN SALT) VERSUS TABLE SALT IN PREHYPERTENSIVE INDIANS

S. Tanwar, N. Sen. *Baba Yogi Neta Nath Hospital, Bhiwani, India*

Background: Black salt (Himalayan salt) contains sodium chloride and traces of various minerals and chemical compounds such as sodium sulfate (Na2SO4), magnesia (MgO), iron in form of ferrous sulfate (FeSO4), ferric oxide etc. Black salt contains 36.8% to 38.8% sodium content, 0.28% potassium, 0.1% magnesium versus table salt which contains 38.8% to 39.8% sodium content, 0.12% potassium, <0.01% magnesium. Thus it is considered best for heart patients. To determine effect of black salt versus table

S. Tanwar, N. Sen. Effects on Blood Pressure of Black Salt (Himalayan Salt) Versus Table Salt in Prehypertensive Indians Indian Heart JournalVolume 71, Supplement 1November 2019Pages s77-s78

Keep in mind that studies can either be reviews (a summary of several studies around the same topic) or research studies (original study looking at answering one research question with an experiment). The research studies only provide you with one new piece of information. This means you must read several studies in order to fully understand a concept or topic.

How do I know the article is peer-reviewed?

Typically, articles that can be found in the databases suggested are peer-reviewed. To confirm, find the date the article was accepted by the journal, reviewed, revised by the author and finally published. For example, "Received April 15th, 2019, Accepted August 29th, 2019. Published in Science on June 21st, 2020." Other tips include looking at the lay-out. Does it include a title, list of authors and their affiliations and an abstract? Are there references listed or works cited throughout the article. For example, "Chocolate tastes delicious (Hamm et al, 2020)." Typically academic (or scholarly or peer-reviewed) work includes journal articles, monographs, books of edited readings, conference papers and theses. Non-academic work includes newspapers, magazines, newsletters, journals published weekly or more frequently, short articles (one or two pages) or articles with no list of references.

Properly Citing and Referencing your sources

You may want to report on a certain nutritional trend using the latest in scientific findings. This will entail spending some time in the academic journal databases looking for peer-reviewed articles. Once you have collected all of the articles relevant to your topic, you may decide to stay organized by creating a literature review matrix. This is essentially a spreadsheet in which you write the important pieces of information from each article. The matrix will vary depending on your project and on your area of study but typically includes: the title, the authors, the year of publication, the purpose of the study, the target population, the intervention (methods), sampling strategy, and the results. See example below:

Figure 2.5 Literature Review Matrix

	Year	Purpose	Life style addressed	Intervention	Sampling	Number of participants	Results
A randomized controlled trial of a health promotion education programme for people with multiple sclerosis. Ennis M. *et al.* Clinical rehabilitation 2006 20;783-792	2006	Evaluate effectiveness of a health promotion education programme for people with multiple sclerosis	Exercise, fatigue, stress, nutrition	Group based eight weekly sessions of 3 hours, "Optimize"	Patients attending a multiple sclerosis clinic at a regional neuroscience center	61 patients randomised, 31 in intervention, 30 in control	Significant higher levels of health promotion activity undertaken.
Education in stroke prevention: Efficacy of an educational counselling intervention to increase knowledge in stroke survivors. Green T. *et al.* Canadian Journal of Neuroscience Nursing 2007 29(2);13-20	2007	Examine impact of one-to-one brief nurse-patient interview on acquisition of knowledge of stroke and influence on lifestyle behaviour change	Smoking, exercise, alcohol	Nurse consultation and lifestyle class	Patients consulting an ambulatory stroke prevention clinic	200 patients randomised, 100 in intervention, 100 in control	No significant difference between groups on the identified risk factors
A quasi-experimental study on a community-based stroke prevention programme for clients with minor stroke. Sit JWH *et al.* Journal of clinical nursing 2007(16)272-281	2007	Determine the effectiveness of a community stroke-prevention programme	Stroke prevention issues, food, smoking, blood pressure	Nursing consultation (nurses as facilitators), 8 weekly 2 hours sessions	Participants who have had a minor stroke	190 patients, 107 in intervention, 83 in control (randomized by time slots)	No significant improvement in smoking or drinking alcohol, maintaining exercise in intervention group

Once your matrix is full and once you are satisfied with the number of articles that you have summarized, you can beginning the writing process. All scientific reports should start with an introduction in which you present your topic and justify why it is relevant or important. You then present the findings of all of the papers reviewed in a logical order, as though you are telling a story that has a beginning and an end. At the end of your paper, include a paragraph to summarize the main findings and the purpose of your paper. You can rely on the marking rubric of the instructor and the specific assignment for more details.

In a report, you are presenting the information you collected in the peer-reviewed article. In Nutrition, you typically use one to five sentences to summarize an article. You address the answer to the question they addressed and the strength and weaknesses of the argument (limitations). The population and intervention may also be worth mentioning depending on the topic. Any time you report information from an article, you must cite the article. Since you did not produce the new information, you must give credit to the authors by mentioning their last name and the year the article was published. This is called citing. In this course, we will use the American Psychology Association (APA) citation style. Here is a fictitious example represented in three acceptable ways:

1. In 2020, Hamm found caffein to have a positive effect on ….
   OR
2. Hamm (2020) found caffein to have a positive effect on…
   OR
3. Caffein has a positive effect on (Hamm, 2020)…

When PARAPHRASING or referring to an idea contained in another work, APA encourages but does not require one to "provide a page or paragraph number, especially when it would help an interested reader locate the relevant passage in a long or complex text." (*Publication manual*, 2010, p. 171).

There are specific ways of referring to the authors of the text depending on the number of authors. Where there are **TWO AUTHORS**, cite both names each time the reference occurs in the text. e.g.

The most recent study (Hamm & Duval, 2019) …

When there are **THREE TO FIVE AUTHORS**, cite all the names the first time. From then on, use only the first name followed by **et al.** (Latin abbreviation for "and others"). e.g.

First citation: Hamm, Duval, Murray and Johnson (2017) discovered that …

Later citations: Hamm et al. (1983) also discovered that …

When there are **SIX OR MORE AUTHORS**, cite only the surname of the first author followed by et al. and the year for all citations in text. e.g.

First citation: Hamm et al. (2016) demonstrated that …

Later citations: … as has been shown by Hamm et al. (2016).

Write out in full the whole name of a **GROUP OR ORGANIZATION THAT SERVES AS AUTHOR** every time, unless the abbreviation is well known. e.g.

First citation: The police report (Royal Canadian Mounted Police, 1979) …

Later citations: The RCMP report (1979) …

In Nutrition, <u>we rarely use direct quotations from texts</u>, we prefer paraphrasing and citing appropriately. For more information on APA referencing and for more examples, please consult the Douglas College Library website:

https://guides.douglascollege.ca/APA-6/home

At the end of your report, you should list the references from all of the citations included in your paper. Instructions on proper referencing in APA style can be found at the link above.

CHAPTER 3. THE HUMAN BODY AND DIGESTION

Introduction

Image by Henrique Felix on unsplash.com / CC0

Learning Objectives

By the end of this chapter, you will be able to:

- Explain the anatomy and physiology of the digestive system and other supporting organ systems
- Describe the relationships between each of the organ systems

A famous quote by the Greek physician Hippocrates over two thousand years ago, "Let food be thy medicine and medicine be thy food" bear much relevance on our food choices and their connection to our health. Today, the scientific community echoes Hippocrates' statement as it recognizes some foods as functional foods. Functional foods are defined as "whole foods and fortified, enriched, or enhanced foods that have a potentially beneficial effect on health when consumed as part of a varied diet on a regular basis, at effective levels."

In the latter nineteenth century, a Russian doctor of immunology, Elie Metchnikoff, was intrigued by the healthy life spans of people who lived in the tribes of the northern Caucasus Mountains. What contributed to their long lifespan and their resistance to life-threatening diseases? A possible factor lay wrapped up in a leather satchel used to hold fermented milk. Observing the connection between the beverage and longevity, Dr. Elie Metchnikoff began his research on beneficial bacteria and the longevity of life that led to his book, The Prolongation of Life. He studied the biological effects and chemical properties of the kefir elixir whose name came from the Turkish word "kef" or "pleasure." To this day, kefir is one of the most widely enjoyed beverages in Russia.

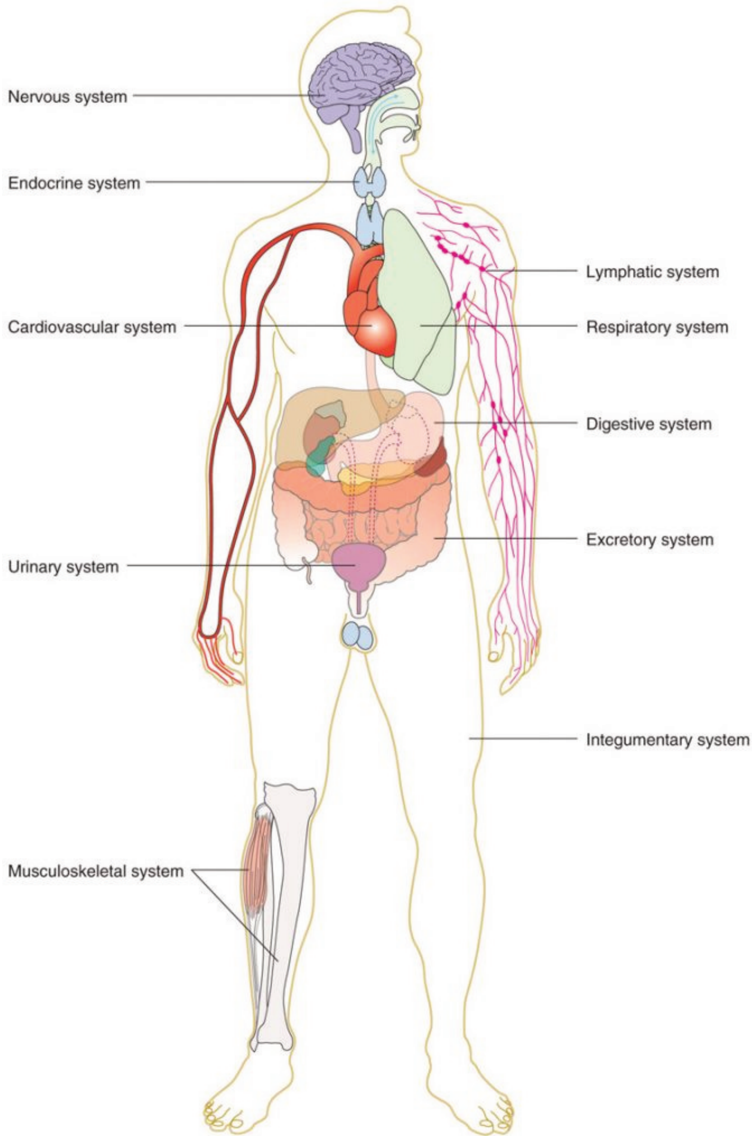
Kefir has since found its way into Canada, where it is marketed in several flavors and can be found at your local grocery store. It is one product of the billion-dollar functional food industry marketed with all sorts of health claims from improving digestion to preventing cancer. What is the scientific evidence that kefir is a functional food? Expert nutritionists agree that probiotics, such as kefir, reduce the symptoms of lactose intolerance and can ward off virally caused diarrhea. While some health claims remain unsubstantiated, scientific studies are ongoing to determine the validity of other health benefits of probiotics.

Another well-known probiotic is Kimchi. Kimchi is a traditional Korean food that is manufactured by fermenting vegetables (usually cabbage). Similar to the kefir, kimchi also has shown to have similar health benefits as a probiotic food.[1]

The Japanese also have traditional fermented foods such as natto. Natto is made from fermented soybeans and has many health benefits as a probiotic. Along with the beneficial components, natto is very nutrient-dense containing carbohydrates, fats, protein, fiber, vitamins and minerals.[2] Other common foods we ferment in our diet include miso, sauerkraut, kombucha, and tempeh.

Figure 3.1 Components of Organ Systems in the Human Body

1. Park K, Jeong J, et al. Health Benefits of Kimchi. Journal of Medicinal Food. 2014; 17(1), 6-20. https://www.ncbi.nlm.nih.gov/pubmed/24456350. Accessed September 20, 2017.
2. Sanjukta S, Rai AK. Production of bioactive peptides during soy fermentation and their potential health benefits. Trends in Food Science and Technology. 2016; 50, 1-10. http://www.sciencedirect.com/science/article/pii/S0924224415300571. Accessed September 20, 2017.



Knowing how to maintain the balance of friendly bacteria in your intestines through proper diet can promote overall health. Recent scientific studies have shown that probiotic supplements positively affect intestinal microbial flora, which in turn positively affect immune system function. As good nutrition is known to influence immunity, there is great interest in using probiotic foods and other immune-system-friendly foods as a way to prevent illness. In this chapter we will explore not only immune system function, but also all other organ systems in the human body. We will learn the process of nutrient digestion and absorption, which further reiterates the importance of developing a healthy diet to maintain a healthier you. The evidence abounds that food can indeed be "thy medicine."

Basic Biology, Anatomy, and Physiology

The Basic Structural and Functional Unit of Life: The Cell

What distinguishes a living organism from an inanimate object? A living organism conducts self-sustaining biological processes. A cell is the smallest and most basic form of life.

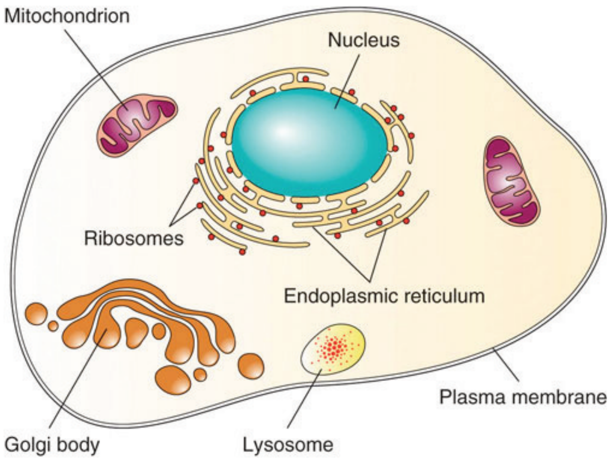
The cell theory incorporates three principles:

Cells are the most basic building units of life. All living things are composed of cells. New cells are made from preexisting cells, which divide in two. Who you are has been determined because of two cells that came together inside your mother's womb. The two cells containing all of your genetic information (DNA) united to begin making new life. Cells divided and differentiated into other cells with specific roles that led to the formation of the body's numerous body organs, systems, blood, blood vessels, bone, tissue, and skin. As an adult, you are made up of trillions of cells. Each of your individual cells is a compact and efficient form of life—self-sufficient, yet interdependent upon the other cells within your body to supply its needs.

Independent single-celled organisms must conduct all the basic processes of life. The single-celled organism must take in nutrients (energy capture), excrete wastes, detect and respond to its environment, move, breathe, grow, and reproduce. Even a one-celled organism must be organized to perform these essential processes. All cells are organized from the atomic level to all its larger forms. Oxygen and hydrogen atoms combine to make the molecule water (H2O). Molecules bond together to make bigger macromolecules. The carbon atom is often referred to as the backbone of life because it can readily bond with four other elements to form long chains and more complex macromolecules. Four macromolecules—carbohydrates, lipids, proteins, and nucleic acids—make up all of the structural and functional units of cells.

Although we defined the cell as the "most basic" unit of life, it is structurally and functionally complex (Figure 3.2 "The Cell Structure")**.** A cell can be thought of as a mini-organism consisting of tiny organs called organelles. The organelles are structural and functional units constructed from several macromolecules bonded together. A typical animal cell contains the following organelles: the nucleus (which houses the genetic material DNA), mitochondria (which generate energy), ribosomes (which produce protein), the endoplasmic reticulum (which is a packaging and transport facility), and the golgi apparatus (which distributes macromolecules). In addition, animal cells contain little digestive pouches, called lysosomes and peroxisomes, which break down macromolecules and destroy foreign invaders. All of the organelles are anchored in the cell's cytoplasm via a cytoskeleton. The cell's organelles are isolated from the surrounding environment by a plasma membrane.

Figure 3.2 The Cell Structure



The cell is structurally and functionally complex.

Tissues, Organs, Organ Systems, and Organisms

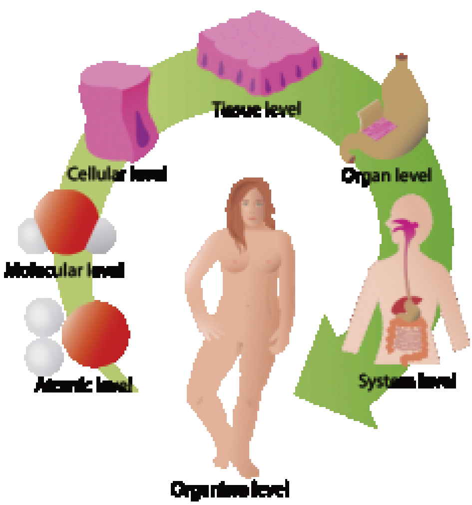
Unicellular (single-celled) organisms can function independently, but the cells of multicellular organisms are dependent upon each other and are organized into five different levels in order to coordinate their specific functions and carry out all of life's biological processes (see Figure 3.3 "Organization of Life").

- Cells are the basic structural and functional unit of all life. Examples include red blood cells and nerve cells. There are hundreds of types of cells. All cells in a person contain the same genetic information in DNA. However, each cell only expresses the genetic codes that relate to the cell's specific structure and function.
- Tissues are groups of cells that share a common structure and function and work together. There are four basic types of human tissues: connective, which connects tissues; epithelial, which lines and protects organs; muscle, which

contracts for movement and support; and nerve, which responds and reacts to signals in the environment.

- Organs are a group of tissues arranged in a specific manner to support a common physiological function. Examples include the brain, liver, and heart.
- Organ systems are two or more organs that support a specific physiological function. Examples include the digestive system and central nervous system. There are eleven organ systems in the human body (see Table 2.1 "The Eleven Organ Systems in the Human Body and Their Major Functions").
- An organism is the complete living system capable of conducting all of life's biological processes.

Figure 3.3 Organization of Life



"Organization Levels of Human Body" by Laia Martinez / CC BY-SA 4.0

Table 3.1 The Eleven Organ Systems in the Human Body and Their Major Functions

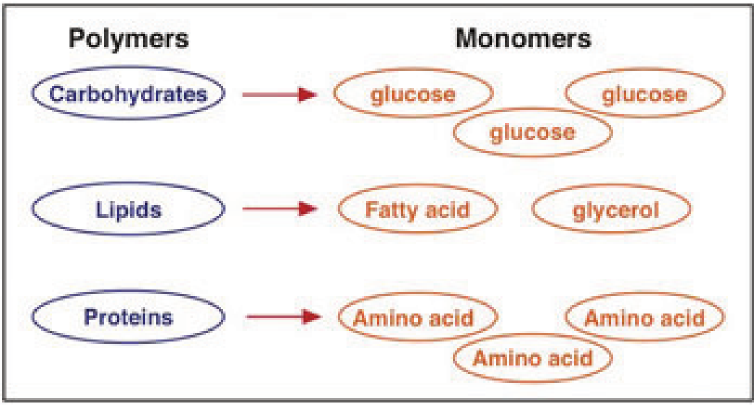
Organ System	Organ Components	Major Function
Cardiovascular	heart, blood/lymph vessels, blood, lymph	Transport nutrients and waste products
Digestive	mouth, esophagus, stomach, intestines	Digestion and absorption
Endocrine	all glands (thyroid, ovaries, pancreas)	Produce and release hormones
Immune	white blood cells, lymphatic tissue, marrow	Defend against foreign invaders
Integumentary	skin, nails, hair, sweat glands	Protective, body temperature regulation
Muscular	skeletal, smooth, and cardiac muscle	Body movement
Nervous	brain, spinal cord, nerves	Interprets and responds to stimuli
Reproductive	gonads, genitals	Reproduction and sexual characteristics
Respiratory	lungs, nose, mouth, throat, trachea	Gas exchange
Skeletal	bones, tendons, ligaments, joints	Structure and support
Urinary	kidneys, bladder, ureters	Waste excretion, water balance

The Digestive System

The process of digestion begins even before you put food into your mouth during the cephalic phase. When you feel hungry, your body sends a message to your brain that it is time to eat. Sights and smells influence your body's preparedness for food. Smelling food sends a message to your brain. Your brain then tells the mouth to get ready, you start to salivate and your stomach starts secreting gastric juices in preparation for your meal.

Once you have eaten, your digestive system (Figure 3.4 "The Human Digestive System") starts the process that breaks down the components of food into smaller components that can be absorbed and taken into the body. To do this, the digestive system functions on two levels, mechanically to move and mix ingested food and chemically to break down large molecules. The smaller nutrient molecules can then be absorbed and processed by cells throughout the body for energy or used as building blocks for new cells. The digestive system is one of the eleven organ systems of the human body, and it is composed of several hollow tube-shaped organs including the mouth, pharynx, esophagus, stomach, small intestine, large intestine (colon), rectum, and anus. It is lined with mucosal tissue that secretes digestive juices (which aid in the breakdown of food) and mucus (which facilitates the propulsion of food through the tract). Smooth muscle tissue surrounds the digestive tract and its contraction produces waves, known as peristalsis, that propel food down the tract. Nutrients, as well as some non-nutrients, are absorbed. Substances such as fiber get left behind and are appropriately excreted.

Figure 3.4 Digestion Breakdown of Macronutrients



Digestion converts components of the food we eat into smaller molecules that can be absorbed into the body and utilized for energy needs or as building blocks for making larger molecules in cells.

Everyday Connection

Image by Gabriel Lee / CC BY-NC-SA

There has been significant talk about pre- and probiotic foods in the mainstream media. The World Health Organization defines probiotics as live bacteria that confer beneficial health effects on their host. They are sometimes called "friendly bacteria." The most common bacteria labeled as probiotic is lactic acid bacteria (lactobacilli). They are added as live cultures to certain fermented foods such as yogurt. Prebiotics are indigestible foods, primarily soluble fibers, that stimulate the growth of certain strains of bacteria in the large intestine and provide health benefits to the host. A review article in the June 2008 issue of the Journal of Nutrition concludes that there is scientific consensus that probiotics ward off viral-induced diarrhea and reduce the symptoms of lactose intolerance.[1]

Expert nutritionists agree that more health benefits of pre- and probiotics will likely reach scientific consensus. As the fields of pre- and probiotic manufacturing and their clinical study progress, more information on proper dosing and what exact strains of bacteria are potentially "friendly" will become available.

You may be interested in trying some of these foods in your diet. A simple food to try is kefir. Several websites provide good recipes, including http://www.kefir.net/recipes.htm.
Kefir, a dairy product fermented with probiotic bacteria, can make a pleasant tasting milkshake.

Figure 3.5 The Human Digestive System

1. Farnworth ER. The Evidence to Support Health Claims for Probiotics. J Nutr. 2008; 138(6), 1250S–4S. http://jn.nutrition.org/content/138/6/1250S.long. Accessed September 22, 2017.

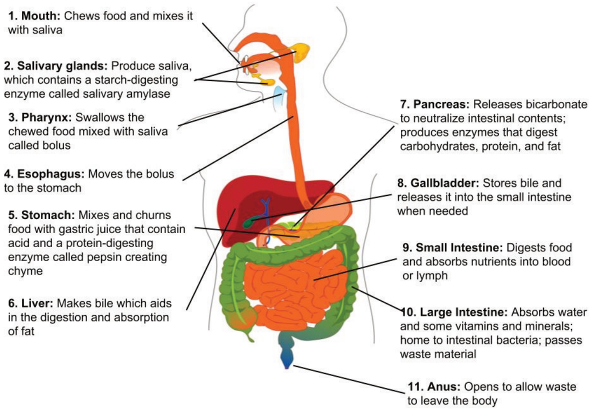


Image by Allison Calabrese / CC BY 4.0

From the Mouth to the Stomach

There are four steps in the digestion process (Figure 3.5 "The Human Digestive System"). The first step is ingestion, which is the intake of food into the digestive tract. It may seem a simple process, but ingestion involves smelling food, thinking about food, and the involuntary release of saliva in the mouth to prepare for food entry. In the mouth, where the second step of digestion starts, the mechanical and chemical breakdown of food begins. The chemical breakdown of food involves enzymes, such as salivary amylase that starts the breakdown of large starch molecules into smaller components and lingual lipase initiating the breakdown of lipids.

Mechanical breakdown starts with mastication (chewing) in the mouth. Teeth crush and grind large food particles, while saliva provides lubrication and enables food movement downward. The slippery mass of partially broken-down food is called a bolus, which moves down the digestive tract as you swallow. Swallowing may seem voluntary at first because it requires conscious effort to push the food with the tongue back toward the throat, but after this, swallowing proceeds involuntarily, meaning it cannot be stopped once it begins. As you swallow, the bolus is pushed from the mouth through the pharynx and into a muscular tube called the esophagus. As the bolus travels through the pharynx, a small flap called the epiglottis closes to prevent choking by keeping food from going into the trachea. Peristaltic contractions also known as peristalsis in the esophagus propel the food bolus down to the stomach (Figure 3.6 "Peristalsis in the Esophagus"). At the junction between the esophagus and stomach there is a sphincter muscle that remains closed until the food bolus approaches. The pressure of the food bolus stimulates the lower esophageal sphincter to relax and open and food then moves from the esophagus into the stomach. The mechanical breakdown of food is accentuated by the muscular contractions of the stomach and small intestine that mash, mix, slosh, and propel food down the alimentary canal. Solid food takes between four and eight seconds to travel down the esophagus, and liquids take about one second.

Figure 3.6 Peristalsis in the Esophagus

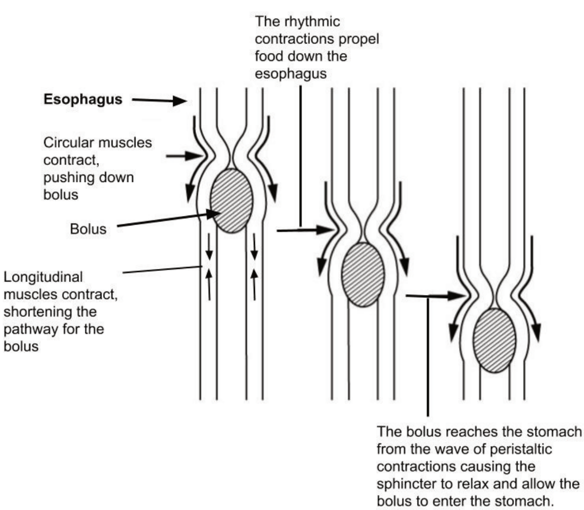


Image by Allison Calabrese / CC BY 4.0

From the Stomach to the Small Intestine

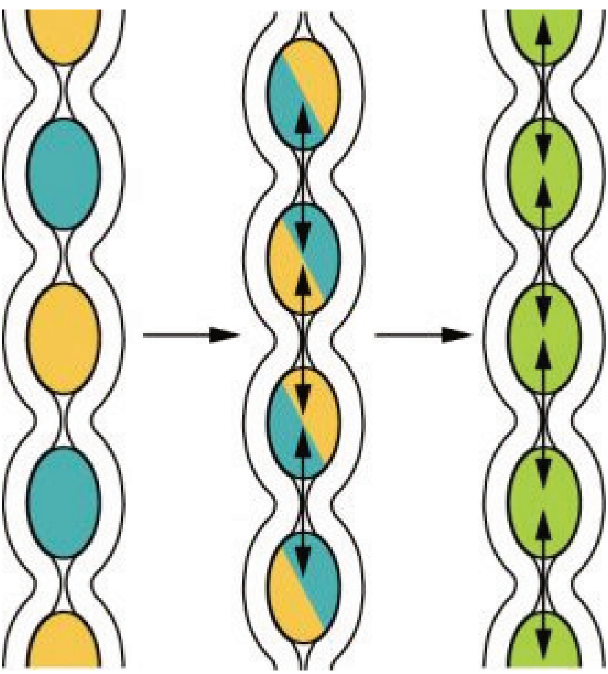
When food enters the stomach, a highly muscular organ, powerful peristaltic contractions help mash, pulverize, and churn food into chyme. Chyme is a semiliquid mass of partially digested food that also contains gastric juices secreted by cells in the stomach. These gastric juices contain hydrochloric acid and the enzyme pepsin, that chemically start breakdown of the protein components of food.

The length of time food spends in the stomach varies by the macronutrient composition of the meal. A high-fat or high-protein meal takes longer to break down than one rich in carbohydrates. It usually takes a few hours after a meal to empty the stomach contents completely into the small intestine.

The small intestine is divided into three structural parts: the duodenum, the jejunum, and the ileum. Once the chyme enters the duodenum (the first segment of the small intestine), the pancreas and gallbladder are stimulated and release juices that aid in digestion. The pancreas secretes up to 1.5 liters (.4 US gallons) of pancreatic juice through a duct into the duodenum per day. This fluid consists mostly of water, but it also contains bicarbonate ions that neutralize the acidity of the stomach-derived chyme and enzymes that further break down proteins, carbohydrates, and lipids. The gallbladder secretes a much smaller amount of a fluid called bile that helps to digest fats. Bile passes through a duct that joins the pancreatic ducts and is released into the duodenum. Bile is made in the liver and stored in the gall bladder. Bile's components act like detergents by surrounding fats similar to the way dish soap removes grease from a frying pan. This allows for the movement of fats in the watery environment of the small intestine. Two different types of muscular contractions, called peristalsis and segmentation, control the movement and mixing of the food in various stages of digestion through the small intestine.

Similar to what occurs in the esophagus and stomach, peristalsis is circular waves of smooth muscle contraction that propel food forward. Segmentation from circular muscle contraction slows movement in the small intestine by forming temporary “sausage link” type of segments that allows chyme to slosh food back and forth in both directions to promote mixing of the chyme and enhance absorption of nutrients (Figure 3.7 “Segmentation”). Almost all the components of food are completely broken down to their simplest units within the first 25 centimeters of the small intestine. Instead of proteins, carbohydrates, and lipids, the chyme now consists of amino acids, monosaccharides, and emulsified components of triglycerides.

Figure 3.7 Segmentation

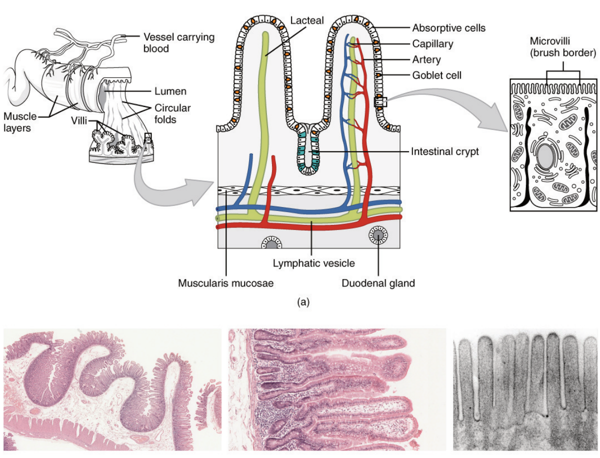


“Segmentation” by OpenStax College / CC BY 3.0

The third step of digestion (nutrient absorption) takes place mainly in the remaining length of the small intestine, or ileum (> 5 meters). The way the small intestine is structured gives it a huge surface area to maximize nutrient absorption. The surface area is increased by folds, villi, and microvilli. Digested nutrients are absorbed into either capillaries or lymphatic vessels contained within each microvillus.

The small intestine is perfectly structured for maximizing nutrient absorption. Its surface area is greater than 200 square meters, which is about the size of a tennis court. The large surface area is due to the multiple levels of folding. The internal tissue of the small intestine is covered in villi, which are tiny finger-like projections that are covered with even smaller projections, called microvilli (Figure 3.8 "Structure of the Small Intestine"). The digested nutrients pass through the absorptive cells of the intestine via diffusion or special transport proteins. Amino acids, short fatty acids, and monosaccharides (sugars) are transported from the intestinal cells into capillaries, but the larger fatty acids, fat-soluble vitamins, and other lipids are transported first through lymphatic vessels, which soon meet up with blood vessels.

Figure 3.8 Structure of the Small Intestine



"Histology Small Intestines" by OpenStax College / CC BY 3.0

From the Small Intestine to the Large Intestine

The process of digestion is fairly efficient. Any food that is still incompletely broken down (usually less than ten percent of food consumed) and the food's indigestible fiber content move from the small intestine to the large intestine (colon) through a connecting valve. A main task of the large intestine is to absorb much of the remaining water. Remember, water is present not only in solid foods and beverages, but also the stomach releases a few hundred milliliters of gastric juice, and the pancreas adds approximately 500 milliliters during the digestion of the meal. For the body to conserve water, it is important that excessive water is not lost in fecal matter. In the large intestine, no further chemical or mechanical breakdown of food takes place unless it is accomplished by the bacteria that inhabit this portion of the intestinal tract. The number of bacteria residing in the large intestine is estimated to be greater than 1014, which is more than the total number of cells in the human body (1013). This may seem rather unpleasant, but the great majority of bacteria in the large intestine are harmless and many are even beneficial.

From the Large Intestine to the Anus

After a few hours in the stomach, plus three to six hours in the small intestine, and about sixteen hours in the large intestine, the digestion process enters step four, which is the elimination of indigestible food matter as feces. Feces contain indigestible food components and gut bacteria (almost 50 percent of content). It is stored in the rectum until it is expelled through the anus via defecation.

Nutrients Are Essential for Cell and Organ Function

When the digestive system has broken down food to its nutrient components, the body eagerly awaits delivery. Water soluble nutrients absorbed into the blood travel directly to the liver via a major blood vessel called the portal vein. One of the liver's primary functions is to regulate metabolic homeostasis. Metabolic homeostasis is achieved when the nutrients consumed and absorbed match the energy required to carry out life's biological processes. Simply put, nutrient energy intake equals energy output. Whereas glucose and amino acids are directly transported from the small intestine to the liver, lipids are transported to the liver by a more circuitous route involving the lymphatic system. The lymphatic system is a one-way system of vessels that transports lymph, a fluid rich in white blood cells, and lipid soluble substances after a meal containing lipids. The lymphatic system slowly moves its contents through the lymphatic vessels and empties into blood vessels in the upper chest area. Now, the absorbed lipid soluble components are in the blood where they can be distributed throughout the body and utilized by cells (see Figure 3.9 "The Absorption of Nutrients").

Figure 3.9 The Absorption of Nutrients

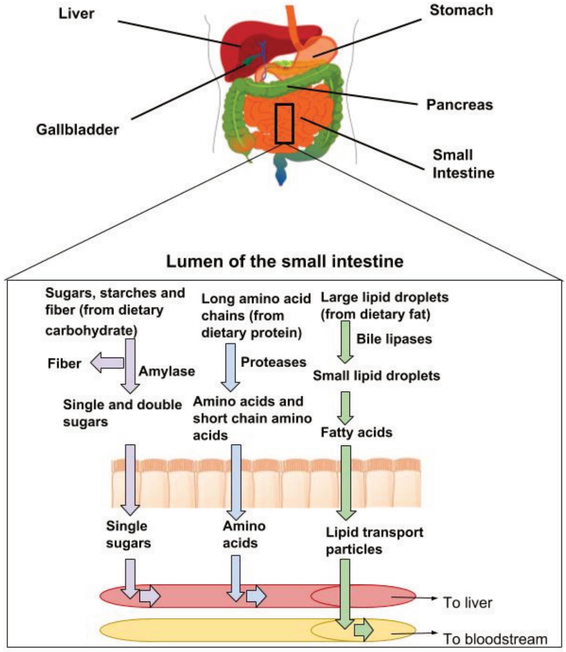


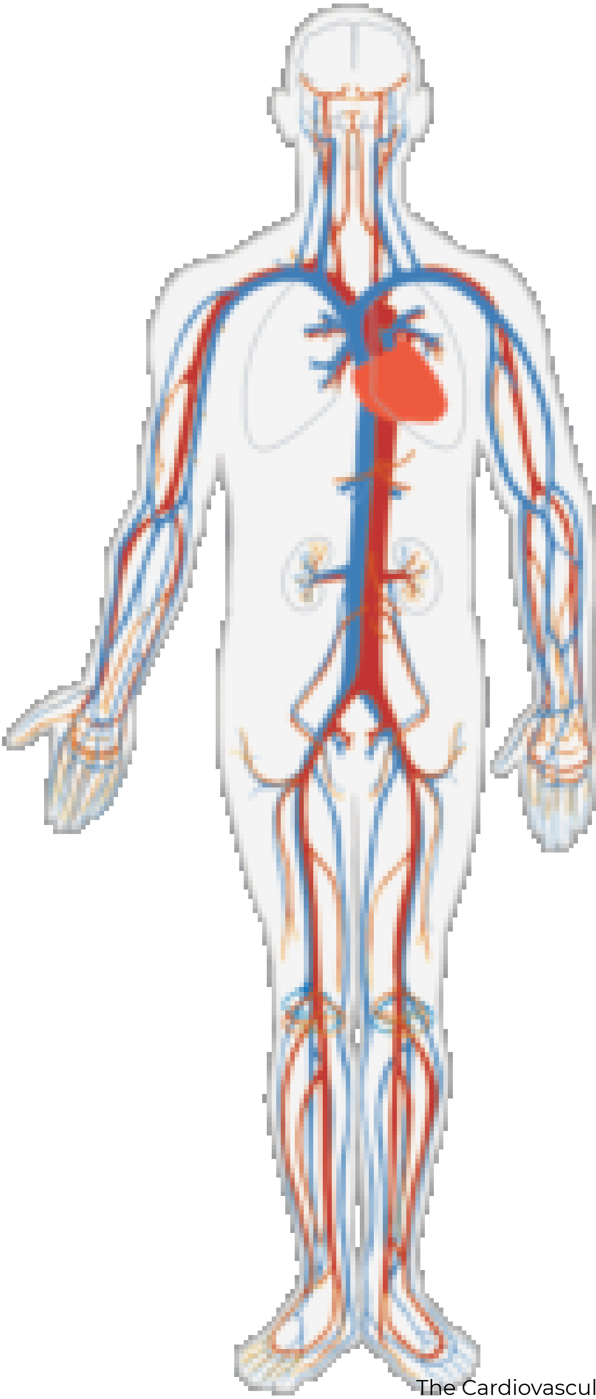
Image by Allison Calabrese / CC BY 4.0

Maintaining the body's energy status quo is crucial because when metabolic homeostasis is disturbed by an eating disorder or disease, bodily function suffers. This will be discussed in more depth in the last section of this chapter. The liver is the only organ in the human body that is capable of exporting nutrients for energy production to other tissues. Therefore, when a person is in between meals (fasted state) the liver exports nutrients, and when a person has just eaten (fed state) the liver stores nutrients within itself. Nutrient levels and the hormones that respond to their levels in the blood provide the input so that the liver can distinguish between the fasted and fed states and distribute nutrients appropriately. Although not considered to be an organ, adipose tissue stores fat in the fed state and mobilizes fat components to supply energy to other parts of the body when energy is needed.

All eleven organ systems in the human body require nutrient input to perform their specific biological functions. Overall health and the ability to carry out all of life's basic processes is fueled by energy-supplying nutrients (carbohydrate, fat, and protein). Without them, organ systems would fail, humans would not reproduce, and the race would disappear. In this section, we will discuss some of the critical nutrients that support specific organ system functions.

The Cardiovascular System

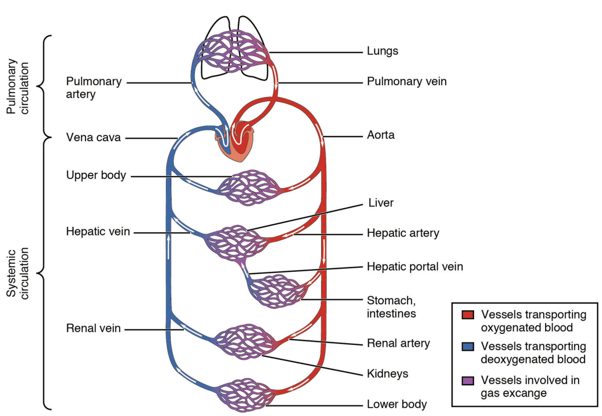
Figure 3.10 The Cardiovascular system



“Simplified diagram of the human Circulatory system in anterior view” by Mariana Ruiz / Public Domain

The cardiovascular system is one of the eleven organ systems of the human body. Its main function is to transport nutrients to cells and wastes from cells (Figure 3.12 "Cardiovascular Transportation of Nutrients"). This system consists of the heart, blood, and blood vessels. The heart pumps the blood, and the blood is the transportation fluid. The transportation route to all tissues, a highly intricate blood-vessel network, comprises arteries, veins, and capillaries. Nutrients absorbed in the small intestine travel mainly to the liver through the hepatic portal vein. From the liver, nutrients travel upward through the inferior vena cava blood vessel to the heart. The heart forcefully pumps the nutrient-rich blood first to the lungs to pick up some oxygen and then to all other cells in the body. Arteries become smaller and smaller on their way to cells, so that by the time blood reaches a cell, the artery's diameter is extremely small and the vessel is now called a capillary. The reduced diameter of the blood vessel substantially slows the speed of blood flow. This dramatic reduction in blood flow gives cells time to harvest the nutrients in blood and exchange metabolic wastes.

Figure 3.11 The Blood Flow in the Cardiovascular System



"Blood Flow Through the Heart" by OpenStax College / CC BY 3.0

Blood's Function in the Body and in Metabolism Support

You know you cannot live without blood, and that your heart pumps your blood over a vast network of veins and arteries within your body, carrying oxygen to your cells. However, beyond these basic facts, what do you know about your blood?

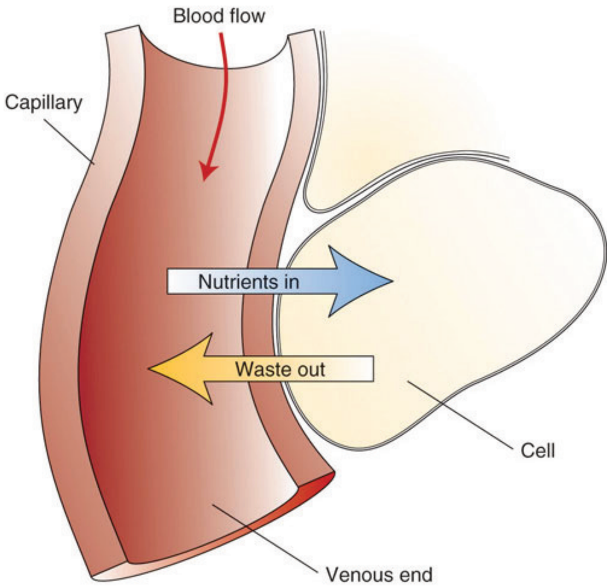
Blood transports absorbed nutrients to cells and waste products from cells. It supports cellular metabolism by transporting synthesized macromolecules from one cell type to another and carrying waste products away from cells. Additionally, it transports molecules, such as hormones, allowing for communication between organs. The volume of blood coursing throughout an adult human body is about 5 liters (1.3 US gallons) and accounts for approximately 8 percent of human body weight.

What Makes Up Blood and How Do These Substances Support Blood Function?

Blood is about 78 percent water and 22 percent solids by volume. The liquid part of blood is called plasma and it is mostly water (95 percent), but also contains proteins, ions, glucose, lipids, vitamins, minerals, waste products, gases, enzymes, and hormones. We have learned that the protein albumin is found in high concentrations in the blood. Albumin helps maintain fluid balance between blood and tissues, as well as helping to maintain a constant blood pH. We have also learned that the water component of blood is essential for its actions as a transport vehicle, and that the electrolytes carried in blood help to maintain fluid balance and a constant pH. Furthermore, the high water content of blood helps maintain body temperature, and the constant flow of blood distributes heat throughout the body. Blood is exceptionally good at temperature control, so much so that the many small blood vessels in your nose are capable of warming frigid air to body temperature before it reaches the lungs.

The cellular components of blood include red blood cells, white blood cells, and platelets. Red blood cells are the most numerous of the components. Each drop of blood contains millions of them. Red blood cells are red because they each contain approximately 270 million hemoglobin proteins, which contain the mineral iron, which turns red when bound to oxygen. The most vital duty of red blood cells is to transport oxygen from the lungs to all cells in the body so that cells can utilize oxygen to produce energy via aerobic metabolism. The white blood cells that circulate in blood are part of the immune system, and they survey the entire body looking for foreign invaders to destroy. They make up about 1 percent of blood volume. Platelets are fragments of cells that are always circulating in the blood in case of an emergency. When blood vessels are injured, platelets rush to the site of injury to plug the wound. Blood is under a constant state of renewal and is synthesized from stem cells residing in bone marrow. Red blood cells live for about 120 days, white blood cells live anywhere from eighteen hours to one year, or even longer, and platelets have a lifespan of about ten days.

Figure 3.12 Cardiovascular Transportation of Nutrients



The cardiovascular system transports nutrients to all cells and carries wastes out.

Nutrients In

Once absorbed from the small intestine, all nutrients require transport to cells in need of their support. Additionally, molecules manufactured in other cells sometimes require delivery to other organ systems. Blood is the conduit and blood vessels are the highway that support nutrient and molecule transport to all cells. Water-soluble molecules, such as some vitamins, minerals, sugars, and many proteins, move independently in blood. Fat-soluble vitamins, triglycerides, cholesterol, and other lipids are packaged into lipoproteins that allow for transport in the watery milieu of blood. Many proteins, drugs, and hormones are dependent on transport carriers, primarily by the plasma protein albumin. In addition to transporting all of these molecules, blood transfers oxygen taken in by the lungs to all cells in the body. As discussed, the iron-containing hemoglobin molecule in red blood cells serves as the oxygen carrier.

Wastes Out

In the metabolism of macronutrients to energy, cells produce the waste products carbon dioxide and water. As blood travels through smaller and smaller vessels, the rate of blood flow is dramatically reduced, allowing for efficient exchange of nutrients and oxygen for cellular waste products through tiny capillaries. The kidneys remove any excess water from the blood, and blood delivers the carbon dioxide to the lungs where it is exhaled. Also, the liver produces the waste product urea from the breakdown of amino acids and detoxifies many harmful substances, all of which require transport in the blood to the kidneys for excretion.

All for One, One for All

The eleven organ systems in the body completely depend on each other for continued survival as a complex organism. Blood allows for transport of nutrients, wastes, water, and heat, and is also a conduit of communication between organ systems. Blood's importance to the rest of the body is aptly presented in its role in glucose delivery, especially to the brain. The brain metabolizes, on average, 6 grams of glucose per hour. In order to avert confusion, coma, and death, glucose must be readily available to the brain at all times. To accomplish this task, cells in the pancreas sense glucose levels in the blood. If glucose levels are low, the hormone glucagon is released into the blood and is transported to the liver where it communicates the signal to ramp-up glycogen breakdown and glucose synthesis.

The liver does just that, and glucose is released into the blood, which transports it to the brain. Concurrently, blood transports oxygen to support the metabolism of glucose to provide energy in the brain. Healthy blood conducts its duties rapidly, avoiding hypoglycemic coma and death. This is just one example of the body's survival mechanisms exemplifying life's mantra "All for one, one for all."

What Makes Blood Healthy?

Maintaining healthy blood, including its continuous renewal, is essential to support its vast array of vital functions. Blood is healthy when it contains the appropriate amount of water and cellular components and proper concentrations of dissolved substances, such as albumin and electrolytes. As with all other tissues, blood needs macro- and micronutrients to optimally function. In the bone marrow, where blood cells are made, amino acids are required to build the massive amount of hemoglobin packed within every red blood cell, along with all other enzymes and cellular organelles contained in each blood cell. Red blood cells, similar to the brain, use only glucose as fuel, and it must be in constant supply to support red-blood-cell metabolism. As with all other cells, the cells in the blood are surrounded by a plasma membrane, which is composed of mainly lipids. Blood health is also acutely sensitive to deficiencies in some vitamins and minerals more than others.

What Can Blood Tests Tell You About Your Health?

Figure 3.13 Blood Tests

Blood tests are helpful tools in diagnosing disease and provide much information on overall health. Image by Thirteen of Clubs / CC BY-SA

Since blood is the conduit of metabolic products and wastes, measuring the components of blood, and particular substances in blood, can reveal not only the health of blood, but also the health of other organ systems. In standard blood tests performed during an annual physical, the typical blood tests conducted can tell your physician about the functioning of a particular organ or about disease risk.

A biomarker is defined as a measurable molecule or trait that is connected with a specific disease or health condition. The concentrations of biomarkers in blood are indicative of disease risk. Some biomarkers are cholesterol, triglycerides, glucose, and prostate-specific antigen. The results of a blood test give the concentrations of substances in a person's blood and display the normal ranges for a certain population group. Many factors, such as physical activity level, diet, alcohol intake, and medicine intake can influence a person's blood-test levels and cause them to fall outside the normal range, so results of blood tests outside the "normal" range are not always indicative of health problems. The assessment of multiple blood parameters aids in the diagnosis of disease risk and is indicative of overall health status. See Table 3.2 "Blood Tests" for a partial list of substances measured in a typical blood test. This table notes only a few of the things that their levels tell us about health.

Table 3.2 Blood Tests

Substance Measured	Indicates
Red-blood-cell count	Oxygen-carrying capacity
Hematocrit (red-blood-cell volume)	Anemia risk
White-blood-cell count	Presence of infection
Platelet count	Bleeding disorders, atherosclerosis risk
pH	Metabolic, kidney, respiratory abnormalities
Albumin	Liver, kidney, and Crohn's disease, dehydration, protein deficiency
Bilirubin	Liver-function abnormality
Oxygen/Carbon Dioxide	Respiratory or metabolic abnormality
Hemoglobin	Oxygen-carrying capacity
Iron	Anemia risk
Magnesium	Magnesium deficiency
Electrolytes (calcium, chloride, magnesium, potassium)	Many illnesses (kidney, metabolic, etc.)
Cholesterol	Cardiovascular disease risk
Triglycerides	Cardiovascular disease risk
Glucose	Diabetes risk
Hormones	Many illnesses (diabetes, reproductive abnormalities)

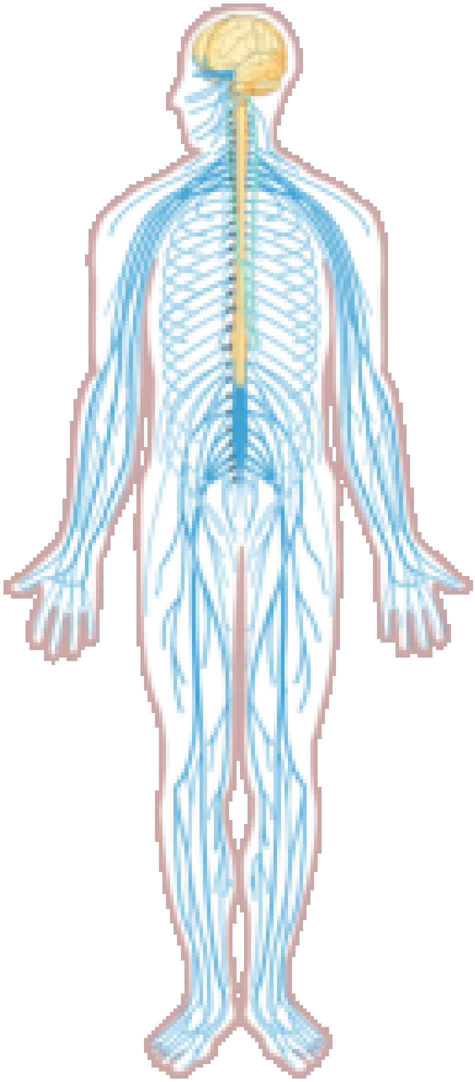
National Heart Lung and Blood Institute. Types of Blood Tests.[1]

1. http://www.nhlbi.nih.gov/health/health-topics/topics/bdt/types.html. Published January 6, 2012. Accessed September 22,2017.

Central Nervous System

The human brain (which weighs only about 3 pounds, or 1,300 kilograms) is estimated to contain over one hundred billion neurons. Neurons form the core of the central nervous system, which consists of the brain, spinal cord, and other nerve bundles in the body. The main function of the central nervous system is to sense changes in the external environment and create a reaction to them. For instance, if your finger comes into contact with a thorn on a rose bush, a sensory neuron transmits a signal from your finger up through the spinal cord and into the brain. Another neuron in the brain sends a signal that travels back to the muscles in your hand and stimulates muscles to contract and you jerk your finger away. All of this happens within a tenth of a second. All nerve impulses travel by the movement of charged sodium, potassium, calcium, and chloride atoms. Nerves communicate with each other via chemicals built from amino acids called neurotransmitters. Eating adequate protein from a variety of sources will ensure the body gets all of the different amino acids that are important for central nervous system function.

Figure 3.14 The Central Nervous System



Nervous System" by William Crochot / CC BY-SA 4.0

The brain's main fuel is glucose and only in extreme starvation will it use anything else. For acute mental alertness and clear thinking, glucose must be systematically delivered to the brain.

This does not mean that sucking down a can of sugary soda before your next exam is a good thing. Just as too much glucose is bad for other organs, such as the kidneys and pancreas, it also produces negative effects upon the brain. Excessive glucose levels in the blood can cause a loss of cognitive function, and chronically high blood-glucose levels can damage brain cells. The brain's cognitive functions include language processing, learning, perceiving, and thinking. Recent scientific studies demonstrate that having continuously high blood-glucose levels substantially elevates the risk for developing Alzheimer's disease, which is the greatest cause of age-related cognitive decline.

The good news is that much research is directed toward determining the best diets and foods that slow cognitive decline and maximize brain health. A study in the June 2010 issue of the Archives of Neurology reports that people over age 65 who adhered to diets that consisted of higher intakes of nuts, fish, poultry, tomatoes, cruciferous vegetables, fruits, salad dressing, and dark green, and leafy vegetables, as well as a lower intake of high-fat dairy products, red meat, organ meat, and butter, had a much reduced risk for Alzheimer's disease.[1]

Other scientific studies provide supporting evidence that foods rich in omega-3 fatty acids and/or antioxidants provide the brain with protection against Alzheimer's disease. One potential "brain food" is the blueberry. The protective effects of blueberries upon the brain are linked to their high content of anthocyanins, which are potent antioxidants and reduce inflammation. A small study published in the April 2010 issue of the Journal of Agricultural and Food Chemistry found that

1. Gu Y, Nieves JW, et al. Food Combination and Alzheimer Disease Risk: A Protective Diet. Arch Neurol. 2010; 67(6), 699–706. https://www.ncbi.nlm.nih.gov/pubmed/20385883. Accessed September 22, 2017.

elderly people who consumed blueberry juice every day for twelve weeks had improved learning and memorization skills in comparison to other subjects given a placebo drink.[2]

However, it is important to keep in mind that this was a short-term study. Blueberries also are high in manganese, and high intake of manganese over time is known to have neurotoxic effects. Variety in the diet is perhaps the most important concept in applied nutrition. More clinical trials are evaluating the effects of blueberries and other foods that benefit the brain and preserve its function as we age.

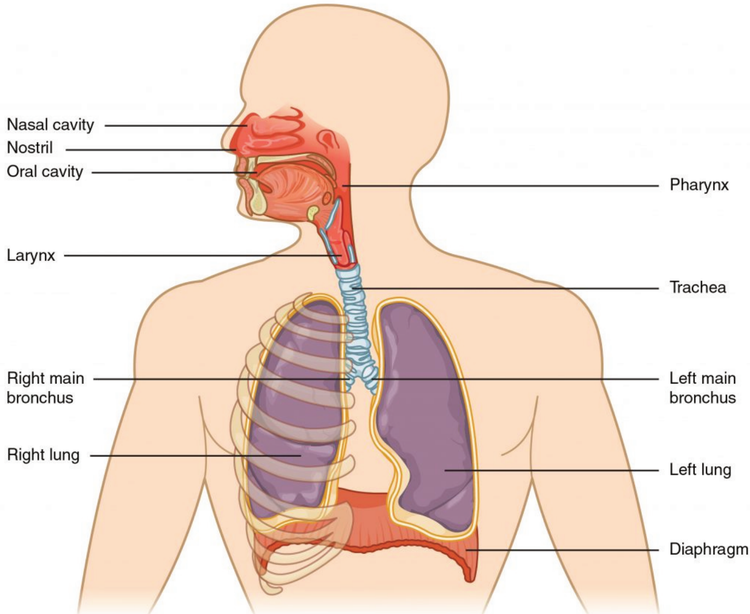
2. Krikorian R, Shidler MD, et al. Blueberry Supplementation Improves Memory in Older Adults. J Agric Food Chem. 2010; 58(7). https://www.ncbi.nlm.nih.gov/pubmed/20047325. Accessed September 22, 2017.

The Respiratory System

A typical human cannot survive without breathing for more than 3 minutes, and even if you wanted to hold your breath longer, your autonomic nervous system would take control. This is because cells need to maintain oxidative metabolism for energy production that continuously regenerates adenosine triphosphate (ATP). For oxidative phosphorylation to occur, oxygen is used as a reactant and carbon dioxide is released as a waste product. You may be surprised to learn that although oxygen is a critical need for cells, it is actually the accumulation of carbon dioxide that primarily drives your need to breathe. Carbon dioxide is exhaled and oxygen is inhaled through the respiratory system, which includes muscles to move air into and out of the lungs, passageways through which air moves, and microscopic gas exchange surfaces covered by capillaries. The cardiovascular system transports gases from the lungs to tissues throughout the body and vice versa. A variety of diseases can affect the respiratory system, such as asthma, emphysema, chronic obstructive pulmonary disorder (COPD), and lung cancer. All of these conditions affect the gas exchange process and result in labored breathing and other difficulties.

The major organs of the respiratory system function primarily to provide oxygen to body tissues for cellular respiration, remove the waste product carbon dioxide, and help to maintain acid-base balance. Portions of the respiratory system are also used for non-vital functions, such as sensing odors, producing speech, and for straining, such as during childbirth or coughing.

Figure 3.15 Major Respiratory Structures



The major respiratory structures span the nasal cavity to the diaphragm. Functionally, the respiratory system can be divided into a conducting zone and a respiratory zone. The conducting zone of the respiratory system includes the organs and structures not directly involved in gas exchange (trachea and bronchi). The gas exchange occurs in the respiratory zone.

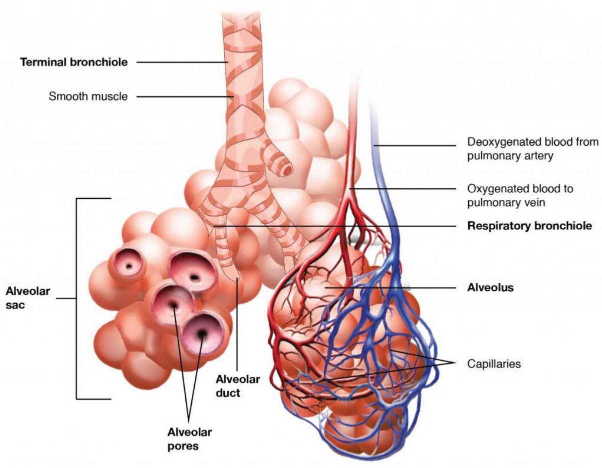
Conducting Zone

The major functions of the conducting zone are to provide a route for incoming and outgoing air, remove debris and pathogens from the incoming air, and warm and humidify the incoming air. Several structures within the conducting zone perform other functions as well. The epithelium of the nasal passages, for example, is essential to sensing odors, and the bronchial epithelium that lines the lungs can metabolize some airborne carcinogens. The conducting zone includes the nose and its adjacent structures, the pharynx, the larynx, the trachea, and the bronchi.

Respiratory Zone

In contrast to the conducting zone, the respiratory zone includes structures that are directly involved in gas exchange. The respiratory zone begins where the terminal bronchioles join a respiratory bronchiole, the smallest type of bronchiole (Figure 3.16 "Respiratory Zone"), which then leads to an alveolar duct, opening into a cluster of alveoli.

Figure 3.16 Respiratory Zone



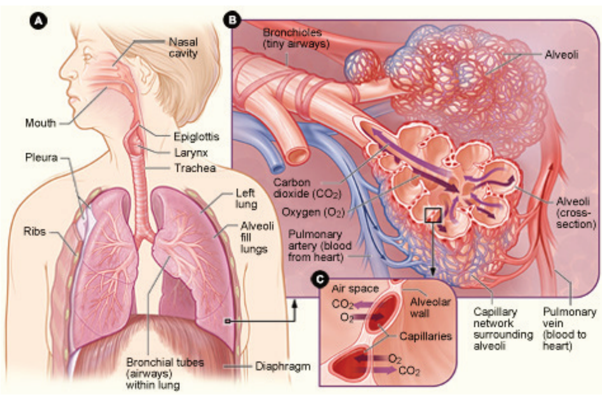
Bronchioles lead to alveolar sacs in the respiratory zone, where gas exchange occurs.

Alveoli

An alveolar duct is a tube composed of smooth muscle and connective tissue, which opens into a cluster of alveoli. An alveolus is one of the many small, grape-like sacs that are attached to the alveolar ducts.

An alveolar sac is a cluster of many individual alveoli that are responsible for gas exchange. An alveolus is approximately 200 μm in diameter with elastic walls that allow the alveolus to stretch during air intake, which greatly increases the surface area available for gas exchange. Alveoli are connected to their neighbors by alveolar pores, which help maintain equal air pressure throughout the alveoli and lung.

Figure 3.17 Location of Respiratory System



"Human Respiratory System" by United States National Institute of Health: National Heart, Lung and Blood Institute / Public Domain

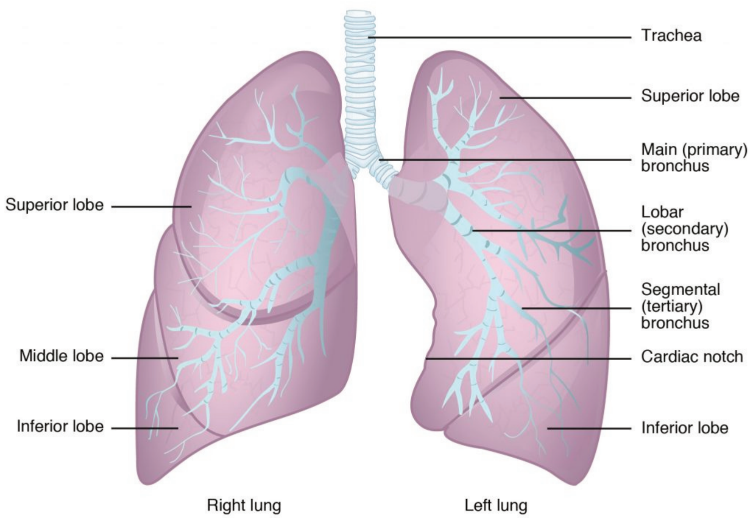
Figure 3.17 shows the location of the respiratory structures in the body. Figure B is an enlarged view of the airways, alveoli (air sacs), and capillaries (tiny blood vessels). Figure C is a close-up view of gas exchange between the capillaries and alveoli. CO2 is carbon dioxide, and O2 is oxygen.

A major organ of the respiratory system, each lung houses structures of both the conducting and respiratory zones. The main function of the lungs is to perform the exchange of oxygen and carbon dioxide with air from the atmosphere. To this end, the lungs exchange respiratory gases across a very large epithelial surface area—about 70 square meters—that is highly permeable to gases.

Gross Anatomy of the Lungs

The lungs are pyramid-shaped, paired organs that are connected to the trachea by the right and left bronchi; below the lungs is the diaphragm, a flat, dome-shaped muscle located at the base of the lungs and thoracic cavity.

Figure 3.18 Basic Anatomy of the Lungs



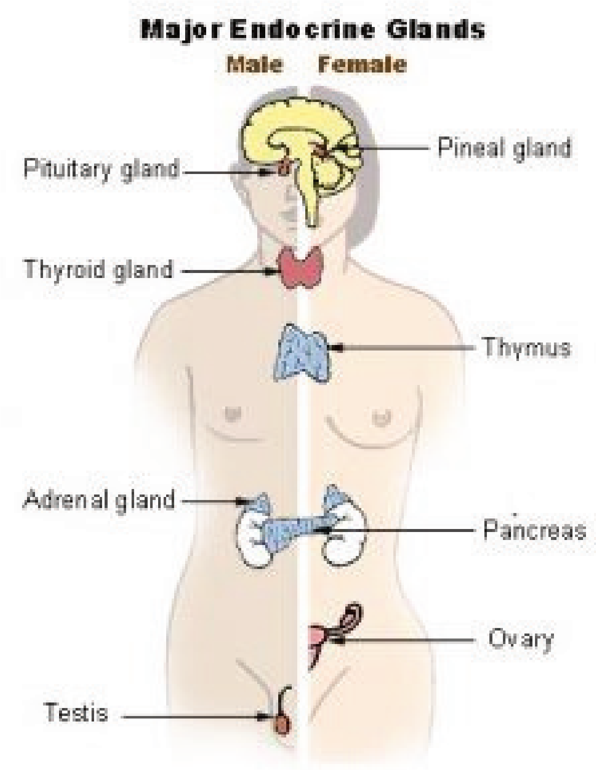
Each lung is composed of smaller units called lobes. Fissures separate these lobes from each other. The right lung consists of three lobes: the superior, middle, and inferior lobes. The left lung consists of two lobes: the superior and inferior lobes.

Blood Supply

The major function of the lungs is to perform gas exchange, which requires blood flowing through the lung tissues (the pulmonary circulation). This blood supply contains deoxygenated blood and travels to the lungs where erythrocytes, also known as red blood cells, pick up oxygen to be transported to tissues throughout the body. The pulmonary artery carries deoxygenated blood to the lungs. The pulmonary artery branches multiple times as it follows the bronchi, and each branch becomes progressively smaller in diameter down to the tiny capillaries where the alveoli release carbon dioxide from blood into the lungs to be exhaled and take up oxygen from inhaled air to oxygenate the blood. Once the blood is oxygenated, it drains from the alveoli by way of multiple pulmonary veins that exit the lungs to carry oxygen to the rest of the body.

The Endocrine System

Figure 3.19 The Endocrine System



"Major Endocrine Glands" by National Cancer Institute / Public Domain

The functions of the endocrine system are intricately connected to the body's nutrition. This organ system is responsible for regulating appetite, nutrient absorption, nutrient storage, and nutrient usage, in addition to other functions, such as reproduction. The glands in the endocrine system are the pituitary, thyroid, parathyroid, adrenals, thymus, pineal, pancreas, ovaries, and testes. The glands secrete hormones, which are biological molecules that regulate cellular processes in other target tissues, so they require transportation by the circulatory system. Adequate nutrition is critical for the functioning of all the glands in the endocrine system. A protein deficiency impairs gonadal-hormone release, preventing reproduction. Athletic teenage girls with very little body fat often do not menstruate. Children who are malnourished usually do not produce enough growth hormone and fail to reach normal height for their age group. Probably the most popularized connection between nutrition and the functions of the endocrine system is that unhealthy dietary patterns are linked to obesity and the development of Type 2 diabetes.

What is the causal relationship between overnutrition and Type 2 diabetes? The prevailing theory is that the overconsumption of high-fat and high-sugar foods causes changes in muscle, fat, and liver cells that leads to a diminished response from the pancreatic hormone insulin. These cells are called "insulin-resistant." Insulin is released after a meal and instructs the liver and other tissues to take up glucose and fatty acids that are circulating in the blood. When cells are resistant to insulin they do not take up enough glucose and fatty acids, so glucose and fatty acids remain at high concentrations in the blood. The chronic elevation of glucose and fatty acids in the blood also causes damage to other tissues over time, so that people who have Type 2 diabetes are at increased risk for cardiovascular disease, kidney disease, nerve damage, and eye disease.

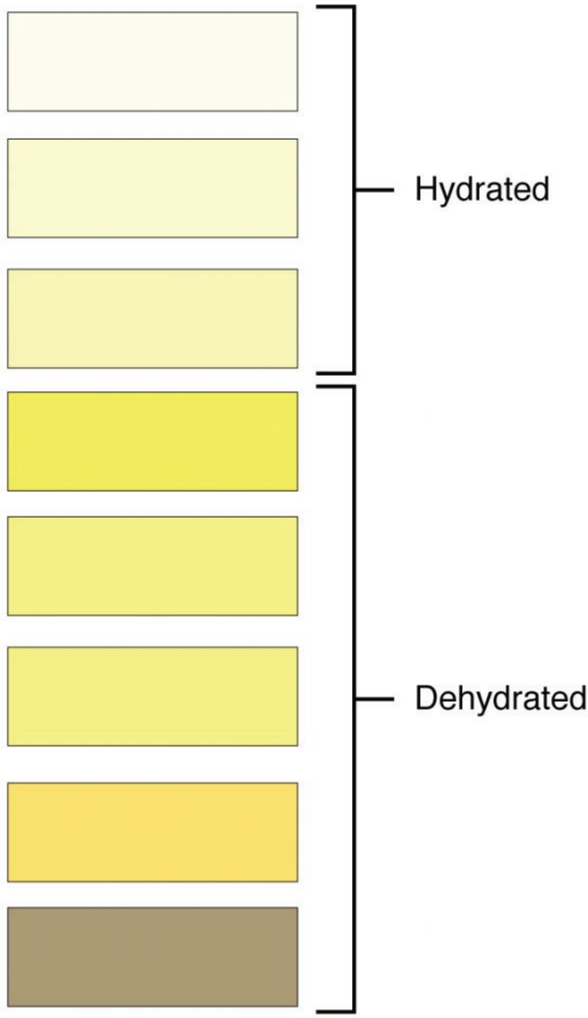
The Urinary System

The urinary system has roles you may be well aware of: cleansing the blood and ridding the body of wastes probably come to mind. However, there are additional, equally important functions played by the system. Take for example, regulation of pH, a function shared with the lungs and the buffers in the blood. Additionally, the regulation of blood pressure is a role shared with the heart and blood vessels. What about regulating the concentration of solutes in the blood? Did you know that the kidney is important in determining the concentration of red blood cells? Eighty-five percent of the erythropoietin (EPO) produced to stimulate red blood cell production is produced in the kidneys. The kidneys also perform the final synthesis step of vitamin D production, converting calcidiol to calcitriol, the active form of vitamin D.

If the kidneys fail, these functions are compromised or lost altogether, with devastating effects on homeostasis. The affected individual might experience weakness, lethargy, shortness of breath, anemia, widespread edema (swelling), metabolic acidosis, rising potassium levels, heart arrhythmias, and more. Each of these functions is vital to your well-being and survival. The urinary system, controlled by the nervous system, also stores urine until a convenient time for disposal and then provides the anatomical structures to transport this waste liquid to the outside of the body. Failure of nervous control or the anatomical structures leading to a loss of control of urination results in a condition called incontinence.

Characteristics of the urine change, depending on influences such as water intake, exercise, environmental temperature, nutrient intake, and other factors . Some of the characteristics such as color and odor are rough descriptors of your state of hydration. For example, if you exercise or work outside, and sweat a great deal, your urine will turn darker and produce a slight odor, even if you drink plenty of water. Athletes are often advised to consume water until their urine is clear. This is good advice; however, it takes time for the kidneys to process body fluids and store it in the bladder. Another way of looking at this is that the quality of the urine produced is an average over the time it takes to make that urine. Producing clear urine may take only a few minutes if you are drinking a lot of water or several hours if you are working outside and not drinking much.

Figure 3.20 Urine Color

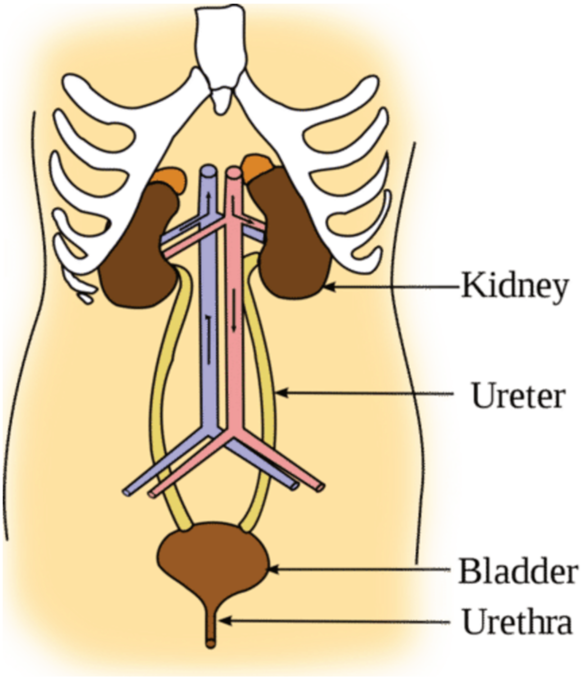


"Urine Color" by OpenStax College / CC BY 3.0

Urine volume varies considerably. The normal range is one to two liters per day. The kidneys must produce a minimum urine volume of about 500 mL/day to rid the body of wastes. Output below this level may be caused by severe dehydration or renal disease and is termed oliguria. The virtual absence of urine production is termed anuria. Excessive urine production is polyuria, which may occur in diabetes mellitus when blood glucose levels exceed the filtration capacity of the kidneys and glucose appears in the urine. The osmotic nature of glucose attracts water, leading to increased water loss in the urine.

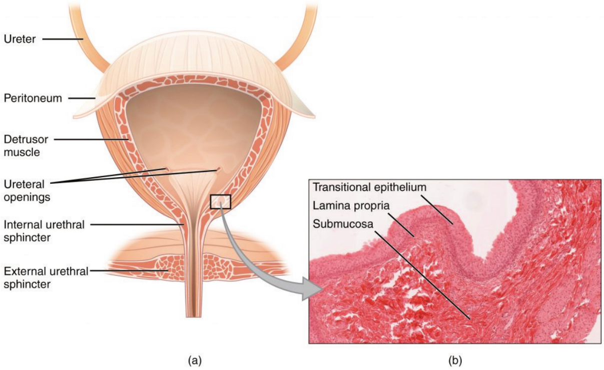
Urine is a fluid of variable composition that requires specialized structures to remove it from the body safely and efficiently. Blood is filtered, and the filtrate is transformed into urine at a relatively constant rate throughout the day. This processed liquid is stored until a convenient time for excretion. All structures involved in the transport and storage of the urine are large enough to be visible to the naked eye. This transport and storage system not only stores the waste, but it protects the tissues from damage due to the wide range of pH and osmolarity of the urine, prevents infection by foreign organisms, and for the male, provides reproductive functions. The urinary bladder collects urine from both ureters (Figure 3.21 "Urinary System Location").

Figure 3.21 Urinary System Location



"Illu Urinary System" by Thstehle / Public Domain

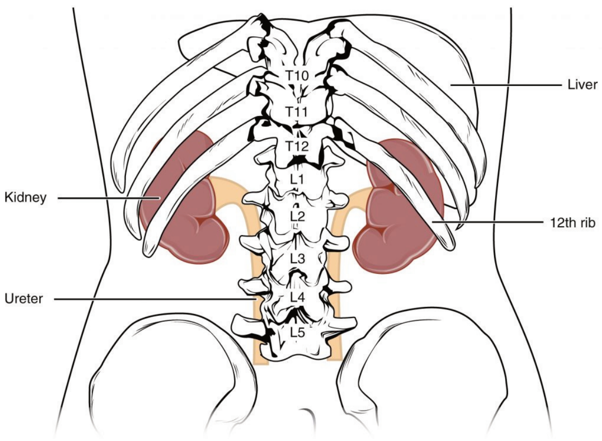
Figure 3.22 The Bladder



"The Bladder" by OpenStax College / CC BY 3.0

The kidneys lie on either side of the spine in the retroperitoneal space behind the main body cavity that contains the intestines. The kidneys are well protected by muscle, fat, and the lower ribs. They are roughly the size of your fist, and the male kidney is typically a bit larger than the female kidney. The kidneys are well vascularized, receiving about 25 percent of the cardiac output at rest.

Figure 3.23 The Kidneys



"Kidney Position in Abdomen" by OpenStax College / CC BY 3.0

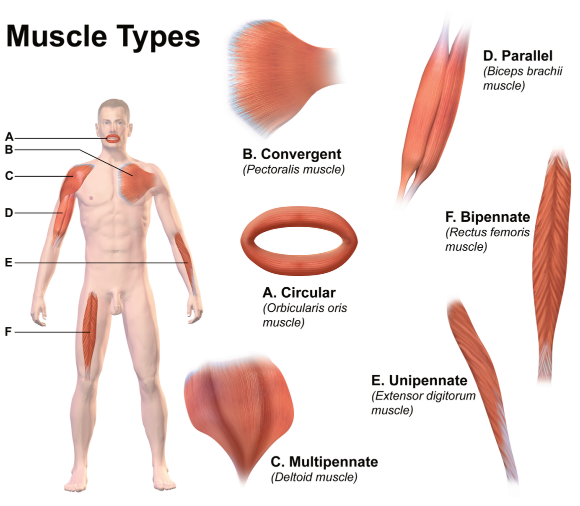
The kidneys (as viewed from the back of the body) are slightly protected by the ribs and are surrounded by fat for protection (not shown).

The effects of failure of parts of the urinary system may range from inconvenient (incontinence) to fatal (loss of filtration and many other functions). The kidneys catalyze the final reaction in the synthesis of active vitamin D that in turn helps regulate Ca++. The kidney hormone EPO stimulates erythrocyte development and promotes adequate O2 transport. The kidneys help regulate blood pressure through Na+ and water retention and loss. The kidneys work with the adrenal cortex, lungs, and liver in the renin–angiotensin–aldosterone system to regulate blood pressure. They regulate osmolarity of the blood by regulating both solutes and water. Three electrolytes are more closely regulated than others: Na^+, Ca^{++}, and K^+. The kidneys share pH regulation with the lungs and plasma buffers, so that proteins can preserve their three-dimensional conformation and thus their function.

The Muscular System

The muscular system allows the body to move voluntarily, but it also controls involuntary movements of other organ systems such as heartbeat in the circulatory system and peristaltic waves in the digestive system. It consists of over six hundred skeletal muscles, as well as the heart muscle, the smooth muscles that surround your entire alimentary canal, and all your arterial blood vessels (see Figure 3.24 "The Muscular System in the Human Body"). Muscle contraction relies on energy delivery to the muscle. Each movement uses up cellular energy, and without an adequate energy supply, muscle function suffers. Muscle, like the liver, can store the energy from glucose in the large polymeric molecule glycogen. But unlike the liver, muscles use up all of their own stored energy and do not export it to other organs in the body. Muscle is not as susceptible to low levels of blood glucose as the brain because it will readily use alternate fuels such as fatty acids and protein to produce cellular energy.

Figure 3.24 The Muscular System in the Human Body



"Muscle Types" by BruceBlaus / CC BY-SA 4.0

The Skeletal System

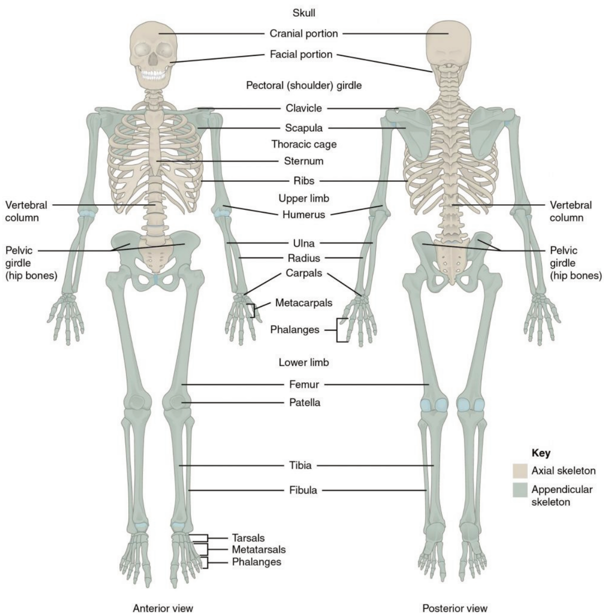
Bone Structure and Function

Your bones are stronger than reinforced concrete. Bone tissue is a composite of fibrous strands of collagen (a type of protein) that resemble the steel rebar in concrete and a hardened mineralized matrix that contains large amounts of calcium, just like concrete. But this is where the similarities end. Bone outperforms reinforced concrete by several orders of magnitude in compression and tension strength tests. Why? The microarchitecture of bone is complex and built to withstand extreme forces. Moreover, bone is a living tissue that is continuously breaking down and forming new bone to adapt to mechanical stresses.

Why Is the Skeletal System Important?

The human skeleton consists of 206 bones and other connective tissues called ligaments, tendons, and cartilage. Ligaments connect bones to other bones, tendons connect bones to muscles, and cartilage provides bones with more flexibility and acts as a cushion in the joints between bones. The skeleton's many bones and connective tissues allow for multiple types of movement such as typing and running. The skeleton provides structural support and protection for all the other organ systems in the body. The skull, or cranium, is like a helmet and protects the eyes, ears, and brain. The ribs form a cage that surrounds and protects the lungs and heart. In addition to aiding in movement, protecting organs, and providing structural support, red and white blood cells and platelets are synthesized in bone marrow. Another vital function of bones is that they act as a storage depot for minerals such as calcium, phosphorous, and magnesium. Although bone tissue may look inactive at first glance, at the microscopic level you will find that bones are continuously breaking down and reforming. Bones also contain a complex network of canals, blood vessels, and nerves that allow for nutrient transport and communication with other organ systems.

Figure 3.25 Human Skeletal Structure



"Axial Skeleton" by Openstax College / CC BY 3.0

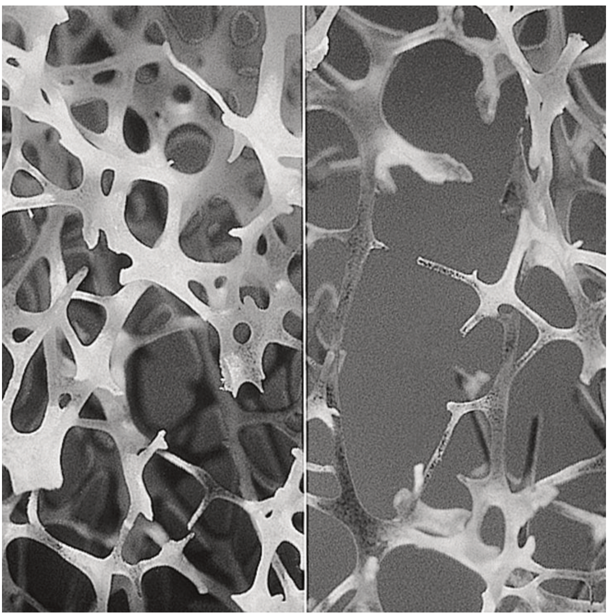
The human skeleton contains 206 bones. It is divided into two main parts, the axial and appendicular.

Bone Anatomy and Structure

To optimize bone health through nutrition, it is important to understand bone anatomy. The skeleton is composed of two main parts, the axial and the appendicular parts. The axial skeleton consists of the skull, vertebral column, and rib cage, and is composed of eighty bones. The appendicular skeleton consists of the shoulder girdle, pelvic girdle, and upper and lower extremities, and is composed of 126 bones. Bones are also categorized by size and shape. There are four types of bone: long bones, short bones, flat bones, and irregular bones. The longest bone in your body is the femur (thigh bone), which extends from your hip to your knee. It is a long bone and functions to support your weight as you stand, walk, or run. Your wrist is composed of eight irregular-shaped bones, which allow for the intricate movements of your hands. Your twelve ribs on each side of your body are curved flat bones that protect your heart and lungs. Thus, the bones' different sizes and shapes allow for their different functions.

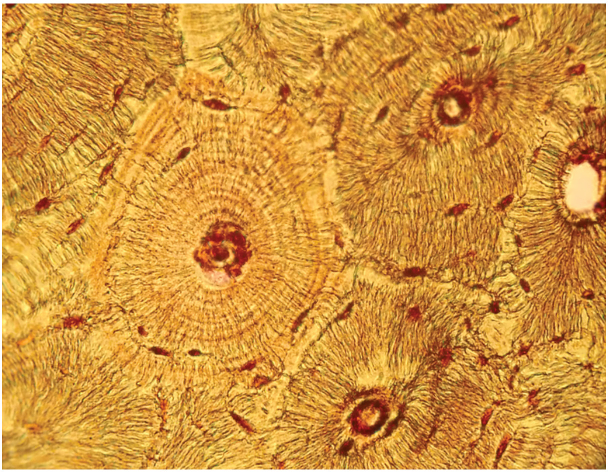
Bones are composed of approximately 65 percent inorganic material known as mineralized matrix. This mineralized matrix consists of mostly crystallized hydroxyapatite. The bone's hard crystal matrix of bone tissue gives it its rigid structure. The other 35 percent of bone is organic material, most of which is the fibrous protein collagen. The collagen fibers are networked throughout bone tissue and provide it with flexibility and strength. The bones' inorganic and organic materials are structured into two different tissue types. There is spongy bone, also called trabecular or cancellous bone, and compact bone, also called cortical bone (Figure 3.26 "The Arrangement of Bone Tissues"). The two tissue types differ in their microarchitecture and porosity. Trabecular bone is 50 to 90 percent porous and appears as a lattice-like structure under the microscope. It is found at the ends of long bones, in the cores of vertebrae, and in the pelvis. Trabecular bone tissue makes up about 20 percent of the adult skeleton. The more dense cortical bone is about 10 percent porous and it looks like many concentric circles, similar to the rings in a tree trunk, sandwiched together (Figure 3.27 “Cortical (Compact) Bone”). Cortical bone tissue makes up approximately 80 percent of the adult skeleton. It surrounds all trabecular tissue and is the only bone tissue in the shafts of long bones.

Figure 3.26 The Arrangement of Bone Tissues



The two basic tissue types of bones are trabecular and cortical. This photo shows normal (left) and degraded (right) trabecular (spongy) bone.

Figure 3.27 Cortical (Compact) Bone.



"Compact Bone with osteons" by Lord of Konrad / CC0

Bone tissue is arranged in an organized manner. A thin membrane, called the periosteum, surrounds the bone. It contains connective tissue with many blood vessels and nerves. Lying below the periosteum is the cortical bone. In some bones, the cortical bone surrounds the less-dense trabecular bone and the bone marrow lies within the trabecular bone, but not all bones contain trabecular tissue or marrow.

Bone Tissues and Cells, Modeling and Remodeling

Bone tissue contains many different cell types that constantly resize and reshape bones throughout growth and adulthood. Bone tissue cells include osteoprogenitor cells, osteoblasts, osteoclasts, and osteocytes. The osteoprogenitor cells are cells that have not matured yet. Once they are stimulated, some will become osteoblasts, the bone builders, and others will become osteoclasts, the cells that break bone down. Osteocytes are the most abundant cells in bone tissue. Osteocytes are star-shaped cells that are networked throughout the bone via their long cytoplasmic arms that allow for the exchange of nutrients and other factors from bones to the blood and lymph.

Bone Modeling and Remodeling

During infancy, childhood, and adolescence, bones are continuously growing and changing shape through two processes called growth (ossification) and modeling. In fact, in the first year of life, almost 100 percent of the bone tissue in the skeleton is replaced. In the process of modeling, bone tissue is dismantled at one site and built up at a different site. In adulthood, our bones stop growing and modeling, but continue to go through a process of bone remodeling. In the process of remodeling, bone tissue is degraded and built up at the same location. About 10 percent of bone tissue is remodeled each year in adults. Bones adapt their structure to the forces acting upon them, even in adulthood. This phenomenon is called Wolff's law, which states that bones will develop a structure that is best able to resist the forces acting upon them. This is why exercising, especially when it involves weight-bearing activities, increases bone strength.

The first step in bone remodeling is osteocyte activation. Osteocytes detect changes in mechanical forces, calcium homeostasis, or hormone levels. In the second step, osteoclasts are recruited to the site of the degradation. Osteoclasts are large cells with a highly irregular ruffled membrane. These cells fuse tightly to the bone and secrete hydrogen ions, which acidify the local environment and dissolve the minerals in the bone tissue matrix. This process is called bone resorption and resembles pit excavation. Our bodies excavate pits in our bone tissue because bones act as storehouses for calcium and other minerals. Bones supply these minerals to other body tissues as the demand arises. Bone tissue also remodels when it breaks so that it can repair itself. Moreover, if you decide to train to run a marathon your bones will restructure themselves by remodeling to be better able to sustain the forces of their new function.

After a certain amount of bone is excavated, the osteoclasts begin to die and bone resorption stops. In the third step of bone remodeling, the site is prepared for building. In this stage, sugars and proteins accumulate along the bone's surface, forming a cement line which acts to form a strong bond between the old bone and the new bone that will be made. These first three steps take approximately two to three weeks to complete. In the last step of bone remodeling, osteoblasts lay down new osteoid tissue that fills up the cavities that were excavated during the resorption process. Osteoid is bone matrix tissue that is composed of proteins such as collagen and is not mineralized yet. To make collagen, vitamin C is required. A symptom of vitamin C deficiency (known as scurvy) is bone pain, which is caused by diminished bone remodeling. After the osteoid tissue is built up, the bone tissue begins to mineralize. The last step of bone remodeling continues for months, and for a much longer time afterward the mineralized bone is continuously packed in a more dense fashion.

Thus, we can say that bone is a living tissue that continually adapts itself to mechanical stress through the process of remodeling. For bone tissue to remodel certain nutrients such as calcium, phosphorus, magnesium, fluoride, vitamin D, and vitamin K are required.

Bone Mineral Density Is an Indicator of Bone Health

Bone mineral density (BMD) is a measurement of the amount of calcified tissue in grams per centimeter squared of bone tissue. BMD can be thought of as the total amount of bone mass in a defined area. When BMD is high, bone strength will be great. Similar to measuring blood pressure to predict the risk of stroke, a BMD measurement can help predict the risk of bone fracture. The most common tool used to measure BMD is called dual energy X-ray absorptiometry (DEXA). During this procedure, a person lies on their back and a DEXA scanner passes two X-ray beams through their body. The amount of X-ray energy that passes through the bone is measured for both beams. The total amount of the X-ray energy that passes through a person varies depending on their bone thickness. Using this information and a defined area of bone, the amount of calcified tissue in grams per unit area (cm2) is calculated. Most often the DEXA scan focuses on measuring BMD in the hip and the spine. These measurements are then used as indicators of overall bone strength and health. DEXA is the cheapest and most accurate way to measure BMD. It also uses the lowest dose of radiation. Other methods of measuring BMD include quantitative computed tomography (QCT) and radiographic absorptiometry. People at risk for developing bone disease are advised to have a DEXA scan. We will discuss the many risk factors linked to an increased incidence of osteoporosis and the steps a person can take to prevent the disease from developing.

The Immune System

The immune system comprises several types of white blood cells that circulate in the blood and lymph. Their jobs are to seek, recruit, attack, and destroy foreign invaders, such as bacteria and viruses. Other less realized components of the immune system are the skin (which acts as a barricade), mucus (which traps and entangles microorganisms), and even the bacteria in the large intestine (which prevent the colonization of bad bacteria in the gut). Immune system functions are completely dependent on dietary nutrients. In fact, malnutrition is the leading cause of immune-system deficiency worldwide. When immune system functions are inadequate there is a marked increase in the chance of getting an infection. Children in many poor, developing countries have protein- and/or energy-deficient diets that are causative of two different syndromes, kwashiorkor and marasmus. These children often die from infections that their bodies would normally have fought off, but because their protein and/or energy intake is so low, the immune system cannot perform its functions.

Other nutrients, such as iron, zinc, selenium, copper, folate, and vitamins A, B6, C, D, and E, all provide benefits to immune system function. Deficiencies in these nutrients can cause an increased risk for infection and death. Zinc deficiency results in suppression of the immune system's barrier functions by damaging skin cells; it is also associated with a decrease in the number of circulating white blood cells. A review of several studies in the journal Pediatrics concluded that zinc supplements administered to children under age five for longer than three months significantly reduces the incidence and severity of diarrhea and respiratory illnesses.[1]

Zinc supplementation also has been found to be therapeutically beneficial for the treatment of leprosy, tuberculosis, pneumonia, and the common cold. Equally important to remember is that multiple studies show that it is best to obtain your minerals and vitamins from eating a variety of healthy foods.

Just as undernutrition compromises immune system health, so does overnutrition. People who are obese are at increased risk for developing immune system disorders such as asthma, rheumatoid arthritis, and some cancers. Both the quality and quantity of fat affect immune system function. High intakes of saturated and trans fats negatively affect the immune system, whereas increasing your intake of omega-3 fatty acids, found in salmon and other oily fish, decreases inflammatory responses. High intakes of omega-3 fatty acids are linked to a reduction in the risk of developing certain autoimmune disorders, such as rheumatoid arthritis, and are used as part of a comprehensive treatment for rheumatoid arthritis.

1. Aggarwal R, Sentz J, Miller MA. Role of Zinc Administration in Prevention of Childhood Diarrhea and Respiratory Illnesses: A Meta-Analysis. Pediatrics. 2007; 119(6), 1120–30. https://www.ncbi.nlm.nih.gov/pubmed/17545379. Accessed September 22, 2017.

Indicators of Health: Body Mass Index, Body Fat Content, and Fat Distribution

Although the terms overweight and obese are often used interchangeably and considered as gradations of the same thing, they denote different things. The major physical factors contributing to body weight are water weight, muscle tissue mass, bone tissue mass, and fat tissue mass. Overweight refers to having more weight than normal for a particular height and may be the result of water weight, muscle weight, or fat mass. Obese refers specifically to having excess body fat. In most cases people who are overweight also have excessive body fat and therefore body weight is an indicator of obesity in much of the population.

The "ideal" healthy body weight for a particular person is dependent on many things, such as frame size, sex, muscle mass, bone density, age, and height. The perception of the "ideal" body weight is additionally dependent on cultural factors and the mainstream societal advertisement of beauty.

To standardize the "ideal" body weight and relate it to health, scientists have devised mathematical formulas to better define a healthy weight. These mathematically derived measurements are used by health professionals to correlate disease risk with populations of people and at the individual level. A clinician will take two measurements, one of weight and one of fat mass, in order to diagnose obesity. Some measurements of weight and body fat that do not require using technical equipment can easily be calculated and help provide an individual with information on weight, fat mass, and distribution, and their relative risk of some chronic diseases.

Figure 3.28 Body Composition

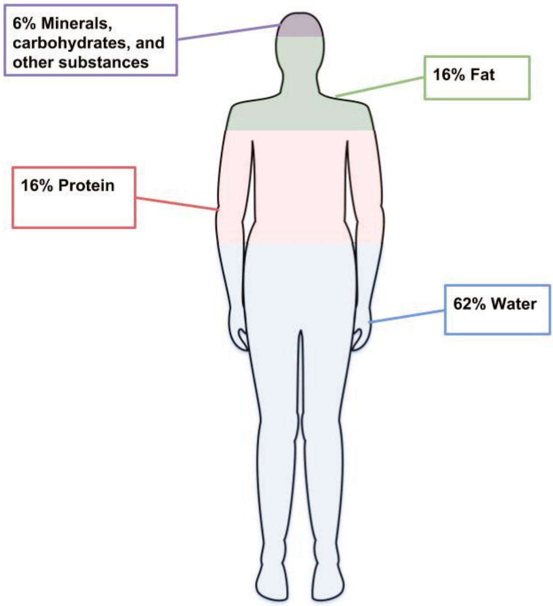


Image by Allison Calabrese / CC BY 4.0

Body Mass Index: How to Measure It and Its Limitations

Body mass index (BMI) is calculated using height and weight measurements and is more predictive of body fatness than weight alone. BMI measurements are used to indicate whether an individual may be underweight (with a BMI less than 18.5), overweight (with a BMI over 25), or obese (with a BMI over 30). High BMI measurements can be warning signs of increased chances of developing health problems such as cardiovascular disease, Type 2 diabetes, and other chronic diseases. BMI-associated health risks vary by race. Asians face greater health risks for the same BMI than Caucasians, and Caucasians face greater health risks for the same BMI than African Americans.

Calculating BMI

To calculate your BMI, multiply your weight in kilograms by the square of your height in meters.

BMI = [weight (kg)] ÷ height^2 (m)^2

To see how your BMI indicates the weight category you are in, see Table 2.3 “BMI Categories” or use a chart of weight and height to figure out your BMI.

Table 3.3 BMI Categories

Categories	BMI
Underweight	< 18.5
Normal weight	18.5–24.9
Overweight	25–29.9
Obese	> 30.0

BMI Limitations

A BMI is a fairly simple measurement and does not take into account fat mass or fat distribution in the body, both of which are additional predictors of disease risk. Body fat weighs less than muscle mass. Therefore, BMI can sometimes underestimate the amount of body fat in overweight or obese people and overestimate it in more muscular people. For instance, a muscular athlete will have more muscle mass (which is heavier than fat mass) than a sedentary individual of the same height. Based on their BMIs the muscular athlete would be less “ideal” and may be categorized as more overweight or obese than the sedentary individual; however this is an infrequent problem with BMI calculation. Additionally, an older person with osteoporosis (decreased bone mass) will have a lower BMI than an older person of the same height without osteoporosis, even though the person with osteoporosis may have more fat mass. BMI is a useful inexpensive tool to categorize people and is highly correlative with disease risk, but other measurements are needed to diagnose obesity and more accurately assess disease risk.

Body Fat and Its Distribution

Next we'll discuss how to measure body fat, and why distribution of body fat is also important to consider when determining health.

Measuring Body Fat Content

Water, organs, bone tissue, fat, and muscle tissue make up a person's weight. Having more fat mass may be indicative of disease risk, but fat mass also varies with sex, age, and physical activity level. Females have more fat mass, which is needed for reproduction and, in part, is a consequence of different levels of hormones. The optimal fat content of a female is between 20 and 30 percent of her total weight and for a male is between 12 and 20 percent. Fat mass can be measured in a variety of ways. The simplest and lowest-cost way is the skin-fold test. A health professional uses a caliper to measure the thickness of skin on the back, arm, and other parts of the body and compares it to standards to assess body fatness. It is a noninvasive and fairly accurate method of measuring fat mass, but similar to BMI, is compared to standards of mostly young to middle-aged adults.

Figure 3.29 Measuring Skinfold Thickness Using Calipers

Image by Shutterstock. All Rights Reserved.

Other methods of measuring fat mass are more expensive and more technically challenging. They include:

- Underwater weighing. This technique requires a chamber full of water big enough for the whole body to fit in. First, a person is weighed outside the chamber and then weighed again while immersed in water. Bone and muscle weigh more than water, but fat does not—therefore a person with a higher muscle and bone mass will weigh more when in water than a person with less bone and muscle mass.
- Bioelectric Impedance Analysis (BIA). This device is based on the fact that fat slows down the passage of electricity through the body. When a small amount of electricity is passed through the body, the rate at which it travels is used to determine body composition. These devices are also sold for home use and commonly called body composition scales.

Figure 3.30 BIA Hand Device

Image by United States Marine Corps / Public Domain

- Dual-energy X-ray absorptiometry (DEXA). This can be used to measure bone density. It also can determine fat content via the same method, which directs two low-dose X-ray beams through the body and determines the amount of the energy absorbed from the beams. The amount of energy absorbed is dependent on the body's content of bone, lean tissue mass, and fat mass. Using standard mathematical formulas, fat content can be accurately estimated.

Figure 3.31 Dual-Energy X-ray Absorptiometry (DEXA)

"A Dual-energy X-ray absorptiometry (DEXA) scan" by Nick Smith / CC BY-SA 3.0

Measuring Fat Distribution

Total body-fat mass is one predictor of health; another is how the fat is distributed in the body. You may have heard that fat on the hips is better than fat in the belly—this is true. Fat can be found in different areas in the body and it does not all act the same, meaning it differs physiologically based on location. Fat deposited in the abdominal cavity is called visceral fat and it is a better predictor of disease risk than total fat mass. Visceral fat releases hormones and inflammatory factors that contribute to disease risk. The only tool required for measuring visceral fat is a measuring tape. The measurement (of waist circumference) is taken just above the belly button. Men with a waist circumference greater than 40 inches and women with a waist circumference greater than 35 inches are predicted to face greater health risks.

Figure 3.32 Fat Distribution

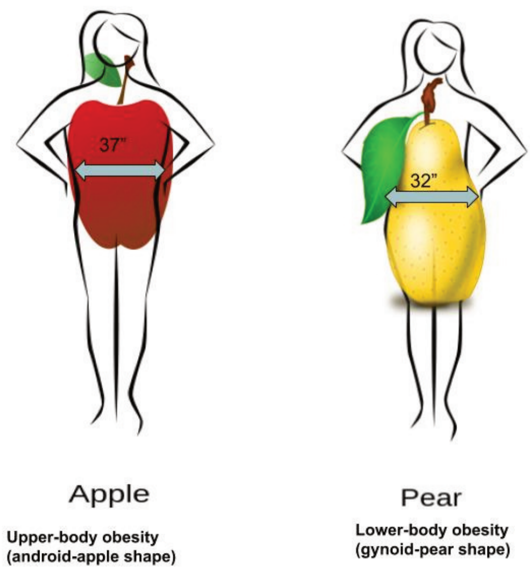


Image by Allison Calabrese / CC BY 4.0

The waist-to-hip ratio is often considered a better measurement than waist circumference alone in predicting disease risk. To calculate your waist-to-hip ratio, use a measuring tape to measure your waist circumference and then measure your hip circumference at its widest part. Next, divide the waist circumference by the hip circumference to arrive at the waist-to-hip ratio. Observational studies have demonstrated that people with "apple-shaped" bodies, (who carry more weight around the waist) have greater risks for chronic disease than those with "pear-shaped" bodies, (who carry more weight around the hips). A study published in the November 2005 issue of Lancet with more than twenty-seven thousand participants from fifty-two countries concluded that the waist-to-hip ratio is highly correlated with heart attack risk worldwide and is a better predictor of heart attacks than BMI.[1]. Abdominal obesity is defined by the World Health Organization (WHO) as having a waist-to-hip ratio above 0.90 for males and above 0.85 for females.

1. Yusuf S, Hawken S, et al. Obesity and the Risk of Myocardial Infarction in 27,000 Participants from 52 Countries: A Case-Control Study. Lancet. 2005; 366(9497), 1640–9. http://www.ncbi.nlm.nih.gov/pubmed/16271645 ?dopt=AbstractPlus. Accessed September 22, 2017.

CHAPTER 4. WATER AND ELECTROLYTES

Introduction

Image by ???? NG on unsplash.com / CC0

Learning Objectives

By the end of this chapter you will be able to:

- Describe the importance of water intake for the body
- Describe the major aspects of water regulation in the body
- Describe the function, balance, sources, and consequences of the imbalance of electrolytes

- Describe the effects and use of popular beverage choices

Maintaining the right level of water in your body is crucial to survival, as either too little or too much water in your body will result in less-than-optimal functioning. One mechanism to help ensure the body maintains water balance is thirst. Thirst is the result of your body's physiology telling your brain to initiate the thought to take a drink. Sensory proteins detect when your mouth is dry, your blood volume too low, or blood electrolyte concentrations too high and send signals to the brain stimulating the conscious feeling to drink.

In the summer of 1965, the assistant football coach of the University of Florida Gators requested scientists affiliated with the university study why the withering heat of Florida caused so many heat-related illnesses in football players and provide a solution to increase athletic performance and recovery post-training or game. The discovery was that inadequate replenishment of fluids, carbohydrates, and electrolytes was the reason for the "wilting" of their football players. Based on their research, the scientists concocted a drink for the football players containing water, carbohydrates, and electrolytes and called it "Gatorade." In the next football season the Gators were nine and two and won the Orange Bowl. The Gators' success launched the sports-drink industry, which is now a multibillion-dollar industry that is still dominated by Gatorade.

According to statistics Canada, milk is the primary source of sugar among children aged 1 to 8, but by ages 9 to 18, regular soft drinks ranked first. Beverages accounted for 35% of adults' daily sugar intake.[1] Excess consumption of sugary soft drinks have been scientifically proven to increase the risk for dental caries, obesity, Type 2 diabetes, and cardiovascular disease. In addition to sugary soft drinks, beverages containing added sugars include fruit drinks, sports drinks, energy drinks and sweetened bottled waters.

Sports drinks are designed to rehydrate the body after excessive fluid depletion. Electrolytes in particular promote normal rehydration to prevent fatigue during physical exertion. Are they a good choice for achieving the recommended fluid intake? Are they performance and endurance enhancers like they claim? Who should drink them?

Typically, eight ounces of a sports drink provides between fifty and eighty calories and 14 to 17 grams of carbohydrate, mostly in the form of simple sugars. Sodium and potassium are the most commonly included electrolytes in sports drinks, with the levels of these in sports drinks being highly variable. The American College of Sports Medicine says a sports drink should contain 125 milligrams of sodium per 8 ounces as it is helpful in replenishing some of the sodium lost in sweat and promotes fluid uptake in the small intestine, improving hydration.

In this chapter we will discuss the importance and functions of fluid and electrolyte balance in the human body, the consequences of getting too much or too little of water and electrolytes, the best dietary sources of these nutrients, and healthier beverage choices. After reading this chapter you will know what to look for in sports drinks and will be able to select the best products to keep hydrated.

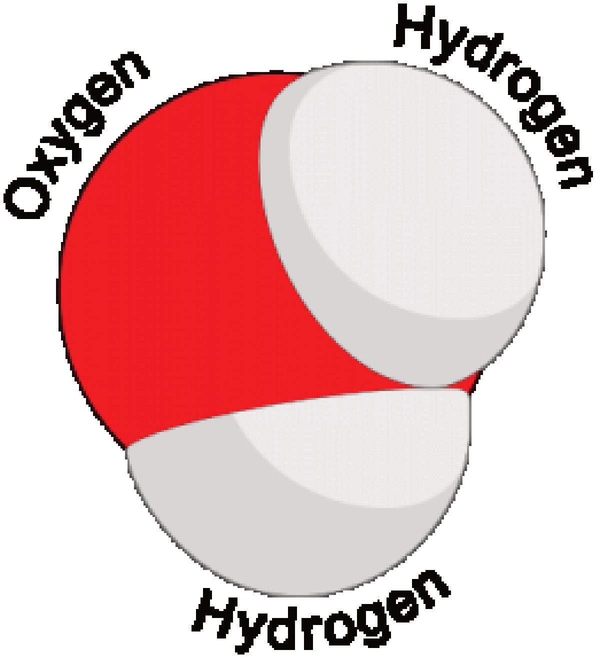
1. Statistics Canada. *Canadian Community Health Survey (CCHS): Cycle 2.2, Nutrition: General Health Component Including Vitamin and Mineral Supplements, and 24-hour Dietary Recall Component*, Derived Variables Documentation. Ottawa: Statistics Canada, 2008.

Overview of Fluid and Electrolyte Balance

Water is made up of 2 hydrogen atoms and 1 oxygen atom (Figure 4.1 “The Water Molecule”). A human body is made up of mostly water. An adult consists of about 37 to 42 liters of water, or about eighty pounds. Fortunately, humans have compartmentalized tissues; otherwise we might just look like a water balloon! Newborns are approximately 70 percent water. Adult males typically are composed of about 60 percent water and females are about 55 percent water. (This gender difference reflects the differences in body-fat content, since body fat is practically water-free. This also means that if a person gains weight in the form of fat the percentage of total body water content declines.) As we age, total body water content also diminishes so that by the time we are in our eighties the percent of water in our bodies has decreased to around 45 percent. Does the loss in body water play a role in the aging process? Alas, no one knows. But, we do know that dehydration accelerates the aging process whereas keeping hydrated decreases headaches, muscle aches, and kidney stones. Additionally a study found that women who drank more than five glasses of water each day had a significantly decreased risk for developing colon cancer.[1]

Figure 4.1 The Water Molecule

1. Shannon JE, et al. Relationship of Food Groups and Water Intake to Colon Cancer Risk. Cancer Epidemiol Biomarkers Prev. 1996; 5(7), 495–502. http://cebp.aacrjournals.org/content/5/7/495.long. Accessed September 22, 2017.



"Water Molecule" by Chris Martin / Public Domain

Fluid and Electrolyte Balance

Although water makes up the largest percentage of body volume, it is not actually pure water but rather a mixture of cells, proteins, glucose, lipoproteins, electrolytes, and other substances. Electrolytes are substances that, when dissolved in water, dissociate into charged ions. Positively charged electrolytes are called cations and negatively charged electrolytes are called anions. For example, in water sodium chloride (the chemical name for table salt) dissociates into sodium cations (Na^+) and chloride anions (Cl^-). Solutes refers to all dissolved substances in a fluid, which may be charged, such as sodium (Na^+), or uncharged, such as glucose. In the human body, water and solutes are distributed into two compartments: inside cells, called intracellular, and outside cells, called extracellular. The extracellular water compartment is subdivided into the spaces between cells also known as interstitial, blood plasma, and other bodily fluids such as the cerebrospinal fluid which surrounds and protects the brain and spinal cord (Figure 4.2 "Distribution of Body Water"). The composition of solutes differs between the fluid compartments. For instance, more protein is inside cells than outside and more chloride anions exist outside of cells than inside.

Figure 4.2 Distribution of Body Water

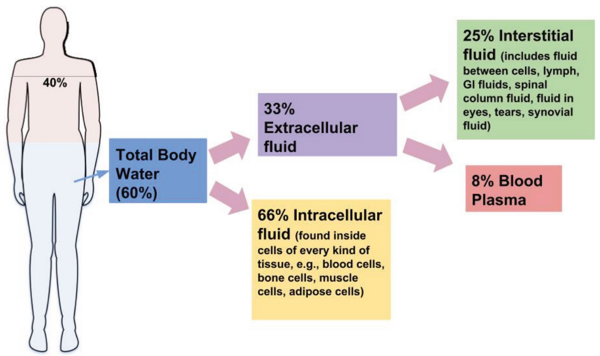


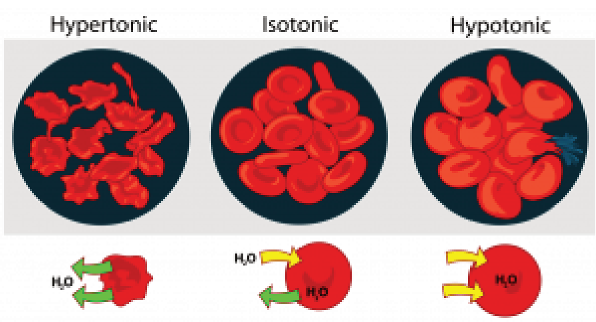
Image by Allison Calabrese / CC BY 4.0

Osmoregulation

One of the essential homeostatic functions of the body is to maintain fluid balance and the differences in solute composition between cells and their surrounding environment. Osmoregulation is the control of fluid balance and composition in the body. The processes involved keep fluids from becoming too dilute or too concentrated. Fluid compartments are separated by selectively permeable membranes, which allow some things, such as water, to move through while other substances require special transport proteins, channels, and often energy. The movement of water between fluid compartments happens by osmosis, which is simply the movement of water through a selectively permeable membrane from an area where it is highly concentrated to an area where it is not so concentrated. Water is never transported actively; that is, it never takes energy for water to move between compartments. Although cells do not directly control water movement, they do control movement of electrolytes and other solutes and thus indirectly regulate water movement by controlling where there will be regions of high and low concentrations.

Cells maintain their water volume at a constant level, but the composition of solutes in a cell is in a continuous state of flux. This is because cells are bringing nutrients in, metabolizing them, and disposing of waste products. To maintain water balance a cell controls the movement of electrolytes to keep the total number of dissolved particles, called osmolality the same inside and outside (Figure 4.3 "Osmoregulation"). The total number of dissolved substances is the same inside and outside a cell, but the composition of the fluids differs between compartments. For example, sodium exists in extracellular fluid at fourteen times the concentration as compared to that inside a cell.

Figure 4.3 Osmoregulation



"Osmosis" by Mariana Ruiz / Public Domain

Cells maintain water volume by actively controlling electrolyte concentrations. Human erythrocytes (red blood cells) are shown here. Three conditions are shown: hypertonic conditions (where the erythrocytes contract and appear "spiky"), isotonic conditions (where the erythrocytes appear normal) and hypotonic conditions (where the etrythrocytes expand and become more round).

If a cell is placed in a solution that contains fewer dissolved particles (hypotonic solution) than the cell itself, water moves into the more concentrated cell, causing it to swell. Alternatively, if a cell is placed in a solution that is more concentrated (known as a hypertonic solution) water moves from inside the cell to the outside, causing it to shrink. Cells keep their water volume constant by pumping electrolytes in and out in an effort to balance the concentrations of dissolved particles on either side of their membranes. When a solution contains an equal concentration of dissolved particles on either side of the membrane, it is known as an isotonic solution.

Water's Importance to Vitality

You get up in the morning, flush wastes down the toilet, take a shower, brush your teeth, drink, eat, drive, wash the grime from your windshield, get to work, and drink coffee. Next to a fountain you eat lunch and down it with a glass of water, you use the toilet again and again, drive home, prepare dinner, etc. Add all the ways you use water every day and you still will not come close to the countless uses water has in the human body. Of all the nutrients, water is the most critical as its absence proves lethal within a few days. Organisms have adapted numerous mechanisms for water conservation. Water uses in the human body can be loosely categorized into four basic functions: transportation vehicle, medium for chemical reactions, lubricant/shock absorber, and temperature regulator.

Image by NASA on unsplash.com / CC0

Water is the foundation of all life—the surface of the earth is

70 percent water; the volume of water in humans is about 60 percent.

Water As a Transportation Vehicle

Water is called the "universal solvent" because more substances dissolve in it than any other fluid. Molecules dissolve in water because of the hydrogen and oxygen molecules ability to loosely bond with other molecules. Molecules of water (H2O) surround substances, suspending them in a sea of water molecules. The solvent action of water allows for substances to be more readily transported. A pile of undissolved salt would be difficult to move throughout tissues, as would a bubble of gas or a glob of fat. Blood, the primary transport fluid in the body is about 78 percent water. Dissolved substances in blood include proteins, lipoproteins, glucose, electrolytes, and metabolic waste products, such as carbon dioxide and urea. These substances are either dissolved in the watery surrounding of blood to be transported to cells to support basic functions or are removed from cells to prevent waste build-up and toxicity. Blood is not just the primary vehicle of transport in the body, but also as a fluid tissue blood structurally supports blood vessels that would collapse in its absence. For example, the brain which consists of 75 percent water is used to provide structure.

Water As a Medium for Chemical Reactions

Water is required for even the most basic chemical reactions. Proteins fold into their functional shape based on how their amino-acid sequences react with water. These newly formed enzymes must conduct their specific chemical reactions in a medium, which in all organisms is water. Water is an ideal medium for chemical reactions as it can store a large amount of heat, is electrically neutral, and has a pH of 7.0, meaning it is not acidic or basic. Additionally, water is involved in many enzymatic reactions as an agent to break bonds or, by its removal from a molecule, to form bonds.

Water As a Lubricant/Shock Absorber

Many may view the slimy products of a sneeze as gross, but sneezing is essential for removing irritants and could not take place without water. Mucus, which is not only essential to discharge nasal irritants, is also required for breathing, transportation of nutrients along the gastrointestinal tract, and elimination of waste materials through the rectum. Mucus is composed of more than 90 percent water and a front-line defense against injury and foreign invaders. It protects tissues from irritants, entraps pathogens, and contains immune-system cells that destroy pathogens. Water is also the main component of the lubricating fluid between joints and eases the movement of articulated bones.

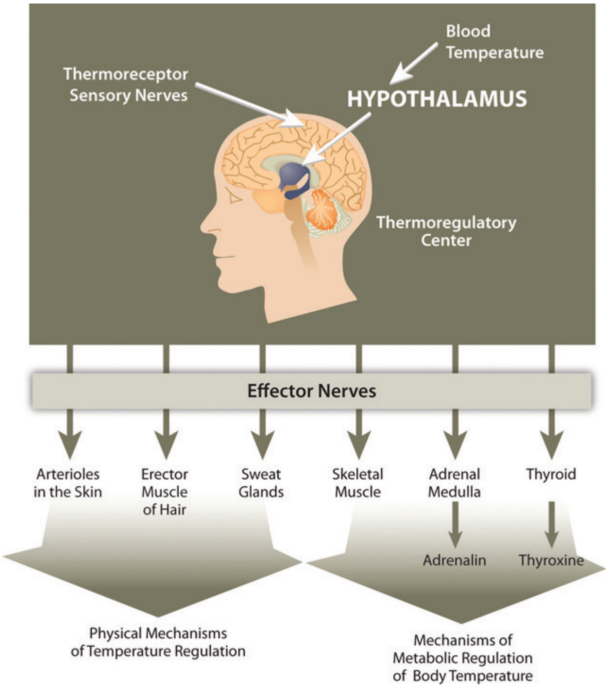
The aqueous and vitreous humors, which are fluids that fill the extra space in the eyes and the cerebrospinal fluid surrounding the brain and spinal cord, are primarily water and buffer these organs against sudden changes in the environment. Watery fluids surrounding organs provide both chemical and mechanical protection. Just two weeks after fertilization water fills the amniotic sac in a pregnant woman providing a cushion of protection for the developing embryo.

Water As a Temperature Regulator

Another homeostatic function of the body, termed thermoregulation is to balance heat gain with heat loss and body water plays an important role in accomplishing this. Human life is supported within a narrow range of temperature, with the temperature set point of the body being 98.6°F (37°C). Too low or too high of a temperature causes enzymes to stop functioning and metabolism is halted. At 82.4°F (28°C) muscle failure occurs and hypothermia sets in. At the opposite extreme of 111.2°F (44°C) the central nervous system fails and death results. Water is good at storing heat, an attribute referred to as heat capacity and thus helps maintain the temperature set point of the body despite changes in the surrounding environment.

There are several mechanisms in place that move body water from place to place as a method to distribute heat in the body and equalize body temperature (Figure 3.4 "Thermoregulatory Center"). The hypothalamus in the brain is the thermoregulatory center. The hypothalamus contains special protein sensors that detect blood temperature. The skin also contains temperature sensors that respond quickly to changes in immediate surroundings. In response to cold sensors in the skin, a neural signal is sent to the hypothalamus, which then sends a signal to smooth muscle tissue surrounding blood vessels causing them to constrict and reduce blood flow. This reduces heat lost to the environment. The hypothalamus also sends signals to muscles to erect hairs and shiver and to endocrine glands like the thyroid to secrete hormones capable of ramping up metabolism. These actions increase heat conservation and stimulate its production in the body in response to cooling temperatures.

Figure 4.4 Thermoregulatory Center



Thermoregulation is the ability of an organism to maintain body temperature despite changing environmental temperatures.

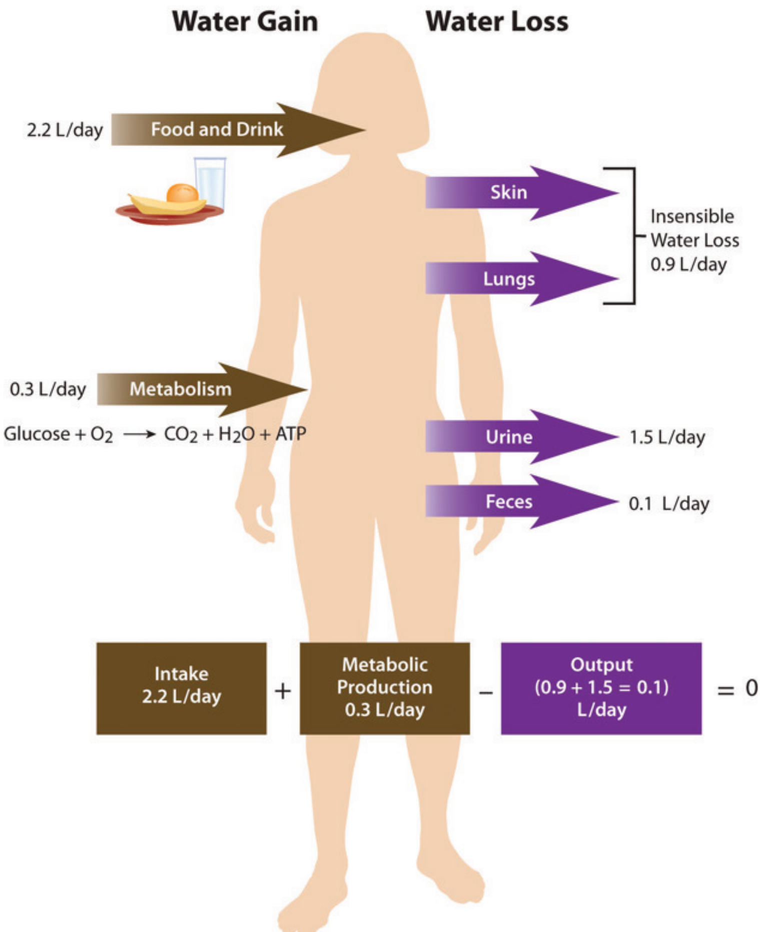
Regulation of Water Balance

As you eat a bite of food, the salivary glands secrete saliva. As the food enters your stomach, gastric juice is secreted. As it enters the small intestine, pancreatic juice is secreted. Each of these fluids contains a great deal of water. How is that water replaced in these organs? What happens to the water now in the intestines? In a day, there is an exchange of about 10 liters of water among the body's organs. The osmoregulation of this exchange involves complex communication between the brain, kidneys, and endocrine system. A homeostatic goal for a cell, a tissue, an organ, and an entire organism is to balance water output with water input.

Regulation of Daily Water Input

Total water output per day averages 2.5 liters. This must be balanced with water input. Our tissues produce around 300 milliliters of water per day through metabolic processes. The remainder of water output must be balanced by drinking fluids and eating solid foods. The average fluid consumption per day is 1.5 liters, and water gained from solid foods approximates 700 milliliters.

Figure 4.5 Daily Fluid Loss and Gain



Dietary Gain of Water

The Adequate Intake (AI) for water for adult males at 3.7 liters

(15.6 cups) and at 2.7 liters (11 cups) for adult females.[1] These intakes are higher than the average intake of 2.2 liters. It is important to note that the AI for water includes water from all dietary sources; that is, water coming from food as well as beverages. People are not expected to consume 15.6 or 11 cups of pure water per day. Approximately 20 percent of dietary water comes from solid foods. See Table 4.1 "Water Content in Foods" for the range of water contents for selected food items. Beverages includes water, tea, coffee, sodas, and juices.

Table 4.1 Water Content in Foods

Percentage	Food Item
90–99	Nonfat milk, cantaloupe, strawberries, watermelon, lettuce, cabbage, celery, spinach, squash
80–89	Fruit juice, yogurt, apples, grapes, oranges, carrots, broccoli, pears, pineapple
70–79	Bananas, avocados, cottage cheese, ricotta cheese, baked potato, shrimp
60–69	Pasta, legumes, salmon, chicken breast
50–59	Ground beef, hot dogs, steak, feta cheese
40–49	Pizza
30–39	Cheddar cheese, bagels, bread
20–29	Pepperoni, cake, biscuits
10–19	Butter, margarine, raisins
1–9	Walnuts, dry-roasted peanuts, crackers, cereals, pretzels, peanut butter
0	Oils, sugars

1. Institute of Medicine Panel on Dietary Reference Intakes for Electrolytes and Water. Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. The National Academies of Science, Engineering, and Medicine. Washington D.C; 2005: 73-185. http://www.nap.edu/openbook.php?record_id=10925&page=73. Accessed September 22, 2017.

Source: National Nutrient Database for Standard Reference, Release 23. US Department of Agriculture, Agricultural Research Service. http://www.ars.usda.gov/ba/bhnrc/ndl. Updated 2010. Accessed September 2017.

There is some debate over the amount of water required to maintain health because there is no consistent scientific evidence proving that drinking a particular amount of water improves health or reduces the risk of disease. In fact, kidney-stone prevention seems to be the only premise for water-consumption recommendations. You may be surprised to find out that the commonly held belief that people need to drink eight 8-ounce glasses of water per day isn't an official recommendation and isn't based on any scientific evidence! The amount of water/fluids a person should consume every day is actually variable and should be based on the climate a person lives in, as well as their age, physical activity level, and kidney function. No maximum for water intake has been set.

Thirst Mechanism: Why Do We Drink?

Thirst is an osmoregulatory mechanism to increase water input. The thirst mechanism is activated in response to changes in water volume in the blood, but is even more sensitive to changes in blood osmolality. Blood osmolality is primarily driven by the concentration of sodium cations. The urge to drink results from a complex interplay of hormones and neuronal responses that coordinate to increase water input and contribute toward fluid balance and composition in the body. The "thirst center" is contained within the hypothalamus, a portion of the brain that lies just above the brainstem. In older people the thirst mechanism is not as responsive and as we age there is a higher risk for dehydration. Thirst happens in the following sequence of physiological events:

1. Receptor proteins in the kidney, heart, and hypothalamus detect decreased fluid volume or increased sodium concentration in the blood.
2. Hormonal and neural messages are relayed to the brain's thirst center in the hypothalamus.
   The hypothalamus sends neural signals to higher sensory areas in the cortex of the brain, stimulating the conscious thought to drink.
3. Fluids are consumed.
4. Receptors in the mouth and stomach detect mechanical movements involved with fluid ingestion.
5. Neural signals are sent to the brain and the thirst mechanism is shut off.

The physiological control of thirst is the backup mechanism to increase water input. Fluid intake is controlled primarily by conscious eating and drinking habits dependent on social and cultural influences. For example, you might have a habit of drinking a glass of orange juice and eating a bowl of cereal every morning before school or work.

Figure 4.6 Regulating Water Intake

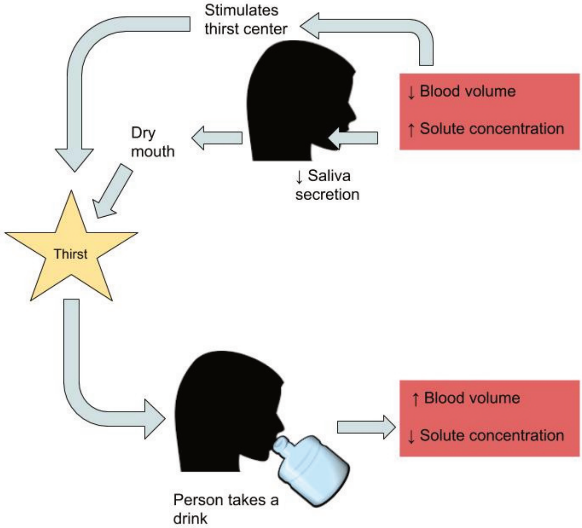


Image by Allison Calabrese / CC BY 4.0

Regulation of Daily Water Output

As stated, daily water output averages 2.5 liters. There are two types of outputs. The first type is insensible water loss, meaning we are unaware of it. The body loses about 400 milliliters of its daily water output through exhalation. Another 500 milliliters is lost through our skin. The second type of output is sensible water loss, meaning we are aware of it. Urine accounts for about 1,500 milliliters of water output, and feces account for roughly 100 milliliters of water output. Regulating urine output is a primary function of the kidneys, and involves communication with the brain and endocrine system.

Figure 4.7 Regulating Water Output

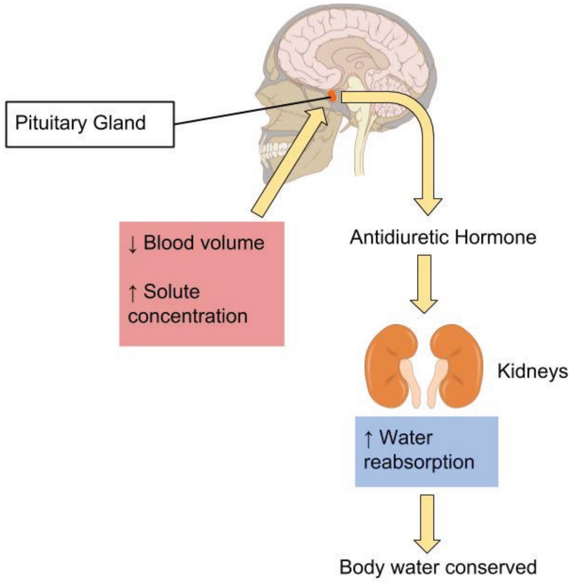


Image by Allison Calabrese / CC BY 4.0

The Kidneys Detect Blood Volume

The kidneys are two bean-shaped organs, each about the size of a fist and located on either side of the spine just below the rib cage. The kidneys filter about 190 liters of blood and produce (on average) 1.5 liters of urine per day. Urine is mostly water, but it also contains electrolytes and waste products, such as urea. The amount of water filtered from the blood and excreted as urine is dependent on the amount of water in, and the electrolyte composition in the blood.

Kidneys have protein sensors that detect blood volume from the pressure, or stretch, in the blood vessels of the kidneys. When blood volume is low, kidney cells detect decreased pressure and secrete the enzyme, renin. Renin travels in the blood and cleaves another protein into the active hormone, angiotensin. Angiotensin targets three different organs (the adrenal glands, the hypothalamus, and the muscle tissue surrounding the arteries) to rapidly restore blood volume and, consequently, pressure.

The Hypothalamus Detects Blood Osmolality

Sodium and fluid balance are intertwined. Osmoreceptors (specialized protein receptors) in the hypothalamus detect sodium concentration in the blood. In response to a high sodium level, the hypothalamus activates the thirst mechanism and concurrently stimulates the release of antidiuretic hormone. Thus, it is not only kidneys that stimulate antidiuretic- hormone release, but also the hypothalamus. This dual control of antidiuretic hormone release allows for the body to respond to both decreased blood volume and increased blood osmolality.

The Adrenal Glands Detect Blood Osmolality

Cells in the adrenal glands sense when sodium levels are low and potassium levels are high in the blood. In response to either stimulus, they release aldosterone. Aldosterone is released in response to angiotensin stimulation and is controlled by blood electrolyte concentrations. In either case, aldosterone communicates the same message, to increase sodium reabsorption and consequently water reabsorption. In exchange, for the reabsorption of sodium and water, potassium is excreted.

Electrolytes Important for Fluid Balance

Cells are about 75 percent water and blood plasma is about 95 percent water. Why then, does the water not flow from blood plasma to cells? The force of water also known as hydrostatic pressure maintains the volumes of water between fluid compartments against the force of all dissolved substances. The concentration is the amount of particles in a set volume of water. (Recall that individual solutes can differ in concentration between the intracellular and extracellular fluids, but the total concentration of all dissolved substances is equal.)

The force driving the water movement through the selectively permeable membrane is the higher solute concentration on the one side. Solutes at different concentrations on either side of a selectively permeable membrane exert a force, called osmotic pressure. The higher concentration of solutes on one side compared to the other of the U-tube exerts osmotic pressure, pulling the water to a higher volume on the side of the U-tube containing more dissolved particles. When the osmotic pressure is equal to the pressure of the water on the selectively permeable membrane, net water movement stops (though it still diffuses back and forth at an equal rate).

One equation exemplifying equal concentrations but different volumes is the following

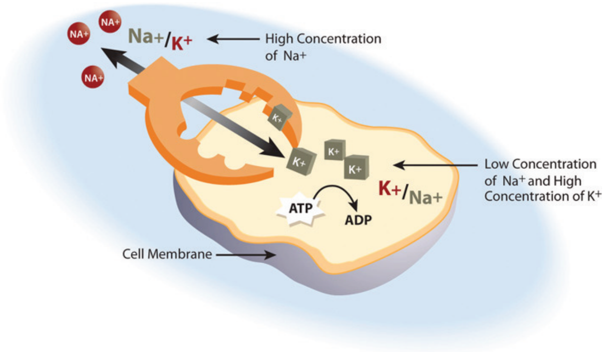
5 grams of glucose in 1 liter = 10 grams of glucose in 2 liters (5g/L = 5g/L)

The differences in concentrations of particular substances provide concentration gradients that cells can use to perform work. A concentration gradient is a form of potential energy, like water above a dam. When water falls through a dam the potential energy is changed to moving energy (kinetic), that in turn is captured by turbines. Similarly, when an electrolyte at higher concentration in the extracellular fluid is transported into a cell, the potential energy is harnessed and used to perform work.

Cells are constantly transporting nutrients in and wastes out. How is the concentration of solutes maintained if they are in a state of flux? This is where electrolytes come into play. The cell (or more specifically the numerous sodium-potassium pumps in its membrane) continuously pumps sodium ions out to establish a chemical gradient. The transport protein, called the glucose symporter, uses the sodium gradient to power glucose movement into the cell. Sodium and glucose both move into the cell. Water passively follows the sodium. To restore balance, the sodium-potassium pump transfers sodium back to the extracellular fluid and water follows. Every cycle of the sodium-potassium pump involves the movement of three sodium ions out of a cell, in exchange for two potassium ions into a cell. To maintain charge neutrality on the outside of cells every sodium cation is followed by a chloride anion. Every cycle of the pump costs one molecule of ATP (adenosine triphosphate). The constant work of the sodium-potassium pump maintains the solute equilibrium and consequently, water distribution between intracellular and extracellular fluids.

The unequal movement of the positively charged sodium and potassium ions makes intracellular fluid more negatively charged than the extracellular fluid. This charge gradient is another source of energy that a cell uses to perform work. You will soon learn that this charge gradient and the sodium-potassium pump are also essential for nerve conduction and muscle contraction. The many functions of the sodium-potassium pump in the body account for approximately a quarter of total resting energy expenditure.

Figure 4.8 The Sodium-Potassium Pump



The sodium-potassium pump is the primary mechanism for cells to maintain water balance between themselves and their surrounding environment.

Sodium

Sodium is vital not only for maintaining fluid balance but also for many other essential functions. In contrast to many minerals, sodium absorption in the small intestine is extremely efficient and in a healthy individual all excess sodium is excreted by the kidneys. In fact, very little sodium is required in the diet (about 200 milligrams) because the kidneys actively reabsorb sodium. Kidney reabsorption of sodium is hormonally controlled, allowing for a relatively constant sodium concentration in the blood.

Other Functions of Sodium in the Body

The second notable function of sodium is in nerve impulse transmission. Nerve impulse transmission results from the transport of sodium cations into a nerve cell, which creates a charge difference (or voltage) between the nerve cell and its extracellular environment. Similar to how a current moves along a wire, a sodium current moves along a nerve cell. Stimulating a muscle contraction also involves the movement of sodium ions as well as other ion movements.

Sodium is essential for nutrient absorption in the small intestine and also for nutrient reabsorption in the kidney. Amino acids, glucose and water must make their way from the small intestine to the blood. To do so, they pass through intestinal cells on their way to the blood. The transport of nutrients through intestinal cells is facilitated by the sodium-potassium pump, which by moving sodium out of the cell, creates a higher sodium concentration outside of the cell (requiring ATP).

Sodium Imbalances

Sweating is a homeostatic mechanism for maintaining body temperature, which influences fluid and electrolyte balance. Sweat is mostly water but also contains some electrolytes, mostly sodium and chloride. Under normal environmental conditions (i.e., not hot, humid days) water and sodium loss through sweat is negligible, but is highly variable among individuals. It is estimated that sixty minutes of high-intensity physical activity, like playing a game of tennis, can produce approximately one liter of sweat; however the amount of sweat produced is highly dependent on environmental conditions. A liter of sweat typically contains between 1 and 2 grams of sodium and therefore exercising for multiple hours can result in a high amount of sodium loss in some people. Additionally, hard labor can produce substantial sodium loss through sweat. In either case, the lost sodium is easily replaced in the next snack or meal.

In athletes hyponatremia, or a low blood-sodium level, is not so much the result of excessive sodium loss in sweat, but rather drinking too much water. The excess water dilutes the sodium concentration in blood. Illnesses causing vomiting, sweating, and diarrhea may also cause hyponatremia. The symptoms of hyponatremia, also called water intoxication (since it is often the root cause) include nausea, muscle cramps, confusion, dizziness, and in severe cases, coma and death. The physiological events that occur in water intoxication are the following:

1. Excessive sodium loss and/or water intake.
2. Sodium levels fall in blood and in the fluid between cells.
3. Water moves to where solutes are more concentrated (i.e. into cells).
4. Cells swell.
5. Symptoms, including nausea, muscle cramps, confusion,

dizziness, and in severe cases, coma and death result.

Hyponatremia in endurance athletes (such as marathon runners) can be avoided by drinking the correct amount of water, which is about 1 cup every twenty minutes during the event. Sports drinks are better at restoring fluid and blood-glucose levels than replacing electrolytes. During an endurance event you would be better off drinking water and eating an energy bar that contains sugars, proteins, and electrolytes. The American College of Sports Medicine suggests if you are exercising for longer than one hour you eat one high carbohydrate (25–40 grams) per hour of exercise along with ample water.[1]

Watch out for the fat content, as sometimes energy bars contain a hefty dose. If you're not exercising over an hour at high intensity, you can skip the sports drinks, but not the water. For those who do not exercise or do so at low to moderate intensity, sports drinks are another source of extra calories, sugar, and salt.

Needs and Dietary Sources of Sodium

The AI level for sodium for healthy adults between the ages of nineteen and fifty at 1,500 milligrams (Table 4.2 "Dietary Reference Intakes for Sodium"). Table salt is approximately 40 percent sodium and 60 percent chloride. As a reference point, only ⅔ teaspoon of salt is needed in the diet to meet the AI for sodium. The AI takes into account the amount of sodium

1. Convertino VA, et al. American College of Sports Medicine Position Stand. Exercise and Fluid Replacement. Medicine and Science in Sports and Exercise. 1996; 28(1) i–vii. http://www.ncbi.nlm.nih.gov/pubmed/9303999. Accessed September 22, 2017.

lost in sweat during recommended physical activity levels and additionally provides for the sufficient intake of other nutrients, such as chloride.The Tolerable Upper Intake Level (UL) for sodium is 2,300 milligrams per day for adults. (Just over 1 teaspoon of salt contains the 2,300 milligrams of sodium recommended). The UL is considered appropriate for healthy individuals but not those with hypertension (high blood pressure). Many scientific studies demonstrate that reducing salt intake prevents hypertension, is helpful in reducing blood pressure after hypertension is diagnosed, and reduces the risk for cardiovascular disease. People over fifty, African Americans, diabetics, and those with chronic kidney disease should consume no more than 1,500 milligrams of sodium per day. All adults, not just those listed, should consume less than 1,500 milligrams of sodium per day to prevent cardiovascular disease because millions of people have risk factors for hypertension and there is scientific evidence supporting that lower-sodium diets are preventive against hypertension.

Table 4.2 Dietary Reference Intakes for Sodium

Age Group	Adequate Intake (mg/day)	Tolerable Upper Intake Level (mg/day)
Infants (0–6 months)	120	ND
Infants (6–12 months)	370	ND
Children (1–3 years)	1,000	1,500
Children (4–8 years)	1,200	1,900
Children (9–13 years)	1,500	2,200
Adolescents (14–18 years)	1,500	2,300
Adults (19–50 years)	1,500	2,300
Adults (50–70 years)	1,300	2,300
Adults (> 70 years)	1,200	2,300
ND = not determined		

Source: Dietary Reference Intakes: Water, Potassium, Sodium, Chloride, and Sulfate. Institute of Medicine. http://www.iom.edu/Reports/2004/Dietary-Reference-Intakes-Water-Potassium-Sodium-Chloride-and-Sulfate.aspx. Updated February 11, 2004. Accessed September 22, 2017.

Food Sources for Sodium

Most sodium in the typical Canadian diet comes from processed and prepared foods. Manufacturers add salt to foods to improve texture and flavor, and also as a preservative. The amount of salt in similar food products varies widely. Some foods, such as meat, poultry, and dairy foods, contain naturally-occurring sodium. For example, one cup of low-fat milk contains 107 milligrams of sodium. Naturally-occurring sodium accounts for less than 12 percent of dietary intake in a typical diet. For the sodium contents of various foods see Table 4.3 "Sodium Contents of Selected Foods".

Figure 4.9 Dietary Sources of Sodium

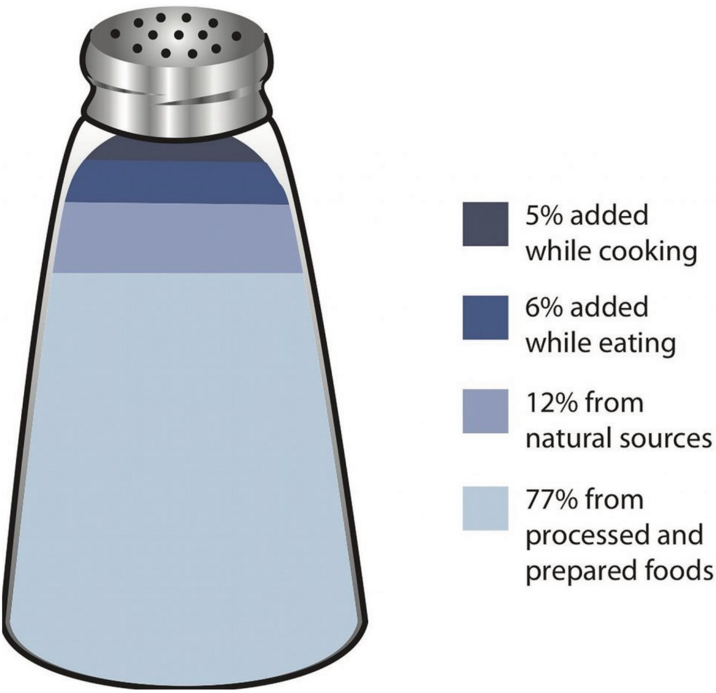


Table 4.3 Sodium Contents of Selected Foods

Food Group	Serving Size	Sodium (mg)
Breads, all types	1 oz.	95–210
Rice Chex cereal	1 ¼ c.	292
Raisin Bran cereal	1 c.	362
Frozen pizza, plain, cheese	4 oz.	450–1200
Frozen vegetables, all types	½ c.	2–160
Salad dressing, regular fat, all types	2 Tbsp.	110–505
Salsa	2 Tbsp.	150–240
Soup (tomato), reconstituted	8 oz.	700–1260
Potato chips	1 oz. (28.4 g)	120–180
Tortilla chips	1 oz. (28.4 g)	105–160
Pork	3 oz.	59
Chicken	(½ breast)	69
Chicken fast food dinner		2243
Chicken noodle soup	1 c.	1107
Dill pickle	1	928
Soy sauce	1 Tbsp.	1029
Canned corn	1 c.	384
Baked beans, canned	1 c.	856
Hot dog	1	639
Burger, fast-food	1	990
Steak	3 oz.	55
Canned tuna	3 oz.	384
Fresh tuna	3 oz.	50
Dry-roasted peanuts	1 c.	986
American cheese	1 oz.	406
Tap water	8 oz.	12

Sodium on the Nutrition Facts Panel

Figure 4.10 Nutrition Label

Sodium levels in milligrams is a required listing on a Nutrition Facts label.

The Nutrition Facts panel displays the amount of sodium (in milligrams) per serving of the food in question (Figure 4.10 "Nutrition Label"). Food additives are often high in sodium, for example, monosodium glutamate (MSG) contains 12 percent sodium. Additionally, baking soda, baking powder, disodium phosphate, sodium alginate, and sodium nitrate or nitrite contain a significant proportion of sodium as well. When you see a food's Nutrition Facts label, you can check the ingredients list to identify the source of the added sodium.

Table 4.4 Food Packaging Claims Regarding Sodium

Claim	Meaning
"Light in Sodium" or "Low in Sodium"	Sodium is reduced by at least 50 percent
"No Salt Added" or "Unsalted"	No salt added during preparation and processing*
"Lightly Salted"	50 percent less sodium than that added to similar food
"Sodium Free" or "Salt Free"	Contains less than 5 mg sodium per serving
"Very Low Salt"	Contains less than 35 mg sodium per serving
"Low Salt"	Contains less than 140 mg sodium per serving
*Must also declare on package "This is not a sodium-free food" if food is not sodium-free	

Source: Food Labeling Guide. US Food and Drug Administration. http://www.fda.gov/Food/GuidanceComplianceRegulatoryInformation/GuidanceDocuments/FoodLabelingNutrition/FoodLabelingGuide/ucm064911.htm. Updated October 2009. Accessed October 2, 2011.

Tools for Change

To decrease your sodium intake, become a salt-savvy shopper by reading the labels and ingredients lists of processed foods and choosing those lower in salt. Even better, stay away from processed foods and control the seasoning of your foods. Eating a diet with less salty foods diminishes salt cravings so you may need to try a lower sodium diet for a week or two before you will be satisfied with the less salty food.

Salt Substitutes

For those with hypertension or those looking for a way to decrease salt use, using a salt substitute for food preparation is one option. However, many salt substitutes still contain sodium, just in lesser amounts than table salt. Also, remember that most salt in the diet is not from table-salt use, but from processed foods. Salt substitutes often replace the sodium with potassium. People with kidney disorders often have problems getting rid of excess potassium in the diet and are advised to avoid salt substitutes containing potassium. People with liver disorders should also avoid salt substitutes containing potassium because their treatment is often accompanied by potassium dysregulation. Table 4.5 "Salt Substitutes" displays the sodium and potassium amounts in some salt substitutes.

Table 4.5 Salt Substitutes

Product	Serving Size	Sodium (mg)	Potassium (mg)
Salt	1 tsp.	2,300	0
Mrs. Dash	1 tsp.	0	40
Spike (Salt-Free)	1 tsp.	0	96
Veg-It	1 tsp.	<65	<65
Accent Low-Sodium Seasoning	1 tsp.	600	0
Salt Sense	1 tsp.	1,560	0
Pleasoning Mini-Mini Salt	1 tsp.	440	0
Morton Lite Salt	1 tsp.	1,100	1,500
Estee Salt-It	1 tsp.	0	3,520
Morton Nature's Seasons	1 tsp.	1,300	2,800
Morton Salt Substitute	1 tsp.	0	2,730
No Salt	1 tsp.	5	2,500
Nu-Salt	1 tsp.	0	529

Source: Health Facts for You: Guidelines for a Low Sodium Diet. University of Wisconsin Hospitals and Clinics Authority. http://www.uhs.wisc.edu/health-topics/nutrition-fitness-and-heart-health/documents/Sodium.pdf. Updated March 2011. Accessed September 22, 2017.

Alternative Seasonings

Table salt may seem an essential ingredient of good food, but there are others that provide alternative taste and zest to your foods. See Table 4.6 "Salt Alternatives" for a list of alternative food seasonings.

Table 4.6 Salt Alternatives

Seasoning	Foods
Allspice	Lean ground meats, stews, tomatoes, peaches, applesauce, cranberry sauce, gravies, lean meat
Almond extract	Puddings, fruits
Caraway seeds	Lean meats, stews, soups, salads, breads, cabbage, asparagus, noodles
Chives	Salads, sauces, soups, lean-meat dishes, vegetables
Cider vinegar	Salads, vegetables, sauces
Cinnamon	Fruits, breads, pie crusts
Curry powder	Lean meats (especially lamb), veal, chicken, fish, tomatoes, tomato soup, mayonnaise,
Dill	fish sauces, soups, tomatoes, cabbages, carrots, cauliflower, green beans, cucumbers, potatoes, salads, macaroni, lamb
Garlic (not garlic salt)	Lean meats, fish, soups, salads, vegetables, tomatoes, potatoes
Ginger	Chicken, fruits
Lemon juice	Lean meats, fish, poultry, salads, vegetables
Mace	Hot breads, apples, fruit salads, carrots, cauliflower, squash, potatoes, veal, lamb
Mustard (dry)	lean ground meats, lean meats, chicken, fish, salads, asparagus, broccoli, Brussels sprouts, cabbage, mayonnaise, sauces
Nutmeg	Fruits, pie crust, lemonade, potatoes, chicken, fish, lean meatloaf, toast, veal, pudding
Onion powder	Lean meats, stews, vegetables, salads, soups
Paprika	Lean meats, fish, soups, salads, sauces, vegetables
Parsley	Lean meats, fish, soups, salads, sauces, vegetables
Peppermint extract	Puddings, fruits
Pimiento	Salads, vegetables, casserole dishes
Rosemary	Chicken, veal, lean meatloaf, lean beef, lean pork, sauces, stuffings, potatoes, peas, lima beans

Sage	Lean meats, stews, biscuits, tomatoes, green beans, fish, lima beans, onions, lean pork
Savory	Salads, lean pork, lean ground meats, soups, green beans, squash, tomatoes, lima beans, peas
Thyme	Lean meats (especially veal and lean pork), sauces, soups, onions, peas, tomatoes, salads
Turmeric	Lean meats, fish, sauces, rice

Source: Shaking the Salt Habit. American Heart Association. http://www.heart.org/HEARTORG/Conditions/HighBloodPressure/PreventionTreatmentofHighBloodPressure/Shaking-the-Salt-Habit_UCM_303241_Article.jsp. Updated June 6, 2012. Accessed September 22, 2017.

Chloride

Chloride is the primary anion in extracellular fluid. In addition to passively following sodium, chloride has its own protein channels that reside in cell membranes. These protein channels are especially abundant in the gastrointestinal tract, pancreas, and lungs.

Chloride's Role in Fluid Balance

Chloride aids in fluid balance mainly because it follows sodium in order to maintain charge neutrality. Chloride channels also play a role in regulating fluid secretion, such as pancreatic juice into the small intestine and the flow of water into mucus. Fluid secretion and mucus are important for many of life's processes. Their importance is exemplified in the signs and symptoms of the genetic disease, cystic fibrosis.

Cystic Fibrosis

Cystic fibrosis (CF) is one of the most prevalent inherited diseases in people of European descent. It is caused by a mutation in a protein that transports chloride ions out of the cell. CF's signs and symptoms include salty skin, poor digestion and absorption (leading to poor growth), sticky mucus accumulation in the lungs (causing increased susceptibility to respiratory infections), liver damage, and infertility.

Other Functions of Chloride

Chloride has several other functions in the body, most importantly in acid-base balance. Blood pH is maintained in a narrow range and the number of positively charged substances is equal to the number of negatively charged substances. Proteins, such as albumin, as well as bicarbonate ions and chloride ions, are negatively charged and aid in maintaining blood pH. Hydrochloric acid (a gastric acid composed of chlorine and hydrogen) aids in digestion and also prevents the growth of unwanted microbes in the stomach. Immune-system cells require chloride, and red blood cells use chloride anions to remove carbon dioxide from the body.

Chloride Imbalances

Low dietary intake of chloride and more often diarrhea can cause low blood levels of chloride. Symptoms typically are similar to those of hyponatremia and include weakness, nausea, and headache. Excess chloride in the blood is rare with no characteristic signs or symptoms.

Needs and Dietary Sources of Chloride

Most chloride in the diet comes from salt. (Salt is 60 percent chloride.) A teaspoon of salt equals 5,600 milligrams, with each teaspoon of salt containing 3,400 milligrams of chloride and 2,200 milligrams of sodium. The chloride AI for adults, set by the IOM, is 2,300 milligrams. Therefore just ⅔ teaspoon of table salt per day is sufficient for chloride as well as sodium. The AIs for other age groups are listed in Table 4.7 "Adequate Intakes for Chloride".

Table 4.7 Adequate Intakes for Chloride

Age Group	mg/day
Infants (0–6 months)	180
Infants (6–12 months)	570
Children (1–3 years)	1,500
Children (4–8 years)	1,900
Children (9–13 years)	2,300
Adolescents (14–18 years)	2,300
Adults (19–50 years)	2,300
Adults (51–70 years)	2,000
Adults (> 70 years)	1,800

Source: Dietary Reference Intakes: Water, Potassium, Sodium, Chloride, and Sulfate. Institute of Medicine. http://www.iom.edu/Reports/2004/Dietary-Reference-Intakes-Water-Potassium-Sodium-Chloride-and-Sulfate.aspx. Updated February 11, 2004. Accessed September 22, 2017.

Other Dietary Sources of Chloride

Chloride has dietary sources other than table salt, namely as another form of salt—potassium chloride. Dietary sources of chloride are: all foods containing sodium chloride, as well as tomatoes, lettuce, olives, celery, rye, whole-grain foods, and seafood. Although many salt substitutes are sodium-free, they may still contain chloride.

Bioavailability

Bioavailability refers to the amount of a particular nutrient in foods that is actually absorbed in the intestine and not eliminated in the urine or feces. Simply put, the bioavailability of chloride is the amount that is on hand to perform its biological functions. In the small intestine, the elements of sodium chloride split into sodium cations and chloride anions. Chloride follows the sodium ion into intestinal cells passively, making chloride absorption quite efficient. When chloride exists as a potassium salt, it is also well absorbed. Other mineral salts, such as magnesium chloride, are not absorbed as well, but bioavailability still remains high.

Potassium

Potassium is the most abundant positively charged ion inside of cells. Ninety percent of potassium exists in intracellular fluid, with about 10 percent in extracellular fluid, and only 1 percent in blood plasma. As with sodium, potassium levels in the blood are strictly regulated. The hormone aldosterone is what primarily controls potassium levels, but other hormones (such as insulin) also play a role. When potassium levels in the blood increase, the adrenal glands release aldosterone. The aldosterone acts on the collecting ducts of kidneys, where it stimulates an increase in the number of sodium-potassium pumps. Sodium is then reabsorbed and more potassium is excreted. Because potassium is required for maintaining sodium levels, and hence fluid balance, about 200 milligrams of potassium are lost from the body every day.

Other Functions of Potassium in the Body

Nerve impulse involves not only sodium, but also potassium. A nerve impulse moves along a nerve via the movement of sodium ions into the cell. To end the impulse, potassium ions rush out of the nerve cell, thereby decreasing the positive charge inside the nerve cell. This diminishes the stimulus. To restore the original concentrations of ions between the intracellular and extracellular fluid, the sodium-potassium pump transfers sodium ions out in exchange for potassium ions in. On completion of the restored ion concentrations, a nerve cell is now ready to receive the next impulse. Similarly, in muscle cells potassium is involved in restoring the normal membrane potential and ending the muscle contraction. Potassium also is involved in protein synthesis, energy metabolism, and platelet function, and acts as a buffer in blood, playing a role in acid-base balance.

Imbalances of Potassium

Insufficient potassium levels in the body (hypokalemia) can be caused by a low dietary intake of potassium or by high sodium intakes, but more commonly it results from medications that increase water excretion, mainly diuretics. The signs and symptoms of hypokalemia are related to the functions of potassium in nerve cells and consequently skeletal and smooth-muscle contraction. The signs and symptoms include muscle weakness and cramps, respiratory distress, and constipation. Severe potassium depletion can cause the heart to have abnormal contractions and can even be fatal. High levels of potassium in the blood, or hyperkalemia, also affects the heart. It is a silent condition as it often displays no signs or symptoms. Extremely high levels of potassium in the blood disrupt the electrical impulses that stimulate the heart and can cause the heart to stop. Hyperkalemia is usually the result of kidney dysfunction.

Needs and Dietary Sources of Potassium

The AI for potassium is based on the levels associated with a decrease in blood pressure, a reduction in salt sensitivity, and a minimal risk of kidney stones. For adult male and females above the age of nineteen, the adequate intake for potassium is 4,700 grams per day. The AIs for other age groups are listed in Table 4.8 "Adequate Intakes for Potassium".

Table 4.8 Adequate Intakes for Potassium

Age Group	mg/day
Infants (0–6 months)	400
Infants (6–12 months)	700
Children (1–3 years)	3,000
Children (4–8 years)	3,800
Children (9–13 years)	4,500
Adolescents (14–18 years)	4,700
Adults (> 19 years)	4,700

Dietary Reference Intakes: Water, Potassium, Sodium, Chloride, and Sulfate. Institute of Medicine. http://www.iom.edu/Reports/2004/Dietary-Reference-Intakes-Water-Potassium-Sodium-Chloride-and-Sulfate.aspx. Updated February 11, 2004. Accessed September 22, 2017.

Food Sources for Potassium

Fruits and vegetables that contain high amounts of potassium are spinach, lettuce, broccoli, peas, tomatoes, potatoes, bananas, apples and apricots. Whole grains and seeds, certain fish (such as salmon, cod, and flounder), and meats are also high in potassium. The Dietary Approaches to Stop Hypertension (DASH diet) emphasizes potassium-rich foods and will be discussed in greater detail in the next section.

Bioavailability

Greater than 90 percent of dietary potassium is absorbed in the small intestine. Although highly bioavailable, potassium is a very soluble mineral and easily lost during cooking and processing of foods. Fresh and frozen foods are better sources of potassium than canned.

Consequences of Deficiency or Excess

As with all nutrients, having too much or too little water has health consequences. Excessive water intake can dilute the levels of critical electrolytes in the blood. Water intoxication is rare, however when it does happen, it can be deadly. On the other hand, having too little water in the body is common. In fact, diarrhea-induced dehydration is the number-one cause of early-childhood death worldwide. In this section we will discuss subtle changes in electrolytes that compromise health on a chronic basis.

High-Hydration Status: Water Intoxication/ Hyponatremia

Water intoxication mainly affects athletes who overhydrate. Water intoxication is extremely rare, primarily because healthy kidneys are capable of excreting up to one liter of excess water per hour. Overhydration was unfortunately demonstrated in 2007 by Jennifer Strange, who drank six liters of water in three hours while competing in a "Hold Your Wee for a Wii" radio contest. Afterward she complained of a headache, vomited, and died.

Low-Hydration Status: Dehydration

Dehydration refers to water loss from the body without adequate replacement. It can result from either water loss or electrolyte imbalance, or, most commonly, both. Dehydration can be caused by prolonged physical activity without adequate water intake, heat exposure, excessive weight loss, vomiting, diarrhea, blood loss, infectious diseases, malnutrition, electrolyte imbalances, and very high glucose levels. Physiologically, dehydration decreases blood volume. The water in cells moves into the blood to compensate for the low blood-volume, and cells shrink. Signs and symptoms of dehydration include thirst, dizziness, fainting, headaches, low blood-pressure, fatigue, low to no urine output, and, in extreme cases, loss of consciousness and death. Signs and symptoms are usually noticeable after about 2 percent of total body water is lost.

Chronic dehydration is linked to higher incidences of some diseases. There is strong evidence that low-hydration status increases the risk for kidney stones and exercise-induced asthma. There is also some scientific evidence that chronic dehydration increases the risk for kidney disease, heart disease, and the development of hyperglycemia in people with diabetes. Older people often suffer from chronic dehydration as their thirst mechanism is no longer as sensitive as it used to be.

Heat Stroke

Heat stroke is a life-threatening condition that occurs when the body temperature is greater than 105.1°F (40.6°C). It is the result of the body being unable to sufficiently cool itself by thermoregulatory mechanisms. Dehydration is a primary cause of heat stroke as there are not enough fluids in the body to maintain adequate sweat production, and cooling of the body is impaired. Signs and symptoms are dry skin (absence of sweating), dizziness, trouble breathing, rapid pulse, confusion, agitation, seizures, coma, and possibly death. Dehydration may be preceded by heat exhaustion, which is characterized by heavy sweating, rapid breathing, and fast pulse. The elderly, infants, and athletes are the most at risk for heat stroke.

Hypertension

Blood pressure is the force of moving blood against arterial walls. It is reported as the systolic pressure over the diastolic pressure, which is the greatest and least pressure on an artery that occurs with each heartbeat. The force of blood against an artery is measured with a device called a sphygmomanometer. The results are recorded in millimeters of mercury, or mmHg. A desirable blood pressure ranges between 90/60 and 120/80 mmHg. Hypertension is the scientific term for high blood pressure and defined as a sustained blood pressure of 140/90 mmHg or greater. Hypertension is a risk factor for cardiovascular disease, and reducing blood pressure has been found to decrease the risk of dying from a heart attack or stroke.

Figure 4.11 Measuring Blood Pressure

Testing a GIs blood pressure at Guantanamo by Charlie Helmholt / Public Domain

There has been much debate about the role sodium plays in hypertension. In the latter 1980s and early 1990s the largest epidemiological study evaluating the relationship of dietary sodium intake with blood pressure, called INTERSALT, was completed and then went through further analyses.[1,2]

1. Intersalt Cooperative Research Group. Intersalt: An International Study of Electrolyte Excretion and Blood Pressure. Results for 24 Hour Urinary Sodium and Potassium Excretion. BMJ. 1988; 297(6644), 319–28. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1834069/. Accessed September 20, 2017.
2. Elliott P, Stamler J, et al. Intersalt Revisited: Further Analyses of 24 Hour Sodium Excretion and Blood Pressure within and across Populations. BMJ. 1996; 312(7041), 1249–53. http://www.ncbi.nlm.nih.gov/pubmed/8634612. Accessed September 22, 2017.

More than ten thousand men and women from thirty-two countries participated in the study. The study concluded that a higher sodium intake is linked to an increase in blood pressure. A more recent study, involving over twelve thousand US citizens, concluded that a higher sodium-to-potassium intake is linked to higher cardiovascular mortality and all-causes mortality.[3]

The DASH-Sodium trial was a clinical trial which evaluated the effects of a specified eating plan with or without reduced sodium intake. The DASH diet is an eating plan that is low in saturated fat, cholesterol, and total fat. Fruits, vegetables, low-fat dairy foods, whole-grain foods, fish, poultry, and nuts are emphasized while red meats, sweets, and sugar-containing beverages are mostly avoided. In this study, people on the low-sodium (1500 milligrams per day) DASH diet had mean systolic blood pressures that were 7.1 mmHg lower than people without hypertension not on the DASH diet. The effect on blood pressure was greatest in participants with hypertension at the beginning of the study who followed the DASH diet. Their systolic blood pressures were, on average, 11.5 mmHg lower than participants with hypertension on the control diet.[4]

Following the DASH diet not only reduces sodium intake, but also increases potassium, calcium, and magnesium intake. All of these electrolytes have a positive effect on blood pressure,

3. Yang Q, Liu T, et al. Sodium and Potassium Intake and Mortality among US Adults: Prospective Data from the Third National Health and Nutrition Examination Survey. Arch Intern Med. 2011; 171(13), 1183–91. https://www.ncbi.nlm.nih.gov/pubmed/21747015. Accessed September 22, 2017.
4. Sacks, FM, Svetkey LP, et al. Effects on Blood Pressure of Reduced Dietary Sodium and the Dietary Approaches to Stop Hypertension (DASH) Diet. N Engl J Med. 2001; 344(1), 3–10. http://www.ncbi.nlm.nih.gov/pubmed/11136953. Accessed September 22, 2017.

although the mechanisms by which they reduce blood pressure are largely unknown.

Salt Sensitivity

High dietary intake of sodium is one risk factor for hypertension and contributes to high blood pressure in many people. However, studies have shown that not everyone's blood pressure is affected by lowering sodium intake. About 10 to 20 percent of the population is considered to be salt-sensitive, meaning their blood pressure is affected by salt intake. Genetics, race, gender, weight, and physical activity level are determinants of salt sensitivity. African Americans, women, and overweight individuals are more salt-sensitive than others. Also, if hypertension runs in a person's family, that person is more likely to be salt-sensitive. Because reducing dietary salt intake will not work for everyone with hypertension or a risk for developing the condition, there are many opponents of reducing dietary salt intake at the national level. Among such opponents is the Salt Institute, a nonprofit trade organization that states, "No evidence demonstrates that current salt intake levels lead to worse health outcomes such as more heart attacks or higher cardiovascular mortality."[5]

5. Salt and Health. The Salt Institute. http://www.saltinstitute.org/Issues-in-focus/Food-salt-health. Updated 2011. Accessed October 2, 2011.

Water Concerns

At this point you have learned how critical water is to support human life, how it is distributed and moved in the body, how fluid balance and composition is maintained, and the recommended amount of fluids a person should consume daily. In Canada you have a choice of thousands of different beverages. Which should you choose to receive the most health benefit and achieve your recommended fluid intake?

Reading the Label

Most beverages marketed in Canada have a Nutrition Facts panel and ingredients list, but some, such as coffee (for home consumption), beer, and wine, do not. As with foods, beverages that are nutrient-dense are the better choices, with the exception of plain water, which contains few to no other nutrients. Beverages do not make you full; they satiate your thirst. Therefore, the fewer calories in a beverage the better it is for avoiding weight gain. For an estimate of kilocalories in various beverages see Table 4.9 "Calories in Various Beverages".

Table 4.9 Calories in Various Beverages

Beverage	Serving Size (oz)	Kilocalories
Soda	12.0	124–189
Bottled sweet tea	12.0	129–143
Orange juice	12.0	157–168
Tomato/vegetable juice	12.0	80
Whole milk	12.0	220
Nonfat milk	12.0	125
Soy milk	12.0	147–191
Coffee, black	12.0	0–4
Coffee, with cream	12.0	39–43
Caffe latte, whole milk	12.0	200
Sports drink	12.0	94
Beer	12.0	153
White wine	5.0	122

Scientific studies have demonstrated that while all beverages are capable of satisfying thirst they do not make you feel full, or satiated. This means that drinking a calorie-containing beverage with a meal only provides more calories, as it won't be offset by eating less food. Soft drinks and fruit drinks, increase energy intake, are not satiating, and that there is little if any reduction in other foods to compensate for the excess calories. All of these factors contribute to increased energy intake and obesity.

Table 4.10 Recommendations

Beverage	Servings per day*
Water	≥ 4 (women), ≥ 6 (men)
Unsweetened coffee and tea	≤ 8 for tea, ≤ 4 for coffee
Nonfat and low-fat milk; fortified soy drinks	≤ 2
Diet beverages with sugar substitutes	≤ 4
100 percent fruit juices, whole milk, sports drinks	≤ 1
Calorie-rich beverages without nutrients	≤ 1, less if trying to lose weight
*One serving is eight ounces.	

Source: Beverage Panel Recommendations and Analysis. University of North Carolina, Chapel Hill. US Beverage Guidance Council. http://www.cpc.unc.edu/projects/nutrans/policy/beverage/us-beverage-panel. Accessed November 6, 2012.

Sources of Drinking Water

Women should drink at least 32 ounces and men drink at least 48 ounces of water daily. Producing water safe for drinking involves some or all of the following processes: screening out large objects, removing excess calcium carbonate from hard water sources, flocculation, which adds a precipitating agent to remove solid particles, clarification, sedimentation, filtration, and disinfection. These processes aim to remove unhealthy substances and produce high-quality, colorless, odorless, good-tasting water.

Most drinking water is disinfected by the process of chlorination, which involves adding chlorine compounds to the water. Chlorination is cheap and effective at killing bacteria. However, it is less effective at removing protozoa, such as Giardia lamblia. Chlorine-resistant protozoa and viruses are instead removed by extensive filtration methods. In the decades immediately following the implementation of water chlorination and disinfection methods in this country, waterborne illnesses, such as cholera and typhoid fever, essentially disappeared. In fact, the treatment of drinking water is touted as one of the top public-health achievements of the last century.

Popular Beverage Choices

Caffeine

Caffeine is a chemical called xanthine found in the seeds, leaves, and fruit of many plants, where it acts as a natural pesticide. It is the most widely consumed psychoactive substance and is such an important part of many people's lives that they might not even think of it as a drug. Up to 90 percent of adults around the world use it on a daily basis. Moderate use of caffeine is "generally recognized as safe." It is considered a legal psychoactive drug and, for the most part, is completely unregulated.

Typical Doses and Dietary Sources

What is a "moderate intake" of caffeine? Caffeine intakes are described in the following manner:

- Low–moderate intake. 130–300 milligrams per day
- Moderate intake. 200–300 milligrams per day
- High intake. 400 or more milligrams per day

The bitter taste of caffeine is palatable for many and coffee is the most readily available source of it, accounting for 70 percent of daily caffeine consumption. The second readily available source of caffeine is soft drinks, delivering 16 percent of daily caffeine. (In this case, the bitter caffeine taste is usually masked by a large amount of added sugar.) Tea is the third common source of caffeine, at 12 percent.

Just how much caffeine is there in a cup of coffee? It varies. The caffeine content of an average cup of coffee can range from 102 to 200 milligrams, and the range for tea is 40 to 120 milligrams. Table 4.11 "Caffeine Content in Various Beverages and Foods" provides useful information on the levels of caffeine found in common beverages. When estimating your total caffeine consumption remember it's not only in beverages, but also some foods and medicine.

Table 4.11 Caffeine Content in Various Beverages and Foods

Beverage/Food	Milligrams
Starbucks Grande Coffee (16 oz.)	380
Plain brewed coffee (8 oz.)	102–200
Espresso (1 oz.)	30–90
Plain, decaffeinated coffee (8 oz.)	3–12
Tea, brewed (8 oz.)	40–120
Green tea (8 oz.)	25–40
Coca-Cola Classic (12 oz.)	35
Dr. Pepper (12 oz.)	44
Jolt Cola (12 oz.)	72
Mountain Dew (12 oz.)	54
Mountain Dew, MDX (12 oz.)	71
Pepsi-Cola (12 oz.)	38
Red Bull (8.5 oz.)	80
Full Throttle (16 oz.)	144
Monster Energy (16 oz.)	160
Spike Shooter (8.4 oz.)	300

Source: Caffeine.MedicineNet.com. http://www.medicinenet.com/caffeine/article.htm. Accessed October 2, 2011.

Health Benefits

The most renowned effects of caffeine on the body are increased alertness and delay of fatigue and sleep. How does caffeine stimulate the brain? Caffeine is chemically similar to a chemical in our brains (adenosine). Caffeine interacts with adenosine's specific protein receptor. It blocks the actions of the adenosine, and affects the levels of signaling molecules in the brain, leading to an increase in energy metabolism. At the molecular level, caffeine stimulates the brain, increasing alertness and causing a delay of fatigue and sleep. At high doses caffeine stimulates the motor cortex of the brain and interferes with the sleep-wake cycle, causing side effects such as shakiness, anxiety, and insomnia. People's sensitivity to the adverse effects of caffeine varies and some people develop side effects at much lower doses. The many effects caffeine has on the brain do not diminish with habitual drinking of caffeinated beverages.

Tools for Change

Consuming caffeine in the evening and in the middle of the night will help keep you awake to study for an exam, but it will not enhance your performance on the next day's test if you do not get enough sleep. Drink caffeinated beverages in moderation at any time of the day or evening to increase alertness (if you are not sensitive to caffeine's adverse effects), but get the recommended amount of sleep.

It is important to note that caffeine has some effects on health that are either promoted or masked by the other beneficial chemicals found in coffee and tea. This means that when assessing the benefits and consequences of your caffeine intake, you must take into account how much caffeine in your diet comes from coffee and tea versus how much you obtain from soft drinks.

Photo by Jeremy Ricketts on unsplash.com / CC0

There is scientific evidence supporting that higher consumption of caffeine, mostly in the form of coffee, substantially reduces the risk for developing Type 2 diabetes and Parkinson's disease. There is a lesser amount of evidence suggesting increased coffee consumption lowers the risk of heart attacks in both men and women, and strokes in women. In smaller population studies, decaffeinated coffee sometimes performs as well as caffeinated coffee, bringing up the hypothesis that there are beneficial chemicals in coffee other than caffeine that play larger roles in the health benefits of coffee. A review of fifteen epidemiological studies in The Journal of the American Medical Association proposes that habitual coffee consumption reduces the risk of Type 2 diabetes.[1] The risk reduction was 35 percent for those who

1. van Dam R M, Hu FB. Coffee Consumption and Risk of Type 2 Diabetes: A Systematic Review. JAMA. 2005; 294(1), 97–104.

consumed greater than 6–7 cups of coffee per day and was 28 percent for those who consumed 4–5 cups daily. These groups were compared with people who consumed less than 2 cups of coffee per day.

Parkinson's disease is an illness of the central nervous system causing many disorders of movement. Research scientists in Hawaiʻi found an inverse relationship between caffeine intake and the incidence of Parkinson's disease. Men who did not consume coffee had a five times more likely chance of Parkinson's disease than men who consumed more than 3 cups of coffee daily.[2]

In this study other caffeine sources, such as soft drinks and tea, were also associated with a reduced risk of Parkinson's disease. A review of several studies, published in the Journal of Alzheimer's Disease, has reaffirmed that caffeine intake may reduce the risk of Parkinson's disease in both men and women.[3] This review also took into consideration caffeine obtained from dietary sources other than caffeine, though the data on these is not as extensive or as strong as for coffee. There is also some scientific evidence that drinking coffee is linked to a much lower risk for dementia and Alzheimer's disease.[4]

http://jamanetwork.com/journals/jama/article-abstract/201177. Accessed September 22, 2017.

2. Ross GW, et al. Association of Coffee and Caffeine Intake with the Risk of Parkinson's Disease. JAMA. 2000; 283(20), 2674–79. http://jamanetwork.com/journals/jama/fullarticle/192731. Accessed September 22, 2017.
3. Costa J, et al. Caffeine Exposure and the Risk of Parkinson's Disease: A Systematic Review and Meta-Analysis of Observational Studies. J Alzheimers Dis. 2010; 20, S221–38. http://www.ncbi.nlm.nih.gov/pubmed/20182023. Accessed September 22, 2017.
4. Patil H, Lavie CJ, O'Keefe JH . Cuppa Joe: Friend or Foe? Effects of Chronic Coffee Consumption on Cardiovascular and Brain Health. Missouri Medical. 2011; 108(6), 431–8. http://www.ncbi.nlm.nih.gov/pubmed/22338737. Accessed September 22, 2017.

Health Consequences

The acute adverse health effects of caffeine ingestion are anxiety, shakiness, and sleep deprivation. On a more chronic basis, some scientific reports suggest that higher caffeine intake is linked to negative effects on heart health and increased cardiovascular disease; although at this point most data suggests caffeine does not significantly increase either. A comprehensive review published in the American Journal of Clinical Nutrition reports that caffeine induces a modest increase in blood pressure lasting less than three hours in people with hypertension, but there is no evidence that habitual coffee consumption increases blood pressure long-term or increases the risk for cardiovascular disease.[5]

There is no good evidence that chronic caffeine exposure increases blood pressure chronically in people without hypertension.

Some have hypothesized that caffeine elevates calcium excretion and therefore could potentially harm bones. The scientific consensus at this time is that caffeine minimally affects calcium levels and intake is not associated with any increased risk for osteoporosis or the incidence of fractures in most women. Although the effect of caffeine on calcium excretion is small, postmenopausal women with risk factors for osteoporosis may want to make sure their dietary caffeine intake is low or moderate and not excessive.

5. Mesas AE, et al. The Effect of Coffee on Blood Pressure and Cardiovascular Disease in Hypertensive Individuals: A Systematic Review and Meta-Analysis. Am J Clin Nutr. 2011; 94(4), 1113–26. http://www.ncbi.nlm.nih.gov/pubmed/21880846. Accessed September 22, 2017.

The Caffeine Myth

A diuretic refers to any substance that elevates the normal urine output above that of drinking water. Caffeinated beverages are commonly believed to be dehydrating due to their diuretic effect, but results from scientific studies do not support that caffeinated beverages increase urine output more so than water. This does not mean that consuming caffeinated beverages does not affect urine output, but rather that it does not increase urine output more than water does. Thus, caffeinated beverages are considered a source of hydration similar to water.

Sports Drinks

Scientific studies under certain circumstances show that consuming sports drinks (instead of plain water) during high-intensity exercise lasting longer than one hour significantly enhances endurance, and some evidence indicates it additionally enhances performance. There is no consistent evidence that drinking sports drinks instead of plain water enhances endurance or performance in individuals exercising less than one hour and at low to moderate intensities. A well-concocted sports drink contains sugar, water, and sodium in the correct proportions so that hydration is optimized. The sugar is helpful in maintaining blood-glucose levels needed to fuel muscles, the water keeps an athlete hydrated, and the sodium enhances fluid absorption and replaces some of that lost in sweat. The American College of Sports Medicine states that the goal of drinking fluids during exercise is to prevent dehydration, which compromises performance and endurance.

The primary source of water loss during intense physical activity is sweat. Perspiration rates are variable and dependent on many factors including body composition, humidity, temperature, and type of exercise. The hydration goal for obtaining optimal endurance and performance is to replace what is lost, not to over-hydrate. A person's sweating rate can be approximated by measuring weight before and after exercise—the difference in weight will be the amount of water weight you lost.

The primary electrolyte lost in sweat is sodium. One liter of sweat can contain between 1,000–2,000 milligrams of sodium. Potassium, magnesium, and calcium are also lost, but in much lower amounts. If you are exercising at high intensity for greater than ninety minutes, it is important to replace sodium as well as water. This can be partly accomplished by consuming a sports drink. The highest content of sodium in commercial sports drinks is approximately 450 milligrams per liter and thus will not replace all lost sodium unless a person drinks several liters. This is NOT recommended, as water intoxication not only compromises performance, but may also be deadly. The sodium in sports drinks enhances fluid absorption so that rehydration is more efficiently accomplished. If you are not exercising for more than ninety minutes at a high intensity, dietary intake of sodium and other electrolytes should be sufficient for replacing lost electrolytes.

Who Needs Sports Drinks?

Children and adult athletes exercising for more than one hour at high-intensity (tennis, rowing, rugby, soccer, etc.) may benefit endurance-wise and possibly performance-wise from consuming a sports drink rather than water. However, consuming sports drinks provides no benefit over water to endurance, performance, or exercise recovery for those exercising less than an hour. In fact, as with all other sugary drinks containing few to no nutrients, they are only another source of calories. Drinking sports drinks when you are doing no exercise at all is not recommended.

Sports Drink Alternatives

Instead of a sports drink, you can replenish lost fluids and obtain energy and electrolytes during exercise by drinking plain water and eating a sports bar or snack that contains carbohydrates, protein, and electrolytes. Post-exercise, low-fat milk has been scientifically shown to be just as effective as a sports drink as a rehydration beverage and it is more nutrient-dense, containing carbohydrates, protein, and electrolytes, in addition to other vitamins.

The Bottom Line

Sports drinks consumed in excess by athletes or used by non-athletes simply are another source of added sugars, and thus extra calories, in the diet and provide no performance, exercise recovery or health benefit.

CHAPTER 5. CARBOHYDRATES

Introduction

Two Breadfruit by Michael Coghlan / CC BY-SA 2.0

Learning Objectives

By the end of this chapter, you will be able to:

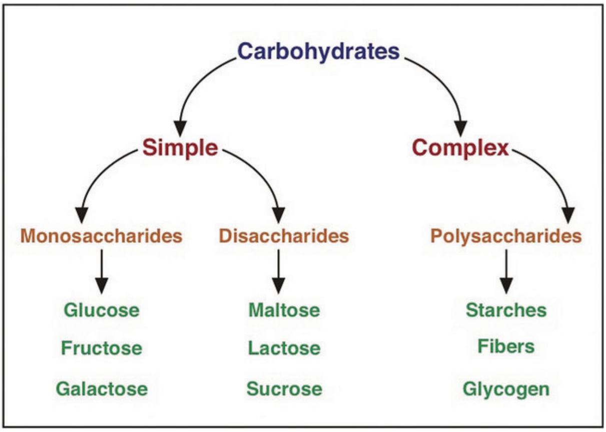
- Describe the different types of simple and complex carbohydrates
- Describe the process of carbohydrate digestion and absorption
- Describe the functions of carbohydrates in the

body
- Describe the body’s carbohydrate needs and how personal choices can lead to health benefits or consequences

Throughout history, carbohydrates have and continue to be a major source of people’s diets worldwide. Carbohydrates are the perfect nutrient to meet your body’s nutritional needs. They nourish your brain and nervous system, provide energy to all of your cells when within proper caloric limits, and help keep your body fit and lean. Specifically, digestible carbohydrates provide bulk in foods, vitamins, and minerals, while indigestible carbohydrates provide a good amount of fiber with a host of other health benefits.

Plants synthesize the fast-releasing carbohydrate, glucose, from carbon dioxide in the air and water, and by harnessing the sun’s energy. Recall that plants convert the energy in sunlight to chemical energy in the molecule, glucose. Plants use glucose to make other larger, more slow-releasing carbohydrates. When we eat plants we harvest the energy of glucose to support life’s processes.

Figure 5.1 Carbohydrate Classification Scheme



Carbohydrates are broken down into the subgroups simple and complex carbohydrates. These subgroups are further categorized into mono-, di-, and polysaccharides.

Carbohydrates are a group of organic compounds containing a ratio of one carbon atom to two hydrogen atoms to one oxygen atom. Basically, they are hydrated carbons. The word “carbo” means carbon and “hydrate” means water. Glucose, the most abundant carbohydrate in the human body, has six carbon atoms, twelve hydrogen atoms, and six oxygen atoms. The chemical formula for glucose is written as $C_6H_{12}O_6$. Synonymous with the term carbohydrate is the Greek word “saccharide,” which means sugar. The simplest unit of a carbohydrate is a monosaccharide. Carbohydrates are broadly classified into two subgroups, simple (“fast-releasing”) and complex (“slow-releasing”). Simple carbohydrates are further grouped into the monosaccharides and disaccharides. Complex carbohydrates are long chains of monosaccharides.

Simple/Fast-Releasing Carbohydrates

Simple carbohydrates are also known more simply as “sugars” and are grouped as either monosaccharides or disaccharides. Monosaccharides include glucose, fructose, and galactose, and the disaccharides include lactose, maltose, and sucrose.

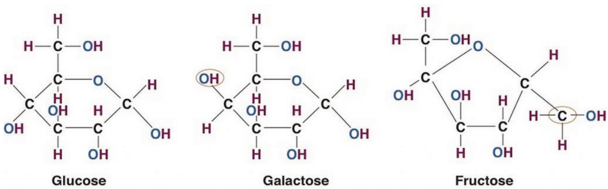
Simple carbohydrates stimulate the sweetness taste sensation, which is the most sensitive of all taste sensations. Even extremely low concentrations of sugars in foods will stimulate the sweetness taste sensation. Sweetness varies between the different carbohydrate types—some are much sweeter than others. Fructose is the top naturally-occurring sugar in sweetness value.

Monosaccharides

For all organisms from bacteria to plants to animals, glucose is the preferred fuel source. The brain is completely dependent on glucose as its energy source (except during extreme starvation conditions). The monosaccharide galactose differs from glucose only in that a hydroxyl (−OH) group faces in a different direction on the number four carbon (Figure 5.2 "Structures of the Three Most Common Monosaccharides: Glucose, Galactose, and Fructose"). This small structural alteration causes galactose to be less stable than glucose. As a result, the liver rapidly converts it to glucose. Most absorbed galactose is utilized for energy production in cells after its conversion to glucose. (Galactose is one of two simple sugars that are bound together to make up the sugar found in milk. It is later freed during the digestion process.)

Fructose also has the same chemical formula as glucose but differs in its chemical structure, as the ring structure contains only five carbons and not six. Fructose, in contrast to glucose, is not an energy source for other cells in the body. Mostly found in fruits, honey, and sugarcane, fructose is one of the most common monosaccharides in nature. It is also found in soft drinks, cereals, and other products sweetened with high fructose corn syrup.

Figure 5.2 Structures of the Three Most Common Monosaccharides: Glucose, Galactose, and Fructose



Circles indicate the structural differences between the three.

Pentoses are less common monosaccharides which have only five carbons and not six. The pentoses are abundant in the nucleic acids RNA and DNA, and also as components of fiber.

Lastly, there are the sugar alcohols, which are industrially synthesized derivatives of monosaccharides. Some examples of sugar alcohols are sorbitol, xylitol, and glycerol. (Xylitol is similar in sweetness as table sugar). Sugar alcohols are often used in place of table sugar to sweeten foods as they are incompletely digested and absorbed, and therefore less caloric. The bacteria in your mouth opposes them, hence sugar alcohols do not cause tooth decay. Interestingly, the sensation of "coolness" that occurs when chewing gum that contains sugar alcohols comes from them dissolving in the mouth, a chemical reaction that requires heat from the inside of the mouth.

Disaccharides

Disaccharides are composed of pairs of two monosaccharides linked together. Disaccharides include sucrose, lactose, and maltose. All of the disaccharides contain at least one glucose molecule.

Sucrose, which contains both glucose and fructose molecules, is otherwise known as table sugar. Sucrose is also found in many fruits and vegetables, and at high concentrations in sugar beets and sugarcane, which are used to make table sugar. Lactose, which is commonly known as milk sugar, is composed of one glucose unit and one galactose unit. Lactose is prevalent in dairy products such as milk, yogurt, and cheese. Maltose consists of two glucose molecules bonded together. It is a common breakdown product of plant starches and is rarely found in foods as a disaccharide.

Figure 5.3 The Most Common Disaccharides

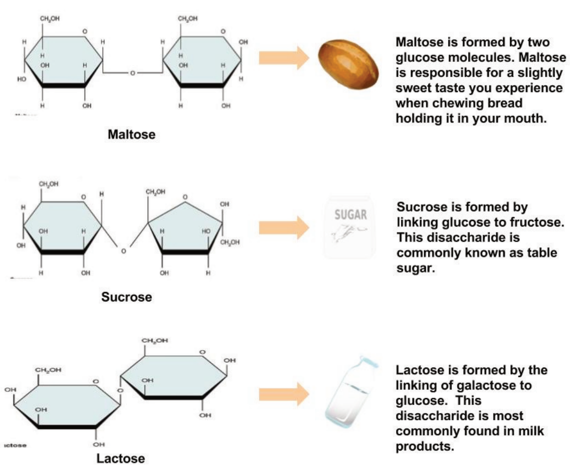


Image by Allison Calabrese / CC BY 4.0

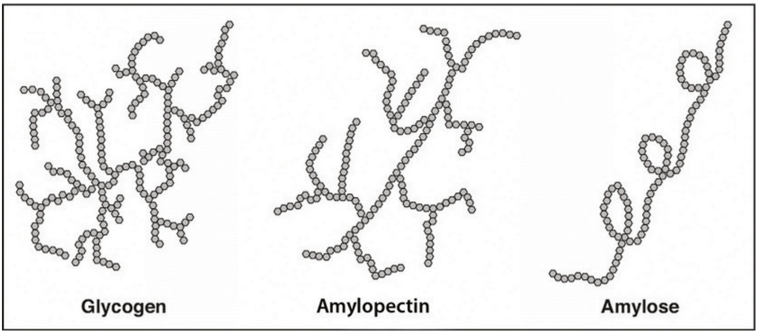
Complex/Slow-Releasing Carbohydrates

Complex carbohydrates are polysaccharides, long chains of monosaccharides that may be branched or not branched. There are two main groups of polysaccharides: starches and fibers.

Starches

Starch molecules are found in abundance in grains, legumes, and root vegetables, such as potatoes. Amylose, a plant starch, is a linear chain containing hundreds of glucose units. Amylopectin, another plant starch, is a branched chain containing thousands of glucose units. These large starch molecules form crystals and are the energy-storing molecules of plants. These two starch molecules (amylose and amylopectin) are contained together in foods, but the smaller one, amylose, is less abundant. Eating raw foods containing starches provides very little energy as the digestive system has a hard time breaking them down. Cooking breaks down the crystal structure of starches, making them much easier to break down in the human body. The starches that remain intact throughout digestion are called resistant starches. Bacteria in the gut can break some of these down and may benefit gastrointestinal health. Isolated and modified starches are used widely in the food industry and during cooking as food thickeners.

Figure 5.4 Structures of the Plant Starches and Glycogen



Humans and animals store glucose energy from starches in the form of the very large molecule, glycogen. It has many branches that allow it to break down quickly when energy is needed by cells in the body. It is predominantly found in liver and muscle tissue in animals.

Dietary Fibers

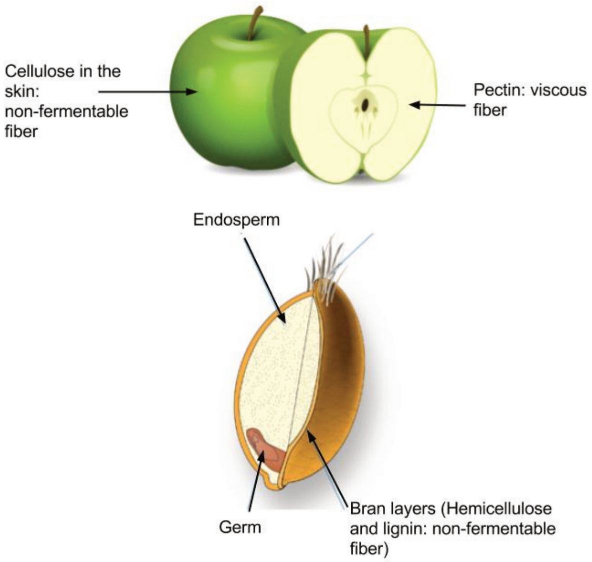
Dietary fibers are polysaccharides that are highly branched and cross-linked. Some dietary fibers are pectin, gums, cellulose, hemicellulose, and lignin. Lignin, however, is not composed of carbohydrate units. Humans do not produce the enzymes that can break down dietary fiber; however, bacteria in the large intestine (colon) do. Dietary fibers are very beneficial to our health. There is enough scientific evidence to support that diets high in fiber reduce the risk for obesity and diabetes, which are primary risk factors for cardiovascular disease.[1]

Dietary fiber is categorized as either water-soluble or insoluble. Some examples of soluble fibers are inulin, pectin, and guar gum and they are found in peas, beans, oats, barley, and rye. Cellulose and lignin are insoluble fibers and a few dietary sources of them are whole-grain foods, flax, cauliflower, and avocados. Cellulose is the most abundant fiber in plants, making up the cell walls and providing structure. Soluble fibers are more easily accessible to bacterial enzymes in the large intestine so they can be broken down to a greater extent than insoluble fibers, but even some breakdown of cellulose and other insoluble fibers occurs.

1. US Department of Agriculture. Part D. Section 5: Carbohydrates. In Report of the DGAC on the Dietary Guidelines for Americans, 2010. http://www.cnpp.usda.gov/Publications/DietaryGuidelines/2010/DGAC/Report/D-5-Carbohydrates.pdf. Accessed September 30, 2011.

The last class of fiber is functional fiber. Functional fibers have been added to foods and have been shown to provide health benefits to humans. Functional fibers may be extracted from plants and purified or synthetically made. An example of a functional fiber is psyllium-seed husk. Scientific studies show that consuming psyllium-seed husk reduces blood-cholesterol levels. Total dietary fiber intake is the sum of dietary fiber and functional fiber consumed.

Figure 5.5 Dietary Fiber

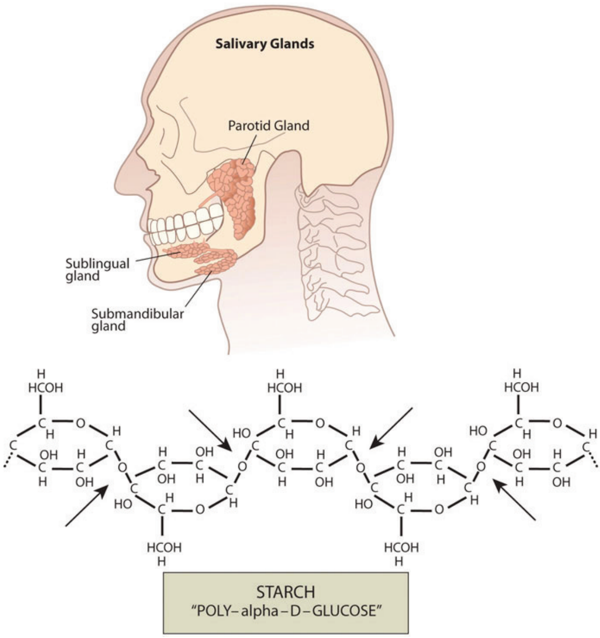


Digestion and Absorption of Carbohydrates

From the Mouth to the Stomach

The mechanical and chemical digestion of carbohydrates begins in the mouth. Chewing, also known as mastication, crumbles the carbohydrate foods into smaller and smaller pieces. The salivary glands in the oral cavity secrete saliva that coats the food particles. Saliva contains the enzyme, salivary amylase. This enzyme breaks the bonds between the monomeric sugar units of disaccharides, oligosaccharides, and starches. The salivary amylase breaks down amylose and amylopectin into smaller chains of glucose, called dextrins and maltose. The increased concentration of maltose in the mouth that results from the mechanical and chemical breakdown of starches in whole grains is what enhances their sweetness. Only about five percent of starches are broken down in the mouth. (This is a good thing as more glucose in the mouth would lead to more tooth decay.) When carbohydrates reach the stomach no further chemical breakdown occurs because the amylase enzyme does not function in the acidic conditions of the stomach. But mechanical breakdown is ongoing—the strong peristaltic contractions of the stomach mix the carbohydrates into the more uniform mixture of chyme.

Figure 5.6 Salivary Glands in the Mouth



Salivary glands secrete salivary amylase, which begins the chemical breakdown of carbohydrates by breaking the bonds between monomeric sugar units.

From the Stomach to the Small Intestine

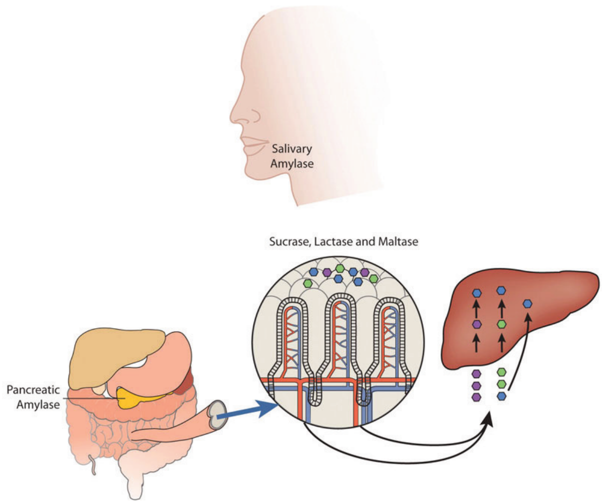
The chyme is gradually expelled into the upper part of the small intestine. Upon entry of the chyme into the small intestine, the pancreas releases pancreatic juice through a duct. This pancreatic juice contains the enzyme, pancreatic amylase, which starts again the breakdown of dextrins into shorter and shorter carbohydrate chains. Additionally, enzymes are secreted by the intestinal cells that line the villi. These enzymes, known collectively as disaccharidase, are sucrase, maltase, and lactase. Sucrase breaks sucrose into glucose and fructose molecules. Maltase breaks the bond between the two glucose units of maltose, and lactase breaks the bond between galactose and glucose. Once carbohydrates are chemically broken down into single sugar units they are then transported into the inside of intestinal cells.

When people do not have enough of the enzyme lactase, lactose is not sufficiently broken down resulting in a condition called lactose intolerance. The undigested lactose moves to the large intestine where bacteria are able to digest it. The bacterial digestion of lactose produces gases leading to symptoms of diarrhea, bloating, and abdominal cramps. Lactose intolerance usually occurs in adults. Most people with lactose intolerance can tolerate some amount of dairy products in their diet. The severity of the symptoms depends on how much lactose is consumed and the degree of lactase deficiency.

Absorption: Going to the Blood Stream

The cells in the small intestine have membranes that contain many transport proteins in order to get the monosaccharides and other nutrients into the blood where they can be distributed to the rest of the body. The first organ to receive glucose, fructose, and galactose is the liver. The liver takes them up and converts galactose to glucose, breaks fructose into even smaller carbon-containing units, and either stores glucose as glycogen or exports it back to the blood. How much glucose the liver exports to the blood is under hormonal control and you will soon discover that even the glucose itself regulates its concentrations in the blood.

Figure 5.7 Carbohydrate Digestion



Carbohydrate digestion begins in the mouth and is most extensive in the small intestine. The resultant monosaccharides are absorbed into the bloodstream and transported to the liver.

Maintaining Blood Glucose Levels: The Pancreas and Liver

Glucose levels in the blood are tightly controlled, as having either too much or too little glucose in the blood can have health consequences. Glucose regulates its levels in the blood via a process called negative feedback. An everyday example of negative feedback is in your oven because it contains a thermostat. When you set the temperature to cook a delicious homemade noodle casserole at 375°F the thermostat senses the temperature and sends an electrical signal to turn the elements on and heat up the oven. When the temperature reaches 375°F the thermostat senses the temperature and sends a signal to turn the element off. Similarly, your body senses blood glucose levels and maintains the glucose "temperature" in the target range. The glucose thermostat is located within the cells of the pancreas. After eating a meal containing carbohydrates glucose levels rise in the blood.

Insulin-secreting cells in the pancreas sense the increase in blood glucose and release the hormone, insulin, into the blood. Insulin sends a signal to the body's cells to remove glucose from the blood by transporting it into different organ cells around the body and using it to make energy. In the case of muscle tissue and the liver, insulin sends the biological message to store glucose away as glycogen. The presence of insulin in the blood signifies to the body that glucose is available for fuel. As glucose is transported into the cells around the body, the blood glucose levels decrease. Insulin has an opposing hormone called glucagon. Glucagon-secreting cells in the pancreas sense the drop in glucose and, in response, release glucagon into the blood. Glucagon communicates to the cells in the body to stop using all the glucose. More specifically, it signals the liver to break down glycogen and release the stored glucose into the blood, so that glucose levels stay within the target range and all cells get the needed fuel to function properly.

Figure 5.8 The Regulation of Glucose

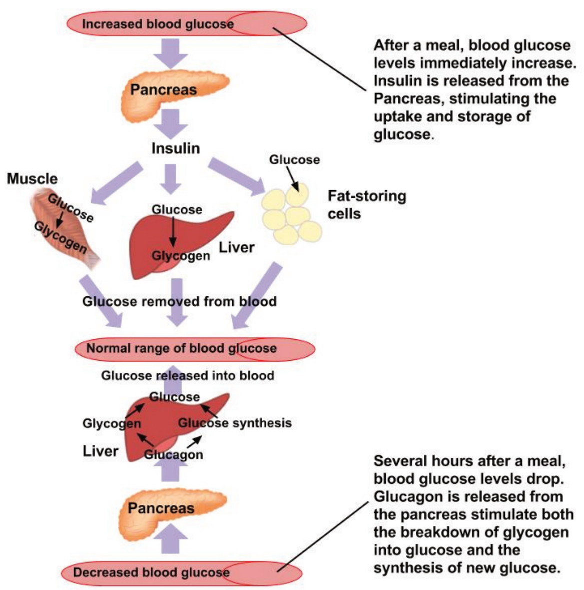


Image by Allison Calabrese / CC BY 4.0

Leftover Carbohydrates: The Large Intestine

Almost all of the carbohydrates, except for dietary fiber and resistant starches, are efficiently digested and absorbed into the body. Some of the remaining indigestible carbohydrates are broken down by enzymes released by bacteria in the large intestine. The products of bacterial digestion of these slow-releasing carbohydrates are short-chain fatty acids and some gases. The short-chain fatty acids are either used by the bacteria to make energy and grow, are eliminated in the feces, or are absorbed into cells of the colon, with a small amount being transported to the liver. Colonic cells use the short-chain fatty acids to support some of their functions. The liver can also metabolize the short-chain fatty acids into cellular energy. The yield of energy from dietary fiber is about 2 kilocalories per gram for humans, but is highly dependent upon the fiber type, with soluble fibers and resistant starches yielding more energy than insoluble fibers. Since dietary fiber is digested much less in the gastrointestinal tract than other carbohydrate types (simple sugars, many starches) the rise in blood glucose after eating them is less, and slower. These physiological attributes of high-fiber foods (i.e. whole grains) are linked to a decrease in weight gain and reduced risk of chronic diseases, such as Type 2 diabetes and cardiovascular disease.

Figure 5.9 Overview of Carbohydrate Digestion

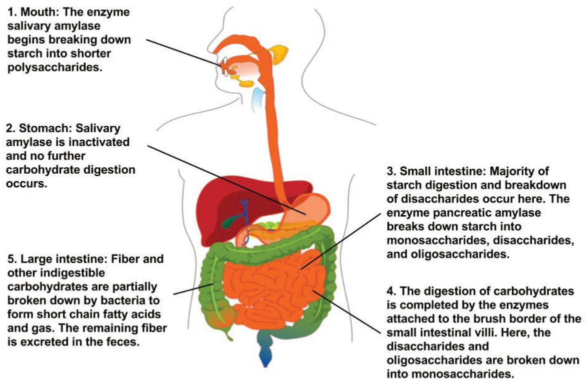


Image by Allison Calabrese / CC BY 4.0

A Carbohydrate Feast

You are at a your grandma's house for family dinner and you just consumed ham, white rice, sweet potatoes, mac salad, chicken long rice and a hot sweet bread roll dripping with butter. Less than an hour later you top it off with a slice of apple pie and then lie down on the couch to watch TV. The "hormone of plenty," insulin, answers the nutrient call. Insulin sends out the physiological message that glucose is abundant in the blood, so that cells can absorb it and either use it or store it. The result of this hormone message is maximization of glycogen stores and all the excess glucose, protein, and lipids are stored as fat.

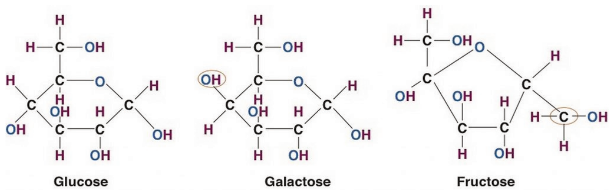


Image by Allison Calabrese / CC BY 4.0

A typical Thanksgiving meal contains many foods that are dense in carbohydrates, with the majority of those being simple sugars and starches. These types of carbohydrate foods are rapidly digested and absorbed. Blood glucose levels rise quickly causing a spike in insulin levels. Contrastingly, foods containing high amounts of fiber are like time-release capsules of sugar. A measurement of the effects of a carbohydrate-containing food on blood-glucose levels is called the glycemic response.

Glycemic Index

The glycemic responses of various foods have been measured and then ranked in comparison to a reference food, usually a slice of white bread or just straight glucose, to create a numeric value called the glycemic index (GI). Foods that have a low GI do not raise blood-glucose levels neither as much nor as fast as foods that have a higher GI. A diet of low-GI foods has been shown in epidemiological and clinical trial studies to increase weight loss and reduce the risk of obesity, Type 2 diabetes, and cardiovascular disease.[1]

Table 5.1 The Glycemic Index: Foods In Comparison To Glucose

1. Brand-Miller J, et al. Dietary Glycemic Index: Health Implications. J Am Coll Nutr. 2009; 28(4), 446S–49S.https://www.ncbi.nlm.nih.gov/pubmed/20234031. Accessed September 27, 2017.

Foods	GI Value
Low GI Foods (< 55)	
Apple, raw	36
Orange, raw	43
Banana, raw	51
Mango, raw	51
Carrots, boiled	39
Taro, boiled	53
Corn tortilla	46
Spaghetti (whole wheat)	37
Baked beans	48
Soy milk	34
Skim milk	37
Whole milk	39
Yogurt, fruit	41
Yogurt, plain	14
Icecream	51
Medium GI Foods (56–69)	
Pineapple, raw	59
Cantaloupe	65
Mashed potatoes	70
Whole-wheat bread	69
Brown rice	55
Cheese pizza	60
Sweet potato, boiled	63
Macaroni and cheese	64
Popcorn	65
High GI Foods (70 and higher)	
Banana (over-ripe)	82
Corn chips	72

Pretzels	83
White bread	70
White rice	72
Bagel	72
Rice milk	86
Cheerios	74
Raisin Bran	73
Fruit roll-up	99
Gatorade	78

For the Glycemic Index on different foods, visit http://www.mendosa.com/gilists.htm.

The type of carbohydrate within a food affects the GI along with its fat and fiber content. Increased fat and fiber in foods increases the time required for digestion and delays the rate of gastric emptying into the small intestine which, ultimately reduces the GI. Processing and cooking also affects a food's GI by increasing their digestibility. Advancements in the technologies of food processing and the high consumer demand for convenient, precooked foods in Canada has created foods that are digested and absorbed more rapidly, independent of the fiber content. Modern breakfast cereals, breads, pastas, and many prepared foods have a high GI. In contrast, most raw foods have a lower GI. (However, the more ripened a fruit or vegetable is, the higher its GI.)

The GI can be used as a guide for choosing healthier carbohydrate choices but has some limitations. The first is GI does not take into account the amount of carbohydrates in a portion of food, only the type of carbohydrate. Another is that combining low- and high-GI foods changes the GI for the meal. Also, some nutrient-dense foods have higher GIs than less nutritious food. (For instance, oatmeal has a higher GI than chocolate because the fat content of chocolate is higher.)

Lastly, meats and fats do not have a GI since they do not contain carbohydrates.

More Resources

Visit this online database to discover the glycemic indices of foods. Foods are listed by category and also by low, medium, or high glycemic index.
http://www.gilisting.com/

The Functions of Carbohydrates in the Body

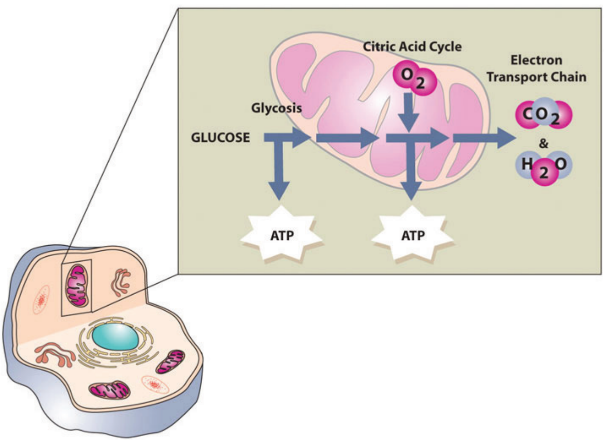
There are five primary functions of carbohydrates in the human body. They are energy production, energy storage, building macromolecules, sparing protein, and assisting in lipid metabolism.

Energy Production

The primary role of carbohydrates is to supply energy to all cells in the body. Many cells prefer glucose as a source of energy versus other compounds like fatty acids. Some cells, such as red blood cells, are only able to produce cellular energy from glucose. The brain is also highly sensitive to low blood-glucose levels because it uses only glucose to produce energy and function (unless under extreme starvation conditions). About 70 percent of the glucose entering the body from digestion is redistributed (by the liver) back into the blood for use by other tissues. Cells that require energy remove the glucose from the blood with a transport protein in their membranes. The energy from glucose comes from the chemical bonds between the carbon atoms. Sunlight energy was required to produce these high-energy bonds in the process of photosynthesis. Cells in our bodies break these bonds and capture the energy to perform cellular respiration. Cellular respiration is basically a controlled burning of glucose versus an uncontrolled burning. A cell uses many chemical reactions in multiple enzymatic steps to slow the release of energy (no explosion) and more efficiently capture the energy held within the chemical bonds in glucose.

The first stage in the breakdown of glucose is called glycolysis. Glycolysis, or the splitting of glucose, occurs in an intricate series of ten enzymatic-reaction steps. The second stage of glucose breakdown occurs in the energy factory organelles, called mitochondria. One carbon atom and two oxygen atoms are removed, yielding more energy. The energy from these carbon bonds is carried to another area of the mitochondria, making the cellular energy available in a form cells can use.

Figure 5.10 Cellular Respiration



Cellular respiration is the process by which energy is captured from glucose.

Energy Storage

If the body already has enough energy to support its functions, the excess glucose is stored as glycogen (the majority of which is stored in the muscles and liver). A molecule of glycogen may contain in excess of fifty thousand single glucose units and is highly branched, allowing for the rapid dissemination of glucose when it is needed to make cellular energy.

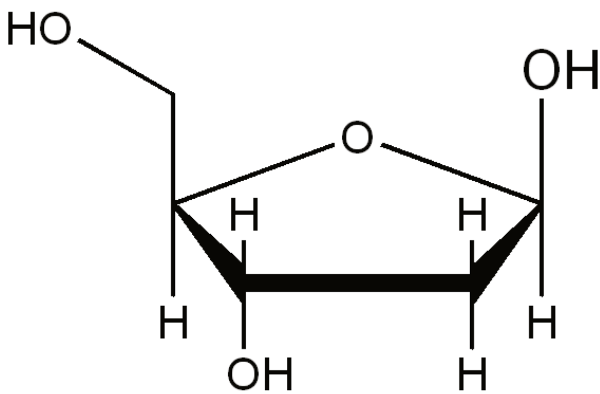
The amount of glycogen in the body at any one time is equivalent to about 4,000 kilocalories—3,000 in muscle tissue and 1,000 in the liver. Prolonged muscle use (such as exercise for longer than a few hours) can deplete the glycogen energy reserve. Remember that this is referred to as "hitting the wall" or "bonking" and is characterized by fatigue and a decrease in exercise performance. The weakening of muscles sets in because it takes longer to transform the chemical energy in fatty acids and proteins to usable energy than glucose. After prolonged exercise, glycogen is gone and muscles must rely more on lipids and proteins as an energy source. Athletes can increase their glycogen reserve modestly by reducing training intensity and increasing their carbohydrate intake to between 60 and 70 percent of total calories three to five days prior to an event. People who are not hardcore training and choose to run a 5-kilometer race for fun do not need to consume a big plate of pasta prior to a race since without long-term intense training the adaptation of increased muscle glycogen will not happen.

The liver, like muscle, can store glucose energy as a glycogen, but in contrast to muscle tissue it will sacrifice its stored glucose energy to other tissues in the body when blood glucose is low. Approximately one-quarter of total body glycogen content is in the liver (which is equivalent to about a four-hour supply of glucose) but this is highly dependent on activity level. The liver uses this glycogen reserve as a way to keep blood-glucose levels within a narrow range between meal times. When the liver's glycogen supply is exhausted, glucose is made from amino acids obtained from the destruction of proteins in order to maintain metabolic homeostasis.

Building Macromolecules

Although most absorbed glucose is used to make energy, some glucose is converted to ribose and deoxyribose, which are essential building blocks of important macromolecules, such as RNA, DNA, and ATP. Glucose is additionally utilized to make the molecule NADPH, which is important for protection against oxidative stress and is used in many other chemical reactions in the body. If all of the energy, glycogen-storing capacity, and building needs of the body are met, excess glucose can be used to make fat. This is why a diet too high in carbohydrates and calories can add on the fat pounds—a topic that will be discussed shortly.

Figure 5.11 Chemical Structure of Deoxyribose



The sugar molecule deoxyribose is used to build the backbone of DNA. Image by rozeta / CC BY-SA 3.0

Figure 5.12 Double-stranded DNA

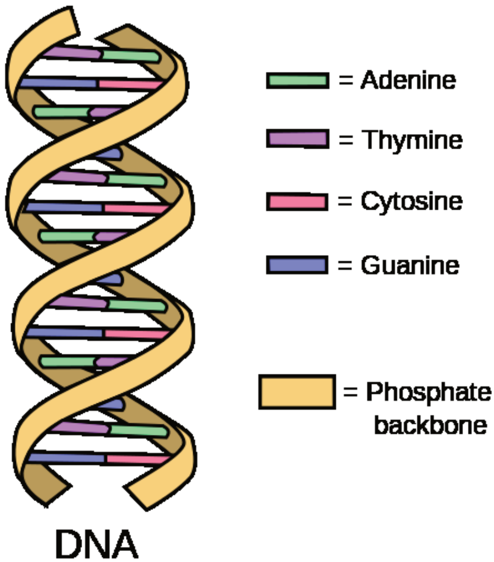


Image by Forluvoft / Public Domain

Sparing Protein

In a situation where there is not enough glucose to meet the body's needs, glucose is synthesized from amino acids. Because there is no storage molecule of amino acids, this process requires the destruction of proteins, primarily from muscle tissue. The presence of adequate glucose basically spares the breakdown of proteins from being used to make glucose needed by the body.

Lipid Metabolism

As blood-glucose levels rise, the use of lipids as an energy source is inhibited. Thus, glucose additionally has a "fat-sparing" effect. This is because an increase in blood glucose stimulates release of the hormone insulin, which tells cells to use glucose (instead of lipids) to make energy. Adequate glucose levels in the blood also prevent the development of ketosis. Ketosis is a metabolic condition resulting from an elevation of ketone bodies in the blood. Ketone bodies are an alternative energy source that cells can use when glucose supply is insufficient, such as during fasting. Ketone bodies are acidic and high elevations in the blood can cause it to become too acidic. This is rare in healthy adults, but can occur in alcoholics, people who are malnourished, and in individuals who have Type 1 diabetes. The minimum amount of carbohydrate in the diet required to inhibit ketosis in adults is 50 grams per day.

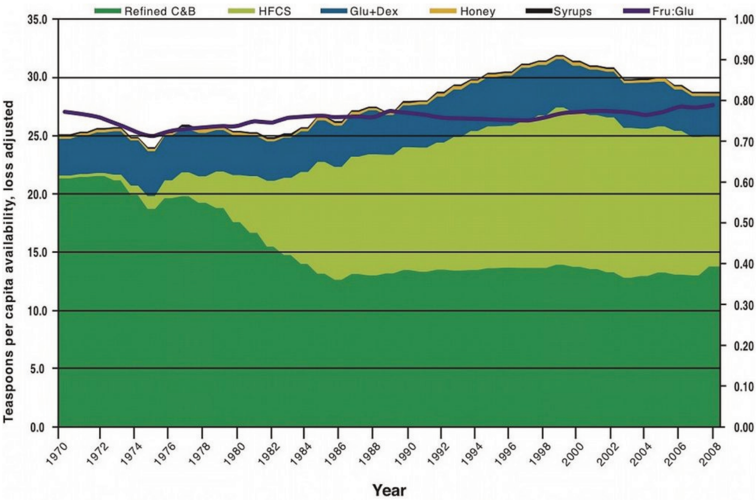
Carbohydrates are critical to support life's most basic function—the production of energy. Without energy none of the other life processes are performed. Although our bodies can synthesize glucose it comes at the cost of protein destruction. As with all nutrients though, carbohydrates are to be consumed in moderation as having too much or too little in the diet may lead to health problems.

Health Consequences and Benefits of High-Carbohydrate Diets

Can we blame the obesity epidemic on the higher consumption of added sugars and refined grains? This is a hotly debated topic by both the scientific community and the general public. In this section, we will give a brief overview of the scientific evidence.

Added Sugars

Figure 5.13 Sugar Consumption (In Teaspoons) From Various Sources



Added sugars are defined as "sugars and syrups that are added to foods during processing or preparation. Major sources of added sugars include soft drinks, sports drinks, cakes, cookies, pies, fruitades, fruit punch, dairy desserts, and candy." Processed foods, even microwaveable dinners, also contain added sugars. Added sugars do not include sugars that occur naturally in whole foods (such as an apple), but do include natural sugars such as brown sugar, corn syrup, dextrose, fructose, fruit juice concentrates, maple syrup, sucrose, and raw sugar that are then added to create other foods (such as cookies). Results from a survey of forty-two thousand Americans reports that in 2008 the average intake of added sugars is 15 percent of total calories, a drop from 18 percent of total calories in 2000.[1] The numbers in Canada are similar.

1. Welsh JA, Sharma AJ, et al. Consumption of Added Sugars Is Decreasing in the United States. Am J Clin Nutr. 2011; 94(3), 726–34.

Obesity, Diabetes, and Heart Disease and Their Hypothesized Link to Excessive Sugar and Refined Carbohydrate Consumption

The obesity epidemic has reached young adults and children and will markedly affect the prevalence of serious health consequences in adulthood. Health consequences linked to being overweight or obese include Type 2 diabetes, cardiovascular disease, arthritis, depression, and some cancers. An infatuation with sugary foods and refined grains likely contributes to the epidemic proportion of people who are overweight or obese in this country, but so do the consumption of high-calorie foods that contain too much saturated fat and the sedentary lifestyle of most Canadians. There is much disagreement over whether high-carbohydrate diets increase weight-gain and disease risk, especially when calories are not significantly higher between compared diets. Many scientific studies demonstrate positive correlations between diets high in added sugars with weight gain and disease risk, but some others do not show a significant relationship. In regard to refined grains, there are no studies that show consumption of refined grains increases weight gain or disease risk. What is clear, however, is that getting more of your carbohydrates from dietary sources containing whole grains instead of refined grains stimulates weight loss and reduces disease risk.

A major source of added sugars in the Canadian diet is soft

http://www.ncbi.nlm.nih.gov/pubmed/21753067. Accessed September 22, 2017.

drinks. There is consistent scientific evidence that consuming sugary soft drinks increases weight gain and disease risk. An analysis of over thirty studies in the American Journal of Clinical Nutrition concluded that there is much evidence to indicate higher consumption of sugar-sweetened beverages is linked with weight gain and obesity.[2] A study at the Harvard School of Public Health linked the consumption of sugary soft drinks to an increased risk for heart disease.[3]

While the sugar and refined grains and weight debate rages on, the results of all of these studies has led some public health organizations like the Canadian Heart and Stroke Foundation to recommend even a lower intake of sugar per day (fewer than 9 teaspoons per day for men and fewer than 6 teaspoons for women) than what used to be deemed acceptable. The following recommendations were made:

- First, know the number of total calories you should eat each day.
- Consume an overall healthy diet and get the most nutrients for the calories, using foods high in added sugars as discretionary calories (those left over after getting all recommended nutrients subtracted from the calories used).
- Lower sugar intake, especially when the sugars in foods are not tied to positive nutrients such as in sugary drinks, candies, cakes, and cookies.
- Focus on calories in certain food categories such as

2. Malik VS, Schulze MB, Hu FB. Intake of Sugar-Sweetened Beverages and Weight Gain: A Systematic Review. Am J Clin Nutr. 2006; 84(2), 274–88. http://www.ajcn.org/content/84/2/274.long. Accessed September 22, 2017.
3. Public Health Takes Aim at Sugar and Salt. Harvard School of Public Health. https://www.hsph.harvard.edu/news/magazine/sugar-and-salt/. Published 2009. Accessed September 30, 2017.

> beverages and confections, and encourage consumption of positive nutrients and foods such as cereals and low-fat or fat-free dairy products.

The Most Notorious Sugar

Before high-fructose corn syrup (HFCS) was marketed as the best food and beverage sweetener, sucrose (table sugar) was the number-one sweetener in North America. (Recall that sucrose, or table sugar, is a disaccharide consisting of one glucose unit and one fructose unit.) HFCS also contains the simple sugars fructose and glucose, but with fructose at a slightly higher concentration. In the production of HFCS, corn starch is broken down to glucose, and some of the glucose is then converted to fructose. Fructose is sweeter than glucose; hence many food manufacturers choose to sweeten foods with HFCS. HFCS is used as a sweetener for carbonated beverages, condiments, cereals, and a great variety of other processed foods.

Some scientists, public health personnel, and healthcare providers believe that fructose is the cause of the obesity epidemic and its associated health consequences. The majority of their evidence stems from the observation that since the early 1970s the number of overweight or obese North Americans has dramatically increased and so has the consumption of foods containing HFCS. However, as discussed, so has the consumption of added sugars in general. Animal studies that fuel the fructose opponents show fructose is not used to produce energy in the body; instead it is mostly converted to fat in the liver—potentially contributing to insulin resistance and the development of Type 2 diabetes. Additionally, fructose does not stimulate the release of certain appetite-suppressing hormones, like insulin, as glucose does.

Thus, a diet high in fructose could potentially stimulate fat deposition and weight gain.

In human studies, excessive fructose intake has sometimes been associated with weight gain, but results are inconsistent. Moderate fructose intake is not associated with weight gain at all. Moreover, other studies show that some fructose in the diet actually improves glucose metabolism especially in people with Type 2 diabetes.[4]

In fact, people with diabetes were once advised to use fructose as an alternative sweetener to table sugar. Overall, there is no good evidence that moderate fructose consumption contributes to weight gain and chronic disease. At this time conclusive evidence is not available on whether fructose is any worse than any other added sugar in increasing the risk for obesity, Type 2 diabetes, and cardiovascular disease.

Do Low-Carbohydrate Diets Affect Health?

Since the early 1990s, marketers of low-carbohydrate diets have bombarded us with the idea that eating fewer carbohydrates promotes weight loss and that these diets are superior to others in their effects on weight loss and overall health. The most famous of these low-carbohydrate diets is the Atkins diet. Others include the "South Beach" diet, the "Zone" diet, and the "Earth" diet. Despite the claims these diets make, there is little scientific evidence to support that low-carbohydrate diets are significantly better than other diets in promoting long-

4. Elliott SS, Keim NL, et al. Fructose, Weight Gain, and the Insulin Resistance Syndrome. Am J Clin Nutr. 2002; 76(5),911–22. http://www.ajcn.org/content/76/5/911.full. Accessed September 27, 2017.

term weight loss. A study in The Nutritional Journal concluded that all diets, (independent of carbohydrate, fat, and protein content) that incorporated an exercise regimen significantly decreased weight and waist circumference in obese women.[5]

Some studies do provide evidence that in comparison to other diets, low-carbohydrate diets improve insulin levels and other risk factors for Type 2 diabetes and cardiovascular disease. The overall scientific consensus is that consuming fewer calories in a balanced diet will promote health and stimulate weight loss, with significantly better results achieved when combined with regular exercise.

Health Benefits of Whole Grains in the Diet

While excessive consumption of simple carbohydrates is potentially bad for your health, consuming more complex carbohydrates is extremely beneficial to health. There is a wealth of scientific evidence supporting that replacing refined grains with whole grains decreases the risk for obesity, Type 2 diabetes, and cardiovascular disease. Whole grains are great dietary sources of fiber, vitamins, minerals, healthy fats, and a vast amount of beneficial plant chemicals, all of which contribute to the effects of whole grains on health. Eating a high-fiber meal as compared to a low-fiber meal (see Figure 5.14 "Fibers Role in Carbohydrate Digestion and Absorption")

5. Kerksick CM, Wismann-Bunn J, et al. Changes in Weight Loss, Body Composition, and Cardiovascular Disease Risk after Altering Macronutrient Distributions During a Regular Exercise Program in Obese Women. J Nutr. 2010; 9(59). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3000832/ . Accessed September 27, 2017.

can significantly slow down the absorption process therefore affecting blood glucose levels. Canadians typically do not consume the recommended amount of whole grains, which is 50 percent or more of grains from whole grains.

Figure 5.14 Fibers Role in Carbohydrate Digestion and Absorption

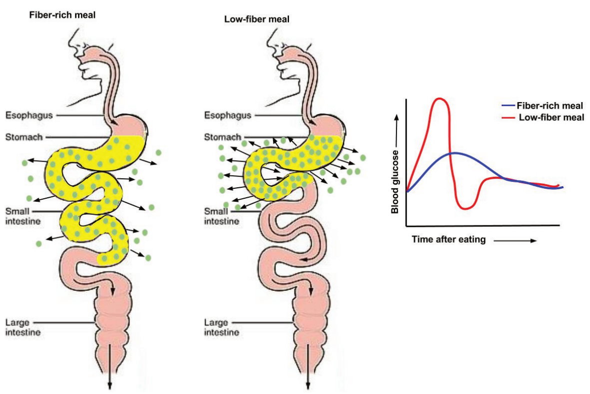


Image by Allison Calabrese / CC BY 4.0

Diets high in whole grains have repeatedly been shown to decrease weight. A large group of studies all support that consuming more than two servings of whole grains per day reduces one's chances of getting Type 2 diabetes by 21 percent.[6] A study found that women who consumed two to three servings of whole grain products daily were 30 percent less likely to have a heart attack.[7]

6. de Munter JS, Hu FB, et al. Whole Grain, Bran, and Germ Intake and Risk of Type 2 Diabetes: A Prospective Cohort Study and Systematic Review. PLoS Medicine. 2007; 4(8), e261. https://www.ncbi.nlm.nih.gov/pubmed/17760498. Accessed September 27, 2017.
7. Liu S, Stampfer MJ, et al. Whole-Grain Consumption and Risk of Coronary Heart Disease: Results from the Nurses' Health Study. Am J

Regarding while grains:

- "Dietary fiber from whole grains, as part of an overall healthy diet, helps reduce blood cholesterol levels and may lower risk of heart disease."
- "Fiber-containing foods, such as whole grains, help provide a feeling of fullness with fewer calories and may help with weight management."

Clin Nutr. 1999; 70(3), 412–19. http://www.ajcn.org/content/70/3/412.long. Accessed September 27, 2017.

Carbohydrates and Personal Diet Choices

In this chapter, you learned what carbohydrates are, the different types of carbohydrates in your diet, and that excess consumption of some types of carbohydrates cause disease while others decrease disease risk. Now that we know the benefits of eating the right carbohydrate, we will examine exactly how much should be eaten to promote health and prevent disease.

How Many Carbohydrates Does a Person Need?

The Recommended Dietary Allowance (RDA) of carbohydrates for children and adults at 130 grams per day. This is the average minimum amount the brain requires to function properly. The Acceptable Macronutrient Distribution Range (AMDR) for carbohydrates is between 45 and 65 percent of your total caloric daily intake. This means that on a 2,000 kilocalorie diet, a person should consume between 225 and 325 grams of carbohydrate each day. No more than 25 percent of total calories consumed should come from added sugars. The World Health Organization recommends much lower intakes of added sugars—10 percent or less of total calories consumed. The Adequate Intakes for dietary fiber, are 38 and 25 grams for men and women, respectively. The recommendations for dietary fiber are based upon the intake levels known to prevent against heart disease.

Table 5.2 Dietary Reference Intakes For Carbohydrates And Fiber

Carbohydrate Type	RDA (g/day)	AMDR (% calories)
Total Carbohydrates	130	45–65
Added Sugars		< 25
Fiber	38 (men),* 25 (women)*	
* denotes Adequate Intake		

Dietary Sources of Carbohydrates

Carbohydrates are contained in all five food groups: grains, fruits, vegetables, meats, beans (only in some processed meats and beans), and dairy products. Fast-releasing carbohydrates are more prevalent in fruits, fruit juices, and dairy products, while slow-releasing carbohydrates are more plentiful in starchy vegetables, beans, and whole grains. Fast-releasing carbohydrates are also found in large amounts in processed foods, soft drinks, and sweets. On average, a serving of fruits, whole grains, or starches contains 15 grams of carbohydrates. A serving of dairy contains about 12 grams of carbohydrates, and a serving of vegetables contains about 5 grams of carbohydrates. Table 5.3 “Carbohydrates in Foods (grams/serving)” gives the specific amounts of carbohydrates, fiber, and added sugar of various foods.

Table 5.3 Carbohydrates in Foods (grams/serving)

Foods	Total Carbohydrates	Sugars	Fiber	Added Sugars
Banana	27 (1 medium)	14.40	3.1	0
Lentils	40 (1 c.)	3.50	16.0	0
Snap beans	8.7 (1 c.)	1.60	4.0	0
Green pepper	5.5 (1 medium)	2.90	2.0	0
Corn tortilla	10.7 (1)	0.20	1.5	0
Bread, wheat bran	17.2 (1 slice)	3.50	1.4	3.4
Bread, rye	15.5 (1 slice)	1.20	1.9	1.0
Bagel (plain)	53 (1 medium)	5.30	2.3	4.8
Brownie	36 (1 square)	20.50	1.2	20.0
Oatmeal cookie	22.3 (1 oz.)	12.00	2.0	7.7
Cornflakes	23 (1 c.)	1.50	0.3	1.5
Pretzels	47 (10 twists)	1.30	1.7	0
Popcorn (homemade)	58 (100 g)	0.50	10.0	0
Skim milk	12 (1 c.)	12.00	0	0
Cream (half and half)	0.65 (1 Tbs.)	0.02	0	0
Cream substitute	1.0 (1 tsp.)	1.00	0	1.0
Cheddar cheese	1.3 (1 slice)	0.50	0	0
Yogurt (with fruit)	32.3 (6 oz.)	32.30	0	19.4
Caesar dressing	2.8 (1 Tbs.)	2.80	0	2.4

Sources:

- National Nutrient Database for Standard Reference. US Department of Agriculture. http://www.nal.usda.gov/fnic/foodcomp/search/. Updated December 7, 2011. Accessed September 17, 2017.
- Database for the Added Sugars Content of Selected Foods. US Department of Agriculture. http://www.nal.usda.gov/fnic/foodcomp/search/. Published February 2006.

Accessed September 27, 2017.

It's the Whole Nutrient Package

In choosing dietary sources of carbohydrates the best ones are those that are nutrient dense, meaning they contain more essential nutrients per calorie of energy. In general, nutrient-dense carbohydrates are minimally processed and include whole-grain breads and cereals, low-fat dairy products, fruits, vegetables, and beans. In contrast, empty-calorie carbohydrate foods are highly processed and often contain added sugars and fats. Soft drinks, cakes, cookies, and candy are examples of empty-calorie carbohydrates. They are sometimes referred to as 'bad carbohydrates,' as they are known to cause health problems when consumed in excess.

Understanding Carbohydrates from Product Information

While nutrition facts labels aid in determining the amount of carbohydrates you eat, they do not help in determining whether a food is refined or not. The ingredients list provides some help in this regard. It identifies all of the food's ingredients in order of concentration, with the most concentrated ingredient first. When choosing between two breads, pick the one that lists whole wheat (not wheat flour) as the first ingredient, and avoid those with other flour ingredients, such as white flour or corn flour. (Enriched wheat flour refers to white flour with added vitamins.) Eat less of products that list HFCS and other sugars such as sucrose, honey, dextrose, and cane sugar in the first five ingredients. If you want to eat less processed foods then, in general, stay away from products with long ingredient lists. On the front of food and beverages the manufacturers may include claims such as "sugar-free," "reduced sugar," "high fiber," etc.

Table 5.4 Food Labels Pertaining to Carbohydrates

Label	Meaning
Sugar-free	Contains less than 0.5 grams of sugar per serving
Reduced sugar	Contains 25 percent less sugar than similar product
Less sugar	Contains 25 percent less sugar than similar product, and was not altered by processing to become so
No sugars added	No sugars added during processing
High fiber	Contains at least 20 percent of daily value of fiber in each serving
A good source of fiber	Contains between 10 and 19 percent of the daily value of fiber per serving
More fiber	Contains 10 percent or more of the daily value of fiber per serving

Source: Appendix A: Definitions of Nutrient Claims. Guidance for Industry: A Food Labeling Guide. US Food and Drug Administration. http://www.fda.gov/Food/GuidanceComplianceRegulatoryInformation/GuidanceDocuments/FoodLabelingNutrition/FoodLabelingGuide/ucm064911.htm. Updated October 2009. Accessed September 22, 2017.

Although the information above is based on American guidelines, The U.S. Food and Drug Administration (FDA) signed an arrangement with the Canadian Food Inspection Agency (CFIA) and the Department of Health Canada (Health Canada) recognizing each other's food safety systems as comparable to each other. References to guidelines made by the FDA is this textbook applies to guidelines that are similar in Canada.

Personal Choices

Carbohydrates are in most foods so you have a great variety of choices with which to meet the carbohydrates recommendations for a healthy diet. Health Canada recommends eating more unrefined carbohydrates and more fiber, and reducing consumption of foods that are high in added sugars. To accomplish these recommendations use some or all of the following suggestions:

- Get more daily carbohydrate servings from whole grains by eating a whole-grain cereal for breakfast, using whole-grain bread to make a sandwich for lunch, and eating a serving of beans and/or nuts with dinner.
- Make sure to get at least three servings (or more) of all the grains you eat as whole grains every day. A serving of whole grains is equal to one slice of whole-wheat bread, one ounce of whole-grain cereal, and one-half cup of cooked cereal, brown rice, or whole-wheat pasta.
  Food products made with cornmeal use the whole grain so choose tortillas, corn cereals, and corn breads with cornmeal listed as the first ingredient.
- When baking, substitute whole-wheat flour or other whole-grain flour for some of the refined white flour.
- If you like bread at dinner, choose a whole-grain muffin over a Kaiser roll or baguette.
  Add beans, nuts, or seeds to salad—they add texture and taste.
- Choose whole-grain pastas and brown rice, cook al dente, and add some beans and vegetables in equal portions.
- Change it up a bit and experience the taste and satisfaction of other whole grains such as barley, quinoa, and bulgur.
- Eat snacks high in fiber, such as almonds, pistachios, raisins, and air-popped popcorn.

Add an artichoke and green peas to your dinner plate more often.

- Calm your “sweet tooth” by eating fruits, such as berries or an apple.
- Replace sugary soft drinks with seltzer water, tea, or a small amount of 100 percent fruit juice added to water or soda water.

The Food Industry: Functional Attributes of Carbohydrates and the Use of Sugar Substitutes

In the food industry, both fast-releasing and slow-releasing carbohydrates are utilized to give foods a wide spectrum of functional attributes, including increased sweetness, viscosity, bulk, coating ability, solubility, consistency, texture, body, and browning capacity. The differences in chemical structure between the different carbohydrates confer their varied functional uses in foods. Starches, gums, and pectins are used as thickening agents in making jam, cakes, cookies, noodles, canned products, imitation cheeses, and a variety of other foods. Molecular gastronomists use slow-releasing carbohydrates, such as alginate, to give shape and texture to their fascinating food creations. Adding fiber to foods increases bulk. Simple sugars are used not only for adding sweetness, but also to add texture, consistency, and browning. In ice cream, the combination of sucrose and corn syrup imparts sweetness as well as a glossy appearance and smooth texture.

Due to the potential health consequences of consuming too many added sugars, sugar substitutes have replaced them in many foods and beverages. Sugar substitutes may be from natural sources or artificially made. Those that are artificially made are called artificial sweeteners and must be approved by the FDA for use in foods and beverages. The artificial sweeteners approved by the FDA are saccharin, aspartame, acesulfame potassium, neotame, advantame, and sucralose. Stevia is an example of a naturally derived sugar substitute. It comes from a plant commonly known as sugarleaf and does not require FDA approval. Sugar alcohols, such as xylitol, sorbitol, erythritol, and mannitol, are sugar alcohols that occur naturally in some fruits and vegetables. However, they are industrially synthesized with yeast and other microbes for use as food additives. The FDA requires that foods disclose the fact that they contain sugar alcohols, but does not require scientific testing of it. (Though many of them have undergone studies anyway.) In comparison to sucrose, artificial sweeteners are significantly sweeter (in fact, by several hundred times), but sugar alcohols are more often less sweet than sucrose (see Table 5.5 "Relative Sweetness of Sugar Substitutes"). Artificial sweeteners and Stevia are not digested or absorbed in significant amounts and therefore are not a significant source of calories in the diet. Sugar alcohols are somewhat digested and absorbed and, on average, contribute about half of the calories as sucrose (4 kilocalories/gram). These attributes make sugar substitutes attractive for many people—especially those who want to lose weight and/or better manage their blood-glucose levels.

Table 5.5 Relative Sweetness Of Sugar Substitutes

Sweetener	Trade Names	Sweeter than Sucrose (times)
Saccharine	“Sweet-N-Lo”	300.0
Aspartame	“NutraSweet,” “Equal”	80-200.0
Acesulfame-K	“Sunette”	200.0
Neotame		7,000.0–13,000.0
Advantame		20,000
Sucralose	“Splenda”	600.0
Stevia		250.0–300.0
Xylitol		0.8
Mannitol		0.5
Sorbitol		0.6
Erythritol		1.0

Benefits of Sugar Substitutes

Consuming foods and beverages containing sugar substitutes may benefit health by reducing the consumption of simple sugars, which are higher in calories, cause tooth decay, and are potentially linked to chronic disease. Artificial sweeteners are basically non-nutrients though not all are completely calorie-free. However, because they are so intense in sweetness they are added in very small amounts to foods and beverages. Artificial sweeteners and sugar alcohols are not “fermentable sugars” and therefore they do not cause tooth decay. Chewing gum with artificial sweeteners is the only proven way that artificial sweeteners promote oral health. The Canadian Dental Association (CDA) allows manufacturers of chewing gum to label packages with a CDA seal if they have convincing scientific evidence demonstrating their product either reduces plaque acids, cavities, or gum disease, or promotes tooth remineralization.

There is limited scientific evidence that consuming products with artificial sweeteners decreases weight. In fact, some studies suggest the intense sweetness of these products increases appetite for sweet foods and may lead to increased weight gain. Also, there is very limited evidence that suggests artificial sweeteners lower blood-glucose levels. Additionally, many foods and beverages containing artificial sweeteners and sugar alcohols are still empty-calorie foods (i.e. chewing sugarless gum or drinking diet soda pop) are not going to better your blood-glucose levels or your health.

Health Concerns

The most common side effect of consuming products containing sugar substitutes is gastrointestinal upset, a result of their incomplete digestion. Since the introduction of sugar substitutes to the food and beverage markets, the public has expressed concern about their safety. The health concerns of sugar substitutes originally stemmed from scientific studies, which were misinterpreted by both scientists and the public.

In the early 1970s scientific studies were published that demonstrated that high doses of saccharin caused bladder tumors in rats. This information fueled the still-ongoing debate of the health consequences of all artificial sweeteners. In actuality, the results from the early studies were completely irrelevant to humans. The large doses (2.5 percent of diet) of saccharine caused a pellet to form in the rat's bladder. That pellet chronically irritated the bladder wall, eventually resulting in tumor development. Since this study, scientific investigation in rats, monkeys, and humans have not found any relationship between saccharine consumption and bladder cancer. In 2000, saccharin was removed from the US National Toxicology Program's list of potential carcinogens.[1]

There have been health concerns over other artificial sweeteners, most notably aspartame (sold under the trade names of NutraSweet and Equal). The first misconception regarding aspartame was that it was linked with an increase in the incidence of brain tumors in the United States. It was subsequently discovered that the increase in brain tumors started eight years prior to the introduction of aspartame to the market. Today, aspartame is accused of causing brain damage, autism, emotional disorders, and a myriad of other disorders and diseases. Some even believe aspartame is part of a governmental conspiracy to make people dumber. The reality is there is no good scientific evidence backing any of these accusations, and that aspartame has been the most scientifically tested food additive. It is approved for use as an artificial sweetener in over ninety countries.

Aspartame is made by joining aspartic acid and phenylalanine to a dipeptide (with a methyl ester). When digested, it is broken down to aspartic acid, phenylalanine, and methanol. People who have the rare genetic disorder phenylketonuria (PKU) have to avoid products containing aspartame. Individuals who have PKU do not have a functional enzyme that converts phenylalanine to the amino acid tyrosine. This causes a buildup of phenylalanine and its metabolic products in the body. If PKU is not treated, the buildup of phenylalanine causes progressive brain damage and seizures. The FDA requires products that contain aspartame to state on the product label, "Phenylketonurics:

1. Artificial Sweeteners and Cancer. National Cancer Institute. http://www.cancer.gov/cancertopics/factsheet/Risk/artificial-sweeteners. Updated August 5, 2009. Accessed September 22, 2017.

Contains Phenylalanine.” For more details on sugar substitutes please refer to Table 5.6 “Sweeteners”.

Table 5.6 Sweeteners

Sweeteners with Trade Name	Calories	Source/Origin	Consumer Recommendations	Controversia Issues
Aspartame • NutraSweet • Equal	4 kcal/g	Composed of two amino acids (phenylalanine + aspartic acid) + methanol.Two hundred times sweeter than sucrose.	FDA set maximum Acceptable Daily Intakes (ADI):50 mg/kg body weight = 16 12 oz. diet soft drinks for adults. *Cannot be used in products requiring cooking. People with PKU should not consume aspartame.	Children hav potential to r ADI if consur many bevera desserts, froz desserts, anc gums contai aspartame routinely.
Saccharin • Sweet 'n' Low	0 kcal/g	Discovered in 1878. The basic substance is benzoic sulfinide.Three hundred times sweeter than sucrose.	ADI: 5 mg/kg body weight.*Can be used in cooking.	1970s, high d of saccharin associated w bladder canc laboratory animals. In 19 FDA propose banning sacc from use in f • protest launchec consume interest groups • warning listed on products about saccharir cancer ri animals u 2001 whe studies conclude that it dic cause ca in humar

Acesulfame K • Sunnette • Sweet One	0 kcal/g	Discovered in 1967. Composed of an organic salt, potassium (K). Structure is very similar to saccharin's.It passes through the body unchanged which means it does not provide energy. Two hundred times sweeter than sucrose.	ADI: 15 mg/kg body weight.Body cannot digest it. *Can be used in cooking.	
Cyclamates • Sugar Twin	0 kcal/g	Thirty times sweeter than sucrose.Discovered in 1937.	No ADI available.	1949, cyclama approved by for use. Cycla was classifiec GRAS (Gener Recognized Safe) until 19 when it was removed fro GRAS status banned from in all food an beverage pro within the U States on the of one study indicated it caused bladd cancer in rats Approval still pending for u the United St since the ban.Canada other countr use this type sweetener.

Sucralose • Splenda	1 Splenda packet contains 3.31 calories = 1g	First discovered in 1976. Approved for use in 1998 in the United States and in 1991 in Canada.Derived from sucrose in which three of its hydroxyl (OH) groups are replaced by chlorine (Cl−). Six hundred times sweeter than sugar.	ADI: 5 mg/kg body weight.*Can be used in cooking.	
Stevioside • Stevia • Sweet Leaf	N/A	Derived from stevia plant found in South America. Stevia rebaudiana leaves.	Classified as GRAS.Considered to be a dietary supplement and approved not as an additive, but as a dietary supplement.	Used sparing stevia may de harm, but FD could not ap extensive use this sweeten due to conce regarding its effect on reproduction cancer developmen energy metabolism.
Sucrose • Sugar	~4 kcal/g	Extracted from either sugar beets or sugar cane, which is then purified and crystallized.	It is illegal to sell true raw sugar in the United States because when raw it contains dirt and insect parts, as well as other byproducts. Raw sugar products sold in the United States have actually gone through more than half of the same steps in the refining process as table sugar.	Over-consun has been link several healt effects such a tooth decay o dental caries contributes t increased ris chronic disea

Honey	3 kcal/g	Made from sucrose. Contains nectar of flowering plants. Made by bees.Sucrose is fructose + glucose; however, honey contains more calories than sucrose because honey is denser.	*Considered safe for baking and cooking.Infants under twelve months old should not be given honey because their digestive tracts cannot handle the bacteria found in honey. Older children and adults are immune to these effects. Honey contains some harmful bacteria that can cause fatal food poisoning in infants.	
HFCS • high fructose corn syrup	Dry form: 4 kcal/g; Liquid form: 3 kcal/g	Corn is milled to produce corn starch, then the cornstarch is further processed to yield corn syrup.		Controversia because it is ubiquitously processed fo products, wh could lead to overconsump Study results varied regard its role in chr disease.
Sugar Alcohols • Sorbitol • Xylitol • Mannitol	2–4 kcal/ g.Not calorie free	Sugar alcohols.Sorbitol is derived from glucose.	Less likely to cause tooth decay than sucrose.Sugar alcohols have a laxative effect.	May cause diarrhea and gastrointesti distress if consumed in amounts.

CHAPTER 6. LIPIDS

Introduction

Image by Phu Thinh Co / CC BY-SA 2.0

Learning Objectives

By the end of this chapter, you will be able to:

- Describe the function and role of lipids in the body
- Describe the process of lipid digestion and absorption
- Describe tools and methods for balancing your diet with lipids

The coconut provided a valuable source of fat to a diet that was generally low in fat as the major nutrient found in the mature coconut is fat. As you read further, you will learn the different types of fats, their essential roles in the body, and the potential health consequences and benefits of diets rich in particular lipids. You will be better equipped to decide the best way to get your nutritional punch from various fats in your diet.

Lipids are important molecules that serve different roles in the human body. A common misconception is that fat is simply fattening. However, fat is probably the reason we are all here. Throughout history, there have been many instances when food was scarce. Our ability to store excess caloric energy as fat for future usage allowed us to continue as a species during these times of famine. So, normal fat reserves are a signal that metabolic processes are efficient and a person is healthy.

Lipids are a family of organic compounds that are mostly insoluble in water. Composed of fats and oils, lipids are molecules that yield high energy and have a chemical composition mainly of carbon, hydrogen, and oxygen. Lipids perform three primary biological functions within the body: they serve as structural components of cell membranes, function as energy storehouses, and function as important signaling molecules.

The three main types of lipids are triglycerides, phospholipids, and sterols. Triglycerides make up more than 95 percent of lipids in the diet and are commonly found in fried foods, vegetable oil, butter, whole milk, cheese, cream cheese, and some meats. Naturally occurring triglycerides are found in many foods, including avocados, olives, corn, and nuts. We commonly call the triglycerides in our food "fats" and "oils." Fats are lipids that are solid at room temperature, whereas oils are liquid. As with most fats, triglycerides do not dissolve in water. The terms fats, oils, and triglycerides are discretionary and can be used interchangeably. In this chapter when we use the word fat, we are referring to triglycerides.

Phospholipids make up only about 2 percent of dietary lipids. They are water-soluble and are found in both plants and animals. Phospholipids are crucial for building the protective barrier, or membrane, around your body's cells. In fact, phospholipids are synthesized in the body to form cell and organelle membranes. In blood and body fluids, phospholipids form structures in which fat is enclosed and transported throughout the bloodstream.

Sterols are the least common type of lipid. Cholesterol is perhaps the best well-known sterol. Though cholesterol has a notorious reputation, the body gets only a small amount of its cholesterol through food—the body produces most of it. Cholesterol is an important component of the cell membrane and is required for the synthesis of sex hormones, vitamin D, and bile salts.

Later in this chapter, we will examine each of these lipids in more detail and discover how their different structures function to keep your body working.

Figure 6.1 Types of Lipids

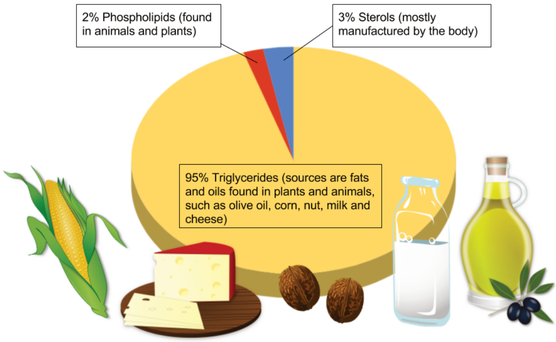


Image by Allison Calabrese / CC BY 4.0

The Functions of Lipids in the Body

Storing Energy

The excess energy from the food we eat is digested and incorporated into adipose tissue, or fatty tissue. Most of the energy required by the human body is provided by carbohydrates and lipids. As discussed in the Carbohydrates chapter, glucose is stored in the body as glycogen. While glycogen provides a ready source of energy, lipids primarily function as an energy reserve. As you may recall, glycogen is quite bulky with heavy water content, thus the body cannot store too much for long. Alternatively, fats are packed together tightly without water and store far greater amounts of energy in a reduced space. A fat gram is densely concentrated with energy—it contains more than double the amount of energy than a gram of carbohydrate. Energy is needed to power the muscles for all the physical work and play an average person or child engages in. For instance, the stored energy in muscles propels an athlete down the track, spurs a dancer's legs to showcase the latest fancy steps, and keeps all the moving parts of the body functioning smoothly.

Unlike other body cells that can store fat in limited supplies, fat cells are specialized for fat storage and are able to expand almost indefinitely in size. An overabundance of adipose tissue can result in undue stress on the body and can be detrimental to your health. A serious impact of excess fat is the accumulation of too much cholesterol in the arterial wall, which can thicken the walls of arteries and lead to cardiovascular disease. Thus, while some body fat is critical to our survival and good health, in large quantities it can be a deterrent to maintaining good health.

Regulating and Signaling

Triglycerides control the body's internal climate, maintaining constant temperature. Those who don't have enough fat in their bodies tend to feel cold sooner, are often fatigued, and have pressure sores on their skin from fatty acid deficiency. Triglycerides also help the body produce and regulate hormones. For example, adipose tissue secretes the hormone leptin, which regulates appetite. In the reproductive system, fatty acids are required for proper reproductive health. Women who lack proper amounts may stop menstruating and become infertile. Omega-3 and omega-6 essential fatty acids help regulate cholesterol and blood clotting and control inflammation in the joints, tissues, and bloodstream. Fats also play important functional roles in sustaining nerve impulse transmission, memory storage, and tissue structure. More specifically in the brain, lipids are focal to brain activity in structure and in function. They help form nerve cell membranes, insulate neurons, and facilitate the signaling of electrical impulses throughout the brain.

Insulating and Protecting

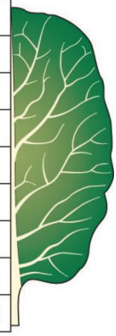
Did you know that up to 30 percent of body weight is comprised of fat tissue? Some of this is made up of visceral fat or adipose tissue surrounding delicate organs. Vital organs such as the heart, kidneys, and liver are protected by visceral fat. The composition of the brain is outstandingly 60 percent fat, demonstrating the major structural role that fat serves within the body. You may be most familiar with subcutaneous fat, or fat underneath the skin. This blanket layer of tissue insulates the body from extreme temperatures and helps keep the internal climate under control. It pads our hands and buttocks and prevents friction, as these areas frequently come in contact with hard surfaces. It also gives the body the extra padding required when engaging in physically demanding activities such as ice- or roller skating, horseback riding, or snowboarding.

Aiding Digestion and Increasing Bioavailability

The dietary fats in the foods we eat break down in our digestive systems and begin the transport of precious micronutrients. By carrying fat-soluble nutrients through the digestive process, intestinal absorption is improved. This improved absorption is also known as increased bioavailability. Fat-soluble nutrients are especially important for good health and exhibit a variety of functions. Vitamins A, D, E, and K—the fat-soluble vitamins—are mainly found in foods containing fat. Some fat-soluble vitamins (such as vitamin A) are also found in naturally fat-free foods such as green leafy vegetables, carrots, and broccoli. These vitamins are best absorbed when combined with foods containing fat. Fats also increase the bioavailability of compounds known as phytochemicals, which are plant constituents such as lycopene (found in tomatoes) and beta-carotene (found in carrots). Phytochemicals are believed to promote health and well-being. As a result, eating tomatoes with olive oil or salad dressing will facilitate lycopene absorption. Other essential nutrients, such as essential fatty acids, are constituents of the fats themselves and serve as building blocks of a cell.

Figure 6.2 Food Sources of Omega 3’s

Tools for Change omega 3 fat sources		
Best	Better	Good
Salmon	Scallops	Halibut
Flax seeds	Cauliflower	Shrimp
Walnuts	Cabbage	Cod
	Cloves	Tuna
	Mustard seeds	Soybeans
		Tofu
		Kale
		Collard greens
		Brussel sprouts



Note that removing the lipid elements from food also takes away the food’s fat-soluble vitamin content. When products such as grain and dairy are processed, these essential nutrients are lost. Manufacturers replace these nutrients through a process called enrichment.

The Role of Lipids in Food

High Energy Source

Fat-rich foods naturally have a high caloric density. Foods that are high in fat contain more calories than foods high in protein or carbohydrates. As a result, high-fat foods are a convenient source of energy. For example, 1 gram of fat or oil provides 9 kilocalories of energy, compared with 4 kilocalories found in 1 gram of carbohydrate or protein. Depending on the level of physical activity and on nutritional needs, fat requirements vary greatly from person to person. When energy needs are high, the body welcomes the high-caloric density of fats. For instance, infants and growing children require proper amounts of fat to support normal growth and development. If an infant or child is given a low-fat diet for an extended period, growth and development will not progress normally. Other individuals with high-energy needs are athletes, people who have physically demanding jobs, and those recuperating from illness.

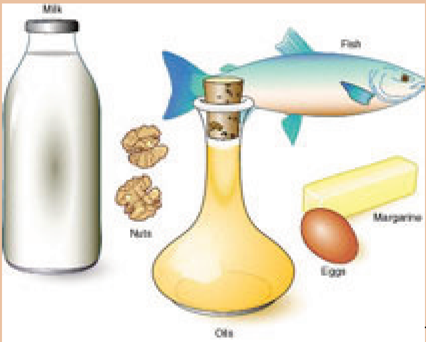
When the body has used all of its calories from carbohydrates (this can occur after just twenty minutes of exercise), it initiates fat usage. A professional swimmer must consume large amounts of food energy to meet the demands of swimming long distances, so eating fat-rich foods makes sense. In contrast, if a person who leads a sedentary lifestyle eats the same high-density fat foods, they will intake more fat calories than their body requires within just a few bites. Use caution—consumption of calories over and beyond energy requirements is a contributing factor to obesity.

Smell and Taste

Fat contains dissolved compounds that contribute to mouth-watering aromas and flavors. Fat also adds texture to food. Baked foods are supple and moist. Frying foods locks in flavor and lessens cooking time. How long does it take you to recall the smell of your favorite food cooking? What would a meal be without that savory aroma to delight your senses and heighten your preparedness for eating a meal?

Fat plays another valuable role in nutrition. Fat contributes to satiety, or the sensation of fullness. When fatty foods are swallowed the body responds by enabling the processes controlling digestion to retard the movement of food along the digestive tract, thus promoting an overall sense of fullness. Oftentimes before the feeling of fullness arrives, people overindulge in fat-rich foods, finding the delectable taste irresistible. Indeed, the very things that make fat-rich foods attractive also make them a hindrance to maintaining a healthful diet.

Tools for Change



There are many sources of omega-3 foods.

It is important to strike a proper balance between omega-3 and omega-6 fats in your diet. Research suggests that a diet that is too high in omega-6 fats distorts the balance of proinflammatory agents, promoting chronic inflammation and causing the potential for health problems such as asthma, arthritis, allergies, or diabetes. Omega-6 fats compete with omega-3 fats for enzymes and will actually replace omega-3 fats. The typical western diet is characterized by an excessive consumption of foods high in omega-6 fatty acids. To gain proper balance between the two, increase your omega-3 fat intake by eating more fatty fish or other sources of omega-3 fatty acids at least two times per week.

How Lipids Work

Lipids are unique organic compounds, each serving key roles and performing specific functions within the body. As we discuss the various types of lipids (triglycerides, phospholipids, and sterols) in further detail, we will compare their structures and functions and examine their impact on human health.

Triglycerides Structure and Functions

Triglycerides are the main form of lipid found in the body and in the diet. Fatty acids and glycerol are the building blocks of triglycerides. Glycerol is a thick, smooth, syrupy compound that is often used in the food industry. To form a triglyceride, a glycerol molecule is joined by three fatty acid chains. triglycerides contain varying mixtures of fatty acids.

Figure 6.3 The Structure of a Triglycerides

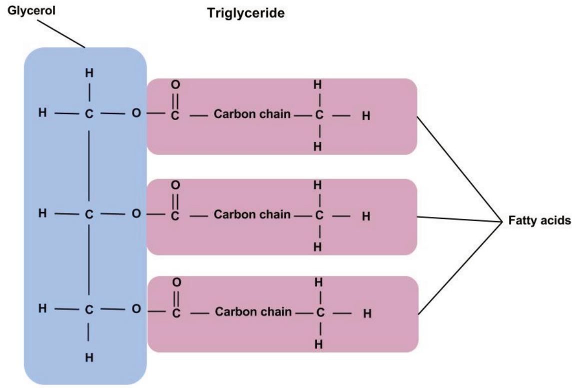


Image by Allison Calabrese/ CC BY 4.0

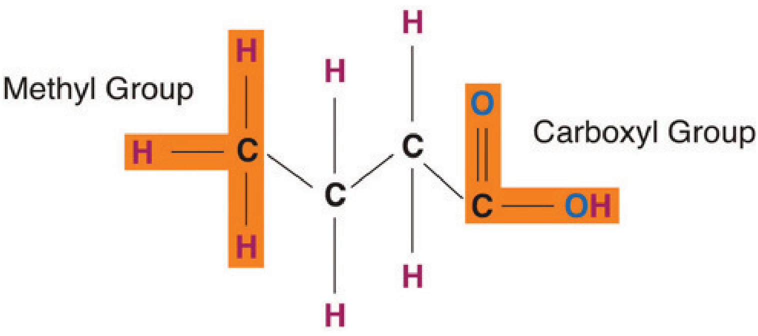
Fatty Acids

Fatty acids determine if the compound is solid or liquid at room temperature. Fatty acids consist of a carboxylic acid (−COOH) group on one end of a carbon chain and a methyl group (−CH3) on the other end. Fatty acids can differ from one another in two important ways—carbon chain length and degree of saturation.

It's All in the Chain

Fatty acids have different chain lengths and different compositions. Foods have fatty acids with chain lengths between four and twenty-four carbons and most of them contain an even number of carbon atoms. When the carbon chain length is shorter, the melting point of the fatty acid becomes lower—and the fatty acid becomes more liquid.

Figure 6.4 Structures of a Saturated, Monounsaturated, and Polyunsaturated Fat



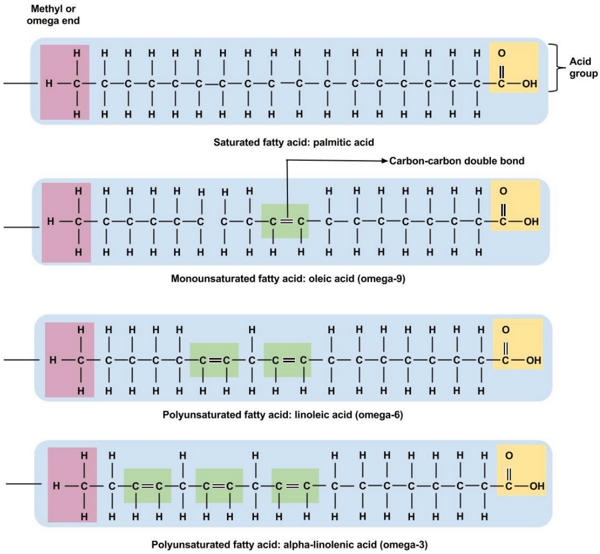


Image by Allison Calabrese / CC BY 4.0

Fatty Acid Types in the Body

The fatty-acid profile of the diet directly correlates to the tissue lipid profile of the body. It may not solely be the quantity of dietary fat that matters. More directly, the type of dietary fat ingested has been shown to affect body weight, composition, and metabolism. The fatty acids consumed are often incorporated into the triglycerides within the body. Evidence confirms that saturated fatty acids are linked to higher rates of weight retention when compared to other types of fatty acids. Alternatively, the fatty acids found in fish oil are proven to reduce the rate of weight gain as compared to other fatty acids.[1]

Degrees of Saturation

Fatty acid chains are held together by carbon atoms that attach to each other and to hydrogen atoms. The term saturation refers to whether or not a fatty acid chain is filled (or "saturated") to capacity with hydrogen atoms. If each available carbon bond holds a hydrogen atom we call this a saturated fatty acid chain. All carbon atoms in such a fatty acid chain are bonded with single bonds. Sometimes the chain has a place where hydrogen atoms are missing. This is referred to as the point of unsaturation.

When one or more bonds between carbon atoms are a double bond (C=C), that fatty acid is called an unsaturated fatty acid, as it has one or more points of unsaturation. Any fatty acid that has only one double bond is a monounsaturated fatty acid, an example of which is olive oil (75 percent of its fat is monounsaturated). Monounsaturated fats help regulate blood cholesterol levels, thereby reducing the risk for heart disease and stroke. A polyunsaturated fatty acid is a fatty acid with two or more double bonds or two or more points of unsaturation. Soybean oil contains high amounts of polyunsaturated fatty acids. Both monounsaturated fats and polyunsaturated fats

1. Mori T, Kondo H. Dietary fish oil upregulates intestinal lipid metabolism and reduces body weight gain in C57BL/6J mice. J Nutr. 2007;137(12):2629-34. http://www.ncbi.nlm.nih.gov/pubmed/18029475. Accessed September 22, 2017.

provide nutrition that is essential for normal cell development and healthy skin.

Foods that have a high percentage of saturated fatty acids tend to be solid at room temperature. Examples of these are fats found in chocolate (stearic acid, an eighteen-carbon saturated fatty acid is a primary component) and meat. Foods rich in unsaturated fatty acids, such as olive oil (oleic acid, an eighteen-carbon unsaturated fatty acid, is a major component) tend to be liquid at room temperature. Flaxseed oil is rich in alpha-linolenic acid, which is an unsaturated fatty acid and becomes a thin liquid at room temperature.

Knowing the connection between chain length, degree of saturation, and the state of the fatty acid (solid or liquid) is important for making food choices. If you decide to limit or redirect your intake of fat products, then choosing unsaturated fat is more beneficial than choosing a saturated fat. This choice is easy enough to make because unsaturated fats tend to be liquid at room temperature (for example, olive oil) whereas saturated fats tend to be solid at room temperature (for example, butter). Avocados are rich in unsaturated fats. Most vegetable and fish oils contain high quantities of polyunsaturated fats. Olive oil and canola oil are also rich in monounsaturated fats. Conversely, tropical oils are an exception to this rule in that they are liquid at room temperature yet high in saturated fat. Palm oil (often used in food processing) is highly saturated and has been proven to raise blood cholesterol. Shortening, margarine, and commercially prepared products (in general) report to use only vegetable-derived fats in their processing. But even so, much of the fat they use may be in the saturated and trans fat categories.

Cis or *Trans* Fatty Acids?

The introduction of a carbon double bond in a carbon chain, as in an unsaturated fatty acid, can result in different structures for the same fatty acid composition. When the hydrogen atoms are bonded to the same side of the carbon chain, it is called a cis fatty acid. Because the hydrogen atoms are on the same side, the carbon chain has a bent structure. Naturally occurring fatty acids usually have a cis configuration.

In a trans fatty acid, the hydrogen atoms are attached on opposite sides of the carbon chain. Unlike cis fatty acids, most trans fatty acids are not found naturally in foods, but are a result of a process called hydrogenation. Hydrogenation is the process of adding hydrogen to the carbon double bonds, thus making the fatty acid saturated (or less unsaturated, in the case of partial hydrogenation). This is how vegetable oils are converted into semisolid fats for use in the manufacturing process.

According to the ongoing Harvard Nurses' Health Study, trans fatty acids have been associated with increased risk for coronary heart disease because of the way they negatively impact blood cholesterol levels.[2]

Figure 6.5 Structures of Saturated, Unsaturated, Cis and Trans fatty Acids

2. Introduction to "Fats and Cholesterol: Out with the Bad, In with the Good" The Nutrition Source. Harvard School of Public Health. http://www.hsph.harvard.edu/nutritionsource/what-should-you-eat/fats-full-story/#references. Updated 2017. Accessed September 28, 2017.

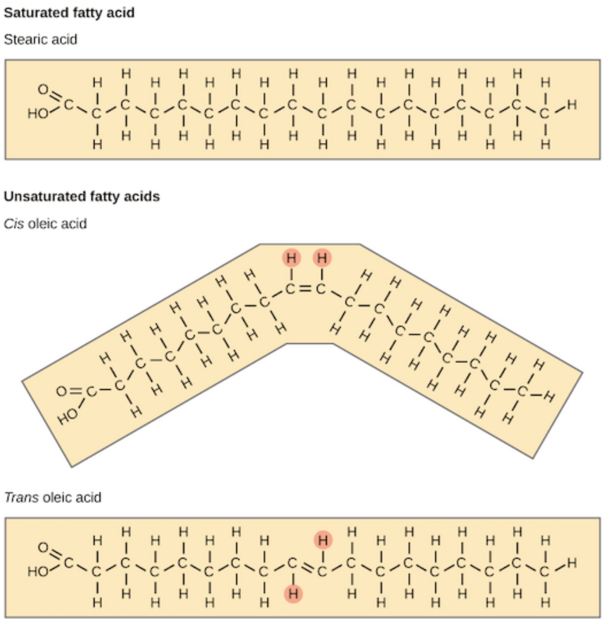


Image by Openstax Biology / CC BY 4.0

Interestingly, some naturally occurring trans fats do not pose the same health risks as their artificially engineered counterparts. These trans fats are found in ruminant animals such as cows, sheep, and goats, resulting in trans fatty acids being present in our meat, milk, and other dairy product supply. These trans fats comprise 15 to 20 percent of the total trans-fat intake in our diet. While we know that trans fats are not exactly harmless, it seems that any negative effect naturally occurring trans fats have are counteracted by the presence of other fatty acid molecules in these animal products, which work to promote human health.

Nonessential and Essential Fatty Acids

Fatty acids are vital for the normal operation of all body systems. The circulatory system, respiratory system, integumentary system, immune system, brain, and other organs require fatty acids for proper function. The body is capable of synthesizing most of the fatty acids it needs from food. These fatty acids are known as nonessential fatty acids. However, there are some fatty acids that the body cannot synthesize and these are called essential fatty acids. It is important to note that nonessential fatty acids doesn't mean unimportant; the classification is based solely on the ability of the body to synthesize the fatty acid.

Essential fatty acids must be obtained from food. They fall into two categories—omega-3 and omega-6. The 3 and 6 refer to the position of the first carbon double bond and the omega refers to the methyl end of the chain. Omega-3 and omega-6 fatty acids are precursors to important compounds called eicosanoids. Eicosanoids are powerful hormones that control many other hormones and important body functions, such as the central nervous system and the immune system. Eicosanoids derived from omega-6 fatty acids are known to increase blood pressure, immune response, and inflammation. In contrast, eicosanoids derived from omega-3 fatty acids are known to have heart-healthy effects. Given the contrasting effects of the omega-3 and omega-6 fatty acids, a proper dietary balance between the two must be achieved to ensure optimal health benefits.

Essential fatty acids play an important role in the life and death of cardiac cells, immune system function, and blood pressure regulation. Docosahexaenoic acid (DHA) is an omega-3 essential fatty acid shown to play important roles in synaptic transmission in the brain during fetal development.

Some excellent sources of omega-3 and omega-6 essential fatty acids are fish, flaxseed oil, hemp, walnuts, and leafy vegetables. Because these essential fatty acids are easily accessible, essential fatty acid deficiency is extremely rare.

Figure 6.6 Essential Fatty Acids

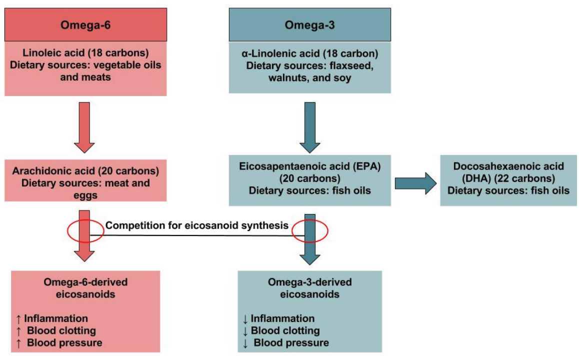


Image by Allison Calabrese / CC BY 4.0

Phospholipids

Like triglycerides, phospholipids have a glycerol backbone. But unlike triglycerides, phospholipids are diglycerides (two fatty-acid molecules attached to the glycerol backbone) while their third fatty-acid chain has a phosphate group coupled with a nitrogen-containing group. This unique structure makes phospholipids water soluble. Phospholipids are what we call amphiphilic—the fatty-acid sides are hydrophobic (dislike water) and the phosphate group is hydrophilic (likes water).

In the body phospholipids bind together to form cell membranes. The amphiphilic nature of phospholipids governs their function as components of cell membranes. The phospholipids form a double layer in cell membranes, thus effectively protecting the inside of the cell from the outside environment while at the same time allowing for transport of fat and water through the membrane.

Figure 6.7 The Structure of a Phospholipid

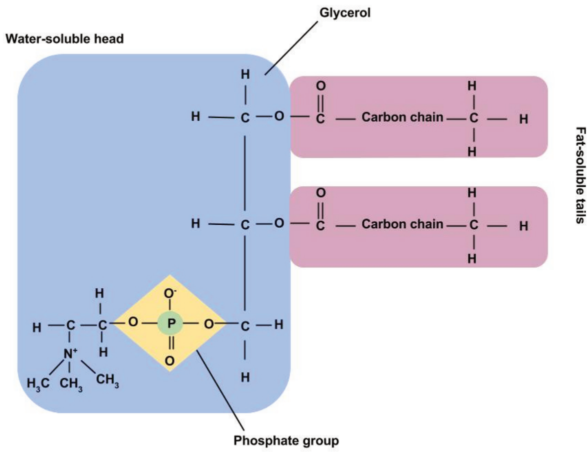


Image by Allison Calabrese / CC BY 4.0

Phospholipids are ideal emulsifiers that can keep oil and water mixed. Emulsions are mixtures of two liquids that do not mix. Without emulsifiers, the fat and water content would be somewhat separate within food. Lecithin (phosphatidylcholine), found in egg yolk, honey, and mustard, is a popular food emulsifier. Mayonnaise demonstrates lecithin's ability to blend vinegar and oil to create the stable, spreadable condiment that so many enjoy. Food emulsifiers play an important role in making the appearance of food appetizing. Adding emulsifiers to sauces and creams not only enhances their appearance but also increases their freshness.

Lecithin's crucial role within the body is clear, because it is present in every cell throughout the body; 28 percent of brain matter is composed of lecithin and 66 percent of the fat in the liver is lecithin. Many people attribute health-promoting properties to lecithin, such as its ability to lower blood cholesterol and aid with weight loss. There are several lecithin supplements on the market broadcasting these claims. However, as the body can make most phospholipids, it is not necessary to consume them in a pill. The body makes all of the lecithin that it needs.

Figure 6.8 The Difference Between Triglycerides and Phospholipids

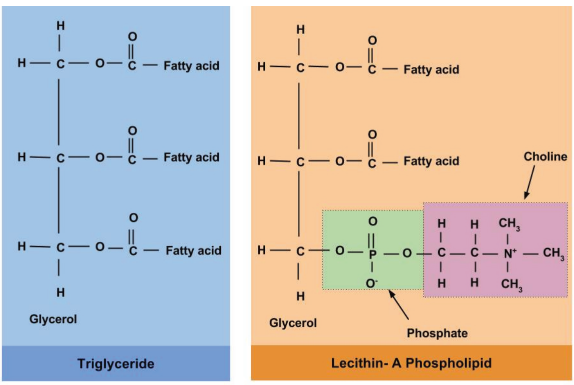


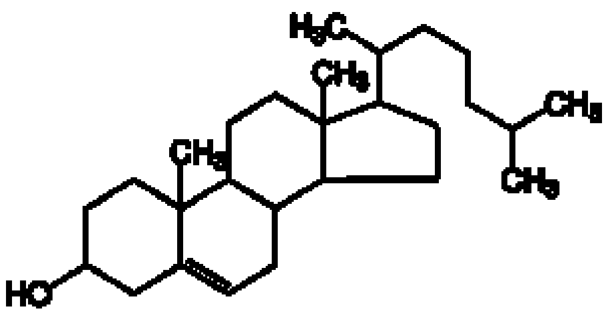
Image by Allison Calabrese / CC BY 4.0

Sterols

Sterols have a very different structure from triglycerides and phospholipids. Most sterols do not contain any fatty acids but rather multiring structures. They are complex molecules that contain interlinking rings of carbon atoms, with side chains of carbon, hydrogen, and oxygen attached. Cholesterol is the best-known sterol because of its role in heart disease. It forms a large part of the plaque that narrows the arteries in atherosclerosis. In stark contrast, cholesterol does have specific beneficial functions to perform in the body. Like phospholipids, cholesterol is present in all body cells as it is an important substance in cell membrane structure. Approximately 25 percent of cholesterol in the body is localized in brain tissue. Cholesterol is used in the body to make a number of important things, including vitamin D, glucocorticoids, and the sex hormones, progesterone, testosterone, and estrogens. Notably, the sterols found in plants resemble cholesterol in structure. However, plant sterols inhibit cholesterol absorption in the human body, which can contribute to lower cholesterol levels.

Although cholesterol is preceded by its infamous reputation, it is clearly a vital substance in the body that poses a concern only when there is excess accumulation of it in the blood. Like lecithin, the body can synthesize cholesterol.

Figure 6.9 The Structure of Cholesterol



"Cholesterol Chemical Structure" by Wesalius / Public Domain

Digestion and Absorption of Lipids

Lipids are large molecules and generally are not water-soluble. Like carbohydrates and protein, lipids are broken into small components for absorption. Since most of our digestive enzymes are water-based, how does the body break down fat and make it available for the various functions it must perform in the human body?

From the Mouth to the Stomach

The first step in the digestion of triglycerides and phospholipids begins in the mouth as lipids encounter saliva. Next, the physical action of chewing coupled with the action of emulsifiers enables the digestive enzymes to do their tasks. The enzyme lingual lipase, along with a small amount of phospholipid as an emulsifier, initiates the process of digestion. These actions cause the fats to become more accessible to the digestive enzymes. As a result, the fats become tiny droplets and separate from the watery components.

Figure 6.10 Lipid Digestion and Absorption

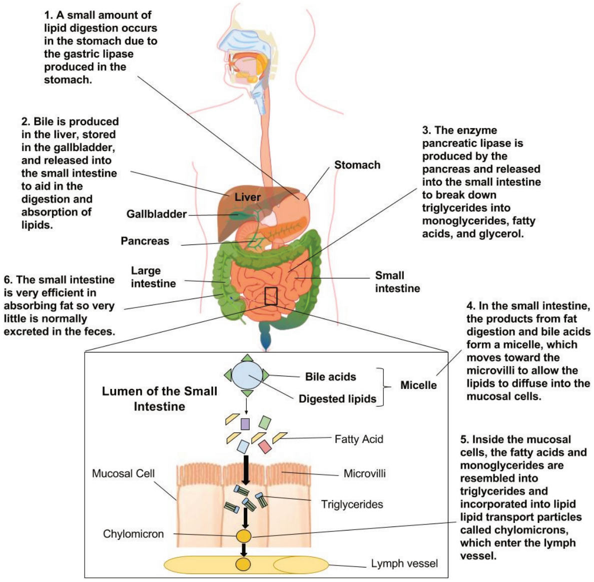


Image by Allison Calabrese / CC BY 4.0

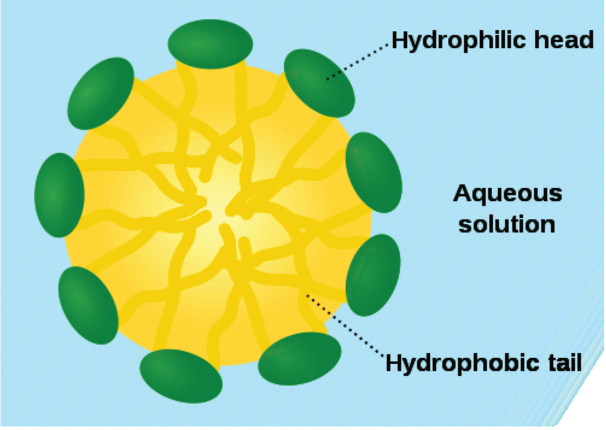
In the stomach, gastric lipase starts to break down triglycerides into diglycerides and fatty acids. Within two to four hours after eating a meal, roughly 30 percent of the triglycerides are converted to diglycerides and fatty acids. The stomach's churning and contractions help to disperse the fat molecules, while the diglycerides derived in this process act as further emulsifiers. However, even amid all of this activity, very little fat digestion occurs in the stomach.

Going to the Bloodstream

As stomach contents enter the small intestine, the digestive system sets out to manage a small hurdle, namely, to combine the separated fats with its own watery fluids. The solution to this hurdle is bile. Bile contains bile salts, lecithin, and substances derived from cholesterol so it acts as an emulsifier. It attracts and holds onto fat while it is simultaneously attracted to and held on to by water. Emulsification increases the surface area of lipids over a thousand-fold, making them more accessible to the digestive enzymes.

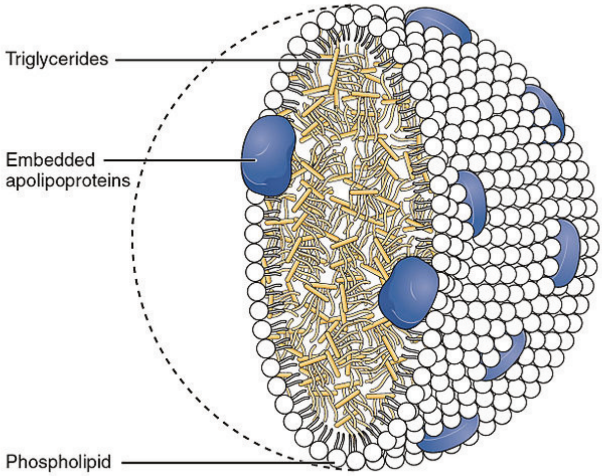
Once the stomach contents have been emulsified, fat-breaking enzymes work on the triglycerides and diglycerides to sever fatty acids from their glycerol foundations. As pancreatic lipase enters the small intestine, it breaks down the fats into free fatty acids and monoglycerides. Yet again, another hurdle presents itself. How will the fats pass through the watery layer of mucus that coats the absorptive lining of the digestive tract? As before, the answer is bile. Bile salts envelop the fatty acids and monoglycerides to form micelles. Micelles have a fatty acid core with a water-soluble exterior. This allows efficient transportation to the intestinal microvillus. Here, the fat components are released and disseminated into the cells of the digestive tract lining.

Figure 6.11 Micelle Formation



Scheme of a micelle formed by phospholipids in an aqueous solution by Emmanuel Boutet / CC BY-SA 3.0

Figure 6.12 Schematic Diagram Of A Chylomicron



Chylomicrons Contain Triglycerides Cholesterol Molecules and other Lipids by OpenStax College / CC BY 3.0

Just as lipids require special handling in the digestive tract to move within a water-based environment, they require similar handling to travel in the bloodstream. Inside the intestinal cells, the monoglycerides and fatty acids reassemble themselves into triglycerides. Triglycerides, cholesterol, and phospholipids form lipoproteins when joined with a protein carrier. Lipoproteins have an inner core that is primarily made up of triglycerides and cholesterol esters (a cholesterol ester is a cholesterol linked to a fatty acid). The outer envelope is made of phospholipids interspersed with proteins and cholesterol. Together they form a chylomicron, which is a large lipoprotein that now enters the lymphatic system and will soon be released into the bloodstream via the jugular vein in the neck. Chylomicrons transport food fats perfectly through the body's water-based environment to specific destinations such as the liver and other body tissues.

Cholesterols are poorly absorbed when compared to phospholipids and triglycerides. Cholesterol absorption is aided by an increase in dietary fat components and is hindered by high fiber content. This is the reason that a high intake of fiber is recommended to decrease blood cholesterol. Foods high in fiber such as fresh fruits, vegetables, and oats can bind bile salts and cholesterol, preventing their absorption and carrying them out of the colon.

If fats are not absorbed properly as is seen in some medical conditions, a person's stool will contain high amounts of fat. If fat malabsorption persists the condition is known as steatorrhea. Steatorrhea can result from diseases that affect absorption, such as Crohn's disease and cystic fibrosis.

Figure 6.13 Cholesterol and Soluble Fiber

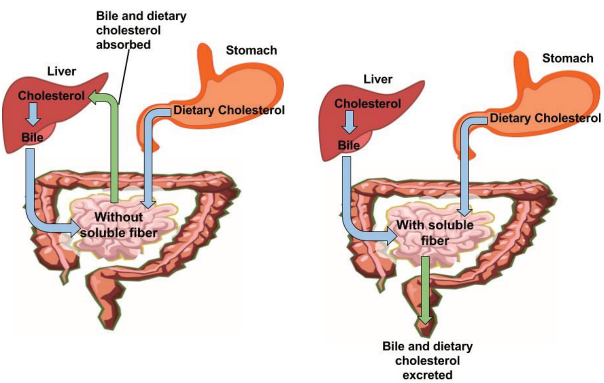


Image by Allison Calabrese / CC BY 4.0

The Truth about Storing and Using Body Fat

Before the prepackaged food industry, fitness centers, and weight-loss programs, our ancestors worked hard to even locate a meal. They made plans, not for losing those last ten pounds to fit into a bathing suit for vacation, but rather for finding food. Today, this is why we can go long periods without eating, whether we are sick with a vanished appetite, our physical activity level has increased, or there is simply no food available. Our bodies reserve fuel for a rainy day.

One way the body stores fat was previously touched upon in the Carbohydrates chapter. The body transforms carbohydrates into glycogen that is in turn stored in the muscles for energy. When the muscles reach their capacity for glycogen storage, the excess is returned to the liver, where it is converted into triglycerides and then stored as fat.

In a similar manner, much of the triglycerides the body receives from food is transported to fat storehouses within the body if not used for producing energy. The chylomicrons are responsible for shuttling the triglycerides to various locations such as the muscles, breasts, external layers under the skin, and internal fat layers of the abdomen, thighs, and buttocks where they are stored by the body in adipose tissue for future use. How is this accomplished? Recall that chylomicrons are large lipoproteins that contain a triglyceride and fatty-acid core. Capillary walls contain an enzyme called lipoprotein-lipase that dismantles the triglycerides in the lipoproteins into fatty acids and glycerol, thus enabling these to enter into the adipose cells. Once inside the adipose cells, the fatty acids and glycerol are reassembled into triglycerides and stored for later use. Muscle cells may also take up the fatty acids and use them for muscular work and generating energy. When a person's energy requirements exceed the amount of available fuel presented from a recent meal or extended physical activity has exhausted glycogen energy reserves, fat reserves are retrieved for energy utilization.

As the body calls for additional energy, the adipose tissue responds by dismantling its triglycerides and dispensing glycerol and fatty acids directly into the blood. Upon receipt of these substances the energy-hungry cells break them down further into tiny fragments. These fragments go through a series of chemical reactions that yield energy, carbon dioxide, and water.

Figure 6.14 Storing and Using Fat

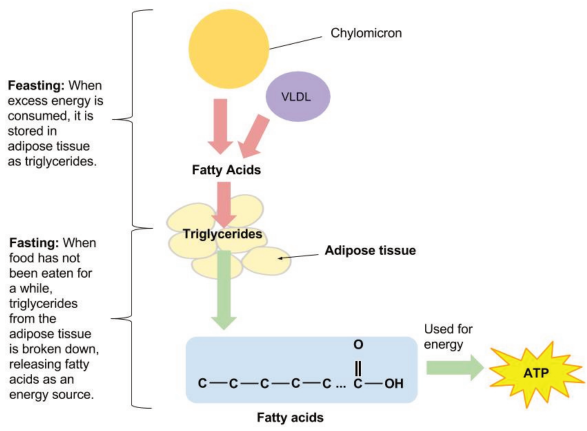


Image by Allison Calabrese / CC BY 4.0

Understanding Blood Cholesterol

You may have heard of the abbreviations LDL and HDL with respect to heart health. These abbreviations refer to low-density lipoprotein (LDL) and high-density lipoprotein (HDL), respectively. Lipoproteins are characterized by size, density, and composition. As the size of the lipoprotein increases, the density decreases. This means that HDL is smaller than LDL. Why are they referred to as "good" and "bad" cholesterol? What should you know about these lipoproteins?

Major Lipoproteins

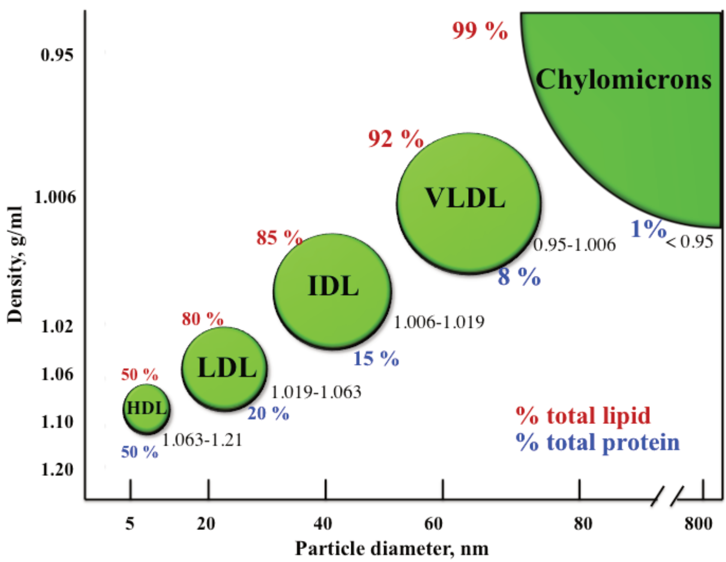
Recall that chylomicrons are transporters of fats throughout the watery environment within the body. After about ten hours of circulating throughout the body, chylomicrons gradually release their triglycerides until all that is left of their composition is cholesterol-rich remnants. These remnants are used as raw materials by the liver to formulate specific lipoproteins. Following is a list of the various lipoproteins and their functions:

- VLDLs. Very low-density lipoproteins are made in the liver from remnants of chylomicrons and transport triglycerides from the liver to various tissues in the body. As the VLDLs travel through the circulatory system, the lipoprotein lipase strips the VLDL of triglycerides. As triglyceride removal persists, the VLDLs become intermediate-density lipoproteins.
- IDLs. Intermediate-density lipoproteins transport a variety of fats and cholesterol in the bloodstream and are a little under half triglyceride in composition. While travelling in the bloodstream, cholesterol is gained from other lipoproteins while circulating enzymes strip its phospholipid component. When IDLs return to the liver, they are transformed into low-density lipoprotein.
- LDLs. As low-density lipoproteins are commonly known as the "bad cholesterol" it is imperative that we understand their function in the body so as to make healthy dietary and lifestyle choices. LDLs carry cholesterol and other lipids from the liver to tissue throughout the body. LDLs are comprised of very small amounts of triglycerides, and house over 50 percent cholesterol and cholesterol esters. How does the body receive the lipids contained therein? As the LDLs deliver cholesterol and other lipids to the cells, each cell's surface has receptor systems specifically designed to bind with LDLs. Circulating LDLs in the bloodstream bind to these LDL receptors and are consumed. Once inside the cell, the LDL is taken apart and its cholesterol is released. In liver cells these receptor systems aid in controlling blood cholesterol levels as they

bind the LDLs. A deficiency of these LDL binding mechanisms will leave a high quantity of cholesterol traveling in the bloodstream, which can lead to heart disease or atherosclerosis. Diets rich in saturated fats will prohibit the LDL receptors which, are critical for regulating cholesterol levels.

- HDLs. High-density lipoproteins are responsible for carrying cholesterol out of the bloodstream and into the liver, where it is either reused or removed from the body with bile. HDLs have a very large protein composition coupled with low cholesterol content (20 to 30 percent) compared to the other lipoproteins. Hence, these high-density lipoproteins are commonly called "good cholesterol."

Figure 6.15 Lipoprotein Classes



The classification of the major types of lipoproteins are based on their densities. Density range is shown as well as lipid (red) and protein (blue) content. (Diagram not to scale) / CC BY 3.0

Blood Cholesterol Recommendations

For healthy total blood cholesterol, the desired range you would want to maintain is under 200 mg/dL. More specifically, when looking at individual lipid profiles, a low amount of LDL and a high amount of HDL prevents excess buildup of cholesterol in the arteries and wards off potential health hazards. An LDL level of less than 100 milligrams per deciliter is ideal while an LDL level above 160 mg/dL would be considered high. In contrast, a low value of HDL is a telltale sign that a person is living with major risks for disease. Values of less than 40 mg/dL for men and 50 mg/dL for women mark a risk factor for developing heart disease. In short, elevated LDL blood lipid profiles indicate an increased risk of heart attack, while elevated HDL blood lipid profiles indicate a reduced risk.The University of Maryland Medical Center reports that omega-3 fatty acids promote lower total cholesterol and lower triglycerides in people with high cholesterol.[1]

It is suggested that people consume omega-3 fatty acids such as alpha-linolenic acid in their diets regularly. Polyunsaturated fatty acids are especially beneficial to consume because they both lower LDL and elevate HDL, thus contributing to healthy blood cholesterol levels. The study also reveals that saturated and trans fatty acids serve as catalysts for the increase of LDL cholesterol. Additionally, trans fatty acids

1. Omega-3 fatty acids. University of Maryland Medical Center. http://www.umm.edu/altmed/articles/omega-3-000316.htm. Updated August 5, 2015. Accessed September 28, 2017.

decrease HDL levels, which can impact negatively on total blood cholesterol.

Tools for Change

Being conscious of the need to reduce cholesterol means limiting the consumption of saturated fats and trans fats. Remember that saturated fats found in some meat, whole-fat dairy products, and tropical oils elevate your total cholesterol. Trans fats, such as the ones often found in margarines, processed cookies, pastries, crackers, fried foods, and snack foods also elevate your cholesterol levels. Read and select from the following suggestions as you plan ahead:

1. Soluble fiber reduces cholesterol absorption in the bloodstream. Try eating more oatmeal, oat bran, kidney beans, apples, pears, citrus fruits, barley, and prunes.
2. Fatty fish are heart-healthy due to high levels of omega-3 fatty acids that reduce inflammation and lower cholesterol levels. Consume mackerel, lake trout, herring, sardines, tuna, salmon, and halibut. Grilling or baking is the best to avoid unhealthy trans fats that could be added from frying oil.
3. Walnuts, almonds, peanuts, hazelnuts, pecans, some pine nuts, and pistachios all contain high levels of unsaturated fatty acids that aid in lowering LDL. Make sure the nuts are raw and unsalted. Avoid sugary or salty nuts. One ounce each day is a good amount.
4. Olive oil contains a strong mix of antioxidants and monounsaturated fat, and may lower LDL while leaving HDL intact. Two tablespoons per day in place of less healthy saturated fats may contribute to these heart-healthy effects without adding extra calories. Extra virgin olive oil promises a greater effect, as the oil is minimally processed and contains more heart-healthy antioxidants.

Testing Your Lipid Profile

The danger of consuming foods rich in cholesterol and saturated and trans fats cannot be overemphasized. Regular testing can provide the foreknowledge necessary to take action to help prevent any life-threatening events.

Current guidelines recommend testing for anyone over age twenty. If there is family history of high cholesterol, your healthcare provider may suggest a test sooner than this. Testing calls for a blood sample to be drawn after nine to twelve hours of fasting for an accurate reading. (By this time, most of the fats ingested from the previous meal have circulated through the body and the concentration of lipoproteins in the blood will be stabilized.)

The following total cholesterol values are used to target treatment[1]

- Desirable. Under 200 mg/dL
- Borderline high. 200–239 mg/dL
- High risk. 240 mg/dL and up

The following desired values are used to measure an overall lipid profile:

- LDL. Less than 160 mg/dL (if you have heart disease or diabetes, less than 100 mg/dL)
- HDL. Greater than 40–60 mg/dL
- triglycerides. 10–150 mg/dL
- VLDL. 2–38 mg/dL

1. High Blood Cholesterol: What You Need to Know. National Heart, Lung, and Blood Institute, National Institutes of Health. NIH Publication. http://www.nhlbi.nih.gov/health/public/heart/chol/wyntk.htm. Updated June 2005.Accessed September 28, 2017.

Balancing Your Diet with Lipids

You may reason that if some fats are healthier than other fats, why not consume as much healthy fat as desired? Remember, everything in moderation. As we review the established guidelines for daily fat intake, the importance of balancing fat consumption with proper fat sources will be explained.

Recommended Fat Intake

The acceptable macronutrient distribution range (AMDR) from the Dietary Reference Intake Committee for adult fat consumption is as follows[2]:

- Fat calories should be limited to 20–35 percent of total calories with most fats coming from polyunsaturated and monounsaturated fats, such as those found in fish, nuts, and vegetable oils.

- Consume fewer than 10 percent of calories from saturated fats. Some studies suggest that lowering the saturated fat content to less than 7 percent can further reduce the risk of heart disease.
- Keep the consumption of trans fats (any food label that reads hydrogenated or partially hydrogenated oil) to a minimum, less than 1 percent of calories.
- Think lean and low-fat when selecting meat, poultry, milk, and milk products.

2. Dietary Reference Intakes: Macronutrients. Institute of Medicine. https://www.nal.usda.gov/sites/default/files/fnic_uploads/DRIEssentialGuideNutReq.pdf. Published 2006. Accessed September 28, 2017.

The current AMDR for child and adolescent fat consumption (for children over four) are as follows:

- For children between ages four and eighteen years, between 25 and 35 percent of caloric intake should be from fat.
- For all age groups, most fats should come from polyunsaturated and monounsaturated fats such as fish, nuts, and vegetable oils.

Identifying Sources of Fat

Population-based studies of American diets have shown that intake of saturated fat is more excessive than intake of trans fat and cholesterol. Saturated fat is a prominent source of fat for most people as it is so easily found in animal fats, tropical oils such as coconut and palm oil, and full-fat dairy products. Oftentimes the fat in the diet of an average young person comes from foods such as cheese, pizza, cookies, chips, desserts, and animal meats such as chicken, burgers, sausages, and hot dogs. To aim for healthier dietary choices, the Heart and Stroke Foundation recommends choosing lean meats and vegetable alternatives, choosing dairy products with low fat content, and minimizing the intake of trans fats. The Heart and Stroke guidelines also recommend consuming fish, especially oily fish, at least twice per week.[3]

These more appropriate dietary choices will allow for enjoyment of a wide variety of foods while providing the body with the recommended levels of fat from healthier sources.

3. https://www.heartandstroke.ca/get-healthy/healthy-eating/fats-and-oils

Evaluate the following sources of fat in your overall dietary pattern:

- Monounsaturated fat. This type of fat is found in plant oils. Common sources are nuts (almonds, cashews, pecans, peanuts, and walnuts) and nut products, avocados, olive oil, sesame oil, high oleic safflower oil, sunflower oil, and canola oil.
- Polyunsaturated fat. This type of fat is found mainly in plant-based foods, oils, and fish. Common sources are nuts (walnuts, hazel nuts, pecans, almonds, and peanuts), soybean oil, corn oil, safflower oil, flaxseed oil, canola oil, and fish (trout, herring, and salmon).
- Saturated fat. This fat is found in animal products, dairy products, palm and coconut oils, and cocoa butter. Limit these products to less than 10 percent of your overall dietary fat consumption.
- Trans fatty acids. Stick margarines, shortening, fast foods, commercial baked goods, and some snack foods contain trans fats. Limit your consumption of these products to keep trans fats to less than 1 percent of your fat consumption.
- Omega-3 fatty acids (linolenic acid). Good sources of these are canola oil, flaxseed oil, soybean oil, olive oil, nuts, seeds, whole grains, legumes, and green leafy vegetables.
- Omega-3 fatty acids (DHA and EPA). Good sources of these are cod liver oil and fish such as tuna, herring, mackerel, salmon, and trout.
- Omega-6 fatty acids (linoleic acid). Eggs, poultry, most vegetable oils, wheat germ oil, whole grains, baked goods, and cereals contain these fatty acids. Omega-6 fatty acids are present abundantly in nuts and seeds such as flaxseeds, sunflower seeds, sesame seeds, and watermelon seeds.

Omega-3 and Omega-6 Fatty Acids

Recall that the body requires fatty acids and is adept at synthesizing the majority of these from fat, protein, and carbohydrate. However, when we say essential fatty acid we are referring to the two fatty acids that the body cannot create on its own, namely, linolenic acid and linoleic acid.

- Omega-3 Fatty Acids. At the helm of the omega-3 fatty acid family is linolenic acid. From this fatty acid, the body can make eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Linolenic acid is found in nuts, seeds, whole grains, legumes, and vegetable oil such as soybean, canola, and flaxseed. EPA and DHA are found abundantly in fatty fish.
- Omega-6 Fatty Acids. At the helm of the omega-6 fatty acid family is linoleic acid. Like linolenic acid, the body uses linoleic acid to make other important substances such as arachidonic acid (ARA) that is used to make eicosanoids. Recall that eicosanoids perform critical roles in the body as they affect a broad spectrum of functions. The word eicosanoid originates from the Greek word eicosa, meaning twenty, because this hormone is derived from ARA that is twenty carbon atoms in length. Eicosanoids affect the synthesis of all other body hormones and control all body systems, such as the central nervous system and the immune system. Among the many functions eicosanoids serve in the body, their primary function is to regulate inflammation. Without these hormones the body would not be able to heal wounds, fight infections, or fight off illness each time a foreign germ presented itself. Eicosanoids work together with the body's immune and inflammatory processes to play a major role in several important body functions, such as circulation, respiration, and muscle movement.

Attain the Omega-3 and Omega-6 Balance

As our food choices evolve, the sources of omega-6 fatty acids in our diets are increasing at a much faster rate than sources of omega-3 fatty acids. Omega-3s are plentiful in diets of non-processed foods where grazing animals and foraging chickens roam free, eating grass, clover, alfalfa, and grass-dwelling insects. In contrast, today's western diets are bombarded with sources of omega-6. For example, we have oils derived from seeds and nuts and from the meat of animals that are fed grain. Vegetable oils used in fast-food preparations, most snack-foods, cookies, crackers, and sweet treats are also loaded with omega-6 fatty acids. Also, our bodies synthesize eicosanoids from omega-6 fatty acids and these tend to increase inflammation, blood clotting, and cell proliferation, while the hormones synthesized from omega-3 fatty acids have just the opposite effect.

While omega-6 fatty acids are essential, they can be harmful when they are out of balance with omega-3 fatty acids. Omega-6 fats are required only in small quantities. Researchers believe that when omega-6 fats are out of balance with omega-3 fats in the diet they diminish the effects of omega-3 fats and their benefits. This imbalance may elevate the risks for allergies, arthritis, asthma, coronary heart disease, diabetes, and many types of cancer, autoimmunity, and neurodegenerative diseases, all of which are believed to originate from some form of inflammation in the body.

Lipids and the Food Industry

What is the first thing that comes to mind when you read ingredients such as "partially hydrogenated oil" and "hydrogenated oil" on a food label? Do you think of heart disease, heart health, or atherosclerosis? Most people probably do not. As we uncover what hydrogenation is and why manufacturers use it, you will be better equipped to adhere to healthier dietary choices and promote your heart health.

Hydrogenation: The Good Gone Bad?

Food manufacturers are aware that fatty acids are susceptible to attack by oxygen molecules because their points of unsaturation render them vulnerable in this regard. When oxygen molecules attack these points of unsaturation the modified fatty acid becomes oxidized. The oxidation of fatty acids makes the oil rancid and gives the food prepared with it an unappetizing taste. Because oils can undergo oxidation when stored in open containers, they must be stored in airtight containers and possibly be refrigerated to minimize damage from oxidation. Hydrogenation poses a solution that food manufacturers prefer.

When lipids are subjected to hydrogenation, the molecular structure of the fat is altered. Hydrogenation is the process of adding hydrogen to unsaturated fatty-acid chains, so that the hydrogen atoms are connected to the points of saturation and results in a more saturated fatty acid. Liquid oils that once contained more unsaturated fatty acids become semisolid or solid (upon complete hydrogenation) and behave like saturated fats. Oils initially contain polyunsaturated fatty acids. When the process of hydrogenation is not complete, for example, not all carbon double bonds have been saturated the end result is a partially hydrogenated oil. The resulting oil is not fully solid. Total hydrogenation makes the oil very hard and virtually unusable. Some newer products are now using fully hydrogenated oil combined with nonhydrogenated vegetable oils to create a usable fat.

Manufacturers favor hydrogenation as a way to prevent oxidation of oils and ensure longer shelf life. Partially hydrogenated vegetable oils are used in the fast food and processed food industries because they impart the desired texture and crispness to baked and fried foods. Partially hydrogenated vegetable oils are more resistant to breakdown from extremely hot cooking temperatures. Because hydrogenated oils have a high smoking point they are very well suited for frying. In addition, processed vegetable oils are cheaper than fats obtained from animal sources, making them a popular choice for the food industry.

Trans fatty acids occur in small amounts in nature, mostly in dairy products. However, the trans fats that are used by the food industry are produced from the hydrogenation process. Trans fats are a result of the partial hydrogenation of unsaturated fatty acids, which cause them to have a trans configuration, rather than the naturally occurring cis configuration.

Health Implications of Trans Fats

No trans fats! Zero trans fats! We see these advertisements on a regular basis. So widespread is the concern over the issue that restaurants, food manufacturers, and even fast-food establishments proudly tout either the absence or the reduction of these fats within their products. Amid the growing awareness that trans fats may not be good for you, let's get right to the heart of the matter. Why are trans fats so bad?

Processing naturally occurring fats to modify their texture from liquid to semisolid and solid forms results in the development of trans fats, which have been linked to an increased risk for heart disease. Trans fats are used in many processed foods such as cookies, cakes, chips, doughnuts, and snack foods to give them their crispy texture and increased shelf life. However, because trans fats can behave like saturated fats, the body processes them as if they were saturated fats. Consuming large amounts of trans fats has been associated with tissue inflammation throughout the body, insulin resistance in some people, weight gain, and digestive troubles. In addition, the hydrogenation process robs the person of the benefits of consuming the original oil because hydrogenation destroys omega-3 and omega-6 fatty acids. Like saturated fats, trans fats raise LDL "bad cholesterol," but unlike saturated fats, trans fats lower HDL "good cholesterol." You should limit trans-fat consumption to less than 1 percent.

How can you benefit from this information? When selecting your foods, steer clear of anything that says "hydrogenated," "fractionally hydrogenated," or "partially hydrogenated," and read food labels in the following categories carefully:

- cookies, crackers, cakes, muffins, pie crusts, pizza dough, and breads
- stick margarines and vegetable shortening
- premixed cake mixes, pancake mixes, and drink mixes
- fried foods and hard taco shells
- snack foods (such as chips), candy, and frozen dinners

Choose brands that don't use trans fats and that are low in saturated fats.

Dietary-Fat Substitutes

In response to the rising awareness and concern over the consumption of trans fat, various fat replacers have been developed. Fat substitutes aim to mimic the richness, taste, and smooth feel of fat without the same caloric content as fat. The carbohydrate-based replacers tend to bind water and thus dilute calories. Fat substitutes can also be made from proteins (for example, egg whites and milk whey). However, these are not very stable and are affected by changes in temperature, hence their usefulness is somewhat limited.

Tools for Change

One classic cinnamon roll can have 5 grams of trans fat, which is quite high for a single snack. Many packaged foods often have their nutrient contents listed for a very small serving size—much smaller than what people normally consume—which can easily lead you to eat many "servings." Labeling laws allow foods containing trans fat to be labeled "trans-fat free" if there are fewer than 0.5 grams per serving. This makes it possible to eat too much trans fat when you think you're not eating any at all because it is labeled trans-fat free.

Always review the label for trans fat per serving. Check the ingredient list, especially the first three to four ingredients, for telltale signs of hydrogenated fat such as partially or fractionated hydrogenated oil. The higher up the words "partially hydrogenated oil" are on the list of ingredients, the more trans fat the product contains.

Measure out one serving and eat one serving only. An even better choice would be to eat a fruit or vegetable. There are no trans fats and the serving size is more reasonable for similar calories. Fruits and vegetables are packed with water, fiber, and many vitamins, minerals, phytonutrients, and antioxidants. At restaurants be aware that phrases such as “cooked in vegetable oil” might mean hydrogenated vegetable oil, and therefore trans fat.

Lipids and Disease

Because heart disease, cancer, and stroke are the three leading causes of death in the Canada, it is critical to address dietary and lifestyle choices that will ultimately decrease risk factors for these diseases. The following risk factors are controllable: high blood pressure, high cholesterol, cigarette smoking, diabetes, poor diet, physical inactivity, being overweight, and obesity.
In light of that, we present the following informational tips to help you define, evaluate, and implement healthy dietary choices to last a lifetime. The amount and the type of fat that composes a person's dietary profile will have a profound effect upon the way fat and cholesterol is metabolized in the body.

Watch Out for Saturated Fat and Cholesterol

In proper amounts, cholesterol is a compound used by the body to sustain many important body functions. In excess, cholesterol is harmful if it accumulates in the structures of the body's vast network of blood vessels. High blood LDL and low blood HDL are major indicators of blood cholesterol risk. The largest influence on blood cholesterol levels rests in the mix of saturated fat and trans fat in the diet. According to the Harvard School of Public Health, for every extra 2 percent of calories from trans fat consumed per day—about the amount found in a midsize order of French fries at a fast-food establishment—the risk of coronary heart disease increases by

23 percent[1]. A buildup of cholesterol in the blood can lead to brittle blood vessels and a blockage of blood flow to the affected area.

How saturated is the fat in your diet? Is it really necessary to eat saturated fat when the body makes all the saturated fat that it needs? Saturated fats should fall into the "bad" category—the body does not demand this kind of fat and it is proven to be a forerunner of cardiovascular disease. In Canada and other developed countries, populations acquire their saturated fat content mostly from meat, seafood, poultry (with skin consumed), and whole-milk dairy products (cheese, milk, and ice cream). Some plant foods are also high in saturated fats, including coconut oil, palm oil, and palm kernel oil.

Food Cholesterol's Effect on Blood Cholesterol

Dietary cholesterol does have a small impact on overall blood cholesterol levels, but not as much as some people may think. The average Canadian female consumes 237 milligrams of dietary cholesterol per day and for males the figure is slightly higher—about 358 milligrams. Most people display little response to normal dietary cholesterol intake as the body responds by halting its own synthesis of the substance in favor of using the cholesterol obtained through food. Genetic factors may also influence the way a person's body modifies cholesterol. Limit saturated fats, thereby indirectly limiting

1. Fats and Cholesterol: Out with the Bad, In with the Good. Harvard School of Public Health. http://www.hsph.harvard.edu/nutritionsource/what-should-you -eat/fats-full-story/. Updated 2017. Accessed September 28, 2017.

dietary cholesterol since foods that are high in cholesterol tend to be high in saturated fats also.

A Prelude to Disease

If left unchecked, improper dietary fat consumption can lead down a path to severe health problems. An increased level of lipids, triglycerides, and cholesterol in the blood is called hyperlipidemia. Hyperlipidemia is inclusive of several conditions but more commonly refers to high cholesterol and triglyceride levels. When blood lipid levels are high, any number of adverse health problems may ensue. Consider the following:

- Cardiovascular disease. According to the Heart and Stroke foundation, cardiovascular disease encompasses a variety of problems, many of which are related to the process of atherosclerosis. Over time the arteries thicken and harden with plaque buildup, causing restricted or at times low or no blood flow to selected areas of the body.
- Heart attack. A heart attack happens when blood flow to a section of the heart is cut off due to a blood clot. Many have survived heart attacks and go on to return to their lives and enjoy many more years of life on this earth. However, dietary and lifestyle changes must be implemented to prevent further attacks.
- Ischemic stroke. The most common type of stroke in Canada, ischemic stroke, occurs when a blood vessel in the brain or leading to the brain becomes blocked, again usually from a blood clot. If part of the brain suffers lack of blood flow and/or oxygen for three minutes or longer, brain cells will start to die.
- Congestive heart failure. Sometimes referred to as heart

failure, this condition indicates that the heart is not pumping blood as well as it should. The heart is still working but it is not meeting the body's demand for blood and oxygen. If left unchecked, it can progress to further levels of malfunction.

- Arrhythmia. This is an abnormal rhythm of the heart. The heart may beat above one hundred beats per minute (known as tachycardia) or below sixty beats per minute (known as bradycardia), or the beats are not regular. The heart may not be able to pump enough volume of blood to meet the body's needs.
- Heart valve problems. Stenosis is a condition wherein the heart valves become compromised in their ability to open wide enough to allow proper blood flow. When the heart valves do not close tightly and blood begins to leak between chambers, this is called regurgitation. When valves bulge or prolapse back into the upper chamber, this condition is called mitral valve prolapse.
- Obesity. Obesity is defined as the excessive accumulation of body fat.
- Obesity has been linked to increased risks of developing diabetes and heart disease. To help combat this problem important dietary changes are necessary. Reducing the type and amount of carbohydrates and sugar consumed daily is critical. Limiting the intake of saturated fats and trans fats, increasing physical activity, and eating fewer calories are all equally important in this fight against obesity.

What You Can Do

Remember that saturated fats are found in large amounts in foods of animal origin. They should be limited within the diet.

Polyunsaturated fats are generally obtained from non-animal sources. While they are beneficial for lowering bad cholesterol they also lower good cholesterol. They are better for you than saturated fats but are not to be consumed in excess. Monounsaturated fats are of plant origin and are found in most nuts, seeds, seed oils, olive oil, canola oil, and legumes. Monounsaturated fats are excellent because they not only lower bad cholesterol, but also they elevate the good cholesterol. Replace current dietary fats with an increased intake of monounsaturated fats.

Choose whole-grain and high-fiber foods. Reduced risk for cardiovascular disease has been associated with diets that are high in whole grains and fiber. Fiber also slows down cholesterol absorption. The AHA recommends that at least half of daily grain intake should originate from whole grains. The Adequate Intake value for fiber is 14 grams per 1,000 kilocalories. These amounts are based upon the amount of fiber that has been shown to reduce cardiovascular risk.

Do not be sedentary. Get more exercise on a regular basis. Increasing your energy expenditure by just twenty minutes of physical activity at least three times per week will improve your overall health. Physical exercise can help you manage or prevent high blood pressure and blood cholesterol levels. Regular activity raises HDL while at the same time decreases triglycerides and plaque buildup in the arteries. Calories are burned consistently, making it easier to lose and manage weight. Circulation will improve, the body will be better oxygenated, and the heart and blood vessels will function more efficiently.

A Personal Choice about Lipids

A Guide to Making Sense of Dietary Fat

On your next trip to the grocery store prepare yourself to read all food labels carefully and to seriously consider everything that goes into your shopping cart. Create a shopping list and divide your list into columns for “Best,” “Better,” “Good,” “Least Desirable,” and “Infrequent Foods.” As you refine your sense of dietary fat, here are key points to bear in mind:

- **Shopping for groceries.** Don’t be bombarded with gratuitous grams of saturated fats and empty grams of trans fats. Read and decipher food labels carefully so that you know exactly what types of fat a food item contains and how much fat it will contribute to your overall fat intake. For snacks and daily eating, gravitate toward foods that are lowest in or absent of harmful trans fats. Restrict other foods to occasional usage based upon their fat content. For example, if selecting prepared foods, choose the ones without high-fat sauces in favor of adding your own flavorings. If selecting precooked meats, avoid those that are fried, coated, or prepared in high-fat sauces. A popular and healthy precooked meat food choice is the rotisserie chicken that most supermarkets carry. When selecting meats be aware of the need to compare different cuts—notice their fat content, color, and marbling. Higher-fat meats tend to have whiter fat marbled throughout. Choose lean cuts and white meat as these are lower in saturated fat. Always choose plenty of fresh fruits, vegetables, nuts, and seeds, as their phytosterols are a good competitor for cholesterol. Keep a collection of nuts in your freezer that can be added to your salads, stir-fry, one-dish foods, soups, desserts, and yogurts.

- **Appearance.** Saturated and trans fats are not good for you and must be placed in your "Least Desirable" column because they increase cholesterol levels and put you at risk for heart disease. Monounsaturated and polyunsaturated fats are better choices to replace these undesirable fats. The key in identifying the "Best" or "Better" fats from the "Least Desirable" fats while you shop is based upon appearance. When choosing fats remember that saturated fats and trans fats are solid at room temperature; think of butter. Monounsaturated and polyunsaturated fats are liquid at room temperature; think of vegetable oil.
- **Try to eliminate as much trans fat as possible from your food selections.** Avoid commercially baked goods and fast foods. Make these your "Infrequent Foods."
- **Choose unsaturated fats.** Fatty fish, walnuts, flaxseeds, flaxseed oil, and canola oil all have good health benefits and should be on the "Best," "Better," and "Good" fat lists. They each provide essential omega-3 fatty acids necessary for overall body health. To derive the most benefit from including these foods, do not add them to an existing diet full of fat. Use these to replace the "Least Desirable" fats that are being removed from the diet.
- **Limit saturated fat intake.** Reduce red meat consumption, processed meats, and whole-fat dairy products. To reduce full-fat dairy items try their low-fat or nonfat counterparts such as mozzarella cheese.
- **Low fat does not equal healthy.** Remember, a fat-free

label does not provide you with a license to consume all the calories you desire. There will be consequences to your weight and your overall health. Common replacements for fat in many fat-free foods are refined carbohydrates, sugar, and calories. Too much of these ingredients can also cause health problems. Choose and consume wisely.

- **A "better-fat" diet will successfully support weight loss.** While cutting "Least Desirable" fat calories are vital to weight loss, remember that "Better" fats are filling and just a handful of nuts can curb an appetite to prevent overeating.
- **Consume omega-3 fats each day.** For optimal health and disease prevention include a moderate serving of fish, walnuts, ground flaxseeds, flaxseed oil, or soybean oil in your diet every day.
- **How much saturated fat is too much?** Your goal is to keep your intake of saturated fat to no more than 10 percent of your total dietary calories on a daily basis. Thus, it is important to learn to reduce the intake of foods high in saturated fat. High-fat foods can be consumed but they must fall within the overall goal for a person's fat allowance for the day.
- **Home cooking.** Limit the use of saturated fats in home preparation of meals. Instead of butter try spreads made from unsaturated oils such as canola or olive oils and the use of cooking sprays. Couple this with the use of herbs and spices to add flavor. Avoid using high-fat meat gravies, cheese, and cream sauces. Limit adding extras to foods such as butter on a baked potato. Use nonfat sour cream instead. Grill, bake, stir-fry, roast, or bake your foods. Never fry in solid fats such as butter or shortening. Marinate foods to be grilled in fruit juices and herbs. Instead of relying upon commercial salad dressings, learn to make your own top-quality dressing from cold-pressed olive oil, flaxseed oil, or sesame oil.

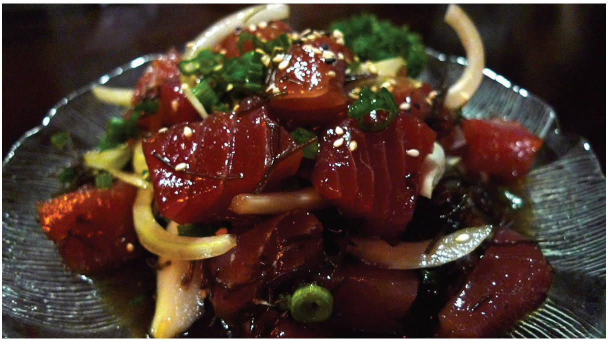
- **Make sure the fat is flavorful.** Adding flavor to food is what makes the eating experience enjoyable. Why not choose unsaturated fats and oils that have strong flavors? In this way you will add good flavor to your meals but use less fat in the process. Some examples are sesame oil, peanut oil, and peanut butter. Replace less flavorful cheeses with small amounts of strongly flavored cheeses such as romano, parmesan, and asiago.

Now that you have gained a wealth of information and food for thought to enable you to make changes to your dietary pattern we hope that your desire to pursue a healthier lifestyle has been solidified. While we realize that making grand strides in this direction may be awkward at first, even the smallest of accomplishments can produce noticeable results that will spur you on and perhaps spark the interest of friends and family to join you in this health crusade.

Becoming aware of the need to limit your total fat intake will facilitate your ability to make better choices. In turn, making better dietary choices requires gaining knowledge. As you understand that your food choices not only impact your personal physical health but also the delicate balance of our ecosystem, we are confident that you will successfully adapt to the dynamics of the ever-changing global food supply. Remember, the food choices you make today will benefit you tomorrow and into the years to come.

CHAPTER 7. PROTEIN

Introduction



Ahi poke by Arnold Gatilao / CC BY 2.0

Learning Objectives

By the end of this chapter, you will be able to:

- Describe the role and structure of proteins
- Describe the functions of proteins in the body
- Describe the consequences of protein imbalance

Protein is a vital constituent of all organs in the body and is required to perform a vast variety of functions. Therefore, protein is an essential nutrient that must be consumed in the diet. Many Pacific Island societies such as the Native Hawaiians accompanied their starch meals with some type of meat or seafood. In Hawaiʻi, a typical meal consisted of taro or poi accompanied with fish. Fish is known to be a complete protein source which means that all nine essential amino acids are present in the recommended amounts needed. Native Hawaiians ate their fish raw, cooked, salted or dried. If the fish was to be eaten raw, it was prepared by mashing the flesh with the fingers (lomi) to soften the meat and allow the salt to penetrate the flesh deeper. If the fish was not soft enough to lomi, it was cut into chunks or slices or left whole. Today, the most popular and contemporary prepared way of eating fish is known as poke. Poke, which means "cut up pieces" in Hawaiian, is chopped up chunks of fish that can be seasoned in a variety of different ways. Some common ways of seasoning include salt, shoyu (soy sauce), limu (seaweed), garlic, and onions. Any type of fish can be used to make poke but ahi (tuna) fish is typically the most desirable option.[1]

Your protein-rich muscles allow for body strength and movement, which enable you to enjoy many activities.

Image by William Hook on unsplash.com / CC0

1. Fish Preparation/Eating. HawaiiHistory.org. http://www.hawaiihistory.org/index.cfm?PageID=382. Updated 2017. Accessed October 30, 2017.

Defining Protein

Protein makes up approximately 20 percent of the human body and is present in every single cell. The word protein is a Greek word, meaning "of utmost importance." Proteins are called the workhorses of life as they provide the body with structure and perform a vast array of functions. You can stand, walk, run, skate, swim, and more because of your protein-rich muscles. Protein is necessary for proper immune system function, digestion, and hair and nail growth, and is involved in numerous other body functions. In fact, it is estimated that more than one hundred thousand different proteins exist within the human body. In this chapter you will learn about the components of protein, the important roles that protein serves within the body, how the body uses protein, the risks and consequences associated with too much or too little protein, and where to find healthy sources of it in your diet.

What Is Protein?

Proteins, simply put, are macromolecules composed of amino acids. Amino acids are commonly called protein's building blocks. Proteins are crucial for the nourishment, renewal, and continuance of life. Proteins contain the elements carbon, hydrogen, and oxygen just as carbohydrates and lipids do, but proteins are the only macronutrient that contains nitrogen. In each amino acid the elements are arranged into a specific conformation around a carbon center. Each amino acid consists of a central carbon atom connected to a side chain, a hydrogen, a nitrogen-containing amino group, and a carboxylic acid group—hence the name "amino acid." Amino acids differ from each other by which specific side chain is bonded to the carbon center.

Figure 7.1 Amino Acid Structure

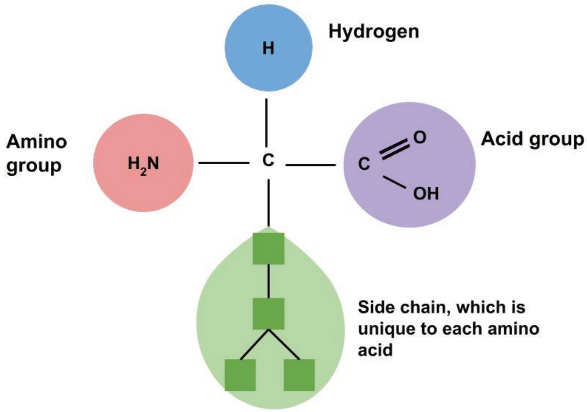


Image by Allison Calabrese / CC BY 4.0

Amino acids contain four elements. The arrangement of elements around the carbon center is the same for all amino acids. Only the side chain (R) differs.

It's All in the Side Chain

The side chain of an amino acid, sometimes called the "R" group, can be as simple as one hydrogen bonded to the carbon center, or as complex as a six-carbon ring bonded to the carbon center. Although each side chain of the twenty amino acids is unique, there are some chemical likenesses among them. Therefore, they can be classified into four different groups. These are nonpolar, polar, acidic, and basic.

Figure 7.2 The Different Groups of Amino Acids

Group	Characteristics	Name	Example (-Rx)
non-polar	hydrophobic	Ala, Val, Leu, Ile, Pro, Phe Trp, Met	$(CH_3)_2CH-CH_2-$ Leu
polar	hydrophilic (non-charged)	Gly, Ser, Thr, Cys, Tyr, Asn Gln	$(OH)(CH_3)CH-$ Thr
acidic	negatively charged	Asp, Glu	$(O=)(O^-)C-CH_2-$ Asp
basic	positively charged	Lys, Arg, His	$NH_3^+-CH_2-CH_2-CH_2-CH_2-$ Lys

Total = 20

Amino acids are classified into four groups. These are nonpolar, polar, acidic, and basic.

Essential and Nonessential Amino Acids

Amino acids are further classified based on nutritional aspects. Recall that there are twenty different amino acids, and we require all of them to make the many different proteins found throughout the body. Eleven of these are called nonessential amino acids because the body can synthesize them. However, nine of the amino acids are called essential amino acids because we cannot synthesize them either at all or in sufficient amounts. These must be obtained from the diet. Sometimes during infancy, growth, and in diseased states the body cannot synthesize enough of some of the nonessential amino acids and more of them are required in the diet. These types of amino acids are called conditionally essential amino acids. The nutritional value of a protein is dependent on what amino acids it contains and in what quantities.

Table 7.1 Essential and Nonessential Amino Acids

Essential	Nonessential
Histidine	Alanine
Isoleucine	Arginine*
Leucine	Asparagine
Lysine	Aspartic acid
Methionine	Cysteine*
Phenylalanine	Glutamic acid
Threonine	Glutamine*
Tryptophan	Glycine*
Valine	Proline*
	Serine
	Tyrosine*

*Conditionally essential

The Many Different Types of Proteins

As discussed, there are over one hundred thousand different proteins in the human body. Different proteins are produced because there are twenty types of naturally occurring amino acids that are combined in unique sequences to form polypeptides. These polypeptide chains then fold into a three-dimensional shape to form a protein (see Figure 7.3 "Formation of Polypeptides"). Additionally, proteins come in many different sizes. The hormone insulin, which regulates blood glucose, is composed of only fifty-one amino acids; whereas collagen, a protein that acts like glue between cells, consists of more than one thousand amino acids. Titin is the largest known protein. It accounts for the elasticity of muscles, and consists of more than twenty-five thousand amino acids! The abundant variations of proteins are due to the unending number of amino acid sequences that can be formed. To compare how so many different proteins can be designed from only twenty amino acids, think about music. All of the music that exists in the world has been derived from a basic set of seven notes C, D, E, F, G, A, B and variations thereof. As a result, there is a vast array of music and songs all composed of specific sequences from these basic musical notes. Similarly, the twenty amino acids can be linked together in an extraordinary number of sequences, much more than are possible for the seven musical notes to create songs. As a result, there are enormous variations and potential amino acid sequences that can be created. For example, if an amino acid sequence for a protein is 104 amino acids long the possible combinations of amino acid sequences is equal to 20104, which is 2 followed by 135 zeros!

Figure 7.3 The Formation of Polypeptides

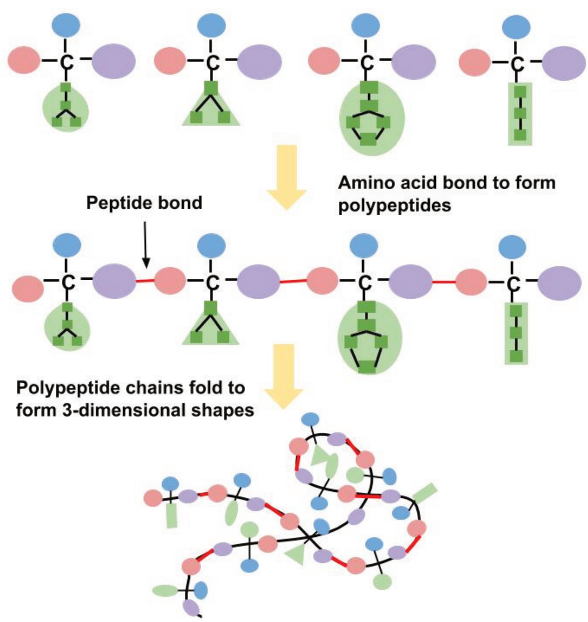
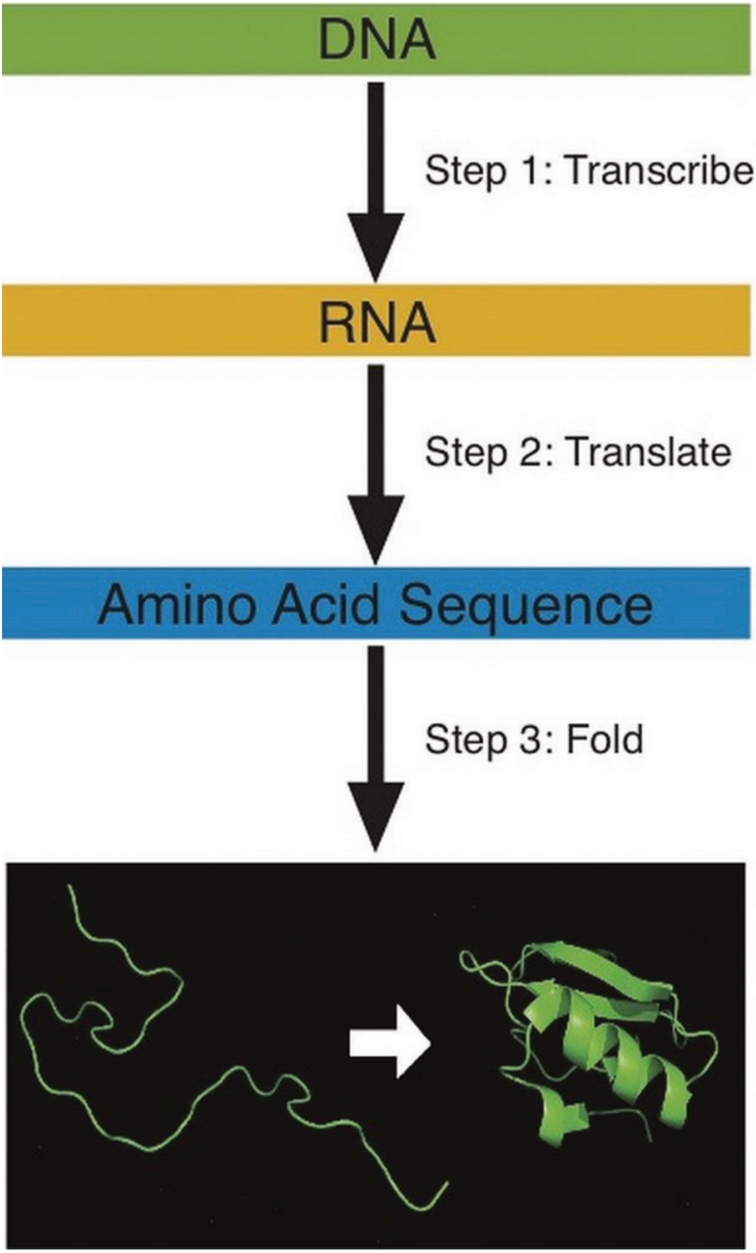


Image by Allison Calabrese / CC BY 4.0

Building Proteins with Amino Acids

The building of a protein consists of a complex series of chemical reactions that can be summarized into three basic steps: transcription, translation, and protein folding. The first step in constructing a protein is the transcription (copying) of the genetic information in double-stranded deoxyribonucleic acid (DNA) into the single-stranded, messenger macromolecule ribonucleic acid (RNA). RNA is chemically similar to DNA, but has two differences; one is that its backbone uses the sugar ribose and not deoxyribose; and two, it contains the nucleotide base uracil, and not thymidine. The RNA that is transcribed from a given piece of DNA contains the same information as that DNA, but it is now in a form that can be read by the cellular protein manufacturer known as the ribosome. Next, the RNA instructs the cells to gather all the necessary amino acids and add them to the growing protein chain in a very specific order. This process is referred to as translation. The decoding of genetic information to synthesize a protein is the central foundation of modern biology.

Figure 7.4 Steps for Building a Protein


DNA
Step 1: Transcribe
RNA
Step 2: Translate
Amino Acid Sequence
Step 3: Fold

Building a protein involves three steps: transcription, translation, and folding. During translation each amino acid is connected to the next amino acid by a special chemical bond called a peptide bond. The peptide bond forms between the carboxylic acid group of one amino acid and the amino group of another, releasing a molecule of water. The third step in protein production involves folding it into its correct shape. Specific amino acid sequences contain all the information necessary to spontaneously fold into a particular shape. A change in the amino acid sequence will cause a change in protein shape. Each protein in the human body differs in its amino acid sequence and consequently, its shape. The newly synthesized protein is structured to perform a particular function in a cell. A protein made with an incorrectly placed amino acid may not function properly and this can sometimes cause disease.

Protein Organization

Protein's structure enables it to perform a variety of functions. Proteins are similar to carbohydrates and lipids in that they are polymers of simple repeating units; however, proteins are much more structurally complex. In contrast to carbohydrates, which have identical repeating units, proteins are made up of amino acids that are different from one another. Furthermore, a protein is organized into four different structural levels.

Primary: The first level is the one-dimensional sequence of amino acids that are held together by peptide bonds. Carbohydrates and lipids also are one-dimensional sequences of their respective monomers, which may be branched, coiled, fibrous, or globular, but their conformation is much more random and is not organized by their sequence of monomers.

Secondary: The second level of protein structure is dependent on the chemical interactions between amino acids, which cause the protein to fold into a specific shape, such as a helix (like a coiled spring) or sheet.

Tertiary: The third level of protein structure is three-dimensional. As the different side chains of amino acids chemically interact, they either repel or attract each other, resulting in the folded structure. Thus, the specific sequence of amino acids in a protein directs the protein to fold into a specific, organized shape.

Quaternary: The fourth level of structure is achieved when protein fragments called peptides combine to make one larger functional protein. The protein hemoglobin is an example of a protein that has quaternary structure. It is composed of four peptides that bond together to form a functional oxygen carrier.

A protein's structure also influences its nutritional quality. Large fibrous protein structures are more difficult to digest than smaller proteins and some, such as keratin, are indigestible. Because digestion of some fibrous proteins is incomplete, not all of the amino acids are absorbed and available for the body to utilize, thereby decreasing their nutritional value.

Figure 7.5 The Four Structural Levels of Proteins

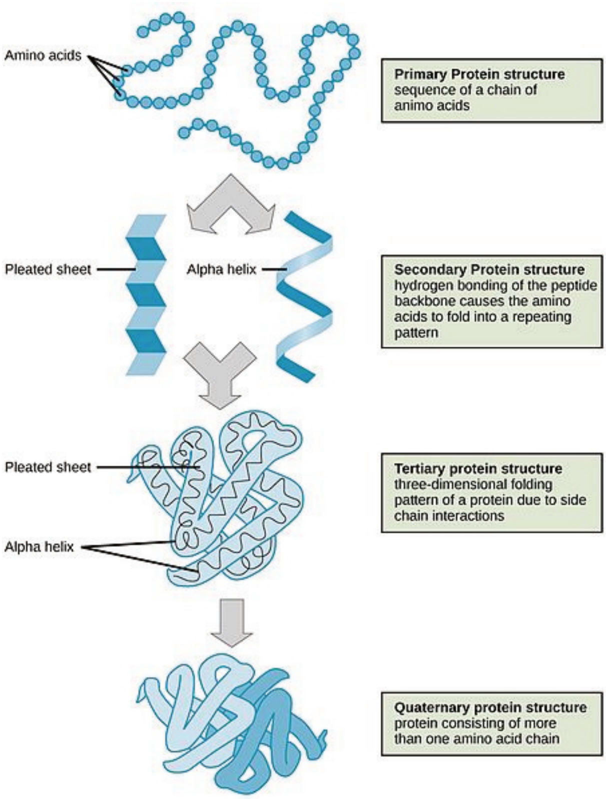


Image by OpenStax / CC BY 4.0

The Role of Proteins in Foods: Cooking and Denaturation

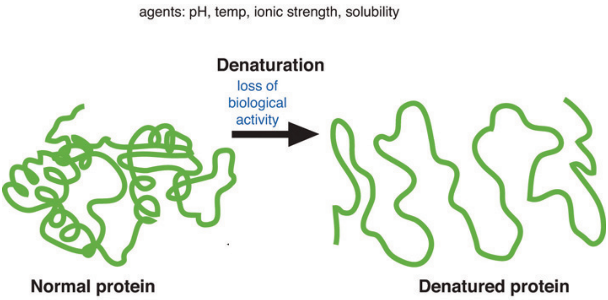
In addition to having many vital functions within the body, proteins perform different roles in our foods by adding certain functional qualities to them. Protein provides food with structure and texture and enables water retention. For example, proteins foam when agitated. (Picture whisking egg whites to make angel food cake. The foam bubbles are what give the angel food cake its airy texture.) Yogurt is another good example of proteins providing texture. Milk proteins called caseins coagulate, increasing yogurt's thickness. Cooked proteins add some color and flavor to foods as the amino group binds with carbohydrates and produces a brown pigment and aroma. Eggs are between 10 and 15 percent protein by weight. Most cake recipes use eggs because the egg proteins help bind all the other ingredients together into a uniform cake batter. The proteins aggregate into a network during mixing and baking that gives cake structure.

Image by Annie Spratt on unspash.com / CC0

Protein Denaturation: Unraveling the Fold

When a cake is baked, the proteins are denatured. Denaturation refers to the physical changes that take place in a protein exposed to abnormal conditions in the environment. Heat, acid, high salt concentrations, alcohol, and mechanical agitation can cause proteins to denature. When a protein denatures, its complicated folded structure unravels, and it becomes just a long strand of amino acids again. Weak chemical forces that hold tertiary and secondary protein structures together are broken when a protein is exposed to unnatural conditions. Because proteins' function is dependent on their shape, denatured proteins are no longer functional. During cooking the applied heat causes proteins to vibrate. This destroys the weak bonds holding proteins in their complex shape (though this does not happen to the stronger peptide bonds). The unraveled protein strands then stick together, forming an aggregate (or network).

Figure 6.7 Protein Denaturation



When a protein is exposed to a different environment, such as increased temperature, it unfolds into a single strand of amino acids.

Protein Digestion and Absorption

How do the proteins from foods, denatured or not, get processed into amino acids that cells can use to make new proteins? When you eat food the body's digestive system breaks down the protein into the individual amino acids, which are absorbed and used by cells to build other proteins and a few other macromolecules, such as DNA. We previously discussed the general process of food digestion, let's follow the specific path that proteins take down the gastrointestinal tract and into the circulatory system (Figure 6.7 "Digestion and Absorption of Protein"). Eggs are a good dietary source of protein and will be used as our example to describe the path of proteins in the processes of digestion and absorption. One egg, whether raw, hard-boiled, scrambled, or fried, supplies about six grams of protein.

Figure 7.7 Digestion and Absorption of Protein

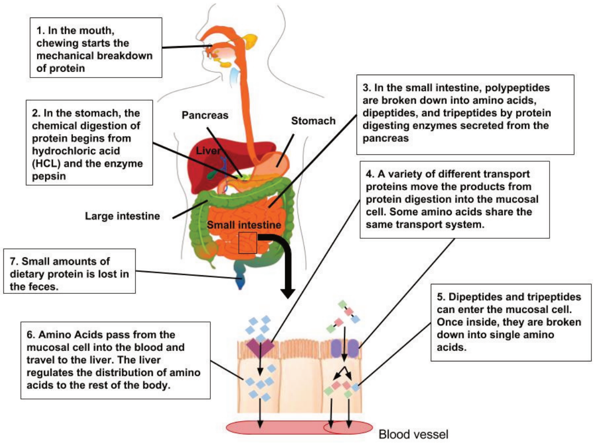


Image by Allison Calabrese / CC BY 4.0

From the Mouth to the Stomach

Unless you are eating it raw, the first step in egg digestion (or any other protein food) involves chewing. The teeth begin the mechanical breakdown of the large egg pieces into smaller pieces that can be swallowed. The salivary glands provide some saliva to aid swallowing and the passage of the partially mashed egg through the esophagus. The mashed egg pieces enter the stomach through the esophageal sphincter. The stomach releases gastric juices containing hydrochloric acid and the enzyme, pepsin, which initiate the breakdown of the protein. The acidity of the stomach facilitates the unfolding of the proteins that still retain part of their three-dimensional structure after cooking and helps break down the protein aggregates formed during cooking. Pepsin, which is secreted by the cells that line the stomach, dismantles the protein chains into smaller and smaller fragments. Egg proteins are large globular molecules and their chemical breakdown requires time and mixing. The powerful mechanical stomach contractions churn the partially digested protein into a more uniform mixture called chyme. Protein digestion in the stomach takes a longer time than carbohydrate digestion, but a shorter time than fat digestion. Eating a high-protein meal increases the amount of time required to sufficiently break down the meal in the stomach. Food remains in the stomach longer, making you feel full longer.

From the Stomach to the Small Intestine

The stomach empties the chyme containing the broken down egg pieces into the small intestine, where the majority of protein digestion occurs. The pancreas secretes digestive juice that contains more enzymes that further break down the protein fragments. The two major pancreatic enzymes that digest proteins are chymotrypsin and trypsin. The cells that line the small intestine release additional enzymes that finally break apart the smaller protein fragments into the individual amino acids. The muscle contractions of the small intestine mix and propel the digested proteins to the absorption sites. In the lower parts of the small intestine, the amino acids are transported from the intestinal lumen through the intestinal cells to the blood. This movement of individual amino acids requires special transport proteins and the cellular energy molecule, adenosine triphosphate (ATP). Once the amino acids are in the blood, they are transported to the liver. As with other macronutrients, the liver is the checkpoint for amino acid distribution and any further breakdown of amino acids, which is very minimal. Recall that amino acids contain nitrogen, so further catabolism of amino acids releases nitrogen-containing ammonia. Because ammonia is toxic, the liver transforms it into urea, which is then transported to the kidney and excreted in the urine. Urea is a molecule that contains two nitrogens and is highly soluble in water. This makes it a good choice for transporting excess nitrogen out of the body. Because amino acids are building blocks that the body reserves in order to synthesize other proteins, more than 90 percent of the protein ingested does not get broken down further than the amino acid monomers.

Amino Acids Are Recycled

Just as some plastics can be recycled to make new products, amino acids are recycled to make new proteins. All cells in the body continually break down proteins and build new ones, a process referred to as protein turnover. Every day over 250 grams of protein in your body are dismantled and 250 grams of new protein are built. To form these new proteins, amino acids from food and those from protein destruction are placed into a "pool." Though it is not a literal pool, when an amino acid is required to build another protein it can be acquired from the additional amino acids that exist within the body. Amino acids are used not only to build proteins, but also to build other biological molecules containing nitrogen, such as DNA, RNA, and to some extent to produce energy. It is critical to maintain amino acid levels within this cellular pool by consuming high-quality proteins in the diet, or the amino acids needed for building new proteins will be obtained by increasing protein destruction from other tissues within the body, especially muscle. This amino acid pool is less than one percent of total body-protein content. Thus, the body does not store protein as it does with carbohydrates (as glycogen in the muscles and liver) and lipids (as triglycerides in adipose tissue).

Figure 7.8 Options For Amino Acid Use In The Human Body

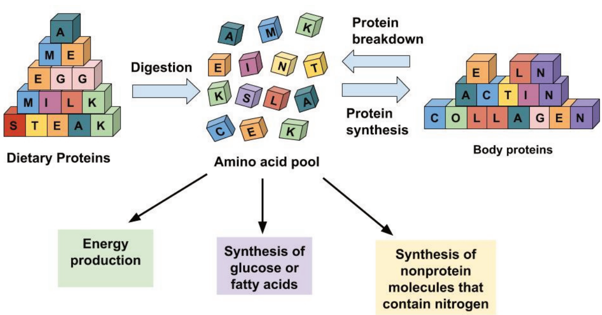
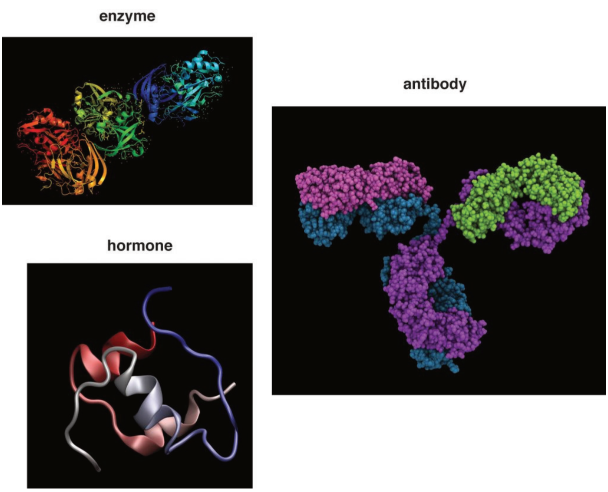


Image by Allison Calabrese / CC BY 4.0

Amino acids in the cellular pool come from dietary protein and from the destruction of cellular proteins. The amino acids in this pool need to be replenished because amino acids are outsourced to make new proteins, energy, and other biological molecules.

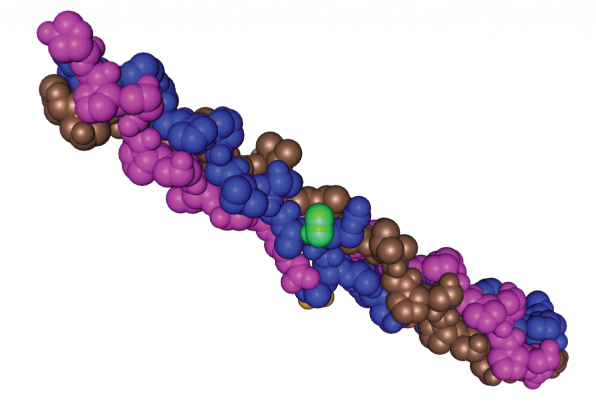
Protein's Functions in the Body



Proteins are the "workhorses" of the body and participate in many bodily functions. Proteins come in all sizes and shapes and each is specifically structured for its particular function.

Structure and Motion

Figure 7.9 Collagen Structure



Collagen Triple Helix by Nevit Dilmen / CC BY-SA 3.0

More than one hundred different structural proteins have been discovered in the human body, but the most abundant by far is collagen, which makes up about 6 percent of total body weight. Collagen makes up 30 percent of bone tissue and comprises large amounts of tendons, ligaments, cartilage, skin, and muscle. Collagen is a strong, fibrous protein made up of mostly glycine and proline. Within its quaternary structure three peptide strands twist around each other like a rope and then these collagen ropes overlap with others. This highly ordered structure is even stronger than steel fibers of the same size. Collagen makes bones strong, but flexible. Collagen fibers in the skin's dermis provide it with structure, and the accompanying elastin protein fibrils make it flexible. Pinch the skin on your hand and then let go; the collagen and elastin proteins in skin allow it to go back to its original shape. Smooth-muscle cells that secrete collagen and elastin proteins surround blood vessels, providing the vessels with structure and the ability to stretch back after blood is pumped through them. Another strong, fibrous protein is keratin, which is what skin, hair, and nails are made of. The closely packed collagen fibrils in tendons and ligaments allow for synchronous mechanical movements of bones and muscle and the ability of these tissues to spring back after a movement is complete.

Enzymes

Although proteins are found in the greatest amounts in connective tissues such as bone, their most extraordinary function is as enzymes. Enzymes are proteins that conduct specific chemical reactions. An enzyme's job is to provide a site for a chemical reaction and to lower the amount of energy and time it takes for that chemical reaction to happen (this is known as "catalysis"). On average, more than one hundred chemical reactions occur in cells every single second and most of them require enzymes. The liver alone contains over one thousand enzyme systems. Enzymes are specific and will use only particular substrates that fit into their active site, similar to the way a lock can be opened only with a specific key. Nearly every chemical reaction requires a specific enzyme. Fortunately, an enzyme can fulfill its role as a catalyst over and over again, although eventually it is destroyed and rebuilt. All bodily functions, including the breakdown of nutrients in the stomach and small intestine, the transformation of nutrients into molecules a cell can use, and building all macromolecules, including protein itself, involve enzymes (see Figure 7.10 "Enzymes Role in Carbohydrate Digestion").

Figure 7.10 Enzymes Role in Carbohydrate Digestion

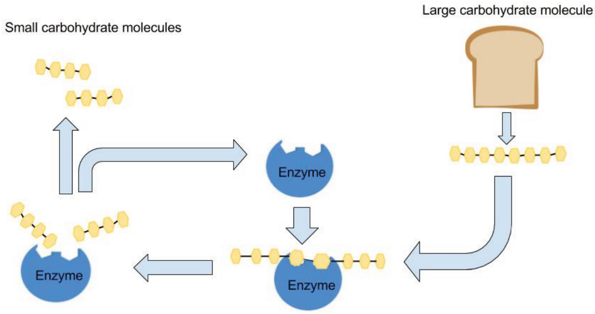


Image by Allison Calabrese / CC BY 4.0

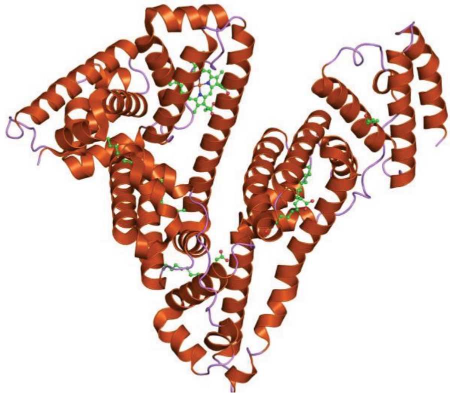
Hormones

Proteins are responsible for hormone synthesis. Hormones are the chemical messages produced by the endocrine glands. When an endocrine gland is stimulated, it releases a hormone. The hormone is then transported in the blood to its target cell, where it communicates a message to initiate a specific reaction or cellular process. For instance, after you eat a meal, your blood glucose levels rise. In response to the increased blood glucose, the pancreas releases the hormone insulin. Insulin tells the cells of the body that glucose is available and to take it up from the blood and store it or use it for making energy or building macromolecules. A major function of hormones is to turn enzymes on and off, so some proteins can even regulate the actions of other proteins. While not all hormones are made from proteins, many of them are.

Fluid and Acid-Base Balance

Proper protein intake enables the basic biological processes of the body to maintain the status quo in a changing environment. Fluid balance refers to maintaining the distribution of water in the body. If too much water in the blood suddenly moves into a tissue, the results are swelling and, potentially, cell death. Water always flows from an area of high concentration to one of a low concentration. As a result, water moves toward areas that have higher concentrations of other solutes, such as proteins and glucose. To keep the water evenly distributed between blood and cells, proteins continuously circulate at high concentrations in the blood. The most abundant protein in blood is the butterfly-shaped protein known as albumin. Albumin's presence in the blood makes the protein concentration in the blood similar to that in cells. Therefore, fluid exchange between the blood and cells is not in the extreme, but rather is minimized to preserve the status quo.

Figure 7.11 The Protein Albumin



PDB 1o9x EBI by Jawahar Swaminathan and MSD staff at the European Bioinformatics Institute / Public Domain The butterfly-shaped protein, albumin, has many functions in the body including maintaining fluid and acid-base balance and transporting molecules.

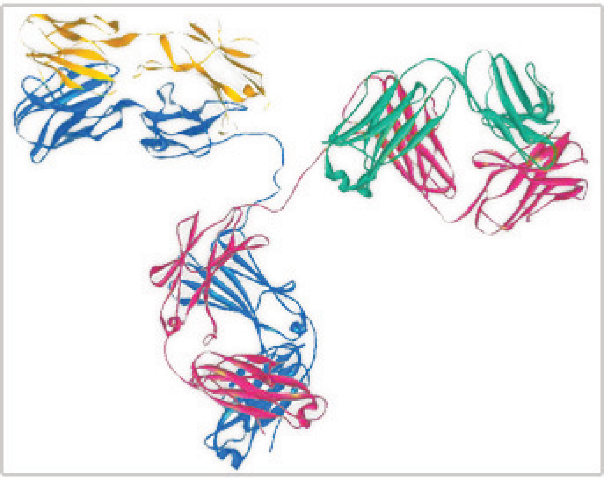
Protein is also essential in maintaining proper pH balance (the measure of how acidic or basic a substance is) in the blood. Blood pH is maintained between 7.35 and 7.45, which is slightly basic. Even a slight change in blood pH can affect body functions. Recall that acidic conditions can cause protein denaturation, which stops proteins from functioning. The body has several systems that hold the blood pH within the normal range to prevent this from happening. One of these is the circulating albumin. Albumin is slightly acidic, and because it is negatively charged it balances the many positively charged molecules, such as protons (H+), calcium, potassium, and magnesium which are also circulating in the blood. Albumin acts as a buffer against abrupt changes in the concentrations of these molecules, thereby balancing blood pH and maintaining the status quo. The protein hemoglobin also participates in acid-base balance by binding and releasing protons.

Transport

Albumin and hemoglobin also play a role in molecular transport. Albumin chemically binds to hormones, fatty acids, some vitamins, essential minerals, and drugs, and transports them throughout the circulatory system. Each red blood cell contains millions of hemoglobin molecules that bind oxygen in the lungs and transport it to all the tissues in the body. A cell's plasma membrane is usually not permeable to large polar molecules, so to get the required nutrients and molecules into the cell many transport proteins exist in the cell membrane. Some of these proteins are channels that allow particular molecules to move in and out of cells. Others act as one-way taxis and require energy to function.

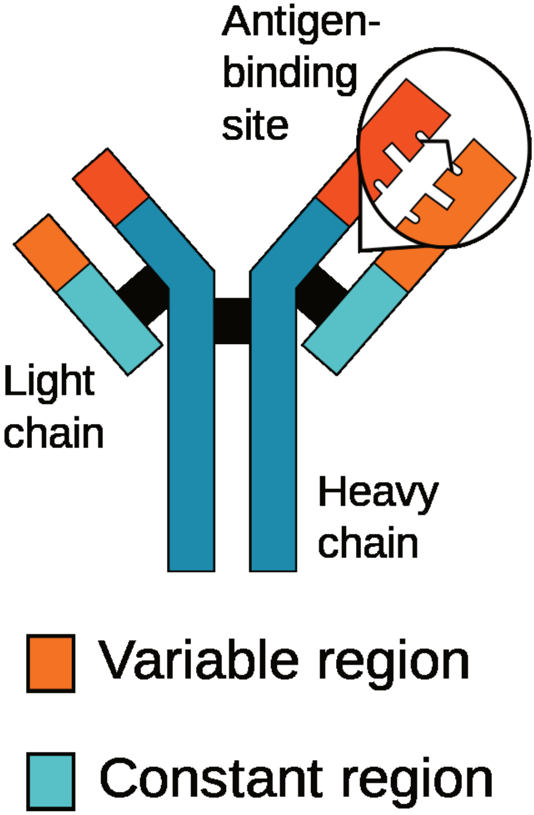
Protection

Figure 7.12 Antibody Proteins



Abagovomab (monoclonal antibody) by Blake C / CC BY-SA 3.0

Figure 7.13 Antigens



Antibody chains by Fred the Oyster / Public Domain

An antibody protein is made up of two heavy chains and two light chains. The variable region, which differs from one antibody to the next, allows an antibody to recognize its matching antigen.

Earlier we discussed that the strong collagen fibers in skin provide it with structure and support. The skin's dense network of collagen fibers also serves as a barricade against harmful substances. The immune system's attack and destroy functions are dependent on enzymes and antibodies, which are also proteins. An enzyme called lysozyme is secreted in the saliva and attacks the walls of bacteria, causing them to rupture. Certain proteins circulating in the blood can be directed to build a molecular knife that stabs the cellular membranes of foreign invaders. The antibodies secreted by the white blood cells survey the entire circulatory system looking for harmful bacteria and viruses to surround and destroy. Antibodies also trigger other factors in the immune system to seek and destroy unwanted intruders.

Wound Healing and Tissue Regeneration

Proteins are involved in all aspects of wound healing, a process that takes place in three phases: inflammatory, proliferative, and remodeling. For example, if you were sewing and pricked your finger with a needle, your flesh would turn red and become inflamed. Within a few seconds bleeding would stop. The healing process begins with proteins such as bradykinin, which dilate blood vessels at the site of injury. An additional protein called fibrin helps to secure platelets that form a clot to stop the bleeding. Next, in the proliferative phase, cells move in and mend the injured tissue by installing newly made collagen fibers. The collagen fibers help pull the wound edges together. In the remodeling phase, more collagen is deposited, forming a scar. Scar tissue is only about 80 percent as functional as normal uninjured tissue. If a diet is insufficient in protein, the process of wound healing is markedly slowed.

While wound healing takes place only after an injury is sustained, a different process called tissue regeneration is ongoing in the body. The main difference between wound healing and tissue regeneration is in the process of regenerating an exact structural and functional copy of the lost tissue. Thus, old, dying tissue is not replaced with scar tissue but with brand new, fully functional tissue. Some cells (such as skin, hair, nails, and intestinal cells) have a very high rate of regeneration, while others, (such as heart-muscle cells and nerve cells) do not regenerate at any appreciable levels. Tissue regeneration is the creation of new cells (cell division), which requires many different proteins including enzymes that synthesize RNA and proteins, transport proteins, hormones, and collagen. In a hair follicle, cells divide and a hair grows in length. Hair growth averages 1 centimeter per month and fingernails about 1 centimeter every one hundred days. The cells lining the intestine regenerate every three to five days. Protein-inadequate diets impair tissue regeneration, causing many health problems including impairment of nutrient digestion and absorption and, most visibly, hair and nail growth.

Energy Production

Some of the amino acids in proteins can be disassembled and used to make energy (Figure 7.14 "Amino Acids Used for Energy"). Only about 10 percent of dietary proteins are catabolized each day to make cellular energy. The liver is able to break down amino acids to the carbon skeleton, which can then be fed into the citric acid cycle. This is similar to the way that glucose is used to make ATP. If a person's diet does not contain enough carbohydrates and fats their body will use more amino acids to make energy, which compromises the synthesis of new proteins and destroys muscle proteins. Alternatively, if a person's diet contains more protein than the body needs, the extra amino acids will be broken down and transformed into fat.

Figure 7.14 Amino Acids Used for Energy

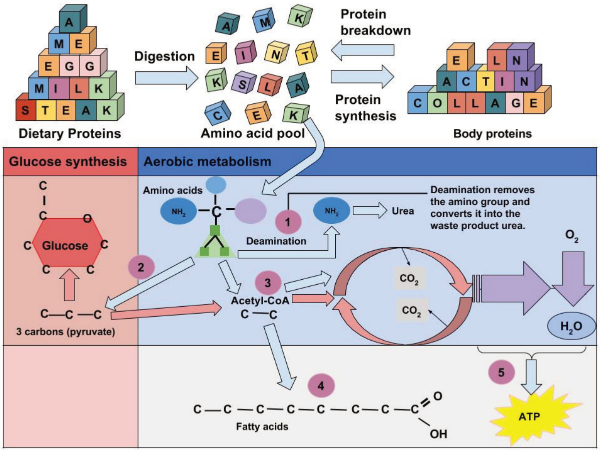


Image by Allison Calabrese / CC BY 4.0

Diseases Involving Proteins

As you may recall, moderation refers to having the proper amount of a nutrient—having neither too little nor too much. A healthy diet incorporates all nutrients in moderation. Low protein intake has several health consequences, and a severe lack of protein in the diet eventually causes death. Severe protein deficiency is a rare occurrence in children and adults in Canada. The Acceptable Macronutrient Distribution Range (AMDR) for protein for adults is between 10 and 35 percent of kilocalories, which is a fairly wide range. The percent of protein in the diet that is associated with malnutrition and its health consequences is less than 10 percent, but this is often accompanied by deficiencies in calories and other micronutrients. In this section we will discuss the health consequences of protein intake that is either too low to support life's processes or too high, thereby increasing the risk of chronic disease. In the last section of this chapter, we will discuss in more detail the personal choices you can make to optimize your health by consuming the right amount of high-quality protein.

Health Consequences of Protein Deficiency

Although severe protein deficiency is rare in the developed world, it is a leading cause of death in children in many poor, underdeveloped countries. There are two main syndromes associated with protein deficiencies: Kwashiorkor and

Marasmus. Kwashiorkor affects millions of children worldwide. When it was first described in 1935, more than 90 percent of children with Kwashiorkor died. Although the associated mortality is slightly lower now, most children still die after the initiation of treatment. The name Kwashiorkor comes from a language in Ghana and means, "rejected one." The syndrome was named because it occurred most commonly in children who had recently been weaned from the breast, usually because another child had just been born. Subsequently the child was fed watery porridge made from low-protein grains, which accounts for the low protein intake. Kwashiorkor is characterized by swelling (edema) of the feet and abdomen, poor skin health, growth retardation, low muscle mass, and liver malfunction. Recall that one of protein's functional roles in the body is fluid balance. Diets extremely low in protein do not provide enough amino acids for the synthesis of albumin. One of the functions of albumin is to hold water in the blood vessels, so having lower concentrations of blood albumin results in water moving out of the blood vessels and into tissues, causing swelling. The primary symptoms of Kwashiorkor include not only swelling, but also diarrhea, fatigue, peeling skin, and irritability. Severe protein deficiency in addition to other micronutrient deficiencies, such as folate (vitamin B9), iodine, iron, and vitamin C all contribute to the many health manifestations of this syndrome.

Figure 7.15 A Young Boy With Kwashiorkor

Source: Photo courtesy of the Centers for Disease Control and Prevention (CDC).

Kwashiorkor is a disease brought on by a severe dietary protein deficiency. Symptoms include edema of legs and feet, light-colored, thinning hair, anemia, a pot-belly, and shiny skin.

Children and adults with marasmus neither have enough protein in their diets nor do they take in enough calories. Marasmus affects mostly children below the age of one in poor countries. Body weights of children with Marasmus may be up to 80 percent less than that of a normal child of the same age. Marasmus is a Greek word, meaning "starvation." The syndrome affects more than fifty million children under age five worldwide. It is characterized by an extreme emaciated appearance, poor skin health, and growth retardation. The symptoms are acute fatigue, hunger, and diarrhea.

Figure 7.16 Children With Marasmus

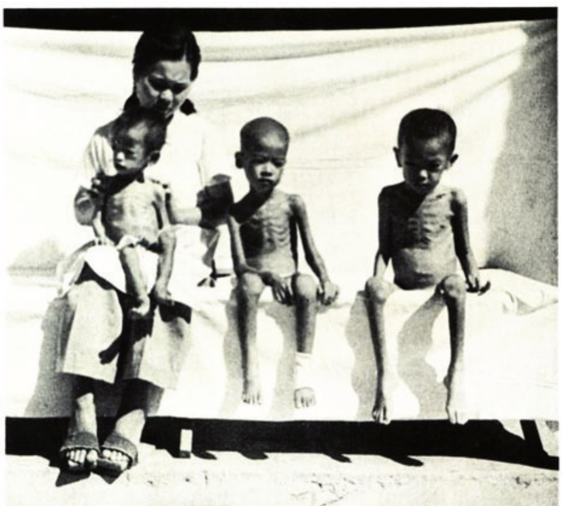
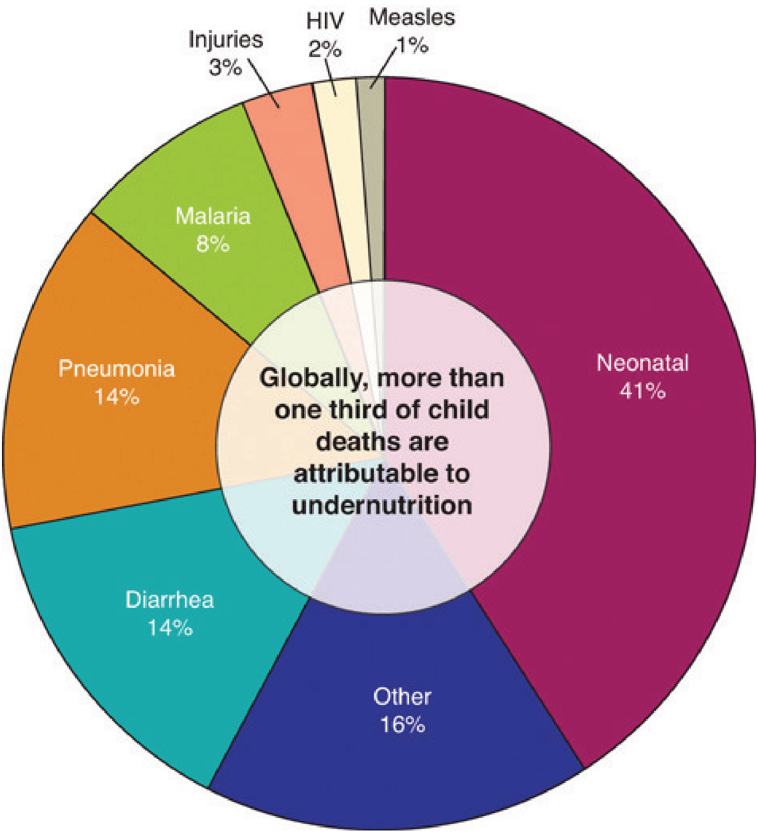


FIGURE 51.—Japanese nurse with dependent children having typical appearance of malnutrition. New Bilibid Prison, September–October 1945.

Japanese nurse with dependent children having typical appearance of malnutrition, New Bilibid Prison, September-October 1945 by Unknown / Public Domain

Kwashiorkor and marasmus often coexist as a combined syndrome termed marasmic kwashiorkor. Children with the combined syndrome have variable amounts of edema and the characterizations and symptoms of marasmus. Although organ system function is compromised by undernutrition, the ultimate cause of death is usually infection. Undernutrition is intricately linked with suppression of the immune system at multiple levels, so undernourished children commonly die from severe diarrhea and/or pneumonia resulting from bacterial or viral infection. The United Nations Children's Fund (UNICEF), the most prominent agency with the mission of changing the world to improve children's lives, reports that undernutrition causes at least one-third of deaths of young children. As of 2008, the prevalence of children under age five who were underweight was 26 percent. The percentage of underweight children has declined less than 5 percent in the last eighteen years despite the Millennium Development Goal of halving the proportion of people who suffer from hunger by the year 2015.

Figure 7.17 Causes Of Death For Children Under The Age Of Five, Worldwide



Health Consequences of Too Much Protein in the Diet

An explicit definition of a high-protein diet has not yet been developed but typically diets high in protein are considered as those that derive more than 30 percent of calories from protein. Many people follow high-protein diets because marketers tout protein's ability to stimulate weight loss. It is true that following high-protein diets increases weight loss in some people. However the number of individuals that remain on this type of diet is low and many people who try the diet and stop regain the weight they had lost. Additionally, there is a scientific hypothesis that there may be health consequences of remaining on high-protein diets for the long-term, but clinical trials are ongoing or scheduled to examine this hypothesis further. As the high-protein diet trend arose so did the intensely debated issue of whether there are any health consequences of eating too much protein. Observational studies conducted in the general population suggest diets high in animal protein, specifically those in which the primary protein source is red meat, are linked to a higher risk for kidney stones, kidney disease, liver malfunction, colorectal cancer, and osteoporosis. However, diets that include lots of red meat are also high in saturated fat and cholesterol and sometimes linked to unhealthy lifestyles, so it is difficult to conclude that the high protein content is the culprit.

High protein diets appear to only increase the progression of kidney disease and liver malfunction in people who already have kidney or liver malfunction, and not to cause these problems. However, the prevalence of kidney disorders is relatively high and underdiagnosed. In regard to colon cancer, an assessment of more than ten studies performed around the world published in the June 2011 issue of PLoS purports that a high intake of red meat and processed meat is associated with a significant increase in colon cancer risk.[1] Although there are a few ideas, the exact mechanism of how proteins, specifically those in red and processed meats, causes colon cancer is not known and requires further study.

Some scientists hypothesize that high-protein diets may accelerate bone-tissue loss because under some conditions the acids in protein block absorption of calcium in the gut, and, once in the blood, amino acids promote calcium loss from bone; however even these effects have not been consistently observed in scientific studies. Results from the Nurses' Health Study suggest that women who eat more than 95 grams of protein each day have a 20 percent higher risk for wrist fracture.[2][3]

Other studies have not produced consistent results. The scientific data on high protein diets and increased risk for osteoporosis remains highly controversial and more research is needed to come to any conclusions about the association between the two.[4]

High-protein diets can restrict other essential nutrients.

1. Chan DS, Lau R, et al. Red and Processed Meat and Colorectal Cancer Incidence: Meta-Analysis of Prospective Studies. PLoS One. 2011; 6(6), e20456. http://dx.plos.org/10.1371/journal.pone.0020456. Accessed September 30, 2017.
2. Protein: The Bottom Line. Harvard School of Public Health.The Nutrition Source. http://www.hsph.harvard.edu/nutritionsource/what-should-you-eat/protein/.Published 2012. Accessed September 28, 2017.
3. Barzel US, Massey LK. Excess Dietary Protein Can Adversely Affect Bone. J Nutr. 1998; 128(6), 1051–53. http://jn.nutrition.org/content/128/6/1051.long. Accessed September 28, 2017.
4. St. Jeor ST, et al. Dietary Protein and Weight Reduction: A Statement for Healthcare Professionals from the Nutrition Committee of the Council on Nutrition, Physical Activity, and Metabolism of the American Heart Association. Circulation. 2001; 104, 1869–74. http://circ.ahajournals.org/cgi/pmidlookup?view=long&pmid=11591629. Accessed September 28, 2017.

High-protein diets are not recommended because they restrict healthful foods that provide essential nutrients and do not provide the variety of foods needed to adequately meet nutritional needs. Individuals who follow these diets are therefore at risk for compromised vitamin and mineral intake, as well as potential cardiac, renal, bone, and liver abnormalities overall.[5]

As with any nutrient, protein must be eaten in proper amounts. Moderation and variety are key strategies to achieving a healthy diet and need to be considered when optimizing protein intake. While the scientific community continues its debate about the particulars regarding the health consequences of too much protein in the diet, you may be wondering just how much protein you should consume to be healthy. Read on to find out more about calculating your dietary protein recommendations, dietary protein sources, and personal choices about protein.

5. St. Jeor ST, et al. Dietary Protein and Weight Reduction: A Statement for Healthcare Professionals from the Nutrition Committee of the Council on Nutrition, Physical Activity, and Metabolism of the American Heart Association. Circulation. 2001; 104, 1869–74. http://circ.ahajournals.org/cgi/pmidlookup?view=long&pmid=11591629. Accessed September 28, 2017.

Proteins in a Nutshell

Image by Braden Collum on unsplash.com / CC0

Proteins are long chains of amino acids folded into precise structures that determine their functions, which are in the tens of thousands. They are the primary construction materials of the body serving as building blocks for bone, skin, hair, muscle, hormones, and antibodies. Without them we cannot breakdown or build macromolecules, grow, or heal from a wound. Too little protein impairs bodily functions and too much can lead to chronic disease. Eat proteins in moderation, at least 10 percent of the calories you take in and not more than 35 percent. Proteins are in a variety of foods. More complete sources are in animal-based foods, but choose those low in saturated fat and cholesterol. Some plant-based foods are also complete protein sources and don't add much to your saturated fat or cholesterol intake. Incomplete protein sources can easily be combined in the daily diet and provide all of the essential amino acids at adequate levels. Growing children and the elderly need to ensure they get enough protein in their diet to help build and maintain muscle strength. Even if you're a hardcore athlete, get your proteins from nutrient-dense foods as you need more than just protein to power up for an event. Nuts are one nutrient-dense food with a whole lot of protein. One ounce of pistachios, which is about fifty nuts, has the same amount of protein as an egg and contains a lot of vitamins, minerals, healthy polyunsaturated fats, and antioxidants. In fact, eating one ounce of nuts per day can lower your risk for heart disease. Can you be a hardcore athlete and a vegetarian?

The analysis of vegetarian diets did not find professional athletes were inadequate in any nutrients, but did state that people who obtain proteins solely from plants should make sure they consume foods with vitamin B12, vitamin D, calcium, omega-3 fatty acids, and choline. Iron and zinc may also be of concern especially for female athletes. Being a vegetarian athlete requires that you pay more attention to what you eat, however this is also a true statement for all athletes. For an exhaustive list that provides the protein, calcium, cholesterol, fat, and fiber content, as well as the number of calories, of numerous foods, go to the website, http://www.soystache.com/protein.htm.

Everyday Connection

Getting All the Nutrients You Need—The Plant-Based Way

Below are five ways to assure you are getting all the nutrients needed on a plant-based diet;

- Get your protein from foods such as soybeans, tofu, tempeh, lentils, and beans, beans, and more beans. Many of these foods are high in zinc too.

- Eat foods fortified with vitamins B12 and D and calcium. Some examples are soy milk and fortified cereals.
- Get enough iron in your diet by eating kidney beans, lentils, whole-grain cereals, and leafy green vegetables.
- To increase iron absorption, eat foods with vitamin C at the same time.
- Don't forget that carbohydrates and fats are required in your diet too, especially if you are training. Eat whole-grain breads, cereals, and pastas. For fats, eat an avocado, add some olive oil to a salad or stir-fry, or spread some peanut or cashew butter on a bran muffin.

Proteins, Diet, and Personal Choices

We have discussed what proteins are, how they are made, how they are digested and absorbed, the many functions of proteins in the body, and the consequences of having too little or too much protein in the diet. This section will provide you with information on how to determine the recommended amount of protein for you, and your many choices in designing an optimal diet with high-quality protein sources.

How Much Protein Does a Person Need in Their Diet?

The recommendations for the Recommended Daily Allowance (RDA) and AMDR for protein for different age groups are listed in Table 7.2 “Dietary Reference Intakes for Protein”. A Tolerable Upper Intake Limit for protein has not been set, but it is recommended that you do not exceed the upper end of the AMDR.

Table 7.2 Dietary Reference Intakes for Protein

Age Group	RDA (g/day)	AMDR (% calories)
Infants (0–6 mo)	9.1*	Not determined
Infants (7–12 mo)	11.0	Not determined
Children (1–3)	13.0	5–20
Children (4–8)	19.0	10–30
Children (9–13)	34.0	10–30
Males (14–18)	52.0	10–30
Females (14–18)	46.0	10–30
Adult Males (19+)	56.0	10–35
Adult Females (19+)	46.0	10–35

* Denotes Adequate Intake

Source: Dietary Reference Intakes: Macronutrients. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. Institute of Medicine. September 5, 2002. Accessed September 28, 2017.

Protein Input = Protein Used by the Body + Protein Excreted

The appropriate amount of protein in a person's diet is that which maintains a balance between what is taken in and what is used. The RDAs for protein were determined by assessing nitrogen balance. Nitrogen is one of the four basic elements contained in all amino acids. When proteins are broken down and amino acids are catabolized, nitrogen is released. Remember that when the liver breaks down amino acids, it produces ammonia, which is rapidly converted to nontoxic, nitrogen-containing urea, which is then transported to the kidneys for excretion. Most nitrogen is lost as urea in the urine, but urea is also excreted in the feces. Proteins are also lost in sweat and as hair and nails grow. The RDA, therefore, is the amount of protein a person should consume in their diet to balance the amount of protein used up and lost from the body. For healthy adults, this amount of protein was determined to be 0.8 grams of protein per kilogram of body weight. You can calculate your exact recommended protein intake per day based on your weight by using the following equation:

(Weight in lbs. ÷ 2.2 lb/kg) × 0.8 g/kg

Note that if a person is overweight, the amount of dietary protein recommended can be overestimated.

To calculate the RDA for protein, we used data from multiple studies that determined nitrogen balance in people of different age groups. A person is said to be in nitrogen balance when the nitrogen input equals the amount of nitrogen used and excreted. A person is in negative nitrogen balance when the amount of excreted nitrogen is greater than that consumed, meaning that the body is breaking down more protein to meet its demands. This state of imbalance can occur in people who have certain diseases, such as cancer or muscular dystrophy. Someone who has a low-protein diet may also be in negative nitrogen balance as they are taking in less protein than what they actually need. Positive nitrogen balance occurs when a person excretes less nitrogen than what is taken in by the diet, such as during child growth or pregnancy. At these times the body requires more protein to build new tissues, so more of what gets consumed gets used up and less nitrogen is excreted. A person healing from a severe wound may also be in positive nitrogen balance because protein is being used up to repair tissues.

Dietary Sources of Protein

The protein food group consists of foods made from meat, seafood, poultry, eggs, soy, dry beans, peas, and seeds. According to the Harvard School of Public Health, "animal protein and vegetable protein probably have the same effects on health. It's the protein package that's likely to make a difference."[1]

Simply put, different protein sources differ in their additional components, so it is necessary to pay attention to the whole nutrient "package." Protein-rich animal-based foods commonly have high amounts of B vitamins, vitamin E, iron, magnesium, and zinc. Seafood often contains healthy fats, and plant sources of protein contain a high amount of fiber. Some animal-based protein-rich foods have an unhealthy amount of saturated fat and cholesterol. When choosing your dietary sources of protein, take note of the other nutrients and also the non-nutrients, such as cholesterol, dyes, and preservatives, in order to make good selections that will benefit your health. For instance, a hamburger patty made from 80 percent lean meat contains 22 grams of protein, 5.7 grams of saturated fat, and 77 milligrams of cholesterol. A burger made from 95 percent lean meat also contains 22 grams of protein, but has 2.3 grams of saturated fat and 60 milligrams of cholesterol. A cup of boiled soybeans contains 29 grams of protein, 2.2 grams of saturated fat, and no cholesterol. For more comparisons of protein-rich foods, see Table 7.3 "Sources of Dietary Protein".

Table 7.3 Sources of Dietary Protein

1. Protein: The Bottom Line. Harvard School of Public Health. The Nutrition Source. http://www.hsph.harvard.edu/nutritionsource/what-should-you-eat/protein/. Published 2012. Accessed September 30, 2017.

Food	Protein Content (g)	Saturated Fat (g)	Cholesterol (mg)	Calories
Hamburger patty 3 oz. (80% lean)	22.0	5.7	77	230
Hamburger patty 3 oz. (95% lean)	22.0	2.3	60	139
Top sirloin 3 oz.	25.8	2.0	76	158
Beef chuck 3 oz. (lean, trimmed)	22.2	1.8	51	135
Pork loin 3 oz.	24.3	3.0	69	178
Pork ribs (country style, 1 piece)	56.4	22.2	222	790
Chicken breast (roasted, 1 c.)	43.4	1.4	119	231
Chicken thigh (roasted, 1 thigh)	13.5	1.6	49	109
Chicken leg (roasted, 1 leg)	29.6	4.2	105	264
Salmon 3 oz.	18.8	2.1	54	175
Tilapia 3 oz.	22.2	0.8	48	109
Halibut 3 oz.	22.7	0.4	35	119
Shrimp 3 oz.	17.8	0.2	166	84
Shrimp (breaded, fried, 6–8 pcs.)	18.9	5.4	200	454
Tuna 3 oz. (canned)	21.7	0.2	26	99
Soybeans 1 c. (boiled)	29.0	2.2	0	298
Lentils 1 c. (boiled)	17.9	0.1	0	226
Kidney beans 1 c. (canned)	13.5	0.2	0	215
Sunflower seeds 1 c.	9.6	2.0	0	269

To select protein-rich foods that benefit health, select lean meats, such as round steaks, top sirloin, extra lean ground beef, pork loin, and skinless chicken. Additionally, a person should consume 8 ounces of cooked seafood every week (typically as two 4-ounce servings) to assure they are getting the healthy omega-3 fatty acids that have been linked to a lower risk for heart disease. Another tip is choosing to eat dry beans, peas, or soy products as a main dish. Some of the menu choices include chili with kidney and pinto beans, hummus on pita bread, and black bean enchiladas. You could also enjoy nuts in a variety of ways. You can put them on a salad, in a stir-fry, or use them as a topping for steamed vegetables in place of meat or cheese. If you do not eat meat, you can get all the protein you need from a plant-based diet. When choosing the best protein-rich foods to eat, pay attention to the whole nutrient package and remember to select from a variety of protein sources to get all the other essential micronutrients.

Protein Quality

While protein is contained in a wide variety of foods, it differs in quality. High-quality protein contains all the essential amino acids in the proportions needed by the human body. The amino acid profile of different foods is therefore one component of protein quality. Foods that contain some of the essential amino acids are called incomplete protein sources, while those that contain all nine essential amino acids are called complete protein sources, or high-quality protein sources. Foods that are complete protein sources include animal foods such as milk, cheese, eggs, fish, poultry, and meat, and a few plant foods, such as soy and quinoa. The only animal-based protein that is not complete is gelatin, which is made of the protein, collagen.

Figure 7.18 Complete and Incomplete Protein Sources

Protein-rich Foods by Smastronardo / CC BY-SA 4.0

Examples of complete protein sources include soy, dairy products, meat, and seafood. Examples of incomplete protein sources include legumes and corn.

Most plant-based foods are deficient in at least one essential amino acid and therefore are incomplete protein sources. For example, grains are usually deficient in the amino acid lysine, and legumes are deficient in methionine or tryptophan. Because grains and legumes are not deficient in the same amino acids they can complement each other in a diet. Incomplete protein foods are called complementary foods because when consumed in tandem they contain all nine essential amino acids at adequate levels. Some examples of complementary protein foods are given in Table 7.4 "Complementing Protein Sources the Vegan Way". Complementary protein sources do not have to be consumed at the same time—as long as they are consumed within the same day, you will meet your protein needs.

Table 7.4 Complementing Protein Sources the Vegan Way

Foods	Lacking Amino Acids	Complementary Food	Complementary Menu
Legumes	Methionine, tryptophan	Grains, nuts, and seeds	Hummus and whole-wheat pita
Grains	Lysine, isoleucine, threonine	Legumes	Cornbread and kidney bean chili
Nuts and seeds	Lysine, isoleucine	Legumes	Stir-fried tofu with cashews

The second component of protein quality is digestibility, as not all protein sources are equally digested. In general, animal-based proteins are completely broken down during the process of digestion, whereas plant-based proteins are not. This is because some proteins are contained in the plant's fibrous cell walls and these pass through the digestive tract unabsorbed by the body.

Protein Digestibility Corrected Amino Acid Score (PDCAAS)

The PDCAAS is a method to determine a food's protein quality. It is calculated using a formula that incorporates the total amount of amino acids in the food and the amount of protein in the food that is actually digested by humans. The food's protein quality is then ranked against the foods highest in protein quality. Milk protein, egg whites, whey, and soy all have a ranking of one, the highest ranking. Other foods' ranks are listed in Table 7.5 "PDCAAS of Various Foods".

Table 7.5 PDCAAS of Various Foods

Food	PDCAAS*
Milk protein	1.00
Egg white	1.00
Whey	1.00
Soy protein	1.00
Beef	0.92
Soybeans	0.91
Chickpeas	0.78
Fruits	0.76
Vegetables	0.73
Whole wheat	0.42

*1 is the highest rank, 0 is the lowest

Protein Needs: Special Considerations

Some groups may need to examine how to meet their protein needs more closely than others. We will take a closer look at the special protein considerations for vegetarians, the elderly, and athletes.

Vegetarians and Vegans

People who follow variations of the vegetarian diet and consume eggs and/or dairy products can meet their protein requirements by consuming adequate amounts of these foods. Vegetarians and vegans can also attain their recommended protein intakes if they give a little more attention to high-quality plant-based protein sources. However, when following a vegetarian diet, the amino acid lysine can be challenging to acquire. Grains, nuts, and seeds are lysine-poor foods, but tofu, soy, quinoa, and pistachios are all good sources of lysine. Following a vegetarian diet and getting the recommended protein intake is also made a little more difficult because the digestibility of plant-based protein sources is lower than the digestibility of animal-based protein.

To begin planning a more plant-based diet, start by finding out which types of food you want to eat and in what amounts you should eat them to ensure that you get the protein you need.

There are three types of vegetarian diets:

- **Plant-based**. Fifty percent of protein is obtained from plant foods.
- **Lacto-ovo vegetarian**. All animal products except eggs and dairy are eliminated.
- **Vegan**. All animal products are eliminated.

The Elderly

As we age, muscle mass gradually declines. This is a process referred to as sarcopenia. A person is sarcopenic when their amount of muscle tissue is significantly lower than the average value for a healthy person of the same age. A significantly lower muscle mass is associated with weakness, movement disorders, and a generally poor quality of life. It is estimated that about half the population of men and women above the age of eighty are sarcopenic. A review published in the September 2010 issue of Clinical Intervention in Aging demonstrates that higher intakes (1.2 to 1.5 grams per kilogram of weight per day) of high-quality protein may prevent aging adults from becoming sarcopenic.[2]

2. Waters DL, et al. Advantages of Dietary, Exercise-Related, and

Currently, the RDA for protein for elderly persons is the same as that for the rest of the adult population, but several clinical trials are ongoing and are focused on determining the amount of protein in the diet that prevents the significant loss of muscle mass specifically in older adults.

Athletes

Muscle tissue is rich in protein composition and has a very high turnover rate. During exercise, especially when it is performed for longer than two to three hours, muscle tissue is broken down and some of the amino acids are catabolized to fuel muscle contraction. To avert excessive borrowing of amino acids from muscle tissue to synthesize energy during prolonged exercise, protein needs to be obtained from the diet. Intense exercise, such as strength training, stresses muscle tissue so that afterward, the body adapts by building bigger, stronger, and healthier muscle tissue. The body requires protein post-exercise to accomplish this. There is no set different RDAs for protein intakes for athletes, but the American College of Sports Medicine, and Dietitians of Canada have the following position statements[3]:

Therapeutic Interventions to Prevent and Treat Sarcopenia in Adult Patients: An Update. Clin Interv Aging. 2010; 5, 259–70. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2938033/?tool=pubmed. Accessed September 28, 2017.

3. American College of Sports Medicine, Academy of Nutrition and Dietetics, and Dietitians of Canada. Joint Position Statement: Nutrition and Athletic Performance. Med Sci Sports Exerc. 2009; 41(3), 709-31. http://journals.lww.com/acsm-msse/fulltext/2009/03000/Nutrition_and_Athletic_Performance.27.aspx. Accessed September 28, 2017.

- Nitrogen balance studies suggest that dietary protein intake necessary to support nitrogen balance in endurance athletes ranges from 1.2 to 1.4 grams per kilogram of body weight per day.
- Recommended protein intakes for strength-trained athletes range from approximately 1.2 to 1.7 grams per kilogram of weight per day.

An endurance athlete who weighs 170 pounds should take in 93 to 108 grams of protein per day (170 ÷ 2.2 × 1.2 and 170 ÷ 2.2 × 1.4). On a 3,000-kilocalorie diet, that amount is between 12 and 14 percent of total kilocalories and within the AMDR. There is general scientific agreement that endurance and strength athletes should consume protein from high-quality sources, such as dairy, eggs, lean meats, or soy; however eating an excessive amount of protein at one time does not further stimulate muscle-protein synthesis. Nutrition experts also recommend that athletes consume some protein within one hour after exercise to enhance muscle tissue repair during the recovery phase, but some carbohydrates and water should be consumed as well. The recommended ratio from nutrition experts for exercise-recovery foods is 4 grams of carbohydrates to 1 gram of protein.

Table 7.8 Snacks for Exercise Recovery

Foods	Protein (g)	Carbohydrates (g)	Calories
Whole grain cereal with nonfat milk	14	53	260
Medium banana with nonfat milk	10	39	191
Power bar	10	43	250

In response to hard training, a person's body also adapts by becoming more efficient in metabolizing nutrient fuels both for energy production and building macromolecules. However, this raises another question: if athletes are more efficient at using protein, is it necessary to take in more protein from dietary sources than the average person? There are two scientific schools of thought on this matter. One side believes athletes need more protein and the other thinks the protein requirements of athletes are the same as for nonathletes. There is scientific evidence to support both sides of this debate. The consensus of both sides is that few people exercise at the intensity that makes this debate relevant. It is good to remember that the increased protein intake recommended by the American College of Sports Medicine, and Dietitians of Canada still lies within the AMDR for protein.

Protein Supplements

Protein supplements include powders made from compounds such as whey, soy or amino acids that either come as a powder or in capsules. We have noted that the protein requirements for most people, even those that are active, is not high. Is taking protein supplements ever justified, then? Neither protein nor amino acid supplements have been scientifically proven to improve exercise performance or increase strength. In addition, the average Canadian already consumes more protein than is required. Despite these facts, many highly physically active individuals use protein or amino acid supplements. According to the American College of Sports Medicine, and Dietitians of Canada, "the current evidence indicates that protein and amino acid supplements are no more or no less effective than food when energy is adequate for gaining lean body mass."[4]

4. American College of Sports Medicine, Academy of Nutrition and Dietetics, and Dietitians of Canada. Joint Position Statement: Nutrition and Athletic Performance. Med Sci Sports Exerc. 2009; 41(3), 709-31.

Branched-chain amino acids, such as leucine, are often touted as a way to build muscle tissue and enhance athletic performance. Despite these marketing claims, a review in the June 2005 issue of The Journal of Nutrition shows that most studies that evaluated a variety of exercise types failed to show any performance-enhancing effects of taking branched-chain amino acids.[5]

Moreover, the author of this review claims that high-quality protein foods are a better and cheaper source for branched-chain amino acids and says that a chicken breast (100 grams) contains the equivalent of seven times the amount of branched-chain amino acids as one supplement tablet. This means if you are interested in enhancing exercise performance or building muscle, you do not need to support the $20 billion supplement industry.

Although the evidence for protein and amino acid supplements impacting athletic performance is lacking, there is some scientific evidence that supports consuming high-quality dairy proteins, such as casein and whey, and soy proteins positively influences muscle recovery in response to hard training. If you choose to buy a bucket of whey protein, use it to make a protein shake after an intense workout and do not add more than what is required to obtain 20 to 25 grams of protein. As always, choosing high-quality protein foods will help you build muscle and not empty your wallet as much as buying supplements. Moreover, relying on supplements for extra protein instead of food will not provide you with any of the other essential nutrients. The bottom line is that whether you

http://journals.lww.com/acsm-msse/fulltext/2009/03000/Nutrition_and_Athletic_Performance.27.aspx. Accessed September 28, 2017.

5. Gleeson, M. Interrelationship between Physical Activity and Branched-Chain Amino Acids. J Nutr. 2005; 135(6), 1591S–5S. http://jn.nutrition.org/content/135/6/1591S.long. Accessed October 1, 2017.

are an endurance athlete or strength athlete, or just someone who takes Zumba classes, there is very little need to put your money into commercially sold protein and amino acid supplements. The evidence to show that they are superior to regular food in enhancing exercise performance is not sufficient.

What about the numerous protein shakes and protein bars on the market? Are they a good source of dietary protein? Do they help you build muscle or lose weight as marketers claim? These are not such a bad idea for an endurance or strength athlete who has little time to fix a nutritious exercise-recovery snack. However, before you ingest any supplement, do your homework. Read the label, be selective, and don't use them to replace meals, but rather as exercise-recovery snacks now and then. Some protein bars have a high amount of carbohydrates from added sugars and are not actually the best source for protein, especially if you are not an athlete. Protein bars are nutritionally designed to restore carbohydrates and protein after endurance or strength training; therefore they are not good meal replacements. If you want a low-cost alternative after an intense workout, make yourself a peanut butter sandwich on whole-grain bread and add some sliced banana for less than fifty cents.

Supermarket and health-food store shelves offer an extraordinary number of high-protein shake mixes. While the carbohydrate count is lower now in some of these products than a few years ago, they still contain added fats and sugars. They also cost, on average, more than two dollars per can. If you want more nutritional bang for your buck, make your own shakes from whole foods. Use the AMDRs for macronutrients as a guide to fill up the blender. Your homemade shake can now replace some of the whole foods on your breakfast, lunch, or dinner plate. Unless you are an endurance or strength athlete and consume commercially sold protein bars and shakes only postexercise, these products are not a good dietary source of protein.

CHAPTER 8. ALCOHOL

Introduction

Image by Allison Calabrese / CC BY 4.0

Learning Objectives

By the end of this chapter, you will be able to:

- Describe the process of alcohol metabolism
- Describe the health benefits and health risks associated with alcohol consumption

Alcohol is both a beverage providing some sustenance and a drug. For thousands of years, alcohol has been consumed in a medicinal, celebratory, and ritualistic manner. It is drunk in just about every country and often in excessive amounts. Alcohol can be made from a variety of different starch foods through the processes called fermentation. Fermentation of a starchy food such as barley or wheat can produce ethanol and CO2 which makes up what is commonly known as beer.

Alcohol is a psychoactive drug. A psychoactive drug is any substance that crosses the blood-brain barrier primarily affecting the functioning of the brain, be it altering mood, thinking, memory, motor control, or behavior. Alcohols in chemistry refer to a group of similar organic compounds, but in beverages the only alcohol consumed is ethanol.

More than half of the adult population drank alcohol in the past thirty days.[1] Of the total population who drank alcohol, approximately 5 percent drank heavily, while 15 percent binge drank. Binge drinking (as defined by the National Institute on Alcohol Abuse and Alcoholism) is when men consume five or more drinks, and when women consume four or more drinks, in two hours or less.[2]

Alcohol in excess is detrimental to health; however since its beginnings it has been suspected and promoted as a benefit to the body and mind when consumed in moderation. Moderate alcohol intake is defined as no more than one drink per day for women and no more than two drinks per day for men.[3] Although drunkenness has pervaded many cultures,

1. Alcohol and Public Health. Centers for Disease Control and Prevention. http://www.cdc.gov/alcohol/. Updated March 5, 2012. Accessed October 1, 2017.
2. Alcohol and Public Health. Centers for Disease Control and Prevention. http://www.cdc.gov/alcohol/. Updated March 5, 2012. Accessed October 1, 2017.
3. Alcoholic Beverages.US Department of Agriculture and US Department of Health and Human Services.http://www.health.gov/

drinking in moderation has long been a mantra of multiple cultures with access to alcohol.

More than 90 percent of ingested alcohol is metabolized in the liver. The remaining amount stays in the blood and is eventually excreted through the breath (which is how Breathalyzers work), urine, saliva, and sweat. The blood alcohol concentration (BAC) is measured in milligrams percent, comparing units of alcohol to units of blood. BAC is a measurement used legally to assess intoxication and the impairment and ability to perform certain activities, as in driving a car. As a general rule, the liver can metabolize one standard drink (defined as 12 ounces of beer, 5 ounces of wine, or 1 ½ ounces of hard liquor) per hour. Drinking more than this, or more quickly, will cause BAC to rise to potentially unsafe levels. Table 8.1 "Mental and Physical Effects of Different BAC Levels" summarizes the mental and physical effects associated with different BAC levels.

Table 8.1 Mental and Physical Effects of Different BAC Levels

DIETARYGUIDELINES/dga2005/document/html/chapter9.htm. Published 2005. Accessed October 5, 2017.

BAC Percent	Typical Effects
0.02	Some loss of judgment, altered mood, relaxation, increased body warmth
0.05	Exaggerated behavior, impaired judgment, may have some loss of muscle control (focusing eyes), usually good feeling, lowered alertness, release of inhibition
0.08	Poor muscle coordination (balance, speech, vision, reaction time), difficulty detecting danger, and impaired judgment, self-control, reasoning, and memory
0.10	Clear deterioration of muscle control and reaction time, slurred speech, poor coordination, slowed thinking
0.15	Far less muscle control than normal, major loss of balance, vomiting

In addition to the one drink per hour guideline, the rate at which an individual's BAC rises is affected by the following factors:

- Sex (A woman's BAC will rise more quickly than a man's.)
- Weight (BAC will rise more slowly for heavier people.)
- Genetics
- Length of time as a heavy drinker
- Type of alcohol consumed
- Amount of alcohol consumed
- Consumption rate
- Consumption before or after a meal (food in the stomach slows absorption)
- Mixture (carbonated mixers speed absorption)
- Medications may increase the bioavailability of alcohol

Alcohol Metabolism

Image by Serge Esteve on unsplash.com / CC0

Giving the liver enough time to fully metabolize the ingested alcohol is the only effective way to avoid alcohol toxicity. Drinking coffee or taking a shower will not help. The legal limit for intoxication is a BAC of 0.08. Taking into account the rate at which the liver metabolizes alcohol after drinking stops, and the alcohol excretion rate, it takes at least five hours for a legally intoxicated person to achieve sobriety.

Figure 8.1 Alcohol Metabolism Summary

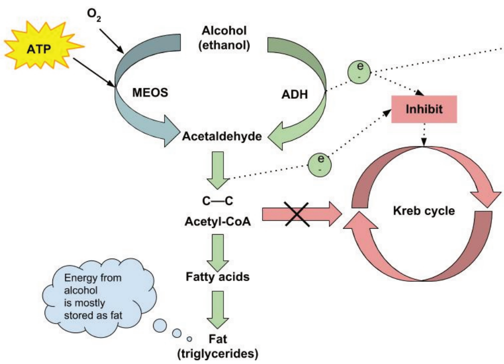


Image by Allison Calabrese / CC BY 4.0

Ethanol Consumption

Distilled spirits have exceptionally few nutrients, but beer and wine do provide some nutrients, vitamins, minerals, and beneficial plant chemicals along with calories. A typical beer is 150 kilocalories, a glass of wine contains approximately 80 kilocalories, and an ounce of hard liquor (without mixer) is around 65 kilocalories.

As a person starts drinking alcohol, up to 5% of the ingested ethanol is directly absorbed and metabolized by some of cells of the gastrointestinal tract (the mouth, tongue, esophagus and stomach). Up to 100% of the remaining ethanol travels in circulation. This is one reason why blood tests are more accurate in measuring alcohol levels.

The lungs and kidneys will excrete about 2% to 10% of this circulatory ethanol. The more you drink the more quick trips to the restroom. The human body dehydrates as a result of these frequent trips to the restroom. This dehydration affects every single cell in your body, including your brain cells. This is the cause of the so-called "morning hangover". Do not take Tylenol (acetaminophen). Alcohol metabolism activates an enzyme that transforms acetaminophen into a toxic metabolite that causes liver inflammation and damage. Liver damage may not be irreversible. Instead, drink water with electrolytes or sport drinks to rehydrate the body's cells.

Alcohol is a volatile (flammable) organic substance and can be converted to a gas. The lungs exhale alcohol as a gas. The more alcohol consumed, the stronger the smell of alcohol in a person's breathe. Breathalyzer tests measure the exhaled alcohol levels in the lungs to determine the state of inebriation.

The liver metabolizes up to 85% – 98% of the circulatory ethanol. The liver uses two metabolic processes to get rid of this circulatory ethanol as quickly and safely as possible.

1. Alcohol dehydrogenase system
2. Microsomal ethanol oxidizing system (MEOS)

Alcohol Dehydrogenase System

About 80 to 90% of the total hepatic ethanol uptake is processed via the alcohol dehydrogenase system.The degradation of ethanol begins in the liver. The enzyme that catalyzes this reaction is called alcohol dehydrogenase. The products from this reaction are acetaldehyde, NADH (a reduced coenzyme that carries electrons from one reaction to another) and H+ ion. Acetaldehyde is very toxic to the liver and the body's cells. The moment acetaldehyde is produced; it must be degraded to protect the liver cells. The enzyme that will carry this type of degradation reaction is acetaldehyde dehydrogenase (ALDH). Acetaldehyde dehydrogenase converts acetaldehyde into acetate, a non-toxic molecule.

Microsomal Ethanol Oxidizing System

(MEOS)

In a moderate drinker, about 10 to 20% of the total liver ethanol uptake is processed via the microsomal ethanol oxidizing system (MEOS). During periods of heavy drinking, the MEOS system will metabolize most of the excess ethanol ingested. Heavy drinking stimulates the human body to include the MEOS system enzymes to clear ethanol faster from the body.

The MEOS system is also located in the liver. Similar to the Alcohol dehydrogenase system, acetaldehyde dehydrogenase will immediately convert acetaldehyde into acetate, a non-toxic molecule. Other products from this reaction are NADH and H+ ion.

Fate of Acetate

The acetate produced (from the alcohol dehydrogenase system and microsomal ethanol oxidizing system) is either released into circulation or retained inside the liver cells. In the liver cells, acetate is converted to acetyl CoA where it is used to produce other molecules like CO2 or used in the synthesis of fatty acids and cholesterol.

Health Consequences of Alcohol Abuse

Alcoholic drinks in excess contribute to weight gain by substantially increasing caloric intake. However, alcohol displays its two-faced character again in its effects on body weight, making many scientific studies contradictory. Multiple studies show high intakes of hard liquor are linked to weight gain, although this may be the result of the regular consumption of hard liquor with sugary soft drinks, juices, and other mixers. On the other hand drinking beer and, even more so, red wine, is not consistently linked to weight gain and in some studies actually decreases weight gain. The contradictory results of scientific studies that have examined the association of alcohol intake with body weight are partly due to the fact that alcohol contributes calories to the diet. When alcohol is drunk in excess, it reduces the secretion of pancreatic juice and damages the lining of the gastrointestinal system, impairing nutrient digestion and absorption. The impaired digestion and absorption of nutrients in alcoholics contributes to their characteristic "skinniness" and multiple associated micronutrient deficiencies. The most common macronutrient deficiency among alcoholics is water, as it is excreted in excess. Commonly associated micronutrient deficiencies include thiamine, pyridoxine, folate, vitamin A, magnesium, calcium, and zinc. Furthermore, alcoholics typically replace calories from alcohol with those of nutritious foods, sometimes getting 50 percent or more of their daily caloric intake from alcoholic beverages.

Effects of Alcohol Abuse on the Brain

A small amount (up to 10%) of the liver acetaldehyde may accumulate inside the liver cells. As more alcohol is ingested, this stimulates the production of acetaldehyde by both the alcohol dehydrogenase and MEOS systems. As the levels of acetaldehyde increase inside the liver cells with heavy consumption of alcohol, some of the acetaldehyde diffuse into the blood circulation. In circulation, high levels of acetaldehyde cause nausea and vomiting. Vomiting causes more body dehydration and loss of electrolytes. If the dehydration becomes severe enough, this can impair brain function and a person may lose consciousness.

Alcohol can adversely affect nearly every area of the brain. When BAC rises, the central nervous system is depressed. Alcohol disrupts the way nerve cells communicate with each other by interfering with receptors on certain cells. The immediate impact of alcohol on the brain can be seen in the awkwardly displayed symptoms of confusion, blurred vision, slurred speech, and other signs of intoxication. These symptoms will go away once drinking stops, but abusive alcohol consumption over time can lead to long-lasting damage to the brain and nervous system. This is because alcohol and its metabolic byproducts kill brain cells.

Effects of Excessive Alcohol on the Liver

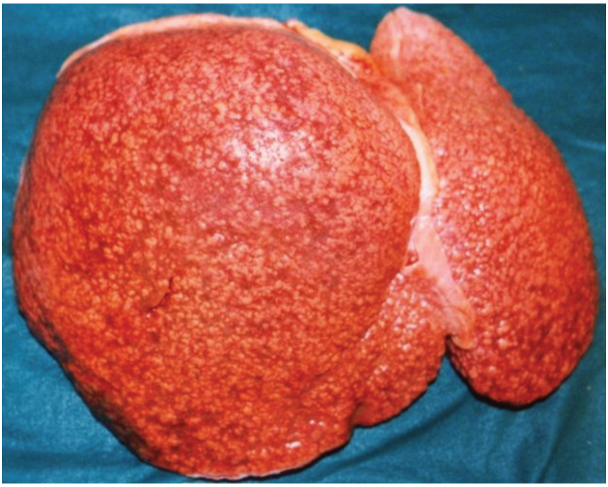
Alcohol stimulates the release of epinephrine from the kidneys. Epinephrine binds to receptors in the liver cells to stimulate the release of glucagon from the pancreas. Glucagon and epinephrine stimulate glycogenolysis in the liver cells.

Epinephrine also stimulates the breakdown of triglycerides and glycerol into free fatty acids in adipose tissue and are released into the bloodstream and travel to the liver.

A portion of these triglycerides are stored in the liver cells; while, the remainder of these triglycerides are converted to very low density lipoprotein (VLDL). The increased accumulation of both stored triglycerides and VLDL particles inside the liver cells causes a condition called fatty liver or hepatic steatosis. This can impair normal liver function. The more alcohol consumed, the more lipids produced and stored inside the liver cells. These effects are cumulative over time.

Drinking-related liver-disease is on the rise in Canada. Although not every alcoholic or heavy drinker will die from liver problems, the liver is one of the body's main filtering organs and is severely stressed by alcohol abuse. The term Alcoholic Liver Disease (ALD) is used to describe liver problems linked to excessive alcohol intake. ALD can be progressive, with individuals first suffering from a fatty liver and going on to develop cirrhosis. It is also possible to have different forms of ALD at the same time.

Figure 8.2 Liver Cirrhosis



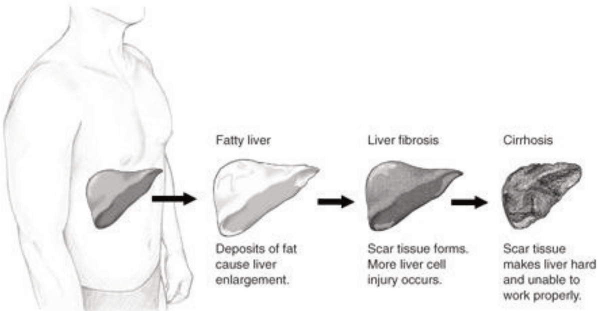
Cirrosi Micronodular by Amanda Alvarez / CC BY SY 4.0

Excessive alcohol consumption causes the destruction of liver cells. In an attempt to repair itself, the liver initiates an inflammatory and reparation process causing scar tissue to form. In the liver's attempt to replace the dead cells, surviving liver cells multiply. The result is clusters of newly formed liver cells, also called regenerative nodules, within the scar tissue. This state is called cirrhosis of the liver.

The three most common forms of ALD are:

- Fatty liver. A rather benign disorder that develops after excessive alcohol consumption; however it can progress to more fatal diseases. Fatty liver is reversible if alcohol use is brought under control.
- Alcoholic hepatitis. The symptoms of this alcohol-induced liver inflammation are a swollen liver, abdominal pain, nausea, fever, jaundice, and vomiting. Although linked to alcohol use, even people who drink moderately can sometimes develop this condition, and not all alcohol abusers do. If a person stops drinking alcohol, the liver damage can be reversed. But if they continue, cirrhosis may develop and death can result.
- Cirrhosis. This serious and sometimes fatal form of ALD develops when liver cells die and form scar tissue, which blocks blood flow and causes wastes and toxins to build up in the system. Strictly speaking, cirrhosis cannot be cured. It can, however, be stopped with medical treatment and complications can be managed if the individual stops drinking, and many do survive. Not all cases of cirrhosis are strictly due to alcoholism, and not all alcoholics develop the disease. Symptoms of cirrhosis include the buildup of abdominal fluid (ascites), abdominal pain, fever, thirst, confusion, and fatigue.

Figure 8.3 The Progression of ALD



Stages of Liver Damage by National Digestive Diseases Information Clearinghouse / Public Domain

As the liver cells release VLDL particles into circulation, this increases the levels of VLDL particles in blood. As VLDL particles continue to accumulate in blood, this cause a condition called hyperlipidemia. In their journey through circulation, VLDL particles are eventually degraded to low density lipoproteins (LDL) particles. LDL particles are also known as “bad cholesterol”. Higher levels of LDL particles in circulation lead to the build-up of cholesterol deposition plaques inside the walls of the blood vessels (known as atherosclerosis). These plaques can impair or stop blood flow to the cells. If an artery is blocked, the cells cannot make enough energy and eventually stop working. If the artery remains blocked for more than a few minutes, the cells may die. When a cardiac artery is blocked, this causes a heart attack (acute myocardial infarction). Depending on the length and severity of the blockage, damage to the cardiac cells may be permanent and irreversible. Once the heart structure and function is compromised, the more susceptible a patient would be to suffer a second heart attack.

Health Benefits of Moderate Alcohol Intake

In contrast to excessive alcohol intake, moderate alcohol intake has been shown to provide health benefits. The data is most convincing for preventing heart disease in middle-aged and older people. A review of twenty-nine studies concluded that moderate alcohol intake reduces the risk of coronary heart disease by about 30 percent in comparison to those who do not consume alcohol.[1]

Several other studies demonstrate that moderate alcohol consumption reduces the incidences of stroke and heart attack, and also death caused by cardiovascular and heart disease. The drop in risk for these adverse events ranges between percent. Moreover, there is some scientific evidence that moderate alcohol intake reduces the risk for metabolic syndrome, Type 2 diabetes, and gallstones. In addition to providing some health benefits, moderate alcohol intake also serves as a digestive aid, a source of comfort and relaxation, and inducing social interactions, thereby benefiting all aspects of the health triangle. It has not been clearly demonstrated that moderate alcohol consumption benefits younger populations, and the risks of any alcohol consumption do not outweigh the benefits for pregnant women, those who are taking

1. Ronksley PE, et al. Association of Alcohol Consumption with Selected Cardiovascular Disease Outcomes: A Systematic Review and Meta-Analysis. BMJ. 2011; 342, d671. http://www.bmj.com/content/342/bmj.d671. Accessed October 5, 2017.

medications that interact with alcohol, and those who are unable to drink in moderation.

The Reality

Alcohol is a diuretic that results in dehydration. It suppresses the release of antidiuretic hormone and less water is reabsorbed and more is excreted. Drinking alcohol in excess can lead to a "hangover," of which the majority of symptoms are the direct result of dehydration.

CHAPTER 9. ENERGY METABOLISM

Introduction

Learning Objectives

By the end of this chapter, you will be able to:

- Describe the body's use, storage and balance of energy
- Describe the process of calculating Body Mass

Index (BMI)

- Describe factors that contribute to weight management
- Identify evidence-based nutritional recommendations

Months and months of training lead up to one of the most prestigious one-man (or woman) outrigger canoe paddling races in the world, the Kaʻiwi Channel Solo World Championship. Athletes from Hawaiʻi and across the world paddle from the island of Molokai to Oahu in the Kaʻiwi Channel, whose name carries the meanings of its two core words "the bones." The channel is said to be one of the most treacherous bodies of water and depending on the ocean conditions top paddlers finish between 3 1/2 and 6 hours. Paddlers spend hours and hours each week training to physically prepare their bodies and minds for the race but equally important is the refueling that takes place off the water. Each paddler will say they have their own "secret" training nutrition plan which may consist of a specific food or drink they prefer, but the bottom line is that the energy from carbohydrates, protein, and fat they ingest is required to fuel their body for training, recovering and repairing so they are able to continue to perform at high levels. Having a nutrition plan for race day is equally important for achieving peak performance and there are all sorts of products available with claims about digestibility, energy-sustenance, and promises of optimal performance results.

Energy is essential to life. Normal function of the human body requires a constant input and output of energy to maintain life. Various chemical components of food provide the input of energy to the body. The chemical breakdown of those chemicals provides the energy needed to carry out thousands of body functions that allow the body to perform daily functions and tasks such as breathing, walking up a flight of steps, and studying for a test.

Energy is classified as either potential or kinetic. Potential energy is stored energy, or energy waiting to happen. Kinetic energy is energy in motion. To illustrate this, think of an Olympic swimmer standing at the pool's edge awaiting the sound of the whistle to begin the race. While he waits for the signal, he has potential energy. When the whistle sounds and he dives into the pool and begins to swim, his energy is kinetic (in motion).

In food and in components of the human body, potential energy resides in the chemical bonds of specific molecules such as carbohydrates, fats, proteins, and alcohol. This potential energy is converted into kinetic energy in the body that drives many body functions ranging from muscle and nerve function to driving the synthesis of body protein for growth. After potential energy is released to provide kinetic energy, it ultimately becomes thermal energy or heat. You can notice this when you exercise and your body heats up.

The Calorie Is a Unit of Energy

The amount of energy in nutrients or the amount of energy expended by the body can be quantified with a variety of units used to measure energy. In Canada, the kilocalorie (kcal) is most commonly used and is often just referred to as a calorie. Strictly speaking, a kcal is 1000 calories. In nutrition, the term calories almost always refers to kcals. Sometimes the kcal is indicated by capitalizing calories as "Calories." A kilocalorie is the amount of energy in the form of heat that is required to heat one kilogram of water one degree Celsius.

Most other countries use the kilojoule (kJ) as their standard unit of energy. The Joule is a measure of energy based on work accomplished – the energy needed to produce a specific amount of force. Since calories and Joules are both measures of energy, one can be converted to the other – 1 kcal = 4.18 kJ.

Estimating Caloric Content

The energy contained in energy-yielding nutrients differs because the energy-yielding nutrients are composed of different types of chemical bonds. The carbohydrate or protein in a food yields approximately 4 kilocalories per gram, whereas the triglycerides that compose the fat in a food yield 9 kilocalories per gram. A kilocalorie of energy performs one thousand times more work than a calorie. On the Nutrition Facts panel found on packaged food, the calories listed for a particular food are actually kilocalories.

Estimating the number of calories in commercially prepared food is fairly easy since the total number of calories in a serving of a particular food is listed on the Nutrition Facts panel. If you wanted to know the number of calories in the breakfast you consumed this morning just add up the number of calories in each food. For example, if you ate one serving of yogurt that contained 150 calories, on which you sprinkled half of a cup of low-fat granola cereal that contained 209 calories, and drank a glass of orange juice that contained 100 calories, the total number of calories you consumed at breakfast is 150 + 209 + 100 = 459 calories. If you do not have a Nutrition Facts panel for a certain food, such as a half cup of blueberries, and want to find out the amount of calories it contains, go to Food-a-pedia, a website maintained by the USDA. EAtracker was the Canadian version of the website hosted by the Dieticians of Canada but it was discontinued at the end of 2019.

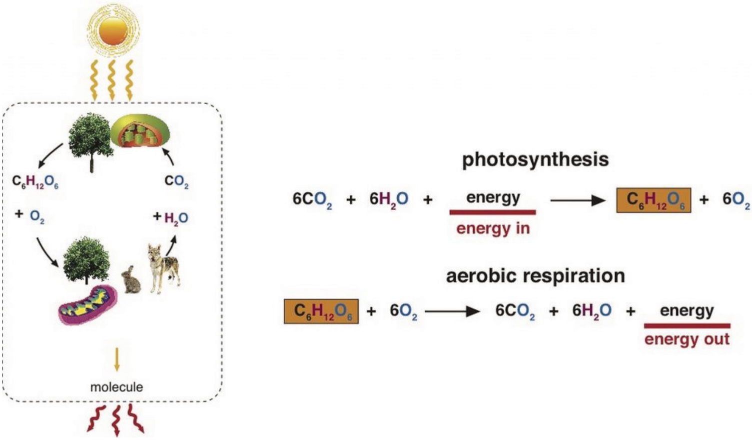
An Organism Requires Energy and Nutrient Input

Energy is required in order to build molecules into larger macromolecules (like proteins), and to turn macromolecules into organelles and cells, which then turn into tissues, organs, and organ systems, and finally into an organism. Proper nutrition provides the necessary nutrients to make the energy that supports life's processes. Your body builds new macromolecules from the nutrients in food.

Nutrient and Energy Flow

Energy is stored in a nutrient's chemical bonds. Energy comes from sunlight, which plants capture and, via photosynthesis, use it to transform carbon dioxide in the air into the molecule glucose. When the glucose bonds are broken, energy is released. Bacteria, plants, and animals (including humans) harvest the energy in glucose via a biological process called cellular respiration. In this process oxygen is required and the chemical energy of glucose is gradually released in a series of chemical reactions. Some of this energy is trapped in the molecule adenosine triphosphate (ATP) and some is lost as heat. ATP can be used when needed to drive chemical reactions in cells that require an input of energy. Cellular respiration requires oxygen (aerobic) and it is provided as a byproduct of photosynthesis. The byproducts of cellular respiration are carbon dioxide (CO2) and water, which plants use to conduct photosynthesis again. Thus, carbon is constantly cycling between plants and animals.

Figure 9.1 Energy Flow From Sun to Plants to Animals



Plants harvest energy from the sun and capture it in the molecule glucose. Humans harvest the energy in glucose and capture it into the molecule ATP.

Food Quality

One measurement of food quality is the amount of nutrients it contains relative to the amount of energy it provides. High-quality foods are nutrient dense, meaning they contain lots of nutrients relative to the amount of calories they provide. Nutrient-dense foods are the opposite of "empty-calorie" foods such as carbonated sugary soft drinks, which provide many calories and very little, if any, other nutrients. Food quality is additionally associated with its taste, texture, appearance, microbial content, and how much consumers like it.

The Atom

Cells are the basic building blocks of life, but atoms are the basic building blocks of all matter, living and nonliving. The structural elements of an atom are protons (positively charged), neutrons (no charge), and electrons (negatively charged). Protons and neutrons are contained in the dense nucleus of the atom; the nucleus thus has a positive charge. Because opposites attract, electrons are attracted to this nucleus and move around it in the electron cloud.

Electrons contain energy, and this energy is stored within the charge and movement of electrons and the bonds atoms make with one another. However, this energy is not always stable, depending on the number of electrons within an atom. Atoms are more stable when their electrons orbit in pairs. An atom with an odd number of electrons must have an unpaired electron. In most cases, these unpaired electrons are used to create chemical bonds. A chemical bond is the attractive force between atoms and contains potential energy. By bonding, electrons find pairs and chemicals become part of a molecule.

Bond formation and bond breaking are chemical reactions that involve the movement of electrons between atoms. These chemical reactions occur continuously in the body. We previously reviewed how glucose breaks down into water and carbon dioxide as part of cellular respiration. The energy released by breaking those bonds is used to form molecules of adenosine triphosphate (ATP). Recall how during this process electrons are extracted from glucose in a stepwise manner and transferred to other molecules. Occasionally electrons “escape” and, instead of completing the cellular respiration cycle, are transferred to an oxygen molecule. Oxygen (a molecule with two atoms) with one unpaired electron is known as superoxide (Figure 8.2).

Atoms and molecules such as superoxide that have unpaired electrons are called free radicals; those containing oxygen are more specifically referred to as reactive oxygen species. The unpaired electron in free radicals destabilizes them, making them highly reactive. Other reactive oxygen species include hydrogen peroxide and the hydroxyl radical.

Figure 9.2 Superoxide

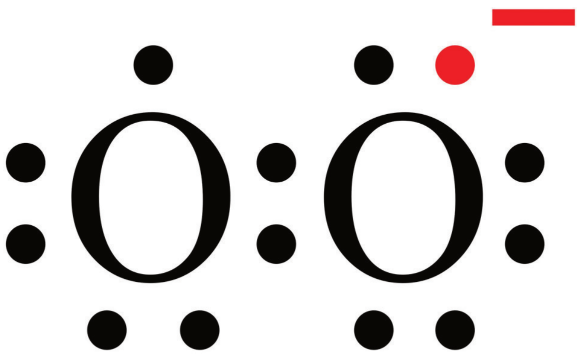


Image by DoSiDo / CC BY-SA 3.0

A molecule with one unpaired electron, which makes it a free radical.

The reactivity of free radicals is what poses a threat to macromolecules such as DNA, RNA, proteins, and fatty acids. Free radicals can cause chain reactions that ultimately damage cells. For example, a superoxide molecule may react with a fatty acid and steal one of its electrons. The fatty acid then becomes a free radical that can react with another fatty acid nearby. As this chain reaction continues, the permeability and fluidity of cell membranes changes, proteins in cell membranes experience decreased activity, and receptor proteins undergo changes in structure that either alter or stop their function. If receptor proteins designed to react to insulin levels undergo a structural change it can negatively affect glucose uptake. Free radical reactions can continue unchecked unless stopped by a defense mechanism.

Metabolism Overview

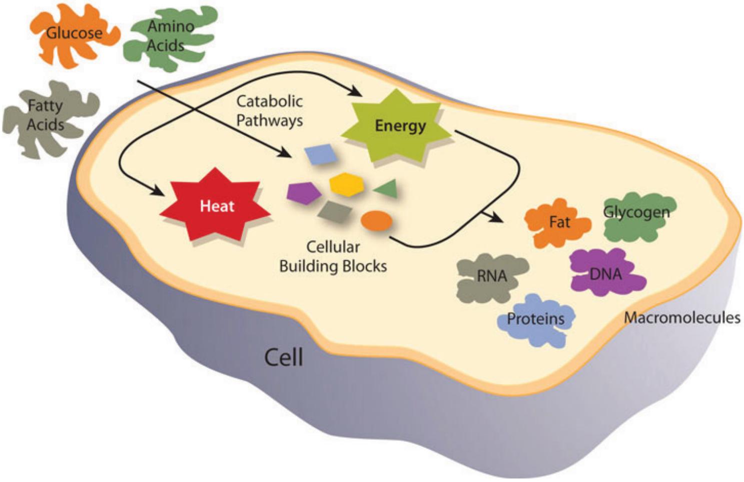
Metabolism is defined as the sum of all chemical reactions required to support cellular function and hence the life of an organism. Metabolism is either categorized as catabolism, referring to all metabolic processes involved in molecule breakdown, or anabolism, which includes all metabolic processes involved in building bigger molecules. Generally, catabolic processes release energy and anabolic processes consume energy. The overall goals of metabolism are energy transfer and matter transport. Energy is transformed from food macronutrients into cellular energy, which is used to perform cellular work. Metabolism transforms the matter of macronutrients into substances a cell can use to grow and reproduce and also into waste products. For example, enzymes are proteins and their job is to catalyze chemical reactions. Catalyze means to speed-up a chemical reaction and reduce the energy required to complete the chemical reaction, without the catalyst being used up in the reaction. Without enzymes, chemical reactions would not happen at a fast enough rate and would use up too much energy for life to exist. A metabolic pathway is a series of enzyme catalyzed reactions that transform the starting material (known as a substrate) into intermediates, that are the substrates for subsequent enzymatic reactions in the pathway, until, finally, an end product is synthesized by the last enzymatic reaction in the pathway. Some metabolic pathways are complex and involve many enzymatic reactions, and others involve only a few chemical reactions.

To ensure cellular efficiency, the metabolic pathways involved in catabolism and anabolism are regulated in concert by energy status, hormones, and substrate and end-product levels. The concerted regulation of metabolic pathways prevents cells from inefficiently building a molecule when it is already available. Just as it would be inefficient to build a wall at the same time as it is being broken down, it is not metabolically efficient for a cell to synthesize fatty acids and break them down at the same time.

Catabolism of food molecules begins when food enters the mouth, as the enzyme salivary amylase initiates the breakdown of the starch in foods. The entire process of digestion converts the large polymers in food to monomers that can be absorbed. Starches are broken down to monosaccharides, lipids are broken down to fatty acids, and proteins are broken down to amino acids. These monomers are absorbed into the bloodstream either directly, as is the case with monosaccharides and amino acids, or repackaged in intestinal cells for transport by an indirect route through lymphatic vessels, as is the case with most fatty acids and other fat-soluble molecules.

Once absorbed, water-soluble nutrients first travel to the liver which controls their passage into the blood that transports the nutrients to cells throughout the body. The fat-soluble nutrients gradually pass from the lymphatic vessels into blood flowing to body cells. Cells requiring energy or building blocks take up the nutrients from the blood and process them in either catabolic or anabolic pathways. The organ systems of the body require fuel and building blocks to perform the many functions of the body, such as digesting, absorbing, breathing, pumping blood, transporting nutrients in and wastes out, maintaining body temperature, and making new cells.

Figure 9.3 Cellular Metabolic Processes



Energy metabolism refers more specifically to the metabolic pathways that release or store energy. Some of these are catabolic pathways, like glycolysis (the splitting of glucose), β-oxidation (fatty-acid breakdown), and amino acid catabolism. Others are anabolic pathways, and include those involved in storing excess energy (such as glycogenesis), and synthesizing triglycerides (lipogenesis). Table 9.1 "Metabolic Pathways" summarizes some of the catabolic and anabolic pathways and their functions in energy metabolism.

Table 9.1 Metabolic Pathways

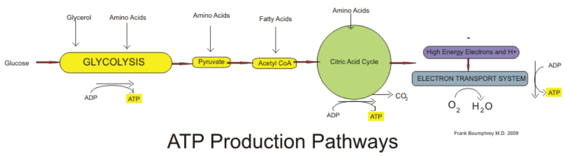
Catabolic Pathways	Function	Anabolic Pathways	Function
Glycolysis	Glucose breakdown	Gluconeogenesis	Synthesize glucose
Glycogenolysis	Glycogen breakdown	Glycogenesis	Synthesize glycogen
β-oxidation	Fatty-acid breakdown	Lipogenesis	Synthesize triglycerides
Proteolysis	Protein breakdown to amino acids	Protein synthesis	Synthesize proteins

Catabolism: The Breakdown

All cells are in tune to their energy balance. When energy levels are high cells build molecules, and when energy levels are low catabolic pathways are initiated to make energy. Glucose is the preferred energy source by most tissues, but fatty acids and amino acids also can be catabolized to release energy that can drive the formation of ATP. ATP is a high energy molecule that can drive chemical reactions that require energy. The catabolism of nutrients to release energy can be separated into three stages, each containing individual metabolic pathways. The three stages of nutrient breakdown are the following:

- **Stage 1**. Glycolysis for glucose, β-oxidation for fatty acids, or amino-acid catabolism
- **Stage 2**. Citric Acid Cycle (or Krebs cycle)
- **Stage 3**. Electron Transport Chain and ATP synthesis

Figure 9.4 ATP Production Pathway



"Aerobic Production Pathways" by Boumphrey fr / CC BY-SA 3.0

The breakdown of glucose begins with glycolysis, which is a ten-step metabolic pathway yielding two ATP per glucose molecule; glycolysis takes place in the cytosol and does not require oxygen. In addition to ATP, the end-products of glycolysis include two three-carbon molecules, called pyruvate. Pyruvate can either be shuttled to the citric acid cycle to make more ATP or follow an anabolic pathway. If a cell is in negative-energy balance, pyruvate is transported to the mitochondria where it first gets one of its carbons chopped off, yielding acetyl-CoA. The breakdown of fatty acids begins with the catabolic pathway, known as β-oxidation, which takes place in the mitochondria. In this catabolic pathway, four enzymatic steps sequentially remove two-carbon molecules from long chains of fatty acids, yielding acetyl-CoA molecules. In the case of amino acids, once the nitrogen is removed from the amino acid the remaining carbon skeleton can be enzymatically converted into acetyl-CoA or some other intermediate of the citric acid cycle. Acetyl-CoA, a two-carbon molecule common to glucose, lipid, and protein metabolism enters the second stage of energy metabolism, the citric acid cycle.

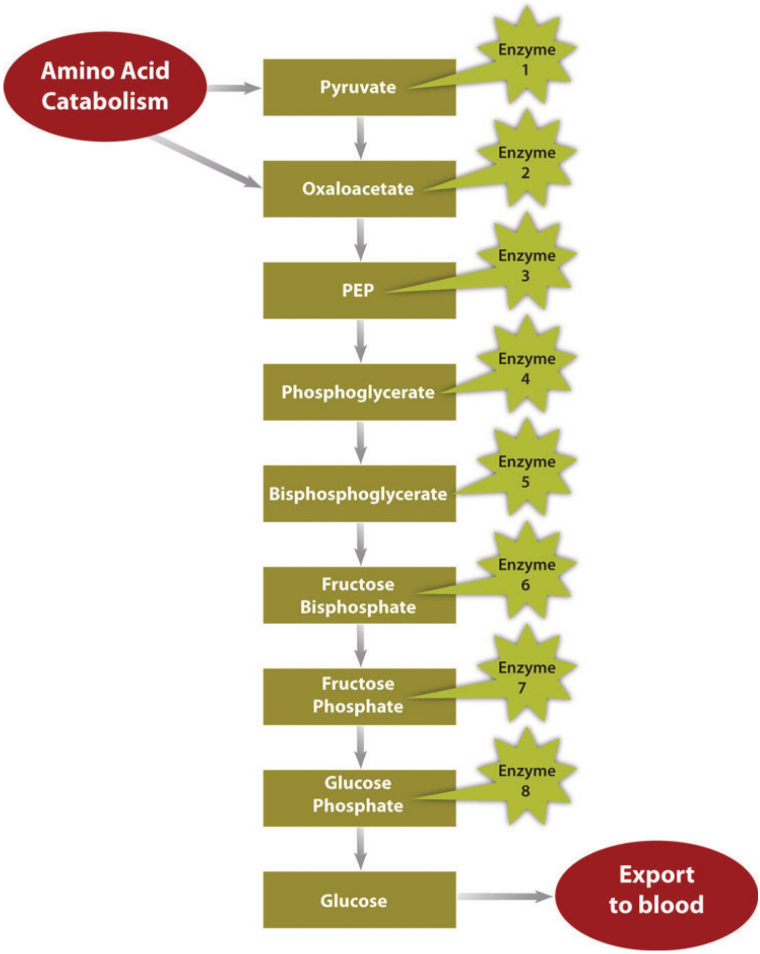
In the citric acid cycle, acetyl-CoA is joined to a four-carbon molecule. In this multistep pathway, two carbons are lost as two molecules of carbon dioxide. The energy obtained from the breaking of chemical bonds in the citric acid cycle is transformed into two more ATP molecules (or equivalents thereof) and high energy electrons that are carried by the molecules, nicotinamide adenine dinucleotide (NADH) and flavin adenine dinucleotide (FADH2). NADH and FADH2 carry the electrons to the inner membrane in the mitochondria where the third stage of energy release takes place, in what is called the electron transport chain. In this metabolic pathway a sequential transfer of electrons between multiple proteins occurs and ATP is synthesized. The entire process of nutrient catabolism is chemically similar to burning, as carbon and hydrogen atoms are combusted (oxidized) producing carbon dioxide, water, and heat. However, the stepwise chemical reactions in nutrient catabolism pathways slow the oxidation of carbon atoms so that much of the energy is captured and not all transformed into heat and light. Complete nutrient catabolism is between 30 and 40 percent efficient, and some of the energy is therefore released as heat. Heat is a vital product of nutrient catabolism and is involved in maintaining body temperature. If cells were too efficient at trapping nutrient energy into ATP, humans would not last to the next meal, as they would die of hypothermia (excessively low body temperature).

Anabolism: The Building

The energy released by catabolic pathways powers anabolic pathways in the building of macromolecules such as the proteins RNA and DNA, and even entire new cells and tissues. Anabolic pathways are required to build new tissue, such as muscle, after prolonged exercise or the remodeling of bone tissue, a process involving both catabolic and anabolic pathways. Anabolic pathways also build energy-storage molecules, such as glycogen and triglycerides. Intermediates in the catabolic pathways of energy metabolism are sometimes diverted from ATP production and used as building blocks instead. This happens when a cell is in positive-energy balance. For example, the citric-acid-cycle intermediate, α-ketoglutarate can be anabolically processed to the amino acids glutamate or glutamine if they are required. The human body is capable of synthesizing eleven of the twenty amino acids that make up proteins. The metabolic pathways of amino acid synthesis are all inhibited by the specific amino acid that is the end-product of a given pathway. Thus, if a cell has enough glutamine it turns off its synthesis.

Anabolic pathways are regulated by their end-products, but even more so by the energy state of the cell. When there is ample energy, bigger molecules, such as protein, RNA and DNA, will be built as needed. Alternatively, when energy is insufficient, proteins and other molecules will be destroyed and catabolized to release energy. A dramatic example of this is seen in children with marasmus, a form of advanced starvation. These children have severely compromised bodily functions, often culminating in death by infection. Children with marasmus are starving for calories and protein, which are required to make energy and build macromolecules. The negative-energy balance in children who have marasmus results in the breakdown of muscle tissue and tissues of other organs in the body's attempt to survive. The large decrease in muscle tissue makes children with marasmus look emaciated or "muscle-wasted."

Figure 9.5 Metabolic Pathway of Gluconeogenesis



In a much less severe example, a person is also in negative-energy balance between meals. During this time, blood-glucose levels start to drop. In order to restore blood-glucose levels to their normal range, the anabolic pathway, called gluconeogenesis, is stimulated. Gluconeogenesis is the process of building glucose molecules mostly from certain amino acids and it occurs primarily in the liver (Figure 8.5 "Metabolic Pathway of Gluconeogenesis"). The liver exports the synthesized glucose into the blood for other tissues to use.

Energy Storage

In contrast, in the "fed" state (when energy levels are high), extra energy from nutrients will be stored. Glucose is stored mainly in muscle and liver tissues. In these tissues it is stored as glycogen, a highly branched macromolecule consisting of thousands of glucose molecules held together by chemical bonds. The glucose molecules are joined together by an anabolic pathway called glycogenesis. For each molecule of glucose stored, one molecule of ATP is used. Therefore, it costs energy to store energy. Glycogen levels do not take long to reach their physiological limit and when this happens excess glucose will be converted to fat. A cell in positive-energy balance detects a high concentration of ATP as well as acetyl-CoA produced by catabolic pathways. In response, the rate of catabolism is slowed or shut off and the synthesis of fatty acids, which occurs by an anabolic pathway called lipogenesis, is turned on. The newly made fatty acids are transported to fat-storing cells called adipocytes where they are stored as triglycerides. Fat is a better alternative to glycogen for energy storage as it is more compact (per unit of energy) and, unlike glycogen, the body does not store water along with fat. Water weighs a significant amount, and increased glycogen stores, which are accompanied by water, would dramatically increase body weight. When the body is in positive-energy balance, excess carbohydrates, lipids, and protein can all be metabolized to fat.

Weight Management

Photo by Hope House Press on unsplash.com / CC0

“Obesogenic” is a word that has sprung up in the language of public health professionals in the last two decades. Obesogenic is defined as “an environment that promotes increased food intake, non-healthful foods, and physical inactivity.”[1]

In Canada, 64% of Canadians over the age of 18 are overweight or obese, and about 30% of children aged 5-17 are overweight or obese. The health consequences of too much

1. Obesogenic Environments. Center for Disease Control and Prevention (CDC). https://www.cdc.gov/pcd/issues/2015/14_0559.htm. Published 2013. Accessed September 22, 2017.

body fat are numerous, including increased risks for cardiovascular disease, Type 2 diabetes, and some cancers. The medical costs related to obesity are well over 7 billion in Canada which is expected to increase to 9 billion by 2021.

Numerous obesogenic agents that contribute to this immense public health problem have become a part of everyday life in Canadian society. The fast food industry has been growing for decades and continues to grow despite the latest economic slump. In Canada today there are over 14 000 McDonald's restaurants, while in 1967 there was one. Food portions have been getting bigger since the 1960s, and in the 1990s North American society experienced the "super-size" marketing boom, which still endures. Escalators, elevators, and horizontal walkways now dominate shopping malls and office buildings, factory work has become increasingly mechanized and robotized, the typical Canadian watches more than four hours of television daily, and in many work places the only tools required to conduct work are a chair and a computer. The list of all the societal obesogenic factors goes on and on. They are the result of modernization, industrialization, and urbanization continuing on without individuals, public health officials, or government adequately addressing the concurrent rise in overweight and obesity.

With obesity at epidemic proportions in North America it is paramount that policies be implemented or reinforced at all levels of society, and include education, agriculture, industry, urban planning, healthcare, and government. Reversing and stopping obesity are two different things. The former will require much more societal and individual change than the latter. The following are some ideas for constructing an environment in Canada that promotes health and confronts the obesity epidemic:

Individual Level

- Purchase less prepared foods and eat more whole foods.

- Decrease portion sizes when eating or serving food.
- Eat out less, and when you do eat out choose low-calorie options.
- Walk or bike to work. If this is not feasible, walk while you are at work.
- Take the stairs when you come upon them or better yet, seek them out.
- Walk your neighborhood and know your surroundings. This benefits both health and safety.
- Watch less television.

Community Level

- Request that your college/workplace provides more access to healthy low-cost foods.
- Support changes in school lunch programs.
- Participate in cleaning up local green spaces and then enjoy them during your leisure time.
- Patronize local farms and fruit-and-vegetable stands.
- Talk to your grocer and ask for better whole-food choices and seafood at a decent price.
- Ask the restaurants you frequently go to, to serve more nutritious food and to accurately display calories of menu items.

National Level

- Support policies that increase the walkability of cities.
- Support national campaigns addressing obesity.
- Support policies that support local farmers and the increased access and affordability of healthy food.

It is critical for the nation's health to change our environment to one that promotes weight loss and/or weight maintenance. However, action is needed on multiple fronts to reverse the obesity epidemic trend within one generation.

In this section you will learn how to assess body weight and percentage body fat. You will also learn that it is not only society and environment that play a role in body weight and percentage body fat, but also physiology, genetics, and behavior—and that all of them interact. We will also discuss the health risks of being underweight and overweight, learn evidence-based solutions to maintain body weight at the individual level, and assess the current state of affairs of combating the obesity epidemic.

Balancing Energy Input with Energy Output

Photo by Jon Flobrant on unsplash.com / CC0

To Maintain Weight, Energy Intake Must Balance Energy Output

Recall that the macronutrients you consume are either converted to energy, stored, or used to synthesize macromolecules. A nutrient's metabolic path is dependent upon energy balance. When you are in a positive energy balance the excess nutrient energy will be stored or used to grow (e.g., during childhood, pregnancy, and wound healing). When you are in negative energy balance you aren't taking in enough energy to meet your needs, so your body will need to use its stores to provide energy. Energy balance is achieved when intake of energy is equal to energy expended. Weight can be thought of as a whole body estimate of energy balance; body weight is maintained when the body is in energy balance, lost when it is in negative energy balance, and gained when it is in positive energy balance. In general, weight is a good predictor of energy balance, but many other factors play a role in energy intake and energy expenditure. Some of these factors are under your control and others are not. Let us begin with the basics on how to estimate energy intake, energy requirement, and energy output. Then we will consider the other factors that play a role in maintaining energy balance and hence, body weight.

Estimating Energy Requirement

To maintain body weight you have to balance the calories obtained from food and beverages with the calories expended every day. Here, we will discuss how to calculate your energy needs in kilocalories per day so that you can determine whether your caloric intake falls short, meets, or exceeds your energy needs. A formula was devised for calculating your Estimated Energy Requirement (EER). It takes into account your age, sex, weight, height, and physical activity level (PA). The EER is a standardized mathematical prediction of a person's daily energy needs in kilocalories per day required to maintain weight. It is calculated for those over 18 years of age via the following formulas:

Adult male: EER = 662 − [9.53 X age (y)] + PA X [15.91 X wt (kg) + 5.39.6 X ht (m)]

Adult female: EER = 354 − [6.91 x age (y)] + PA x [9.36 x wt (kg) + 726 x ht (m)]

Note: to convert pounds to kilograms, divide weight in pounds by 2.2. To convert feet to meters, divide height in feet by 3.3.

Estimating Caloric Intake

Table 9.3 Physical Activity (PA) Categories and Values[2]

Activity Level	Men PA Value	Women PA Value	Description
Sedentary	1.00	1.00	No physical activity beyond that required for independent living
Low	1.11	1.12	Equivalent to walking 1.5 to 3 miles per day
Moderate	1.25	1.27	Equivalent to walking 3 to 10 miles per day
High	1.48	1.45	Equivalent to walking 10 or more miles per day
These values only apply to normal weight adults and not to children or pregnant or lactating women.			

2. Dietary Reference Intake Tables.Health Canada. http://www.hc-sc.gc.ca/fn-an/nutrition/reference/table/index-eng.php#eeer. Updated November 29, 2010. Accessed September 22, 2017.

These values only apply to normal weight adults and not to children or pregnant or lactating women.

The numbers within the equations for the EER were derived from measurements taken from a group of people of the same sex and age with similar body size and physical activity level. These standardized formulas are then applied to individuals whose measurements have not been taken, but who have similar characteristics, in order to estimate their energy requirements. Thus, a person's EER is, as the name suggests, an estimate for an average person of similar characteristics. EER values are different for children, pregnant or lactating women, and for overweight and obese people. Also, remember the EER is calculated based on weight maintenance, not for weight loss or weight gain.

The 2015 Dietary Guidelines provides a table (Table 8.4 "Estimated Daily Calorie Needs") that gives the estimated daily calorie needs for different age groups of males and females with various activity levels. The Dietary Guidelines also states that while knowing the number of calories you need each day is useful, it is also pertinent to obtain your calories from nutrient-dense foods and consume the various macronutrients in their Acceptable Macronutrient Distribution Ranges (AMDRs) (Table 8.5 "Acceptable Macronutrient Distribution Ranges").

Table 9.4 Estimated Daily Calorie Needs

Sex	Age (years)	Sedentary	Moderately Active	Active
Child (female and male)	2–3	1,000	1,000–1,400 (male)1,000-1,200 (female)	1,000–1,400
Female	4–8	1,200–1,400	1,400–1,600	1,400–1,800
Female	9–13	1,400–1,600	1,600–2,000	1,800–2,200
Female	14–18	1,800	2,000	2,400
Female	19–30	1,800–2,000	2,000–2,200	2,400
Female	31–50	1,800	2,000	2,200
Female	51+	1,600	1,800	2,000–2,200
Male	4–8	1,200–1,400	1,400–1,600	1,600–2,000
Male	9–13	1,600–2,000	1,800–2,200	2,000–2,600
Male	14–18	2,000–2,400	2,400–2,800	2,800–3,200
Male	19–30	2,400–2,600	2,600–2,800	3,000
Male	31–50	2,200–2,400	2,400–2,600	2,800–3,000
Male	51+	2,000–2,200	2,200–2,400	2,400–2,800

Source: 2010 Dietary Guidelines for Americans.US Department of Agriculture. http://health.gov/dietaryguidelines/dga2010/DietaryGuidelines2010.pdf. Published 2010. Accessed September 22, 2017.

Table 9.5 Acceptable Macronutrient Distribution Ranges

Age	Carbohydrates (% of Calories)	Protein (% of Calories)	Fat (% of Calories)
Young Children (1–3)	45–65	5–20	30–40
Older children/ adolescents (4–18)	45–65	10–30	25–35
Adults (19 and older)	45–65	10–35	20–35

Source:Dietary Reference Intakes: Macronutrients." Dietary Reference Intakes for Energy, Carbohydrate. Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. Institute of Medicine. http://nationalacademies.org/hmd/~/media/Files/

Activity%20Files/Nutrition/DRI-Tables/
8_Macronutrient%20Summary.pdf?la=en. Accessed September 22, 2017.

Total Energy Expenditure (Output)

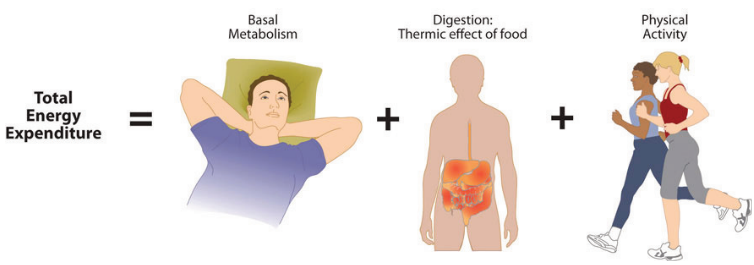
The amount of energy you expend every day includes not only the calories you burn during physical activity, but also the calories you burn while at rest (basal metabolism), and the calories you burn when you digest food. The sum of caloric expenditure is referred to as total energy expenditure (TEE). Basal metabolism refers to those metabolic pathways necessary to support and maintain the body's basic functions (e.g. breathing, heartbeat, liver and kidney function) while at rest. The basal metabolic rate (BMR) is the amount of energy required by the body to conduct its basic functions over a certain time period. The great majority of energy expended (between 50 and 70 percent) daily is from conducting life's basic processes. Of all the organs, the liver requires the most energy (Table 8.6 "Energy Breakdown of Organs"). Unfortunately, you cannot tell your liver to ramp up its activity level to expend more energy so you can lose weight. BMR is dependent on body size, body composition, sex, age, nutritional status, and genetics. People with a larger frame size have a higher BMR simply because they have more mass. Muscle tissue burns more calories than fat tissue even while at rest and thus the more muscle mass a person has, the higher their BMR. Since females typically have less muscle mass and a smaller frame size than men, their BMRs are generally lower than men's. As we get older muscle mass declines and thus so does BMR. Nutritional status also affects basal metabolism. Caloric restriction, as occurs while dieting, for example, causes a decline in BMR. This is because the body attempts to maintain homeostasis and will adapt by slowing down its basic functions to offset the decrease in energy intake. Body temperature and thyroid hormone levels are additional determinants of BMR.

Table 9.6 Energy Breakdown of Organs

Organ	Percent of Energy Expended
Liver	27
Brain	19
Heart	7
Kidneys	10
Skeletal muscle (at rest)	18
Other organs	19

FAO/WHO/UNU, 1985.
Energy and Protein Requirements. World Health Organization Technical Report Series 724. http://www.fao.org/doCReP/003/aa040e/AA040E00.htm. Updated 1991. Accessed September 17, 2017.

Figure 9.6 Total Energy Expenditure



Total energy expenditure is the sum of energy expended at rest, during digestion, and during physical activity.

The energy required for all the enzymatic reactions that take place during food digestion and absorption of nutrients is called the “thermic effect of food” and accounts for about 10 percent of total energy expended per day. The other energy required during the day is for physical activity. Depending on lifestyle, the energy required for this ranges between 15 and 30 percent of total energy expended. The main control a person has over TEE is to increase physical activity.

How to Calculate Total Energy Expenditure

Calculating TEE can be tedious, but has been made easier as there are now calculators available on the Web. TEE is dependent on age, sex, height, weight, and physical activity level. The equations are based on standardized formulas produced from actual measurements on groups of people with similar characteristics. To get accurate results from web-based TEE calculators, it is necessary to record your daily activities and the time spent performing them. A spreadsheet for doing so is available online at http://www.health-calc.com/Calculate_daily_energy_expenditure.pdf. Health-calc.com offers an interactive TEE calculator. http://www.health-calc.com/diet/energy-expenditure-advanced

Factors Affecting Energy Intake

Photo by Providence Doucet on unsplash.com / CC0

Physiology

In the last few decades scientific studies have revealed that how much we eat and what we eat is controlled not only by our own desires, but also is regulated physiologically and influenced by genetics. The hypothalamus in the brain is the main control point of appetite. It receives hormonal and neural signals, which determine if you feel hungry or full. Hunger is an unpleasant sensation of feeling empty that is communicated to the brain by both mechanical and chemical signals from the periphery. Conversely, satiety is the sensation of feeling full and it also is determined by mechanical and chemical signals relayed from the periphery. The hypothalamus contains distinct centers of neural circuits that regulate hunger and satiety (Figure 9.7).

Figure 9.7 Sagittal View of the Brain

Hypothalamus by Methoxyroxy~commonswiki / Public Domain

This is a scan of a brain. The hypothalamus contains distinct centers of neural circuits that regulate hunger and satiety.

Hunger pangs are real and so is a "growling" stomach. When the stomach is empty it contracts, producing the characteristic pang and "growl." The stomach's mechanical movements relay neural signals to the hypothalamus, which relays other neural signals to parts of the brain. This results in the conscious feeling of the need to eat. Alternatively, after you eat a meal the stomach stretches and sends a neural signal to the brain stimulating the sensation of satiety and relaying the message to stop eating. The stomach also sends out certain hormones when it is full and others when it is empty. These hormones communicate to the hypothalamus and other areas of the brain either to stop eating or to find some food.

Fat tissue also plays a role in regulating food intake. Fat tissue produces the hormone leptin, which communicates to the satiety center in the hypothalamus that the body is in positive energy balance. The discovery of leptin's functions sparked a craze in the research world and the diet pill industry, as it was hypothesized that if you give leptin to a person who is overweight, they will decrease their food intake. Alas, this is not the case. In several clinical trials it was found that people who are overweight or obese are actually resistant to the hormone, meaning their brain does not respond as well to it.[1]

Therefore, when you administer leptin to an overweight or obese person there is no sustained effect on food intake.

Nutrients themselves also play a role in influencing food intake. The hypothalamus senses nutrient levels in the blood. When they are low the hunger center is stimulated, and when they are high the satiety center is stimulated. Furthermore, cravings for salty and sweet foods have an underlying physiological basis. Both undernutrition and overnutrition affect hormone levels and the neural circuitry controlling appetite, which makes losing or gaining weight a substantial physiological hurdle.

Genetic Influences

Genetics certainly play a role in percentage body fat and weight and also affects food intake. Children who have been adopted typically are similar in weight and body fatness to their biological parents. Moreover, identical twins are twice as likely to be of similar weights as compared to fraternal twins. The scientific search for obesity genes is ongoing and a few have been identified, such as the gene that encodes for leptin. However, overweight and obesity that manifests in millions of

1. Dardeno TA, Chou, SH, et al. Leptin in Human Physiology and Therapeutics. Front Neuroendocrinol. 2010; 31(3), 377–93. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2916735/?tool=pubmed. Accessed September 22, 2017.

people is not likely to be attributed to one or even a few genes, but the interactions of hundreds of genes with the environment. In fact, when an individual has a mutated version of the gene coding for leptin, they are obese, but only a few dozen people around the world have been identified as having a completely defective leptin gene.

Psychological/Behavioral Influences

When your mouth waters in response to the smell of a roasting Thanksgiving turkey and steaming hot pies, you are experiencing a psychological influence on food intake. A person's perception of good-smelling and good-tasting food influences what they eat and how much they eat. Mood and emotions are associated with food intake. Depression, low self-esteem, compulsive disorders, and emotional trauma are sometimes linked with increased food intake and obesity.

Certain behaviors can be predictive of how much a person eats. Some of these are how much food a person heaps onto their plate, how often they snack on calorie-dense, salty foods, how often they watch television or sit at a computer, and how often they eat out. A study published in a 2008 issue of Obesity looked at characteristics of Chinese buffet patrons. The study found that those who chose to immediately eat before browsing the buffet used larger plates, used a fork rather than chopsticks, chewed less per bite of food, and had higher BMIs than patrons who did not exhibit these behaviors.[2]

2. Levin BE. Developmental Gene X Environment Interactions Affecting Systems Regulating Energy Homeostasis and Obesity. Front Neuroendocrinol. 2010; 3, 270–83. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2903638/?tool=pubmed. Accessed September 22, 2017.

Of course many behaviors are reflective of what we have easy access to—a concept we will discuss next.

Societal Influences

It is without a doubt that society affects what and how much we eat. Portion sizes have increased dramatically in the past few decades. For example, a bagel is now more than twice the size it was in the 1960s. Today, teenagers have access to a massive amount of calorie-dense foods and beverages, which is a large contributor to the recent rapid increase in overweight and obesity in adolescents in this country.

Most fast food items have little nutritional merit as they are highly processed and rich in saturated fat, salt, and added sugars. Despite fast foods being a poor source of nourishment, we spend over one hundred billion dollars per year on fast food, up from six billion dollars in the early 1970s. The fast food business is likely to continue to grow in North America (and the rest of the world) and greatly affect the diets of whole populations. Because it is unrealistic to say that we should abruptly quit eating fast food to save our health society needs to come up with ideas that push nutrient-dense whole foods into the fast food industry. You may have observed that this largely consumer-driven push is having some effect on the foods the fast food industry serves (just watch a recent Subway commercial, or check the options now available in a McDonald's Happy Meal). Pushing the fast food industry to serve healthier foods is a realistic and positive way to improve the Canadian diet.

Tools for Change

Support the consumer movement of pushing the fast food industry and your favorite local restaurants into serving more nutrient-dense foods. You can begin this task by starting simple, such as requesting extra tomatoes and lettuce on your burger and more nutrient-dense choices in the salad bar. Also, choose their low-calorie menu options and help support the emerging market of healthier choices in the fast food industry. In today's fast-paced society, it is difficult for most people to avoid fast food all the time. When you do need a quick bite on the run, choose the fast food restaurants that serve healthier foods. Also, start asking for caloric contents of foods so that the restaurant becomes more aware that their patrons are being calorie conscious.

Factors Affecting Energy Expenditure

Photo by Martins Zemlickis on unsplash.com / CC0

Physiological and Genetic Influences

Why is it so difficult for some people to lose weight and for others to gain weight? One theory is that every person has a "set point" of energy balance. This set point can also be called a fat-stat or lipostat, meaning the brain senses body fatness and triggers changes in energy intake or expenditure to maintain body fatness within a target range. Some believe that this theory provides an explanation as to why after dieting, most people return to their original weight not long after stopping the diet. Another theory is referred to as the "settling" point system, which takes into account (more so than the "set-point" theory) the contribution of the obesogenic environment to weight gain. In this model, the reservoir of body fatness responds to energy intake or energy expenditure, such that if a person is exposed to a greater amount of food, body fatness increases, or if a person watches more television body fatness increases. A major problem with these theories is that they overgeneralize and do not take into account that not all individuals respond in the same way to changes in food intake or energy expenditure. This brings up the importance of the interactions of genes and the environment.

Not all individuals who take a weight-loss drug lose weight and not all people who smoke are thin. An explanation for these discrepancies is that each individual's genes respond differently to a specific environment. Alternatively, environmental factors can influence a person's gene profile, which is exemplified by the effects of the prenatal environment on body weight and percentage body fat and disease incidence later in life.[1]

One example is a study of the offspring of women who were overweight during pregnancy had a greater propensity for being overweight and for developing Type 2 diabetes. Thus, undernutrition and overnutrition during pregnancy influence body weight and disease risk for offspring later in life. They do so by adapting energy metabolism to the early nutrient and hormonal environment in the womb.

Psychological/Behavioral Influence

Sedentary behavior is defined as the participation in the pursuits in which energy expenditure is no more than one-and-one-half times the amount of energy expended while at

1. Matthews CE, Chen KY, et al. Amount of Time Spent in Sedentary Behaviors in the United States, 2003–2004. Am J Epidemiol. 2008; 167(7), 875–81. https://www.ncbi.nlm.nih.gov/pubmed/18303006. Accessed September 22, 2017.

rest and include sitting, reclining, or lying down while awake. Of course, the sedentary lifestyle of many North Americans contributes to their average energy expenditure in daily life. Simply put, the more you sit, the less energy you expend. A study published in a 2008 issue of the American Journal of Epidemiology reports that 55 percent of Americans spend 7.7 hours in sedentary behavior daily. The statistic in Canada is comparable.[2]

Fortunately, including only a small amount of low-level physical activity benefits weight control. A study published in the June 2001 issue of the International Journal of Behavioral Nutrition and Physical Activity reports that even breaking up sitting-time with frequent but brief increased energy expenditure activities, such as walking for five minutes every hour, helps maintain weight and even aids in weight loss.[3]

Canadians partake in an excessive amount of screen time, which is a sedentary behavior that not only reduces energy expenditure, but also contributes to weight gain because of the exposure to aggressive advertising campaigns for unhealthy foods.

Societal Influence

Many societal factors influence the number of calories burned in a day. Escalators, moving walkways, and elevators (not to

2. Matthews CE, Chen KY, et al. Amount of Time Spent in Sedentary Behaviors in the United States, 2003–2004. Am J Epidemiol. 2008; 167(7), 875–81. https://www.ncbi.nlm.nih.gov/pubmed/18303006. Accessed September 22, 2017.
3. Wu Y. Overweight and Obesity in China. Br Med J. 2006; 333(7564), 362-363. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1550451/. Accessed September 22, 2017.

mention cars!) are common modes of transportation that reduce average daily energy expenditure. Office work, high-stress jobs, and occupations requiring extended working hours are all societal pressures that reduce the time allotted for exercise of large populations. Even the remote controls that many have for various electronic devices in their homes contribute to society being less active. More obesogenic factors were discussed in the weight management section of this chapter.

Socioeconomic status has been found to be inversely proportional to weight gain. One reason for this relationship is that inhabitants of low-income neighborhoods have reduced access to safe streets and parks for walking. Another is that fitness clubs are expensive and few are found in lower-income neighborhoods. The recent and long-lasting economic crisis in this country is predicted to have profound effects on average body weight.

Too Little or Too Much Weight: What Are the Health Risks?

The number of people considered overweight and obese in the world has now surpassed the number that are starving, with some officials estimating that the number of overweight people is nearly double the number of underweight people worldwide. Countries that have more recently modernized, industrialized, and urbanized are experiencing a surge in their overweight and obese populations. China, the most populous country in the world, now has more than 215 million people, approximately one-fifth of their population, that are considered overweight or obese.[4]

The increase in China's waistline is partly attributed to changes in the traditional diet, more sedentary lives, and a massive increase in motor vehicle use. Moreover, China's recent famines in the 1950s, which affected the poor and lower classes to a greater extent than the upper class, have sanctioned lax social attitudes toward body fat and reinspired the age-old Chinese belief that excess body fat represents health and prosperity.

One of the worst statistics regarding overweight and obesity in China is that more than ten million adolescents between ages seventeen and eighteen were overweight in 2000, which is twenty-eight times the number that were overweight in 1985.[5]

The associated diseases of overweight and obesity happen over many years, and signs and symptoms commonly take decades to manifest. With China's younger population and other developed countries experiencing a dramatic weight increase, the associated chronic diseases will come about much earlier in life than in previous generations. This will put an even greater burden on society.

4. Wu Y. Overweight and Obesity in China. Br Med J. 2006; 333(7564), 362-363. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1550451/. Accessed September 22, 2017.
5. Wu Y. Overweight and Obesity in China. Br Med J. 2006; 333(7564), 362-363. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1550451/. Accessed September 22, 2017.

Health Risks of Being Overweight and Being Obese

As BMIs increase over 25, the risks increase for heart disease, Type 2 diabetes, hypertension, endometrial cancer, postmenopausal breast cancer, colon cancer, stroke, osteoarthritis, liver disease, gallbladder disorders, and hormonal disorders. The WHO reports that overweight and obesity are the fifth leading cause for deaths globally, and estimates that more than 2.8 million adults die annually as a result of being overweight or obese.[6] Moreover, overweight and obesity contribute to 44 percent of the Type 2 diabetes burden, 23 percent of the heart disease burden, and between 7 and 41 percent of the burden of certain cancers.[7]

Similar to other public health organizations, the WHO states the main causes of the obesity epidemic worldwide are the increased intake of energy-dense food and decreased level of physical activity that is mainly associated with modernization, industrialization, and urbanization. The environmental changes that contribute to the dietary and physical activity patterns of the world today are associated with the lack of policies that address the obesity epidemic in the food and health industry, urban planning, agriculture, and education sectors.

6. Obesity and Overweight. World Health Organization. http://www.who.int/mediacentre/factsheets/fs311/en/. Updated June 2016. Accessed September 22, 2017.
7. Obesity and Overweight. World Health Organization. http://www.who.int/mediacentre/factsheets/fs311/en/. Updated June 2016. Accessed September 22, 2017.

Dietary, Behavioral, and Physical Activity Recommendations for Weight Management

Photo by Igor Ovsyannikov on unsplash.com / CC0

We have just considered the gravity of the obesity problem in North America and worldwide. Successful weight loss is defined as individuals intentionally losing at least 10 percent of their body weight and keeping it off for at least one year.[1]

1. Wing RR, Hill JO. Successful Weight Loss Maintenance. Annu Rev Nutr. 2001; 21, 323–41. http://www.ncbi.nlm.nih.gov/pubmed/11375440?dopt=Abstract. Accessed September 22, 2017. Wing RR, Hill JO. Successful Weight Loss Maintenance. Annu Rev Nutr. 2001; 21,

Results from lifestyle intervention studies suggest fewer than 20 percent of participants are successful at weight loss. An evaluation of successful weight loss, involving more than fourteen thousand participants published in the November 2011 issue of the International Journal of Obesity estimates that more than one in six Americans (17 percent) who were overweight or obese were successful in achieving long-term weight loss.[2] However, these numbers are on the high end because many similar studies report fewer than 10 percent of participants as successful in weight loss.

A study tracking over ten thousand people who have been successful in losing at least 30 pounds and maintaining this weight loss for at least one year found that 98 percent of participants in the registry modified their food intake and 94 percent increased their physical activity (mainly walking).[3] Although there are a great variety of approaches taken by the participants to achieve successful weight loss, most report that their approach involved adhering to a low-calorie, low-fat diet and doing high levels of activity (about one hour of exercise per day). Moreover, most members eat breakfast every day, watch fewer than ten hours of television per week, and weigh themselves at least once per week. About half of them lost weight on their own, and the other half used some type of weight-loss program. In most scientific studies successful weight loss is accomplished only by changing the diet and by

323–41. http://www.ncbi.nlm.nih.gov/pubmed/11375440?dopt=Abstract. Accessed September 22, 2017.

2. Kraschnewski JL, Boan J, et al. Long-Term Weight Loss Maintenance in the United States. Int J Obes. 2010; 34(11),1644–54. http://www.ncbi.nlm.nih.gov/pubmed/20479763. Accessed September 22, 2017.
3. Research Findings. The National Weight Control Registry. http://www.nwcr.ws/Research/default.htm. Accessed September 22, 2017.

increasing physical activity. Doing one without the other limits the amount of weight lost and the length of time that weight loss is sustained. On an individual level it is quite possible to achieve successful weight loss. Moreover, losing as little as 10 percent of your body weight can significantly improve health and reduce disease risk.[4]

You do not have to be overweight or obese to reap benefits from eating a healthier diet and increasing physical activity as both provide numerous benefits beyond weight loss and maintenance.

Evidence-Based Dietary Recommendations

Canada's Food Guide offers specific, evidence-based recommendations for dietary changes aimed at keeping calorie intake in balance with physical activity, which is key for weight management. These recommendations include:

Follow a healthy eating pattern that accounts for all foods and beverages within an appropriate calorie level that includes:

- A variety of vegetables from all of the subgroups—dark green, red and orange, legumes (beans and peas), starchy, and other
- Fruits, especially whole fruits
- Grains, at least half of which are whole grains
- Fat-free or low-fat dairy, including milk, yogurt, cheese,

4. Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults: The Evidence Report. National Heart, Lung, and Blood Institute. 1998, 51S–210S. http://www.ncbi.nlm.nih.gov/books/NBK2003/. Accessed September 22, 2017.

and/or fortified soy beverages

- A variety of protein foods, including seafood, lean meats and poultry, eggs, legumes (beans and peas), and nuts, seeds, and soy products
- Oils

A healthy eating pattern limits:

- Saturated fats and trans fats
- Added sugars
- Sodium

Evidence-Based Physical Activity Recommendations

The other part of the energy balance equation is physical activity. The Canadian Society for Exercise Physiology (CSEP) in partnership with Participaction have developed physical activity guidelines for Canadians of all ages. The recommendations for adults (18-64 years of age) include 150 minutes of moderate to vigourous-intensity aerobic physical activity per week in bouts of 10 minutes of more. It is also beneficial to add strength training activities 2 days per week.[5] Increased physical activity has been found in scientific studies to lower the risk of heart disease, stroke, high blood pressure, Type 2 diabetes, colon, breast, and lung cancer, falls and fractures, depression, and early death. Increased physical activity not only reduces disease risk, but also improves overall health by increasing cardiovascular and muscular fitness, increasing bone density and strength, improving cognitive

5. http://csep.ca/CMFiles/Guidelines/CSEP_PAGuidelines_0-65plus_en.pdf

function, and assisting in weight loss and weight maintenance.[6]

The key guidelines for adults are the following (those for pregnant women, children, and older people will be given in Chapter 13):

- Even small amounts of activity are beneficial to your health.
- More substantial health benefits are obtained by doing at least two hours and thirty minutes per week of moderate-intensity, or one hour and fifteen minutes per week of vigorous-intensity aerobic physical activity, or an equivalent combination thereof. Aerobic activity has better benefits if performed for at least ten minutes at a time, spread throughout the week.
- More extensive health benefits occur when moderate-intensity physical activity is increased to five hours per week, or to two hours and thirty minutes of vigorous-intensity aerobic physical activity, or a combination thereof. Additional health benefits are gained by going beyond these recommended amounts of physical activity.
- Muscle-strengthening activities at moderate or high intensity involving all major muscle groups two or more days per week provides additional health benefits to aerobic exercise.

Moderate physical activities are described as those when "you can talk while you do them, but can't sing" and vigorous

6. 2008 Physical Activity Guidelines for Americans. US Department of Health and Human Services. http://www.health.gov/paguidelines/guidelines/chapter2.aspx. Published 2008. Accessed September 22, 2017.

activities as those when "you can only say a few words without stopping to catch your breath."[7]

Table 8.7 Moderate and Vigorous Physical Activities[8]

Moderate Activities	Vigorous Activities
Ballroom/line dancing	Aerobic dance
Biking on level ground	Biking (more than 10 miles per hour)
Canoeing	Heavy gardening (digging, hoeing)
Gardening	Hiking uphill
Baseball, softball, volleyball	Fast dancing

The "Small-Change" Approach

Scientific studies have demonstrated that asking people to increase the number of steps they take each day while providing them with pedometers that count the steps they take each day successfully prevented weight gain. A "small-changes" study published in the October 2007 issue of Pediatrics evaluated whether families that made two small lifestyle changes, which were to walk an additional two thousand steps per day and to eliminate 100 kilocalories per day from their typical diet by replacing dietary sugar with a noncaloric sweetener, would prevent weight gain in

7. 2008 Physical Activity Guidelines for Americans. US Department of Health and Human Services. http://www.health.gov/paguidelines/guidelines/chapter2.aspx. Published 2008. Accessed September 22, 2017.
8. Source: 2008 Physical Activity Guidelines for Americans. US Department of Health and Human Services. http://www.health.gov/paguidelines/guidelines/chapter2.aspx. Published 2008. Accessed September 22, 2017.

overweight children.[9] The results of this study were that a higher percentage of children who made the small changes maintained or reduced their BMI in comparison to children of families given a pedometer but not asked to also make physical activity or dietary changes.[10] Several more studies are ongoing and are evaluating the effectiveness of the "small-changes" approach in reducing weight gain.

9. Rodearmel SJ, Wyatt HR, et al. Small Changes in Dietary Sugar and Physical Activity As an Approach to Preventing Excessive Weight Gain: The America on the Move Family Study. Pediatrics. 2007; 120(4), e869–79. http://pediatrics.aappublications.org/content/120/4/e869.long. Accessed September 22, 2017.
10. Rodearmel SJ, Wyatt HR, et al. Small Changes in Dietary Sugar and Physical Activity As an Approach to Preventing Excessive Weight Gain: The America on the Move Family Study. Pediatrics. 2007; 120(4), e869–79. http://pediatrics.aappublications.org/content/120/4/e869.long. Accessed September 22, 2017.

CHAPTER 10. VITAMINS

Introduction

Learning Objectives

By the end of this chapter, you will be able to:

- Describe the role of vitamins as antioxidants in the body

- Describe the functions and sources of antioxidant micronutrients, phytochemicals, and antioxidant minerals
- Describe the functions of vitamins in catabolic pathways, anabolic pathways, and blog

Vitamins are organic compounds that are traditionally assigned to two groups fat-soluble (hydrophobic) or water-soluble (hydrophilic). This classification determines where they act in the body. Water-soluble vitamins act in the cytosol of cells or in extracellular fluids such as blood; fat-soluble vitamins are largely responsible for protecting cell membranes from free radical damage. The body can synthesize some vitamins, but others must be obtained from the diet.

Figure 10.1 The Vitamins

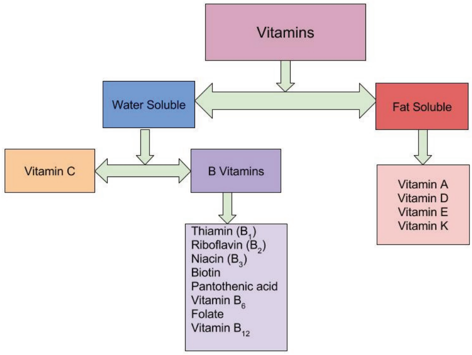


Image by Allison Calabrese / CC BY 4.0

One major difference between fat-soluble vitamins and water-soluble vitamins is the way they are absorbed in the body.

Vitamins are absorbed primarily in the small intestine and their bioavailability is dependent on the food composition of the diet. Fat-soluble vitamins are absorbed along with dietary fat. Therefore, if a meal is very low in fat, the absorption of the fat-soluble vitamins will be impaired. Once fat-soluble vitamins have been absorbed in the small intestine, they are packaged and incorporated into chylomicrons along with other fatty acids and transported in the lymphatic system to the liver. Water-soluble vitamins on the other hand are absorbed in the small intestine but are transported to the liver through blood vessels. (Figure 9.2 "Absorption of Fat-Soluble and Water-Soluble Vitamins").

Figure 10.2 Absorption of Fat-Soluble and Water-Soluble Vitamins

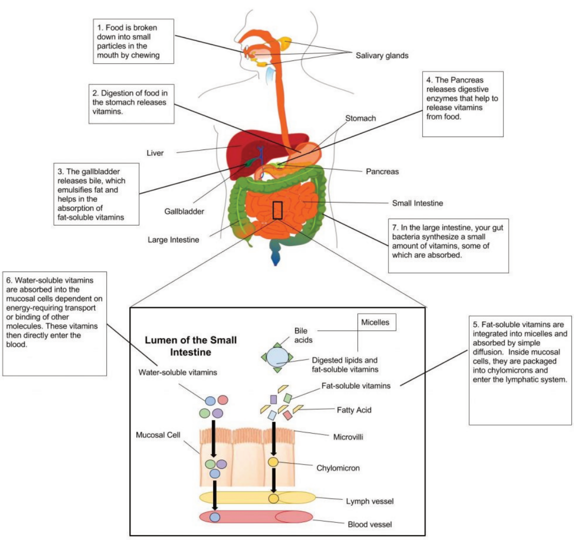


Image by Allison Calabrese / CC BY 4.0

Fat-Soluble Vitamins

Vitamin A Functions and Health Benefits

Vitamin A is a generic term for a group of similar compounds called retinoids. Retinol is the form of vitamin A found in animal-derived foods, and is converted in the body to the biologically active forms of vitamin A: retinal and retinoic acid (thus retinol is sometimes referred to as "preformed vitamin A"). About 10 percent of plant-derived carotenoids, including beta-carotene, can be converted in the body to retinoids and are another source of functional vitamin A. Carotenoids are pigments synthesized by plants that give them their yellow, orange, and red color. Over six hundred carotenoids have been identified and, with just a few exceptions, all are found in the plant kingdom. There are two classes of carotenoids—the xanthophylls, which contain oxygen, and the carotenes, which do not.

In plants, carotenoids absorb light for use in photosynthesis and act as antioxidants. Beta-carotene, alpha-carotene, and beta-cryptoxanthin are converted to some extent to retinol in the body. The other carotenoids, such as lycopene, are not. Many biological actions of carotenoids are attributed to their antioxidant activity, but they likely act by other mechanisms, too.

Vitamin A is fat-soluble and is packaged into chylomicrons in small intestine, and transported to the liver. The liver stores and exports vitamin A as needed; it is released into the blood bound to a retinol-binding protein, which transports it to cells. Carotenoids are not absorbed as well as vitamin A, but similar to vitamin A, they do require fat in the meal for absorption.

In intestinal cells, carotenoids are packaged into the lipid-containing chylomicrons inside small intestine mucosal cells and then transported to the liver. In the liver, carotenoids are repackaged into lipoproteins, which transport them to cells.

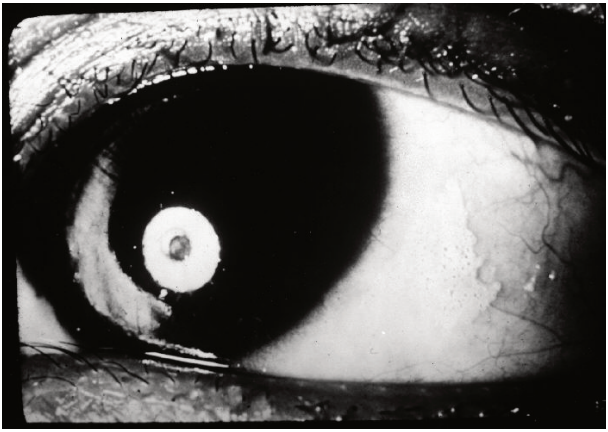
The retinoids are aptly named as their most notable function is in the retina of the eye where they aid in vision, particularly in seeing under low-light conditions. This is why night blindness is the most definitive sign of vitamin A deficiency.Vitamin A has several important functions in the body, including maintaining vision and a healthy immune system. Many of vitamin A's functions in the body are similar to the functions of hormones (for example, vitamin A can interact with DNA, causing a change in protein function). Vitamin A assists in maintaining healthy skin and the linings and coverings of tissues; it also regulates growth and development. As an antioxidant, vitamin A protects cellular membranes, helps in maintaining glutathione levels, and influences the amount and activity of enzymes that detoxify free radicals.

Vision

Retinol that is circulating in the blood is taken up by cells in the eye retina, where it is converted to retinal and is used to help the pigment rhodopsin, which is involved in the eye's ability to see under low light conditions. A deficiency in vitamin A thus results in less rhodopsin and a decrease in the detection of low-level light, a condition referred to as night-blindness.

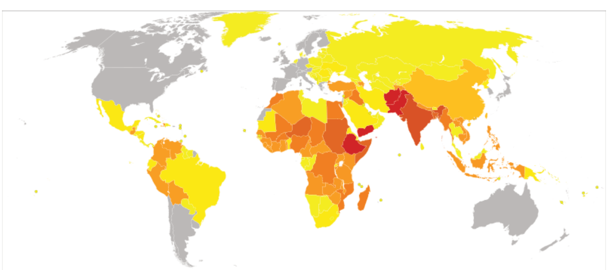
Insufficient intake of dietary vitamin A over time can also cause complete vision loss. In fact, vitamin A deficiency is the number one cause of preventable blindness worldwide. Vitamin A not only supports the vision function of eyes but also maintains the coverings and linings of the eyes. Vitamin A deficiency can lead to the dysfunction of the linings and coverings of the eye (eg. bitot spots), causing dryness of the eyes, a condition called xerophthalmia. The progression of this condition can cause ulceration of the cornea and eventually blindness.

Figure 10.3 Bitot Spot caused by vitamin A deficiency



Malnutrition-Bitot's Spots/ Bitot's Spots caused by vitamin A deficiency by CDC / Nutrition Program

Figure 10.4 Vitamin A Deficiency World Map



Map by Wikipedia user Chris55 / CC BY-SA 4.0

Legend: Disability-adjusted life years (DALY) lost from Vitamin A deficiency in 2012 per million persons.

0-28 31-78 85-85 85-141 144-257 258-376 432-455 558-558 586-883

Immunity

The common occurrence of advanced xerophthalmia in children who died from infectious diseases led scientists to hypothesize that supplementing vitamin A in the diet for children with xerophthalmia might reduce disease-related mortality. In Asia in the late 1980s, targeted populations of children were administered vitamin A supplements, and the death rates from measles and diarrhea declined by up to 50 percent. Vitamin A supplementation in these deficient populations did not reduce the number of children who contracted these diseases, but it did decrease the severity of the diseases so that they were no longer fatal. Soon after the results of these studies were communicated to the rest of the world, the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) commenced worldwide campaigns against vitamin A deficiency. UNICEF estimates that the distribution of over half a billion vitamin A capsules prevents 350,000 childhood deaths annually.[1]

In the twenty-first century, science has demonstrated that vitamin A greatly affects the immune system. What we are still lacking are clinical trials investigating the proper doses of vitamin A required to help ward off infectious disease and how large of an effect vitamin A supplementation has on populations that are not deficient in this vitamin. This brings up one of our common themes in this text—micronutrient deficiencies may contribute to the development, progression, and severity of a disease, but this does not mean that an increased intake of these micronutrients will solely prevent or cure disease. The effect, as usual, is cumulative and depends on the diet as a whole, among other things.

1. Sommer A. Vitamin A Deficiency and Clinical Disease: An Historical Overview. J Nutr. 2008; 138, 1835–39. http://jn.nutrition.org/content/138/10/1835.long. Accessed October 4, 2017.

Growth and Development

Vitamin A acts similarly to some hormones in that it is able to change the amount of proteins in cells by interacting with DNA. This is the primary way that vitamin A affects growth and development. Vitamin A deficiency in children is linked to growth retardation; however, vitamin A deficiency is often accompanied by protein malnutrition and iron deficiency, thereby confounding the investigation of vitamin A's specific effects on growth and development.

In the fetal stages of life, vitamin A is important for limb, heart, eye, and ear development and in both deficiency and excess, vitamin A causes birth defects. Furthermore, both males and females require vitamin A in the diet to effectively reproduce.

Cancer

Vitamin A's role in regulating cell growth and death, especially in tissues that line and cover organs, suggests it may be effective in treating certain cancers of the lung, neck, and liver. It has been shown in some observational studies that vitamin A-deficient populations have a higher risk for some cancers. However, vitamin A supplements have actually been found to increase the risk of lung cancer in people who are at high risk for the disease (i.e., smokers, ex-smokers, workers exposed to asbestos). The Beta-Carotene and Retinol Efficacy Trial (CARET) involving over eighteen thousand participants who were at high risk for lung cancer found that people who took supplements containing very high doses of vitamin A (25,000 international units) and beta-carotene had a 28 percent higher incidence of lung cancer midway through the study, which was consequently stopped.[2]

Vitamin A Toxicity

Vitamin A toxicity, or hypervitaminosis A, is rare. Typically it requires you to ingest ten times the RDA of preformed vitamin A in the form of supplements (it would be hard to consume such high levels from a regular diet) for a substantial amount of time, although some people may be more susceptible to vitamin A toxicity at lower doses. The signs and symptoms of vitamin A toxicity include dry, itchy skin, loss of appetite, swelling of the brain, and joint pain. In severe cases, vitamin A toxicity may cause liver damage and coma.

Vitamin A is essential during pregnancy, but doses above 3,000 micrograms per day (10,000 international units) have been linked to an increased incidence of birth defects. Pregnant women should check the amount of vitamin A contained in any prenatal or pregnancy multivitamin she is taking to assure the amount is below the UL.

Dietary Reference Intakes for Vitamin A

There is more than one source of vitamin A in the diet. There is preformed vitamin A, which is abundant in many animal-

2. Goodman GE, et al. The Beta-Carotene and Retinol Efficacy Trial: Incidence of Lung Cancer and Cardiovascular Disease Mortality During 6-year Follow-up after Stopping Beta-Carotene and Retinol Supplements. J Natl Cancer Inst. 2004; 96(23), 1743–50. http://jnci.oxfordjournals.org/content/96/23/1743.long. Accessed October 6, 2017.

derived foods, and there are carotenoids, which are found in high concentrations in vibrantly colored fruits and vegetables and some oils.

Some carotenoids are converted to retinol in the body by intestinal cells and liver cells. However, only minuscule amounts of certain carotenoids are converted to retinol, meaning fruits and vegetables are not necessarily good sources of vitamin A.

The RDA for vitamin A includes all sources of vitamin A. The RDA for vitamin A is given in mcg of retinol activity requirements (RAE) to take into account the many different forms it is available in. The human body converts all dietary sources of vitamin A into retinol. Therefore, 1 mcg of retinol is equivalent to 12 mcg of beta-carotene, and 24 mcg of alpha-carotene or beta-cryptoxanthin. For example, 12 micrograms of fruit- or vegetable-based beta-carotene will yield 1 microgram of retinol. Currently vitamin A listed in food and on supplement labels use international units (IUs). The following conversions are listed below[3]:

- 1 IU retinol = 0.3 mcg RAE
- 1 IU beta-carotene from dietary supplements = 0.15 mcg RAE
- 1 IU beta-carotene from food = 0.05 mcg RAE
- 1 IU alpha-carotene or beta-cryptoxanthin = 0.025 mcg RAE

The RDA for vitamin A is considered sufficient to support growth and development, reproduction, vision, and immune

3. Dietary Supplement Fact Sheet: Vitamin A. National Institutes of Health, Office of Dietary Supplements. http://ods.od.nih.gov/factsheets/VitaminA-QuickFacts/. Updated September 5, 2012. Accessed October 7, 2017.

system function while maintaining adequate stores (good for four months) in the liver.

Table 10.1 Dietary Reference Intakes for Vitamin A

Age Group	RDA Males and Females mcg RAE/ day	UL
Infants (0–6 months)	400*	600
Infants (7–12 months)	500*	600
Children (1–3 years)	300	600
Children (4–8 years)	400	900
Children (9–13 years)	600	1,700
Adolescents (14–18 years)	Males: 900	2,800
Adolescents (14–18 years)	Females: 700	2,800
Adults (> 19 years)	Males: 900	3,000
Adults (> 19 years)	Females: 700	3,000
*denotes Adequate Intake		

Source: Source: Dietary Supplement Fact Sheet: Vitamin A. National Institutes of Health, Office of Dietary Supplements. http://ods.od.nih.gov/factsheets/VitaminA-QuickFacts/. Updated September 5, 2012. Accessed October 7, 2017.

Dietary Sources of Vitamin A and Beta-Carotene

Preformed vitamin A is found only in foods from animals, with the liver being the richest source because that's where vitamin A is stored (see Table 10.2 "Vitamin A Content of Various Foods"). The dietary sources of carotenoids will be given in the following text.

Table 10.2 Vitamin A Content of Various Foods

Food	Serving	Vitamin A (IU)	Percent Daily Value
Beef liver	3 oz.	27,185	545
Chicken liver	3 oz.	12,325	245
Milk, skim	1 c.	500	10
Milk, whole	1 c.	249	5
Cheddar cheese	1 oz.	284	6

Source: Dietary Supplement Fact Sheet: Vitamin A. National Institutes of Health, Office of Dietary Supplements. http://ods.od.nih.gov/factsheets/VitaminA-QuickFacts/. Updated September 5, 2012. Accessed October 7, 2017.

The most consumed carotenoids are alpha-carotene, beta-carotene, beta-cryptoxanthin, lycopene, lutein, and zeaxanthin. See Table 10.3 "Alpha- and Beta-Carotene Content of Various Foods" for the carotenoid content of various foods.

Table 10.3 Alpha- and Beta-Carotene Content of Various Foods

Food	Serving	Beta-carotene (mg)	Alpha-carotene (mg)
Pumpkin, canned	1c.	17.00	11.70
Carrot juice	1c.	22.00	10.20
Carrots, cooked	1c.	13.00	5.90
Carrots, raw	1 medium	5.10	2.10
Winter squash, baked	1c.	5.70	1.40
Collards, cooked	1c.	11.60	0.20
Tomato	1 medium	0.55	0.10
Tangerine	1 medium	0.13	0.09
Peas, cooked	1c.	1.20	0.09

Source:2010. USDA National Nutrient Database for Standard Reference, Release 23. US Department of Agriculture, Agricultural Research Service. http://www.ars.usda.gov/ba/bhnrc/ndl. Accessed October 22, 2017.

Vitamin D Functions and Health Benefits

Vitamin D refers to a group of fat-soluble vitamins derived from cholesterol. Vitamins D2 (ergocalciferol) and D3 (calcitriol) are the only ones known to have biological actions in the human body. The skin synthesizes vitamin D when exposed to sunlight. In fact, for most people, more than 90 percent of their vitamin D3 comes from the casual exposure to the UVB rays in sunlight. Anything that reduces your exposure to the sun's UVB rays decreases the amount of vitamin D3 your skin synthesizes. That would include long winters, your home's altitude, whether you are wearing sunscreen, and the color of your skin (including tanned skin). Do you ever wonder about an increased risk for skin cancer by spending too much time in the sun? Do not fret. Less than thirty minutes of sun exposure to the arms and legs will increase blood levels of vitamin D3 more than orally taking 10,000 IU (250 micrograms) of vitamin D3.

Figure 10.5 The Functions of Vitamin D

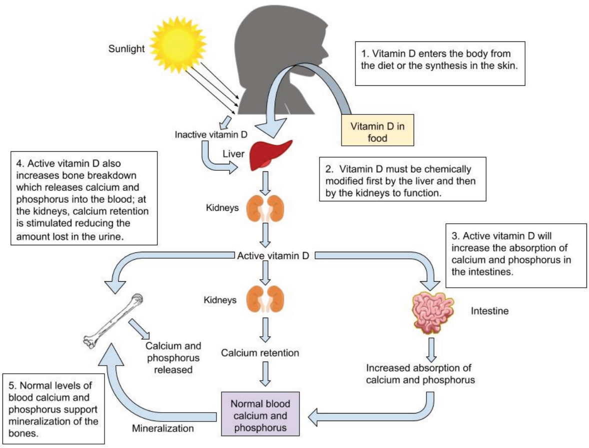


Image by Allison Calabrese / CC BY 4.0

Vitamin D's Functional Role

Activated vitamin D3 (calcitriol) regulates blood calcium levels in concert with parathyroid hormone. In the absence of an adequate intake of vitamin D, less than 15 percent of calcium is absorbed from foods or supplements. The effects of calcitriol on calcium homeostasis are critical for bone health. A deficiency of vitamin D in children causes the bone disease nutritional rickets. Rickets is very common among children in developing countries and is characterized by soft, weak, deformed bones that are exceptionally susceptible to fracture. In adults, vitamin D deficiency causes a similar disease called osteomalacia, which is characterized by low BMD. Osteomalacia has the same symptoms and consequences as osteoporosis and often coexists with osteoporosis. Vitamin D deficiency is common, especially in the elderly population, dark-skinned populations, and in the many people who live in the northern latitudes where sunlight exposure is much decreased during the long winter season.

Figure 10.6 Rickets in Children

Rickets, stages of development for children from Wellcome Images / CC BY 4.0

Health Benefits

Observational studies have shown that people with low levels of vitamin D in their blood have lower BMD and an increased incidence of osteoporosis. In contrast, diets with high intakes of salmon, which contains a large amount of vitamin D, are linked with better bone health. A review of twelve clinical trials, published in the May 2005 issue of the Journal of the American Medical Association, concluded that oral vitamin D supplements at doses of 700–800 international units per day, with or without coadministration of calcium supplements, reduced the incidence of hip fracture by 26 percent and other nonvertebral fractures by 23 percent.[4] A reduction in fracture risk was not observed when people took vitamin D supplements at doses of 400 international units.

Many other health benefits have been linked to higher intakes of vitamin D, from decreased cardiovascular disease to the prevention of infection. Furthermore, evidence from laboratory studies conducted in cells, tissues, and animals suggest vitamin D prevents the growth of certain cancers, blocks inflammatory pathways, reverses atherosclerosis, increases insulin secretion, and blocks viral and bacterial infection and many other things. Vitamin D deficiency has been linked to an increased risk for autoimmune diseases. Immune diseases, rheumatoid arthritis, multiple sclerosis, and Type 1 diabetes have been observed in populations with inadequate vitamin D levels. Additionally, vitamin D deficiency is linked to an increased incidence of hypertension. Until the results come out from the VITAL study, the bulk of scientific evidence touting other health benefits of vitamin D is from laboratory and observational studies and requires confirmation in clinical intervention studies.

Vitamin D Toxicity

Although vitamin D toxicity is rare, too much can cause high levels of calcium concentrations or hypercalcemia. Hypercalcemia can lead to a large amount of calcium to be excreted through the urine which can cause kidney damage. Calcium deposits may also develop in soft tissues such as the

4. Fracture Prevention with Vitamin D Supplementation: A Meta-Analysis of Randomized Controlled Trials. JAMA. 2005; 293(18), 2257–64. http://jama.ama-assn.org/content/293/18/2257.long. Accessed October 12, 2017.

kidneys, blood vessels, or other parts of the cardiovascular system. However, it is important to know that the synthesis of vitamin D from the sun does not cause vitamin D toxicity due to the skin production of vitamin D3 being a tightly regulated process.

Dietary Reference Intake for Vitamin D

The Institute of Medicine RDAs for vitamin D for different age groups is listed in Table 10.4 "Dietary Reference Intakes for Vitamin D". For adults, the RDA is 600 international units (IUs), which is equivalent to 15 micrograms of vitamin D. Slightly higher levels are recommended for adults fifty and older. It is recommended they get between 800 and 1,000 international units of vitamin D every day. The tolerable upper intake level (UL) for vitamin D is 4,000 international units per day. Toxicity from excess vitamin D is rare, but certain diseases such as hyperparathyroidism, lymphoma, and tuberculosis make people more sensitive to the increases in calcium caused by high intakes of vitamin D.

Table 10.4 Dietary Reference Intakes for Vitamin D

Age Group	RDA (mcg/day)	UL (mcg/day)
Infant (0–6 months)	10*	25
Infants (6–12 months)	10*	25
Children (1–3 years)	15	50
Children (4–8 years)	15	50
Children (9–13 years)	15	50
Adolescents (14–18 years)	15	50
Adults (19–71 years)	15	50
Adults (> 71 years)	20	50

* denotes Adequate Intake

Source: Ross, A. C. et al. The 2011 Report on Dietary Reference Intakes for Calcium and Vitamin D from the Institute of Medicine: What Clinicians Need to Know. J Clin Endocrinol Metab. 2011; 96(1), 53–8. http://www.ncbi.nlm.nih.gov/pubmed/21118827. Accessed October 10, 2017.

Dietary Sources of Vitamin D

Table 10.5 Vitamin D Content of Various Foods

Food	Serving	Vitamin D (IU)	Percent Daily Value
Swordfish	3 oz.	566	142
Salmon	3 oz.	447	112
Tuna fish, canned in water, drained	3 oz.	154	39
Orange juice fortified with vitamin D	1 c.	137	34
Milk, nonfat, reduced fat, and whole, vitamin D- fortified	1 c.	115-124	29-31
Margarine, fortified	1 tbsp.	60	15
Sardines, canned in oil, drained	2 e.	46	12
Beef liver	3 oz.	42	11
Egg, large	1 e.	41	10

Source: Dietary Supplement Fact Sheet: Vitamin D. National Institutes of Health, Office of Dietary Supplements.https://ods.od.nih.gov/factsheets/VitaminD-HealthProfessional/#h3. Updated September 5, 2012. Accessed October 22, 2017.

Vitamin E Functions and Health Benefits

Vitamin E occurs in eight chemical forms, of which alpha-tocopherol appears to be the only form that is recognized to meet human requirements. Alpha-tocopherol and vitamin E's other constituents are fat-soluble and primarily responsible for protecting cell membranes against lipid destruction caused by free radicals, therefore making it an antioxidant. When alpha-tocopherol interacts with a free radical it is no longer capable of acting as an antioxidant unless it is enzymatically regenerated. Vitamin C helps to regenerate some of the alpha-tocopherol, but the remainder is eliminated from the body. Therefore, to maintain vitamin E levels, you ingest it as part of your diet.

Insufficient levels are rare (signs and symptoms of such conditions are not always evident) but are primarily the result of nerve degeneration. People with malabsorption disorders, such as Crohn's disease or cystic fibrosis, and babies born prematurely, are at higher risk for vitamin E deficiency.

Vitamin E has many other important roles and functions in the body such as boosting the immune system by helping to fight off bacteria and viruses. It also enhances the dilation of blood vessels and inhibiting the formation of blood clotting. Despite vitamin E's numerous beneficial functions when taken in recommended amounts, large studies do not support the idea that taking higher doses of this vitamin will increase its power to prevent or reduce disease risk.[5,6]

5. Goodman M, Bostlick RM, Kucuk O, Jones DP. Clinical trials of antioxidants as cancer prevention agents: past, present, and future. Free Radic Biol Med. 2011; 51(5), 1068–84. https://www.ncbi.nlm.nih.gov/pubmed/21683786. Accessed October 5, 2017.
6. McGinley C, Shafat A. Donnelly AE. Does antioxidant vitamin supplementation protect against muscle damage. Sports Med. 2009;

Fat in the diet is required for vitamin E absorption as it is packaged into lipid-rich chylomicrons in intestinal cells and transported to the liver. The liver stores some of the vitamin E or packages it into lipoproteins, which deliver it to cells.

Cardiovascular Disease

Vitamin E reduces the oxidation of LDLs, and it was therefore hypothesized that vitamin E supplements would protect against atherosclerosis. However, large clinical trials have not consistently found evidence to support this hypothesis. In fact, in the "Women's Angiographic Vitamin and Estrogen Study," postmenopausal women who took 400 international units (264 milligrams) of vitamin E and 500 milligrams of vitamin C twice per day had higher death rates from all causes.[7]

Other studies have not confirmed the association between increased vitamin E intake from supplements and increased mortality. There is more consistent evidence from observational studies that a higher intake of vitamin E from foods is linked to a decreased risk of dying from a heart attack.

Cancer

The large clinical trials that evaluated whether there was a

39(12), 1011–32. https://www.ncbi.nlm.nih.gov/pubmed/19902983. Accessed October 5, 2017.

7. Waters DD, et al. Effects of Hormone Replacement Therapy and Antioxidant Vitamin Supplements on Coronary Atherosclerosis in Postmenopausal Women: A Randomized Controlled Trial. JAMA. 2002; 288(19), 2432–40. https://jamanetwork.com/journals/jama/fullarticle/195531. Accessed October 5, 2017.

link between vitamin E and cardiovascular disease risk also looked at cancer risk. These trials, called the HOPE-TOO Trial and Women's Health Study, did not find that vitamin E at doses of 400 international units (264 milligrams) per day or 600 international units (396 milligrams) every other day reduced the risk of developing any form of cancer.[8,9]

Eye Conditions

Oxidative stress plays a role in age-related loss of vision, called macular degeneration. Age-related macular degeneration (AMD) primarily occurs in people over age fifty and is the progressive loss of central vision resulting from damage to the center of the retina, referred to as the macula. There are two forms of AMD, dry and wet, with wet being the more severe form.

In the dry form, deposits form in the macula; the deposits may or may not directly impair vision, at least in the early stages of the disease. In the wet form, abnormal blood vessel growth in the macula causes vision loss. Clinical trials evaluating the effects of vitamin E supplements on AMD and cataracts (clouding of the lens of an eye) did not consistently observe a decreased risk for either. However, scientists do believe vitamin E in combination with other antioxidants such

8. HOPE and HOPE-TOO Trial Investigators. Effects of Long-Term Vitamin E Supplementation on Cardiovascular Events and Cancer. JAMA. 2005; 293, 1338–47. http://jama.ama-assn.org/content/293/11/1338.long., Accessed October 5, 2017.
9. Lee IM, et al. Vitamin E in the Primary Prevention of Cardiovascular Disease and Cancer: The Women's Health Study. JAMA.2005; 294, 56–65. http://jama.ama-assn.org/content/294/1/56.long. Accessed October 5, 2017.

as zinc and copper may slow the progression of macular degeneration in people with early-stage disease.

Dementia

The brain's high glucose consumption makes it more vulnerable than other organs to oxidative stress. Oxidative stress has been implicated as a major contributing factor to dementia and Alzheimer's disease. Some studies suggest vitamin E supplements delay the progression of Alzheimer's disease and cognitive decline, but again, not all of the studies confirm the relationship. A recent study with over five thousand participants published in the July 2010 issue of the Archives of Neurology demonstrated that people with the highest intakes of dietary vitamin E were 25 percent less likely to develop dementia than those with the lowest intakes of vitamin E.[10]

More studies are needed to better assess the dose and dietary requirements of vitamin E and, for that matter, whether other antioxidants lower the risk of dementia, a disease that not only devastates the mind, but also puts a substantial burden on loved ones, caretakers, and society in general.

Vitamin E Toxicity

Currently, researchers have not found any adverse effects from consuming vitamin E in food. Although that may be the case,

10. Devore EE, et al. Dietary Antioxidants and Long-Term Risk of Dementia. Arch Neurol. 2010; 67(7), 819–25. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2923546/?tool=pubmed. Accessed October 5, 2017.

supplementation of alpha-tocopherol in animals has shown to cause hemorrhage and disrupt blood coagulation. Extremely high levels of vitamin E can interact with vitamin K-dependent clotting factors causing an inhibition of blood clotting.[11]

Dietary Reference Intakes for Vitamin E

The Recommended Dietary Allowances (RDAs) and Tolerable Upper Intake Levels (ULs) for different age groups for vitamin E are given in Table 10.6 “Dietary Reference Intakes for Vitamin E”.

Table 10.6 Dietary Reference Intakes for Vitamin E

Age Group	RDA Males and Females mg/day	UL
Infants (0–6 months)	4*	–
Infants (7–12 months)	5*	–
Children (1–3 years)	6	200
Children (4–8 years)	7	300
Children (9–13 years)	11	600
Adolescents (14–18 years)	15	800
Adults (> 19 years)	15	1,000
*denotes Adequate Intake		

Source: Dietary Supplement Fact Sheet: Vitamin E.National Institutes of Health, Office of Dietary Supplements. http://ods.od.nih.gov/factsheets/VitaminE-QuickFacts/. Updated October 11, 2011. Accessed October 5, 2017.

11. Dietary Supplement Fact Sheet: Vitamin E.National Institutes of Health, Office of Dietary Supplements. http://ods.od.nih.gov/factsheets/VitaminE-QuickFacts/. Updated October 11, 2011. Accessed October 5, 2017.

Vitamin E supplements often contain more than 400 international units, which is almost twenty times the RDA. The UL for vitamin E is set at 1,500 international units for adults. There is some evidence that taking vitamin E supplements at high doses has negative effects on health. As mentioned, vitamin E inhibits blood clotting and a few clinical trials have found that people taking vitamin E supplements have an increased risk of stroke. In contrast to vitamin E from supplements, there is no evidence that consuming foods containing vitamin E compromises health.

Dietary Sources of Vitamin E

Add some nuts to your salad and make your own dressing to get a healthy dietary dose of vitamin E.

Image by rawpixel.com on unsplash.com / CC0

Vitamin E is found in many foods, especially those higher in fat, such as nuts and oils. Some spices, such as paprika and red chili pepper, and herbs, such as oregano, basil, cumin, and thyme, also contain vitamin E. (Keep in mind spices and herbs are commonly used in small amounts in cooking and therefore are a lesser source of dietary vitamin E.) See Table 10.7 "Vitamin E Content of Various Foods" for a list of foods and their vitamin E contents.

Everyday Connection

To increase your dietary intake of vitamin E from plant-based foods try a spinach salad with tomatoes and sunflower seeds, and add a dressing made with sunflower oil, oregano, and basil.

Table 10.7 Vitamin E Content of Various Foods

Food	Serving Size	Vitamin E (mg)	Percent Daily Value
Sunflower seeds	1 oz.	7.4	37
Almonds	1 oz.	6.8	34
Sunflower oil	1 Tbsp	5.6	28
Hazelnuts 1 oz.	1 oz.	4.3	22
Peanut butter	2 Tbsp.	2.9	15
Peanuts 1 oz.	1 oz.	2.2	11
Corn oil 1 Tbsp.	1 Tbsp.	1.9	10
Kiwi	1 medium	1.1	6
Tomato	1 medium	0.7	4
Spinach	1 c. raw	0.6	3

Source: Dietary Supplement Fact Sheet: Vitamin E.National Institutes of Health, Office of Dietary Supplements. http://ods.od.nih.gov/factsheets/VitaminE-QuickFacts/. Updated October 11, 2011. Accessed October 5, 2017.

Vitamin K Functions and Health Benefits

Vitamin K refers to a group of fat-soluble vitamins that are similar in chemical structure. Vitamin K is critical for blood function acting as coenzymes which play an essential role in blood coagulation (aka blood clotting). Blood-clotting proteins are continuously circulating in the blood. Upon injury to a blood vessel, platelets stick to the wound forming a plug. Without vitamin K, blood would not clot.

A deficiency in vitamin K causes bleeding disorders. It is relatively rare, but people who have liver or pancreatic disease, celiac disease, or malabsorption conditions are at higher risk for vitamin K deficiency. Signs and symptoms include nosebleeds, easy bruising, broken blood vessels, bleeding gums, and heavy menstrual bleeding in women. The function of the anticoagulant drug warfarin is impaired by excess vitamin K intake from supplements. Calcium additionally plays a role in activation of blood-clotting proteins.

Bone Health

Vitamin K is also required for maintaining bone health. It modifies the protein osteocalcin, which is involved in the bone remodeling process. All the functions of osteocalcin and the other vitamin K-dependent proteins in bone tissue are not well understood and are under intense study. Some studies do show that people who have diets low in vitamin K also have an increased risk for bone fractures.

Dietary Reference Intake and Food Sources for Vitamin K

The AI of vitamin K for adult females is 90 micrograms per day, and for males it is 120 micrograms per day. A UL for vitamin K has not been set. There is no UL for vitamin K because it has a low potential for toxicity. No adverse effects associated with vitamin K consumption from food or supplements have been reported in humans or animals.

Table 10.8 Dietary Reference Intakes for Vitamin K

Age Group	RDA (mcg/day)
Infants (0–6 months)	2.0*
Infants (6–12 months)	2.5*
Children (1–3 years)	30
Children (4–8 years)	55
Children (9–13 years)	60
Adolescents (14–18 years)	75
Adult Males (> 19 years)	120
Adult Females (> 19 years)	90
* denotes Adequate Intake	

Source: Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. Institute of Medicine. http://www.iom.edu/Reports/2001/Dietary-Reference-Intakes-for-Vitamin-A-Vitamin-K-Arsenic-Boron-Chromium-Copper-Iodine-Iron-Manganese-Molybdenum-Nickel-Silicon-Vanadium-and-Zinc.aspx. Published January 9, 2001. Accessed October 10, 2017.

Dietary Sources of Vitamin K

Vitamin K is present in many foods. It is found in highest concentrations in green vegetables such as broccoli, cabbage, kale, parsley, spinach, and lettuce. Additionally, vitamin K can be synthesized via bacteria in the large intestine. The exact amount of vitamin K synthesized by bacteria that is actually absorbed in the lower intestine is not known, but likely contributes less than 10 percent of the recommended intake. Newborns have low vitamin K stores and it takes time for the sterile newborn gut to acquire the good bacteria it needs to produce vitamin K. So, it has become a routine practice to inject newborns with a single intramuscular dose of vitamin K. This practice has basically eliminated vitamin K-dependent bleeding disorders in babies.

Table 10.9 Dietary Sources of Vitamin K

Food	Serving	Vitamin K (mcg)	Percent Daily Value
Broccoli	½ c.	160	133
Asparagus	4 spears	34	28
Cabbage	½ c.	56	47
Spinach	½ c.	27	23
Green peas	½ c.	16	13
Cheese	1 oz.	10	8
Ham	3 oz.	13	11
Ground beef	3 oz.	6	5
Bread	1 slice	1.1	<1
Orange	1 e.	1.3	1

Summary of Fat-soluble Vitamins

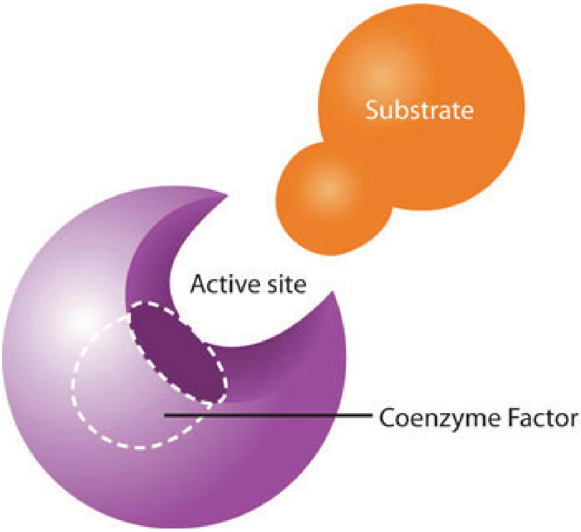
Table 10.10 Fat-Soluble Vitamins

Vitamin	Sources	Recommended Intake for adults	Major functions	Deficien diseases symptom
Vitamin A (retinol, retinal, retinoic acid,carotene, beta-carotene)	Retinol: beef and chicken liver, skim milk, whole milk, cheddar cheese; Carotenoids: pumpkin, carrots, squash, collards, peas	700-900 mcg/ day	Antioxidant,vision, cell differentiation, reproduction, immune function	Xerophth night blindnes infection poor gro dry skin, impairec immune function
Vitamin D	Swordfish, salmon, tuna, orange juice (fortified), milk (fortified), sardines, egg, synthesis from sunlight	600-800 IU/day (15-20 mcg/ day)	Absorption and regulation of calcium and phosphorus, maintenance of bone	Rickets i children: abnorma growth, misshap bones, b legs, soft bones; osteoma in adults
Vitamin E	Sunflower seeds, almonds, hazelnuts,peanuts	15 mg/day	Antioxidant, protects cell membranes	Broken r blood ce nerve da
Vitamin K	Vegetable oils, leafy greens, synthesis by intestinal bacteria	90-120 mcg/ day	Synthesis of blood clotting proteins and proteins needed for bone health and cell growth	Hemorrh

Water-Soluble Vitamins

All water-soluble vitamins play a different kind of role in energy metabolism; they are required as functional parts of enzymes involved in energy release and storage. Vitamins and minerals that make up part of enzymes are referred to as coenzymes and cofactors**,** respectively. Coenzymes and cofactors are required by enzymes to catalyze a specific reaction. They assist in converting a substrate to an end-product. Coenzymes and cofactors are essential in catabolic pathways and play a role in many anabolic pathways too. In addition to being essential for metabolism, many vitamins and minerals are required for blood renewal and function. At insufficient levels in the diet these vitamins and minerals impair the health of blood and consequently the delivery of nutrients in and wastes out, amongst its many other functions. In this section we will focus on the vitamins that take part in metabolism and blood function and renewal.

Figure 10.7 Enzyme Active Site for Cofactors



Coenzymes and cofactors are the particular vitamin or mineral required for enzymes to catalyze a specific reaction.

Vitamin C

Vitamin C, also commonly called ascorbic acid, is a water-soluble micronutrient essential in the diet for humans, although most other mammals can readily synthesize it. Vitamin C's ability to easily donate electrons makes it a highly effective antioxidant. It is effective in scavenging reactive oxygen species, reactive nitrogen species, and many other free radicals. It protects lipids both by disabling free radicals and by aiding in the regeneration of vitamin E.

In addition to its role as an antioxidant, vitamin C is a required part of several enzymes like signaling molecules in the brain, some hormones, and amino acids. Vitamin C is also essential for the synthesis and maintenance of collagen. Collagen is the most abundant protein in the body and used for different functions such as the structure for ligaments, tendons, and blood vessels and also scars that bind wounds together.

Vitamin C acts as the glue that holds the collagen fibers together and without sufficient levels in the body, collagen strands are weak and abnormal. (Figure 10.8 "The Role of Vitamin C in Collagen Synthesis")

Figure 10.8 The Role of Vitamin C in Collagen Synthesis

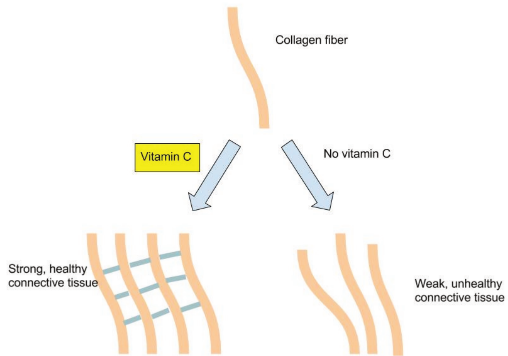


Image by Allison Calabrese / CC BY 4.0

Vitamin C levels in the body are affected by the amount in the diet, which influences how much is absorbed and how much the kidney allows to be excreted, such that the higher the intake, the more vitamin C is excreted. Vitamin C is not stored in any significant amount in the body, but once it has reduced a free radical, it is very effectively regenerated and therefore it can exist in the body as a functioning antioxidant for many weeks.

The classic condition associated with vitamin C deficiency is scurvy. The signs and symptoms of scurvy include skin disorders, bleeding gums, painful joints, weakness, depression, and increased susceptibility to infections. Scurvy is prevented by having an adequate intake of fruits and vegetables rich in vitamin C.

Figure 10.9 Bleeding Gums Associated with Scurvy

Cardiovascular Disease

Vitamin C's ability to prevent disease has been debated for many years. Overall, higher dietary intakes of vitamin C (via food intake, not supplements), are linked to decreased disease risk. A review of multiple studies published in the April 2009 issue of the Archives of Internal Medicine concludes there is moderate scientific evidence supporting the idea that higher dietary vitamin C intakes are correlated with reduced cardiovascular disease risk, but there is insufficient evidence to conclude that taking vitamin C supplements influences cardiovascular disease risk.[1] Vitamin C levels in the body have been shown to correlate well with fruit and vegetable intake, and higher plasma vitamin C levels are linked to reduced risk

1. Mente A, et al. A Systematic Review of the Evidence Supporting a Causal Link between Dietary Factors and Coronary Heart Disease. Arch Intern Med. 2009; 169(7), 659–69. http://archinte.ama-assn.org/cgi/content/full/169/7/659. Accessed October 5, 2017.

of some chronic diseases. In a study involving over twenty thousand participants, people with the highest levels of circulating vitamin C had a 42 percent decreased risk for having a stroke.[2]

Cancer

There is some evidence that a higher vitamin C intake is linked to a reduced risk of cancers of the mouth, throat, esophagus, stomach, colon, and lung, but not all studies confirm this is true. As with the studies on cardiovascular disease, the reduced risk of cancer is the result of eating foods rich in vitamin C, such as fruits and vegetables, not from taking vitamin C supplements. In these studies, the specific protective effects of vitamin C cannot be separated from the many other beneficial chemicals in fruits and vegetables.

Immunity

Vitamin C does have several roles in the immune system, and many people increase vitamin C intake either from diet or supplements when they have a cold. Many others take vitamin C supplements routinely to prevent colds. Contrary to this popular practice, however, there is no good evidence that vitamin C prevents a cold. A review of more than fifty years of studies published in 2004 in the Cochrane Database of

2. Myint PK, et al. Plasma Vitamin C Concentrations Predict Risk of Incident Stroke Over 10 Years in 20,649 Participants of the European Prospective Investigation into Cancer, Norfolk Prospective Population Study. Am J Clin Nutr. 2008; 87(1), 64–69. http://www.ajcn.org/content/87/1/64.long. Accessed September 22, 2017.

Systematic Reviews concluded that taking vitamin C routinely does not prevent colds in most people, but it does slightly reduce cold severity and duration. Moreover, taking megadoses (up to 4 grams per day) at the onset of a cold provides no benefits.[3]

Gout is a disease caused by elevated circulating levels of uric acid and is characterized by recurrent attacks of tender, hot, and painful joints. There is some evidence that a higher intake of vitamin C reduces the risk of gout.

Vitamin C Toxicity

High doses of vitamin C have been reported to cause numerous problems, but the only consistently shown side effects are gastrointestinal upset and diarrhea. To prevent these discomforts the UL for adults is 2,000 milligrams per day (greater than twenty times the RDA).

At very high doses in combination with iron, vitamin C has sometimes been found to increase oxidative stress, reaffirming that getting your antioxidants from foods is better than getting them from supplements, as that helps regulate your intake levels. There is some evidence that taking vitamin C supplements at high doses increases the likelihood of developing kidney stones, however, this effect is most often observed in people that already have multiple risk factors for kidney stones.

3. Douglas RM, et al. Vitamin C for Preventing and Treating the Common Cold. Cochrane Database of Systematic Reviews. 2004; 4. http://www.ncbi.nlm.nih.gov/pubmed/15495002?dopt=Abstract. Accessed October 5, 2017.

Dietary Reference Intakes for Vitamin C

The RDAs and ULs for different age groups for vitamin C are listed in Table 9.11 "Dietary Reference Intakes for Vitamin C". They are considered adequate to prevent scurvy. Vitamin C's effectiveness as a free radical scavenger motivated the Institute of Medicine (IOM) to increase the RDA for smokers by 35 milligrams, as tobacco smoke is an environmental and behavioral contributor to free radicals in the body.

Table 10.11 Dietary Reference Intakes for Vitamin C

Age Group	RDA Males and Females mg/day	UL
Infants (0–6 months)	40*	–
Infants (7–12 months)	50*	–
Children (1–3 years)	15	400
Children (4–8 years)	25	650
Children (9–13 years)	45	1200
Adolescents (14–18 years)	75 (males), 65 (females)	1800
Adults (> 19 years)	90 (males), 75 (females)	2000
*denotes Adequate Intake		

Source: Dietary Supplement Fact Sheet: Vitamin C. National Institutes of Health, Office of Dietary Supplements. http://ods.od.nih.gov/factsheets/VitaminC-QuickFacts/. Updated June 24, 2011. Accessed October 5, 2017.

Dietary Sources of Vitamin C

Citrus fruits are great sources of vitamin C and so are many vegetables. In fact, British sailors in the past were often referred to as "limeys" as they carried sacks of limes onto ships to prevent scurvy. Vitamin C is not found in significant amounts in animal-based foods.

Because vitamin C is water-soluble, it leaches away from foods considerably during cooking, freezing, thawing, and canning. Up to 50 percent of vitamin C can be boiled away. Therefore, to maximize vitamin C intake from foods, you should eat fruits and vegetables raw or lightly steamed. For the vitamin C content of various foods, see Table 10.12 "Vitamin C Content of Various Foods".

Table 10.12 Vitamin C Content of Various Foods

Food	Serving	Vitamin C (mg)	Percent Daily Value
Orange juice	6 oz.	93	155
Grapefruit juice	6 oz.	70	117
Orange	1 medium	70	117
Strawberries	1 c.	85	164
Tomato	1 medium	17	28
Sweet red pepper	½ c. raw	95	158
Broccoli	½ c. cooked	51	65
Romaine lettuce	2 c.	28	47
Cauliflower	1 c. boiled	55	86
Potato	1 medium, baked	17	28

Source: Dietary Supplement Fact Sheet: Vitamin C. National Institutes of Health, Office of Dietary Supplements. http://ods.od.nih.gov/factsheets/VitaminC-QuickFacts/. Updated June 24, 2011. Accessed October 5, 2017.

Thiamin (B_1)

Thiamin is especially important in glucose metabolism. It acts as a cofactor for enzymes that break down glucose for energy production (Figure 10.7 "Enzyme Active Site for Cofactors"). Thiamin plays a key role in nerve cells as the glucose that is catabolized by thiamin is needed for an energy source. Additionally, thiamin plays a role in the synthesis of neurotransmitters and is therefore required for RNA, DNA, and ATP synthesis.

The brain and heart are most affected by a deficiency in thiamin. Thiamin deficiency, also known as beriberi, can cause symptoms of fatigue, confusion, movement impairment, pain in the lower extremities, swelling, and heart failure. It is prevalent in societies whose main dietary staple is white rice. During the processing of white rice, the bran is removed, along with what were called in the early nineteenth century, "accessory factors," that are vital for metabolism. Dutch physician Dr. Christiaan Eijkman cured chickens of beriberi by feeding them unpolished rice bran in 1897. By 1912, Sir Frederick Gowland Hopkins determined from his experiments with animals that the "accessory factors," eventually renamed vitamins, are needed in the diet to support growth, since animals fed a diet of pure carbohydrates, proteins, fats, and minerals failed to grow.[4] Eijkman and Hopkins were awarded the Nobel Prize in Physiology (or Medicine) in 1929 for their discoveries in the emerging science of nutrition.

Another common thiamin deficiency known as Wernicke-Korsakoff syndrome can cause similar symptoms as beriberi

4. Frederick Gowland Hopkins and his Accessory Food Factors. Encyclopedia Brittanica Blog. http://www.britannica.com/blogs/2011/06/frederick-gowland-hopkins-accessory-food-factors/.Published June 20, 2011. Accessed October 1, 2011.

such as confusion, loss of coordination, vision changes, hallucinations, and may progress to coma and death. This condition is specific to alcoholics as diets high in alcohol can cause thiamin deficiency. Other individuals at risk include individuals who also consume diets typically low in micronutrients such as those with eating disorders, elderly, and individuals who have gone through gastric bypass surgery.[5]

Figure 10.10 The Role of Thiamin

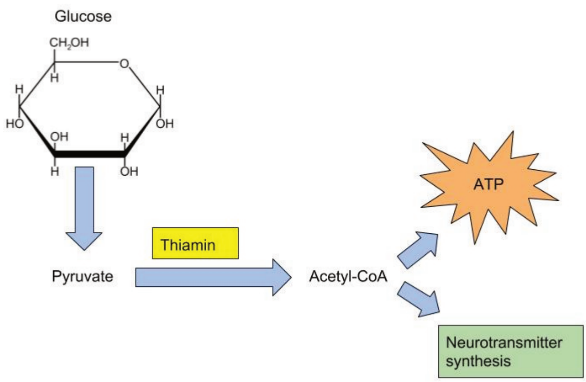


Image by Allison Calabrese / CC BY 4.0

Figure 10.11 Beriberi, Thiamin Deficiency

5. Fact Sheets for Health Professionals: Thiamin. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Thiamin-HealthProfessional/. Updated Feburary 11, 2016. Accessed October 22, 2017.

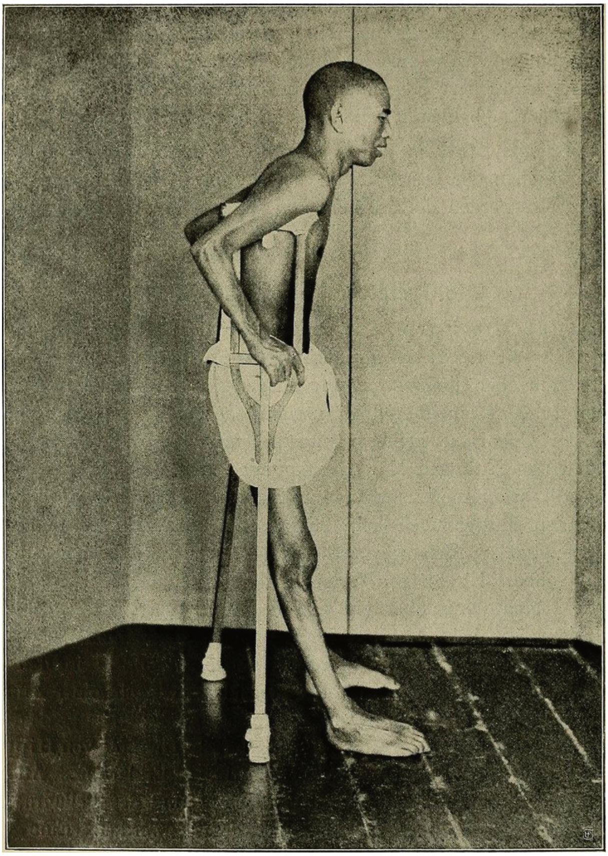


Image by Casimir Funk (1914) / No known copyright restrictions

Dietary Reference Intakes

The RDAs and ULs for different age groups for thiamin are listed in Table 9.13 "Dietary Reference Intakes for Thiamin". There is no UL for thiamin because there has not been any reports on toxicity when excess amounts are consumed from food or supplements.

Table 10.13 Dietary Reference Intakes for Thiamin

Age Group	RDA Males and Females mg/day
Infants (0–6 months)	0.2 *
Infants (7–12 months)	0.3
Children (1–3 years)	0.5
Children (4–8 years)	0.6
Children (9–13 years)	0.9
Adolescents (14–18 years)	1.2 (males), 1.0 (females)
Adults (> 19 years)	1.2 (males), 1.1 (females)
*denotes Adequate Intake	

Health Professional Fact Sheet: Thiamin. National Institutes of Health, Office of Dietary Supplements.https://ods.od.nih.gov/factsheets/Thiamin-HealthProfessional/ . Updated February 11, 2016 . Accessed October 5, 2017.

Dietary Sources

Whole grains, meat and fish are great sources of thiamin. Canada fortifies their refined breads and cereals. For the thiamin content of various foods, see Table 10.14 “Thiamin Content of Various Foods”.

Table 10.14 Thiamin Content of Various Foods

Food	Serving	Thiamin (mg)	Percent Daily Value
Breakfast cereals, fortified	1 serving	1.5	100
White rice, enriched	½ c.	1.4	73
Pork chop, broiled	3 oz.	0.4	27
Black beans, boiled	½ c.	0.4	27
Tuna, cooked	3 oz.	0.2	13
Brown rice, cooked, not enriched	½ c.	0.1	7
Whole wheat bread	1 slice	0.1	7
2% Milk	8 oz.	0.1	7
Cheddar cheese	1 ½ oz	0	0
Apple, sliced	1 c.	0	0

Health Professional Fact Sheet: Thiamin. National Institutes of Health, Office of Dietary Supplements.https://ods.od.nih.gov/factsheets/Thiamin-HealthProfessional/ . Updated February 11, 2016 . Accessed October 5, 2017.

Riboflavin (B2)

Riboflavin is an essential component of flavoproteins, which are coenzymes involved in many metabolic pathways of carbohydrate, lipid, and protein metabolism. Flavoproteins aid in the transfer of electrons in the electron transport chain. Furthermore, the functions of other B-vitamin coenzymes, such as vitamin B_6 and folate, are dependent on the actions of flavoproteins. The "flavin" portion of riboflavin gives a bright yellow color to riboflavin, an attribute that helped lead to its discovery as a vitamin. When riboflavin is taken in excess amounts (supplement form) the excess will be excreted through your kidneys and show up in your urine. Although the color may alarm you, it is harmless. There are no adverse effects of high doses of riboflavin from foods or supplements that have been reported.

Riboflavin deficiency, sometimes referred to as ariboflavinosis, is often accompanied by other dietary deficiencies (most notably protein) and can be common in people that suffer from alcoholism. This deficiency will usually also occur in conjunction with deficiencies of other B vitamins because the majority of B vitamins have similar food sources. Its signs and symptoms include dry, scaly skin, cracking of the lips and at the corners of the mouth, sore throat, itchy eyes, and light sensitivity.

Dietary Reference Intakes

The RDAs for different age groups for riboflavin are listed in Table 10.15 "Dietary Reference Intakes for Riboflavin". There is no UL for riboflavin because no toxicity has been reported when an excess amount has been consumed through foods or supplements.

Table 10.15 Dietary Reference Intakes for Riboflavin

Age Group	RDA Males and Females mg/day
Infants (0–6 months)	0.3 *
Infants (7–12 months)	0.4*
Children (1–3 years)	0.5
Children (4–8 years)	0.6
Children (9–13 years)	0.9
Adolescents (14–18 years)	1.3 (males), 1.0 (females)
Adults (> 19 years)	1.3 (males), 1.1 (females)
*denotes Adequate Intake	

Fact Sheet for Health Professionals, Riboflavin. National

Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Riboflavin-HealthProfessional/. Updated February 11, 2016. Accessed October 22, 2017.

Dietary Sources

Riboflavin can be found in a variety of different foods but it is important to remember that it can be destroyed by sunlight. Milk is one of the best sources of riboflavin in the diet and was once delivered and packaged in glass bottles. This packaging has changed to cloudy plastic containers or cardboard to help block the light from destroying the riboflavin in milk. For the riboflavin content of various foods, see Table 10.16 Riboflavin Content of Various Foods".

Table 10.16 Riboflavin Content of Various Foods

Food	Serving	Riboflavin (mg)	Percent Daily Value
Beef liver	3 oz.	2.9	171
Breakfast cereals, fortified	1 serving	1.7	100
Instant oats, fortified	1 c.	1.1	65
Plain yogurt, fat free	1 c.	0.6	35
2% milk	8 oz.	0.5	29
Beef, tenderloin steak	3 oz.	0.4	24
Portabella mushrooms, sliced	½ c.	0.3	18
Almonds, dry roasted	1 oz.	0.3	18
Egg, scrambled	1 large	0.2	12
Quinoa	1 c.	0.2	12
Salmon, canned	3 oz.	0.2	12
Spinach, raw	1 c.	0.1	6
Brown rice	½ c.	0	0

Fact Sheet for Health Professionals, Riboflavin. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Riboflavin-HealthProfessional/. Updated February 11, 2016. Accessed October 22, 2017.

Niacin (B3)

Niacin is a component of the coenzymes NADH and NADPH, which are involved in the catabolism and/or anabolism of carbohydrates, lipids, and proteins. NADH is the predominant electron carrier and transfers electrons to the electron-transport chain to make ATP. NADPH is also required for the anabolic pathways of fatty-acid and cholesterol synthesis. In contrast to other vitamins, niacin can be synthesized by humans from the amino acid tryptophan in an anabolic process requiring enzymes dependent on riboflavin, vitamin B_6, and iron. Niacin is made from tryptophan only after tryptophan has met all of its other needs in the body. The contribution of tryptophan-derived niacin to niacin needs in the body varies widely and a few scientific studies have demonstrated that diets high in tryptophan have very little effect on niacin deficiency. Niacin deficiency is commonly known as pellagra and the symptoms include fatigue, decreased appetite, and indigestion. These symptoms are then commonly followed by the four D's: diarrhea, dermatitis, dementia, and sometimes death.

Figure 10.12 Conversion of Tryptophan to Niacin

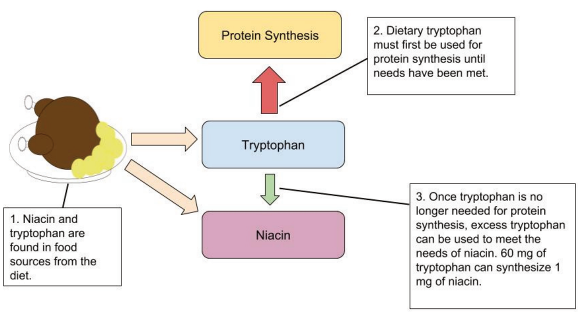


Image by Allison Calabrese / CC BY 4.0

Figure 10.13 Niacin Deficiency, Pellagra

Image by Herbert L. Fred, MD, Hendrik A. van Dijk / CC BY-SA 3.0

Dietary Reference Intakes

The RDAs and ULs for different age groups for Niacin are listed in Table 9.17 “Dietary Reference Intakes for Niacin “. Because Niacin needs can be met from tryptophan, The RDA is expressed in niacin equivalents (NEs). The conversions of NE, Niacin, and tryptophan are: 1 mg NE= 60 mg tryptophan= 1 mg niacin

Table 10.17 Dietary Reference Intakes for Niacin

Age Group	RDA Males and Females mg NE/day)	UL
Infants (0–6 months)	2 *	Not possible to establish
Infants (7–12 months)	4*	Not possible to establish
Children (1–3 years)	6	10
Children (4–8 years)	8	15
Children (9–13 years)	12	20
Adolescents (14–18 years)	16 (males), 14 (females)	30
Adults (> 19 years)	16 (males), 14 (females)	35
*denotes Adequate Intake		

Micronutrient Information Center: Niacin. Oregon State University, Linus Pauling Institute. http://lpi.oregonstate.edu/mic/vitamins/niacin. Updated in July 2013. Accessed October 22, 2017.

Dietary Sources

Niacin can be found in a variety of different foods such as yeast, meat, poultry, red fish, and cereal. In plants, especially mature grains, niacin can be bound to sugar molecules which can significantly decrease the niacin bioavailability. For the niacin content of various foods, see Table 10.18 “Niacin Content of Various Foods”.

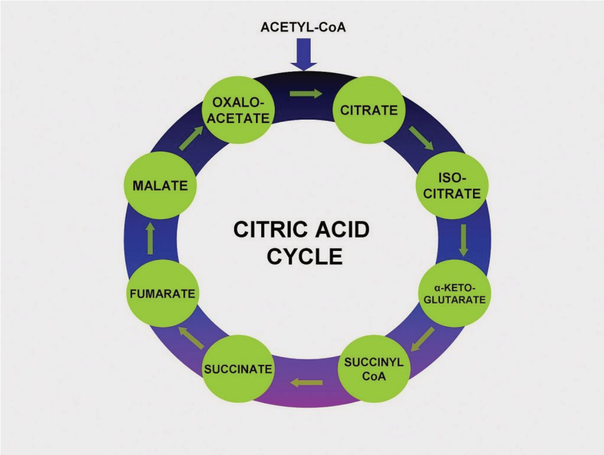
Table 10.18 Niacin Content of Various Foods

Food	Serving	Niacin (mg)	Percent Daily Value
Chicken	3 oz.	7.3	36.5
Tuna	3 oz.	8.6	43
Turkey	3 oz.	10.0	50
Salmon	3 oz.	8.5	42.5
Beef (90% lean)	3 oz.	4.4	22
Cereal (unfortified)	1 c.	5	25
Cereal (fortified)	1 c.	20	100
Peanuts	1 oz.	3.8	19
Whole wheat bread	1 slice	1.3	6.5
Coffee	8 oz.	0.5	2.5

Micronutrient Information Center: Niacin. Oregon State University, Linus Pauling Institute. http://lpi.oregonstate.edu/mic/vitamins/niacin. Updated in July 2013. Accessed October 22, 2017.

Pantothenic Acid (B5)

Figure 10.14 Pantothenic Acid's Role in the Citric Acid Cycle



Pantothenic Acid (Vitamin B5) makes up coenzyme A, which carries the carbons of glucose, fatty acids, and amino acids into the citric acid cycle as Acetyl-CoA.

Pantothenic acid forms coenzyme A, which is the main carrier of carbon molecules in a cell. Acetyl-CoA is the carbon carrier of glucose, fatty acids, and amino acids into the citric acid cycle (Figure 10.14 "Pantothenic Acid's Role in the Citric Acid Cycle"). Coenzyme A is also involved in the synthesis of lipids, cholesterol, and acetylcholine (a neurotransmitter). A Pantothenic Acid deficiency is exceptionally rare. Signs and symptoms include fatigue, irritability, numbness, muscle pain, and cramps. You may have seen pantothenic acid on many ingredients lists for skin and hair care products; however there is no good scientific evidence that pantothenic acid improves human skin or hair.

Dietary Reference Intakes

Because there is little information on the requirements for pantothenic acids, the Adequate Intakes (AI) is based on the observed dietary intakes in healthy population groups. The AI for different age groups for pantothenic acid are listed in Table 10.19 "Dietary Reference Intakes for Pantothenic Acid ".

Table 10.19 Dietary Reference Intakes for Pantothenic Acid

Age Group	AI Males and Females mg/day)
Infants (0–6 months)	1.7
Infants (7–12 months)	1.8
Children (1–3 years)	2
Children (4–8 years)	3
Children (9–13 years)	4
Adolescents (14–18 years)	5
Adults (> 19 years)	5

Micronutrient Information Center: Pantothenic Acid. Oregon State University, Linus Pauling Institute. http://lpi.oregonstate.edu/mic/vitamins/patothenic-acid . Updated in July 2013. Accessed October 22, 2017.

Dietary Sources

Pantothenic Acid is widely distributed in all types of food, which is why a deficiency in this nutrient is rare. Pantothenic Acid gets its name from the greek word "pantothen" which means "from everywhere". For the pantothenic acid content of various foods, see Table 10.20 Pantothenic Acid Content of Various Foods".

Table 10.20 Pantothenic Acid Content of Various Foods

Food	Serving	Pantothenic Acid (mg)	Percent Daily Value
Sunflower seeds	1 oz.	2	20
Fish, trout	3 oz.	1.9	19
Yogurt, plain nonfat	8 oz.	1.6	16
Lobster	3 oz.	1.4	14
Avocado	½ fruit	1	10
Sweet potato	1 medium	1	10
Milk	8 fl oz.	0.87	8.7
Egg	1 large	0.7	7
Orange	1 whole	0.3	3
Whole wheat bread	1 slice	0. 21	2.1

Micronutrient Information Center: Pantothenic Acid. Oregon State University, Linus Pauling Institute. http://lpi.oregonstate.edu/mic/vitamins/patothenic-acid . Updated in July 2013. Accessed October 22, 2017.

Biotin

Biotin is required as a coenzyme in the citric acid cycle and in lipid metabolism. It is also required as an enzyme in the synthesis of glucose and some nonessential amino acids. A specific enzyme, biotinidase, is required to release biotin from protein so that it can be absorbed in the gut. There is some bacterial synthesis of biotin that occurs in the colon; however this is not a significant source of biotin. Biotin deficiency is rare, but can be caused by eating large amounts of egg whites over an extended period of time. This is because a protein in egg whites tightly binds to biotin making it unavailable for absorption. A rare genetic disease-causing malfunction of the biotinidase enzyme also results in biotin deficiency. Symptoms of biotin deficiency are similar to those of other B vitamins, but may also include hair loss when severe.

Dietary Reference Intakes

Because there is little information on the requirements for biotin, the Adequate Intakes (AI) is based on the observed dietary intakes in healthy population groups. The AI for different age groups for biotin are listed in Table 10.21 "Dietary Reference Intakes for Biotin".

Table 10.21 Dietary Reference Intakes for Biotin

Age Group	AI Males and Females mcg/day)
Infants (0–6 months)	5
Infants (7–12 months)	6
Children (1–3 years)	8
Children (4–8 years)	12
Children (9–13 years)	20
Adolescents (14–18 years)	25
Adults (> 19 years)	30

Fact Sheet for Health Professionals: Biotin. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Biotin-HealthProfessional/. Updated October 3, 2017. Accessed November 10, 2017.

Dietary Sources

Biotin can be found in foods such as eggs, fish, meat, seeds, nuts and certain vegetables. For the pantothenic acid content of various foods, see Table 10.22 Biotin Content of Various Foods".

Table 10.22 Biotin Content of Various Foods

Food	Serving	Biotin (mcg)	Percent Daily Value*
Eggs	1 large	10	33.3
Salmon, canned	3 oz.	5	16.6
Pork chop	3 oz.	3.8	12.6
Sunflower seeds	¼ c.	2.6	8.6
Sweet potato	½ c.	2.4	8
Almonds	¼ c.	1.5	5
Tuna, canned	3 oz.	0.6	2
Broccoli	½ c.	0.4	1.3
Banana	½ c.	0.2	0.6

* Current AI used to determine Percent Daily Value

Fact Sheet for Health Professionals: Biotin. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Biotin-HealthProfessional/. Updated October 3, 2017. Accessed November 10, 2017.

Vitamin B_6 (Pyridoxine)

Vitamin B_6 is the coenzyme involved in a wide variety of functions in the body. One major function is the nitrogen transfer between amino acids which plays a role in amino-acid synthesis and catabolism. Also, it functions to release glucose from glycogen in the catabolic pathway of glycogenolysis and is required by enzymes for the synthesis of multiple neurotransmitters and hemoglobin (Figure 9.15 “The Function of Vitamin B_6 in Amino Acid Metabolism”).

Vitamin B_6 is also a required coenzyme for the synthesis of hemoglobin. A deficiency in vitamin B_6 can cause anemia, but it is of a different type than that caused by insufficient folate, cobalamin, or iron; although the symptoms are similar. The size of red blood cells is normal or somewhat smaller but the hemoglobin content is lower. This means each red blood cell has less capacity for carrying oxygen, resulting in muscle weakness, fatigue, and shortness of breath. Other deficiency symptoms of vitamin B_6 can cause dermatitis, mouth sores, and confusion.

Figure 10.15 The Function of Vitamin B6 in Amino Acid Metabolism

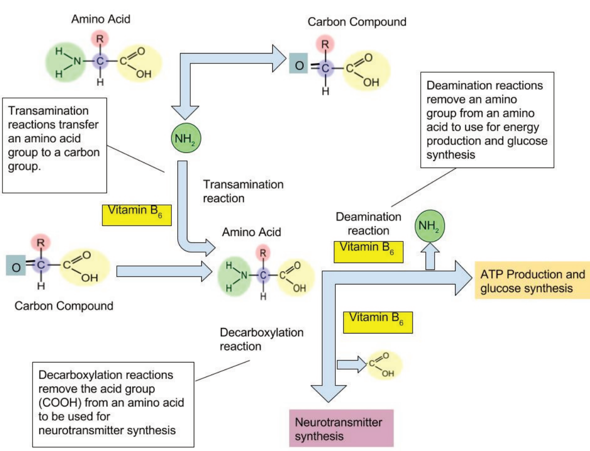


Image by Allison Calabrese / CC BY 4.0

The vitamin B6 coenzyme is needed for a number of different reactions that are essential for amino acid synthesis, catabolism for energy, and the synthesis of glucose and neurotransmitters.

Figure 10.16 Vitamin B_6 Functional Coenzyme Role

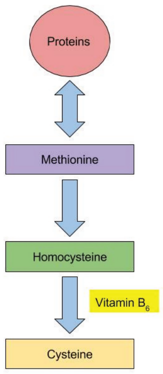


Image by Allison Calabrese / CC BY 4.0

Vitamin B6 coenzyme is essential for the conversion of amino acid methionine into cysteine. With low levels of Vitamin B6, homocysteine will build up in the blood. High levels of homocysteine increases the risk for heart disease.

Vitamin B_6 Toxicity

Currently, there are no adverse effects that have been associated with a high dietary intake of vitamin B6, but large supplemental doses can cause severe nerve impairment. To prevent this from occurring, the UL for adults is set at 100 mg/day.

Dietary Reference Intakes

The RDAs and ULs for different age groups for vitamin B_6 are listed in Table 10.23 "Dietary Reference Intakes for Vitamin B_6".

Table 10.23 Dietary Reference Intakes for Vitamin B_6

Age Group	RDA Males and Females mg/day	UL
Infants (0–6 months)	0.1*	Not possible to determine
Infants (7–12 months)	0.3*	Not possible to determine
Children (1–3 years)	0.5	30
Children (4–8 years)	0.6	40
Children (9–13 years)	1	60
Adolescents (14–18 years)	1.3 (males), 1.2 (females)	80
Adults (> 19 years)	1.3	100
*denotes Adequate Intake		

Dietary Supplement Fact Sheet: Vitamin B_6. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/VitaminB6-HealthProfessional/. Updates February 11, 2016. Accessed October 22, 2017.

Dietary Sources

Vitamin B_6 can be found in a variety of foods. The richest sources include fish, beef liver and other organ meats, potatoes, and other starchy vegetables and fruits. For the Vitamin B_6 content of various foods, see Table 10.24 Vitamin B_6 Content of Various Foods".

Table 10.24 Vitamin B_6 Content of Various Foods

Food	Serving	Vitamin B6 (mg)	Percent Daily Value
Chickpeas	1 c.	1.1	55
Tuna, fresh	3 oz.	0.9	45
Salmon	3 oz.	0.6	30
Potatoes	1 c.	0.4	20
Banana	1 medium	0.4	20
Ground beef patty	3 oz.	0.3	10
White rice, enriched	1 c.	0.1	5
Spinach	½ c	0.1	5

Dietary Supplement Fact Sheet: Vitamin B_6. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/VitaminB6-HealthProfessional/. Updates February 11, 2016. Accessed October 22, 2017.

Folate

Folate is a required coenzyme for the synthesis of the amino acid methionine, and for making RNA and DNA. Therefore, rapidly dividing cells are most affected by folate deficiency. Red blood cells, white blood cells, and platelets are continuously being synthesized in the bone marrow from dividing stem cells. When folate is deficient, cells cannot divide normally A consequence of folate deficiency is macrocytic or megaloblastic anemia. Macrocytic and megaloblastic mean "big cell," and anemia refers to fewer red blood cells or red blood cells containing less hemoglobin. Macrocytic anemia is characterized by larger and fewer red blood cells. It is caused by red blood cells being unable to produce DNA and RNA fast enough—cells grow but do not divide, making them large in size. (Figure 9.17 “Folate and the Formation of Macrocytic Anemia”)

Figure 10.17 Folate and the Formation of Macrocytic Anemia

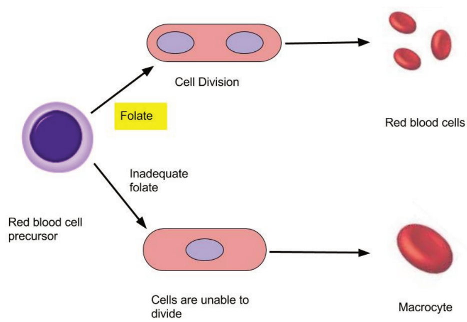
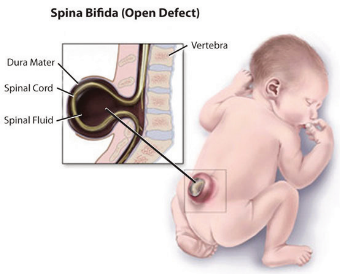


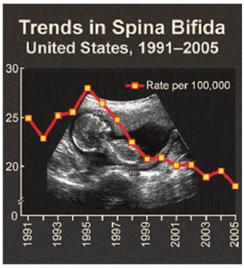
Image by Allison Calabrese / CC BY 4.0

Folate is especially essential for the growth and specialization of cells of the central nervous system. Children whose mothers were folate-deficient during pregnancy have a higher risk of neural-tube birth defects. Folate deficiency is causally linked to the development of spina bifida, a neural-tube defect that occurs when the spine does not completely enclose the spinal cord. Spina bifida can lead to many physical and mental disabilities (Figure 10.18 “Spina Bifida in Infants”). Observational studies show that the prevalence of neural-tube defects was decreased after the fortification of enriched cereal grain products with folate in 1998 in Canada compared to before grain products were fortified with folate.

Additionally, results of clinical trials have demonstrated that neural-tube defects are significantly decreased in the offspring of mothers who began taking folate supplements one month prior to becoming pregnant and throughout the pregnancy. The RDA was raised for folate to 600 micrograms per day for pregnant women. Some were concerned that higher folate intakes may cause colon cancer, however scientific studies refute this hypothesis.

Figure 10.18 Spina Bifida in Infants





Spina bifida is a neural-tube defect that can have severe health consequences.

Dietary Reference Intakes

The RDAs and ULs for different age groups for folate are listed in Table 10.25 "Dietary Reference Intakes for Folate ". Folate is a compound that is found naturally in foods. Folic acid however is the chemical structure form that is used in dietary supplements as well as enriched foods such as grains. The dietary folate equivalents (DFE) was developed to reflect the fact that folic acid is more bioavailable and easily absorbed than folate found in food. The conversions for the different forms are listed below.

1 mcg DFE = 1 mcg food folate

1mcg DFE = 0.6 mcg folic acid from fortified foods or dietary supplements consumed with foods

1 mcg DFE = 0.5 mcg folic acid from dietary supplements taken on an empty stomach

Table 10.25 Dietary Reference Intakes for Folate

Age Group	RDA Males and Females mcg DFE/day	UL
Infants (0–6 months)	65*	Not possible to determine
Infants (7–12 months)	80*	Not possible to determine
Children (1–3 years)	150	300
Children (4–8 years)	200	400
Children (9–13 years)	300	600
Adolescents (14–18 years)	400	800
Adults (> 19 years)	400	1000
*denotes Adequate Intake		

Dietary Supplement Fact Sheet: Folate. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Folate-HealthProfessional/. Updated April 20, 2016. Accessed October 22, 2017.

Dietary Sources

Folate is found naturally in a wide variety of food especially in dark leafy vegetables, fruits, and animal products. Manufacturers can fortify enriched breads, cereals, flours, and cornmeal to increase the consumption of folate by Canadians. For the folate content of various foods, see Table 9.26 “Folate Content of Various Foods”.

Table 10.26 Folate Content of Various Foods

Food	Serving	Folate (mcg DFE)	Percent Daily Value
Beef Liver	3 oz.	215	54
Fortified breakfast cereals	¾ c.	400	100
Spinach	½ c.	131	33
White rice, enriched	½ c.	90	23
Asparagus	4 spears	85	20
White bread, enriched	1 slice	43	11
Broccoli	2 spears	45	10
Avocado	½ c.	59	15
Orange juice	6 oz.	35	9
Egg	1 large	22	6

Dietary Supplement Fact Sheet: Folate. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Folate-HealthProfessional/. Updated April 20, 2016. Accessed October 22, 2017.

Vitamin B12 (Cobalamin)

Vitamin B_{12} contains cobalt, making it the only vitamin that contains a metal ion. Vitamin B_{12} is an essential part of coenzymes. It is necessary for fat and protein catabolism, for folate coenzyme function, and for hemoglobin synthesis. An enzyme requiring vitamin B_{12} is needed by a folate-dependent enzyme to synthesize DNA. Thus, a deficiency in vitamin B_{12} has similar consequences to health as folate deficiency. In children and adults vitamin B_{12} deficiency causes macrocytic anemia, and in babies born to cobalamin-deficient mothers there is an increased risk for neural-tube defects. In order for the human body to absorb vitamin B_{12}, the stomach, pancreas, and small intestine must be functioning properly. Cells in the stomach secrete a protein called intrinsic factor that is necessary for vitamin B_{12} absorption, which occurs in the small intestine. Impairment of secretion of this protein either caused by an autoimmune disease or by chronic inflammation of the stomach (such as that occurring in some people with H.pylori infection), can lead to the disease pernicious anemia, a type of macrocytic anemia. Vitamin B_{12} malabsorption is most common in the elderly, who may have impaired functioning of digestive organs, a normal consequence of aging. Pernicious anemia is treated by large oral doses of vitamin B_{12} or by putting the vitamin under the tongue, where it is absorbed into the bloodstream without passing through the intestine. In patients that do not respond to oral or sublingual treatment vitamin B_{12} is given by injection.

Vitamin B_{12} Relationship with Folate and Vitamin B_6

Figure 10.19 B Vitamins Coenzyme Roles

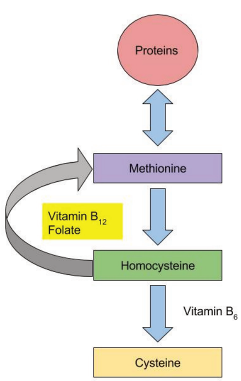


Image by Allison Calabrese / CC BY 4.0

Vitamin B_{12} and folate play key roles in converting homocysteine to amino acid methionine. As mentioned in Figure 9.19 " Vitamin B6 Functional Coenzyme Role", high levels of homocysteine in the blood increases the risk for heart disease. Low levels of vitamin B_{12}, folate or vitamin B6 will increase homocysteine levels therefore increasing the risk of heart disease.

Figure 10.20 The Relationship Between Folate and Vitamin B_{12}

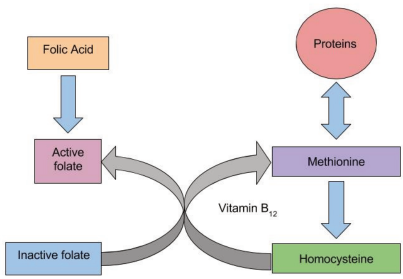


Image by Allison Calabrese / CC BY 4.0

When there is a deficiency in vitamin B_{12} , inactive folate (from food) is unable to be converted to active folate and used in the body for the synthesis of DNA. Folic Acid however (that comes from supplements or fortified foods) is available to be used as active folate in the body without vitamin B_{12} .Therefore, if there is a deficiency in vitamin B_{12} macrocytic anemia may occur. With the fortification of foods incorporated into people's diets, the risk of an individual developing macrocytic anemia is decreased.

Dietary Reference Intakes

The RDAs and ULs for different age groups for Vitamin B_{12} are listed in Table 10.27 "Dietary Reference Intakes for Vitamin B_{12}".

Table 10.27 Dietary Reference Intakes for Vitamin B_{12}

Age Group	RDA Males and Females mcg/day
Infants (0–6 months)	0.4*
Infants (7–12 months)	0.5*
Children (1–3 years)	0.9
Children (4–8 years)	1.2
Children (9–13 years)	1.8
Adolescents (14–18 years)	2.4
Adults (> 19 years)	2.4
*denotes Adequate Intake	

Dietary Fact Sheet: Vitamin B12. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/VitaminB12-HealthProfessional/. Updated February 11, 2016. Accessed October 28, 2017.

Dietary Sources

Vitamin B_{12} is found naturally in animal products such as fish, meat, poultry, eggs, and milk products. Although vitamin B_{12} is not generally present in plant foods, fortified breakfast cereals are also a good source of vitamin B_{12}. For the vitamin B_{12} content of various foods, see Table 10.28 "Vitamin B_{12} Content of Various Foods".

Table 10.28 Vitamin B_{12} Content of Various Foods

Food	Serving	Vitamin B12 (mcg)	Percent Daily Value
Clams	3 oz.	84.1	1,402
Salmon	3 oz.	4.8	80
Tuna, canned	3 oz.	2.5	42
Breakfast cereals, fortified	1 serving	1.5	25
Beef, top sirloin	3 oz.	1.4	23
Milk, lowfat	8 fl oz.	1.2	18
Yogurt, lowfat	8 oz.	1.1	18
Cheese, swiss	1 oz.	0.9	15
Egg	1 large	0.6	10

Dietary Fact Sheet: Vitamin B_{12}. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/VitaminB12-HealthProfessional/. Updated February 11, 2016. Accessed October 28, 2017.

Choline

Choline is a water-soluble substance that is not classified as a vitamin because it can be synthesized by the body. However, the synthesis of choline is limited and therefore it is recognized as an essential nutrient. Choline is need to perform functions such as the synthesis of neurotransmitter acetylcholine, the synthesis of phospholipids used to make cell membranes, lipid transport, and also homocysteine metabolism. A deficiency in choline may lead to interfered brain development in the fetus during pregnancy, and in adults cause fatty liver and muscle damage.

Dietary Reference Intakes

There is insufficient data on choline so the FNB has developed AIs for all ages in order to prevent fatty liver disease. The AI and UL for different age groups for choline are listed in Table 10.29 "Dietary Reference Intakes for Choline".

Table 10.29 Dietary Reference Intakes for Choline

Age Group	AI Males and Females mg/day)	UL
Infants (0–6 months)	125	–
Infants (7–12 months)	150	–
Children (1–3 years)	200	1000
Children (4–8 years)	250	1000
Children (9–13 years)	375	2000
Adolescents (14–18 years)	550 (males), 400 (females)	3000
Adults (> 19 years)	550 (males), 425 (females)	3500

Fact Sheet for Health Professionals: Choline. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Choline-HealthProfessional/. Updated January 25, 2017. Accessed October 28, 2017.

Dietary Sources

Choline can be found in a variety of different foods. The main dietary sources of choline consist of primarily animal based products. For the Choline content of various foods, see Table 10.30 "Choline Content of Various Foods".

Table 10.30 Choline Content of Various Foods

Food	Serving	Choline (mg)	Percent Daily Value
Egg	1 large	147	27
Soybeans	½ cup	107	19
Chicken breast	3 oz.	72	13
Mushrooms, shiitake	½ c.	58	11
Potatoes	1 large	57	10
Kidney beans	½ c.	45	8
Peanuts	¼ c.	24	4
Brown rice	1 c.	19	3

Fact Sheet for Health Professionals: Choline. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Choline-HealthProfessional/. Updated January 25, 2017. Accessed October 28, 2017.

Summary of Water-Soluble Vitamins

Table 10.31 Water-Soluble vitamins

Vitamin	Sources	Recommended Intake for adults	Major Functions	Deficiency diseases and symptoms
Vitamin C (ascorbic acid)	Orange juice, grapefruit juice, strawberries, tomato, sweet red pepper	75-90 mg/day	Antioxidant, collagen synthesis, hormone and neurotransmitter synthesis	Scurvy, bleeding gums, joint pain, poor wound healing,
Thiamin (B1)	Pork, enriched and whole grains, fish, legumes	1.1-1.2 mg/day	Coenzyme: assists in glucose metabolism, RNA, DNA, and ATP synthesis	Beriberi: fatigue, confusion, movement impairment, swelling, hear failure
Riboflavin (B2)	Beef liver, enriched breakfast cereals, yogurt, steak, mushrooms, almonds, eggs	1.1-1.3 mg/day	Coenzyme: assists in glucose, fat and carbohydrate metabolism, electron carrier, other B vitamins are dependent on	Ariboflavinosi dry scaly skin, mouth inflammation and sores, sor throat, itchy eyes, light sensitivity
Niacin (B3)	Meat, poultry, fish, peanuts, enriched grains	14-16 NE/day	Coenzyme: assists in glucose, fat, and protein metabolism, electron carrier	Pellagra: diarrhea, dermatitis, dementia, death
Pantothenic Acid (B5)	Sunflower seeds, fish, dairy products, widespread in foods	5 mg/day	Coenzyme: assists in glucose, fat, and protein metabolism, cholesterol and neurotransmitter synthesis	Muscle numbness and pain, fatigue, irritability
B6(Pyridoxine)	Meat, poultry, fish, legumes, nuts	1.3-1.7 mg/day	Coenzyme; assists in amino-acid synthesis, glycogneolysis, neurotransmitter and hemoglobin synthesis	Muscle weakness, dermatitis, mouth sores, fatigue, confusion

Biotin	Egg yolks, fish, pork, nuts and seeds	30 mcg/day	Coenzyme; assists in glucose, fat, and protein metabolism, amino-acid synthesis	Muscle weakness, dermatitis, fatigue, hair loss
Folate	Leafy green vegetables, enriched grains, orange juice	400 mcg/day	Coenzyme; amino acid synthesis, RNA, DNA, and red blood cell synthesis	Diarrhea, mouth sores, confusion, anemia, neural-tube defects
B12(cobalamin)	Meats, poultry, fish	2.4 mcg/day	Coenzyme; fat and protein catabolism, folate function, red-blood-cell synthesis	Muscle weakness, sore tongue, anemia, nerve damage, neural-tube defects
Choline	Egg yolk, wheat, meat, fish, synthesis in the body	425-550 mg/day	Synthesis of neurotransmitters and cell membranes, lipid transport	Non-alcoholic fatty liver disease, muscle damage, interfered brain development in fetus

Do B-Vitamin Supplements Provide an Energy Boost?

Although some marketers claim taking a vitamin that contains one-thousand times the daily value of certain B vitamins boosts energy and performance, this is a myth that is not backed by science. The “feeling” of more energy from energy-boosting supplements stems from the high amount of added sugars, caffeine, and other herbal stimulants that accompany the high doses of B vitamins. As discussed, B vitamins are needed to support energy metabolism and growth, but taking in more than required does not supply you with more energy. A great analogy of this phenomenon is the gas in your car.

Does it drive faster with a half-tank of gas or a full one? It does not matter; the car drives just as fast as long as it has gas. Similarly, depletion of B vitamins will cause problems in energy metabolism, but having more than is required to run metabolism does not speed it up. Buyers of B-vitamin supplements beware; B vitamins are not stored in the body and all excess will be flushed down the toilet along with the extra money spent.

B vitamins are naturally present in numerous foods, and many other foods are enriched with them. In Canada, B-vitamin deficiencies are rare; however in the nineteenth century some vitamin-B deficiencies plagued many people in North America. Niacin deficiency, also known as pellagra, was prominent in poorer North Americans whose main dietary staple was refined cornmeal. Its symptoms were severe and included diarrhea, dermatitis, dementia, and even death. Some of the health consequences of pellagra are the result of niacin being in insufficient supply to support the body's metabolic functions.

Antioxidants

The market is flooded with advertisements for "super antioxidant" supplements teeming with molecules that block free radical production, stimulate the immune system, prevent cancer, and reduce the signs of aging. Based on the antioxidant-supplement industry's success, the general public appears to believe these health claims. However, these claims are not backed by scientific evidence; rather, there is some evidence suggesting supplements can actually cause harm. While scientists have found evidence supporting the consumption of antioxidant-rich foods as a method of reducing the risk of chronic disease, there is no "miracle cure"; no pill or supplement alone can provide the same benefits as a healthy diet. Remember, it is the combination of antioxidants and other nutrients in healthy foods that is beneficial. In this section, we will review how particular antioxidants function in the body, learn how they work together to protect the body against free radicals, and explore the best nutrient-rich dietary sources of antioxidants. One dietary source of antioxidants is vitamins. In our discussion of antioxidant vitamins, we will focus on vitamins E, C, and A.

Figure 10.21 Antioxidants Role

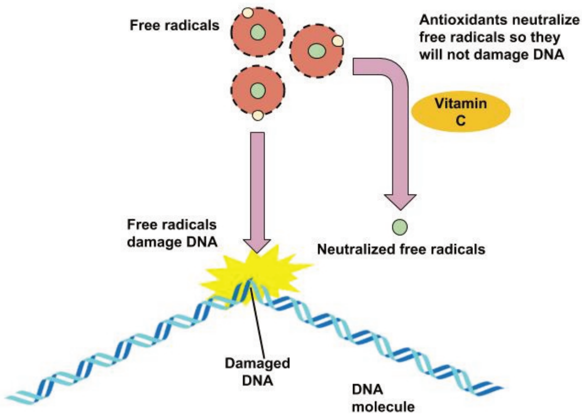


Image by Allison Calabrese / CC BY 4.0

Antioxidant Chemicals Obtained from the Diet

There are many different antioxidants in food, including selenium, which is one of the major antioxidants. However, the antioxidants you may be the most familiar with are vitamins. The "big three" vitamin antioxidants are vitamins E, A, and C, although it may be that they are called the "big three" only because they are the most studied.

Table 10.32 Some Antioxidants Obtained from Diet and Their Related Functions

Antioxidant	Functions Attributed to Antioxidant Capacity
Vitamin A	Protects cellular membranes, prevents glutathione depletion, maintains free radical detoxifying enzyme systems, reduces inflammation
Vitamin E	Protects cellular membranes, prevents glutathione depletion
Vitamin C	Protects DNA, RNA, proteins, and lipids, aids in regenerating vitamin E
Carotenoids	Free radical scavengers
Lipoic acid	Free radical scavenger, aids in regeneration of vitamins C and E
Phenolic acids	Free radical scavengers, protect cellular membranes

The Body's Offense

While our bodies have acquired multiple defenses against free radicals, we also use free radicals to support its functions. For example, the immune system uses the cell-damaging properties of free radicals to kill pathogens. First, immune cells engulf an invader (such as a bacterium), then they expose it to free radicals such as hydrogen peroxide, which destroys its membrane. The invader is thus neutralized. Scientific studies also suggest hydrogen peroxide acts as a signaling molecule that calls immune cells to injury sites, meaning free radicals may aid with tissue repair when you get cut.

Free radicals are necessary for many other bodily functions as well. The thyroid gland synthesizes its own hydrogen peroxide, which is required for the production of thyroid hormone. Reactive oxygen species and reactive nitrogen species, which are free radicals containing nitrogen, have been found to interact with proteins in cells to produce signaling molecules. The free radical nitric oxide has been found to help dilate blood vessels and act as a chemical messenger in the brain. By acting as signaling molecules, free radicals are involved in the control of their own synthesis, stress responses, regulation of cell growth and death, and metabolism.

Sources of Free Radicals in the Environment

Substances and energy sources from the environment can add to or accelerate the production of free radicals within the body. Exposure to excessive sunlight, ozone, smoke, heavy metals, ionizing radiation, asbestos, and other toxic chemicals increase the amount of free radicals in the body. They do so by being free radicals themselves or by adding energy that provokes electrons to move between atoms. Excessive exposure to environmental sources of free radicals can contribute to disease by overwhelming the free radical detoxifying systems and those processes involved in repairing oxidative damage.

Oxidative Stress

Oxidative stress refers to an imbalance in any cell, tissue, or organ between the amount of free radicals and the capabilities of the detoxifying and repair systems. Sustained oxidative damage results only under conditions of oxidative stress—when the detoxifying and repair systems are insufficient. Free radical-induced damage, when left unrepaired, destroys lipids, proteins, RNA, and DNA, and can contribute to disease. Oxidative stress has been implicated as a contributing factor to cancer, atherosclerosis (hardening of arteries), arthritis, diabetes, kidney disease, Alzheimer's disease, Parkinson's disease, schizophrenia, bipolar disorder, emphysema, and cataracts.

Aging is a process that is genetically determined but modulated by factors in the environment. In the process of aging, tissue function declines. The idea that oxidative stress is the primary contributor to age-related tissue decline has been around for decades, and it is true that tissues accumulate free radical-induced damage as we age. Recent scientific evidence slightly modifies this theory by suggesting oxidative stress is not the initial trigger for age-related decline of tissues; it is suggested that the true culprit is progressive dysfunction of metabolic processes, which leads to increases in free radical production, thus influencing the stress response of tissues as they age.

Phytochemicals

Phytochemicals are chemicals in plants that may provide some health benefit. Carotenoids are one type of phytochemical. Phytochemicals also include indoles, lignans, phytoestrogens, stanols, saponins, terpenes, flavonoids, carotenoids, anthocyanidins, phenolic acids, and many more. They are found not only in fruits and vegetables, but also in grains, seeds, nuts, and legumes.

Many phytochemicals act as antioxidants, but they have several other functions, such as mimicking hormones, altering absorption of cholesterol, inhibiting inflammatory responses, and blocking the actions of certain enzymes.

Phytochemicals are present in small amounts in the food supply, and although thousands have been and are currently being scientifically studied, their health benefits remain largely unknown. Also largely unknown is their potential for toxicity, which could be substantial if taken in large amounts in the form of supplements. Moreover, phytochemicals often act in conjunction with each other and with micronutrients. Thus, supplementing with only a few may impair the functions of other phytochemicals or micronutrients. As with the antioxidant vitamins, it is the mixture and variety of phytochemicals in foods that are linked to health benefits.

CHAPTER 11. MAJOR MINERALS

Introduction

Choy Sum by pxhere.com / CCO

Learning Objectives

By the end of this chapter you will be able to:

- Describe the functional role, intake recommendations and sources of major minerals

Similarly to vitamins, minerals are essential to human health and can be obtained in our diet from different types of food.

Minerals are abundant in our everyday lives. From the soil in your front yard to the jewelry you wear on your body, we interact with minerals constantly. There are 20 essential minerals that must be consumed in our diets to remain healthy. The amount of each mineral found in our bodies vary greatly and therefore, so does consumption of those minerals. When there is a deficiency in an essential mineral, health problems may arise.

Major minerals are classified as minerals that are required in the diet each day in amounts larger than 100 milligrams. These include sodium, potassium, chloride, calcium, phosphorus, magnesium, and sulfur. These major minerals can be found in various foods. For example, in Guam, the major mineral, calcium, is consumed in the diet not only through dairy, a common source of calcium, but also through through the mixed dishes, desserts and vegetables that they consume. Consuming a varied diet significantly improves an individual's ability to meet their nutrient needs. [1]

Figure 11.1 The Major Minerals

1. Pobocik RS, Trager A, Monson LM. Dietary Patterns and Food Choices of a Population Sample of Adults on Guam. Asia Pacific Journal of Clinical Nutrition. 2008; 17(1), 94-100. http://apjcn.nhri.org.tw/server/APJCN/17/1/94.pdf. Accessed February 16, 2018.

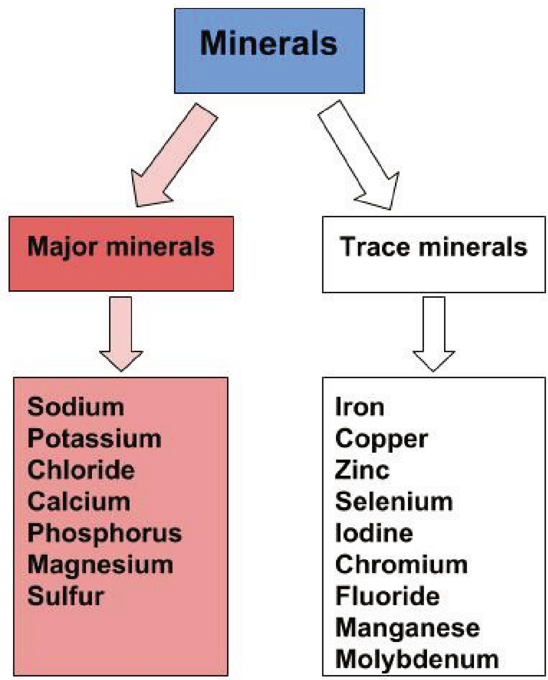


Image by Allison Calabrese / CC BY 4.0

Bioavailability

Minerals are not as efficiently absorbed as most vitamins and so the bioavailability of minerals can be very low. Plant-based foods often contain factors, such as oxalate and phytate, that bind to minerals and inhibit their absorption. In general, minerals are better absorbed from animal-based foods. In most cases, if dietary intake of a particular mineral is increased, absorption will decrease. Some minerals influence the absorption of others. For instance, excess zinc in the diet can impair iron and copper absorption. Conversely, certain vitamins enhance mineral absorption. For example, vitamin C boosts iron absorption, and vitamin D boosts calcium and magnesium absorption. As is the case with vitamins, certain gastrointestinal disorders and diseases, such as Crohn's disease and kidney disease, as well as the aging process, impair mineral absorption, putting people with malabsorption conditions and the elderly at higher risk for mineral deficiencies.

Calcium

Calcium's Functional Roles

Calcium is the most abundant mineral in the body and greater than 99 percent of it is stored in bone tissue. Although only 1 percent of the calcium in the human body is found in the blood and soft tissues, it is here that it performs the most critical functions. Blood calcium levels are rigorously controlled so that if blood levels drop the body will rapidly respond by stimulating bone resorption, thereby releasing stored calcium into the blood. Thus, bone tissue sacrifices its stored calcium to maintain blood calcium levels. This is why bone health is dependent on the intake of dietary calcium and also why blood levels of calcium do not always correspond to dietary intake.

Calcium plays a role in a number of different functions in the body like bone and tooth formation. The most well-known calcium function is to build and strengthen bones and teeth. Recall that when bone tissue first forms during the modeling or remodeling process, it is unhardened, protein-rich osteoid tissue. In the osteoblast-directed process of bone mineralization, calcium phosphates (salts) are deposited on the protein matrix. The calcium salts typically make up about 65 percent of bone tissue. When your diet is calcium deficient, the mineral content of bone decreases causing it to become brittle and weak. Thus, increased calcium intake helps to increase the mineralized content of bone tissue. Greater mineralized bone tissue corresponds to a greater BMD, and to greater bone strength. The remaining calcium plays a role in nerve impulse transmission by facilitating electrical impulse transmission from one nerve cell to another. Calcium in muscle cells is essential for muscle contraction because the flow of calcium ions are needed for the muscle proteins (actin and myosin) to interact. Calcium is also essential in blood clotting by activating clotting factors to fix damaged tissue.

In addition to calcium's four primary functions calcium has several other minor functions that are also critical for maintaining normal physiology. For example, without calcium, the hormone insulin could not be released from cells in the pancreas and glycogen could not be broken down in muscle cells and used to provide energy for muscle contraction.

Maintaining Calcium Levels

Because calcium performs such vital functions in the body, blood calcium level is closely regulated by the hormones parathyroid hormone (PTH), calcitriol, and calcitonin. When blood calcium levels are low, PTH is secreted to increase blood calcium levels via three different mechanisms. First, PTH stimulates the release of calcium stored in the bone. Second, PTH acts on kidney cells to increase calcium reabsorption and decrease its excretion in the urine. Third, PTH stimulates enzymes in the kidney that activate vitamin D to calcitriol. Calcitriol is the active hormone that acts on the intestinal cells and increases dietary calcium absorption. When blood calcium levels become too high, the hormone calcitonin is secreted by certain cells in the thyroid gland and PTH secretion stops. At higher nonphysiological concentrations, calcitonin lowers blood calcium levels by increasing calcium excretion in the urine, preventing further absorption of calcium in the gut and by directly inhibiting bone resorption.

Figure 11.2 Maintaining Blood Calcium Levels

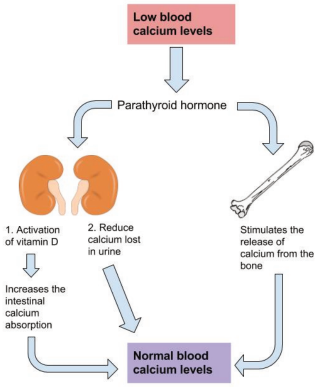


Image by Allison Calabrese / CC BY 4.0

Other Health Benefits of Calcium in the Body

Besides forming and maintaining strong bones and teeth, calcium has been shown to have other health benefits for the body, including:

- **Cancer**. There is enough scientific evidence to conclude that higher intakes of calcium decrease colon cancer risk and may suppress the growth of polyps that often precipitate cancer. Although higher calcium consumption protects against colon cancer, some studies have looked at the relationship between calcium and prostate cancer and found higher intakes may increase the risk for prostate cancer; however the data is inconsistent and more studies are needed to confirm any negative association.
- **Blood pressure**. Multiple studies provide clear evidence that higher calcium consumption reduces blood pressure.

A review of twenty-three observational studies concluded that for every 100 milligrams of calcium consumed daily, systolic blood pressure is reduced 0.34 millimeters of mercury (mmHg) and diastolic blood pressure is decreased by 0.15 mmHg.[1]

- **Cardiovascular health**. There is emerging evidence that higher calcium intakes prevent against other risk factors for cardiovascular disease, such as high cholesterol and obesity, but the scientific evidence is weak or inconclusive.
- **Kidney stones**. Another health benefit of a high-calcium diet is that it blocks kidney stone formation. Calcium inhibits the absorption of oxalate, a chemical in plants such as parsley and spinach, which is associated with an increased risk for developing kidney stones. Calcium's protective effects on kidney stone formation occur only when you obtain calcium from dietary sources. Calcium supplements may actually increase the risk for kidney stones in susceptible people.

Figure 11. 3 Calcium's Effect on Aging

1. Birkett NJ. Comments on a Meta-Analysis of the Relation between Dietary Calcium Intake and Blood Pressure. Am J Epidemiol. 1998;148(3), 223–28. http://aje.oxfordjournals.org/content/148/3/223.long. Accessed October 10, 2017.

Image by James Heilman, MD / CC BY-SA 3.0

Calcium inadequacy is most prevalent in adolescent girls and the elderly. Proper dietary intake of calcium is critical for proper bone health. Here we will take a closer look at particular groups of people who may require extra calcium intake.

- **Adolescent teens**. A calcium-deficient diet is common in teenage girls as their dairy consumption often considerably drops during adolescence.

- **Amenorrheic women and the "female athlete triad"**. Amenorrhea refers to the absence of a menstrual cycle. Women who fail to menstruate suffer from reduced estrogen levels, which can disrupt and have a negative impact on the calcium balance in their bodies. The "female athlete triad" is a combination of three conditions characterized by amenorrhea, disrupted eating patterns, and osteoporosis. Exercise-induced amenorrhea and anorexia nervosa-related amenorrhea can decrease bone mass.[2,3] In female athletes, as well as active women in the military, low BMD, menstrual irregularities, and individual dietary habits together with a history of previous stress issues are related to an increased susceptibility to future stress fractures.[4,5]
- **The elderly**. As people age, calcium bioavailability is reduced, the kidneys lose their capacity to convert vitamin D to its most active form, the kidneys are no longer efficient in retaining calcium, the skin is less effective at

2. Drinkwater B, Bruemner B, Chesnut C. Menstrual History As a Determinant of Current Bone Density in Young Athletes. JAMA. 1990; 263(4), 545–8. http://www.ncbi.nlm.nih.gov/pubmed/2294327?dopt=Abstract. . Accessed November 22, 2017.
3. Marcus R. et al. Menstrual Function and Bone Mass in Elite Women Distance Runners: Endocrine and Metabolic Features. Ann Intern Med. 1985; 102(2), 58–63. http://www.ncbi.nlm.nih.gov/pubmed/3966752?dopt=Abstract. Accessed November 22, 2017.
4. Nattiv A. Stress Fractures and Bone Health in Track and Field Athletes. J Sci Med Sport. 2000; 3(3), 268–79. http://www.ncbi.nlm.nih.gov/pubmed/11101266?dopt=Abstract.,.Accessed November 22, 2017.
5. Johnson AO, et al. Correlation of Lactose Maldigestion, Lactose Intolerance, and Milk Intolerance. Am J Clin Nutr. 1993; 57(3), 399–401. http://www.ncbi.nlm.nih.gov/pubmed/8438774?dopt=Abstract. Accessed November 22, 2017.

synthesizing vitamin D, there are changes in overall dietary patterns, and older people tend to get less exposure to sunlight. Thus the risk for calcium inadequacy is great.[6]

- **Postmenopausal women**. Estrogen enhances calcium absorption. The decline in this hormone during and after menopause puts postmenopausal women especially at risk for calcium deficiency. Decreases in estrogen production are responsible for an increase in bone resorption and a decrease in calcium absorption. During the first years of menopause, annual decreases in bone mass range from 3–5 percent. After age sixty-five, decreases are typically less than 1 percent.[7]
- **Lactose-intolerant people**. Groups of people, such as those who are lactose intolerant, or who adhere to diets that avoid dairy products, may not have an adequate calcium intake.
- **Vegans**. Vegans typically absorb reduced amounts of calcium because their diets favor plant-based foods that contain oxalates and phytates.[8]

In addition, because vegans avoid dairy products, their overall consumption of calcium-rich foods may be less.

If you are lactose intolerant, have a milk allergy, are a vegan,

6. Calcium and Vitamin D in the Elderly. International Osteoporosis Foundation. http://www.iofbonehealth.org/patients-public/about-osteoporosis/prevention /nutrition/calcium-and-vitamin-d-in-the-elderly.html. Published 2012. Accessed November 22, 2017.
7. Daniels CE. Estrogen Therapy for Osteoporosis Prevention in Postmenopausal Women. National Institute of Health: Pharmacy. Update March/April 2000.
8. Dietary Reference Intakes for Calcium and Vitamin D.Food and Nutrition Board, Institute of Medicine. Washington, DC: National Academy Press. 2010.

or you simply do not like dairy products, remember that there are many plant-based foods that have a good amount of calcium and there are also some low-lactose and lactose-free dairy products on the market.

Calcium Supplements: Which One to Buy?

Many people choose to fulfill their daily calcium requirements by taking calcium supplements. Calcium supplements are sold primarily as calcium carbonate, calcium citrate, calcium lactate, and calcium phosphate, with elemental calcium contents of about 200 milligrams per pill. It is important to note that calcium carbonate requires an acidic environment in the stomach to be used effectively. Although this is not a problem for most people, it may be for those on medication to reduce stomach-acid production or for the elderly who may have a reduced ability to secrete acid in the stomach. For these people, calcium citrate may be a better choice. Otherwise, calcium carbonate is the cheapest. The body is capable of absorbing approximately 30 percent of the calcium from these forms.

Beware of Lead

There is public health concern about the lead content of some brands of calcium supplements, as supplements derived from natural sources such as oyster shell, bone meal, and dolomite (a type of rock containing calcium magnesium carbonate) are known to contain high amounts of lead. In one study conducted on twenty-two brands of calcium supplements, it was proven that eight of the brands exceeded the acceptable limit for lead content. This was found to be the case in supplements derived from oyster shell and refined calcium carbonate. The same study also found that brands claiming to be lead-free did, in fact, show very low lead levels. Because lead levels in supplements are not disclosed on labels, it is important to know that products not derived from oyster shell or other natural substances are generally low in lead content. In addition, it was also found that one brand did not disintegrate as is necessary for absorption, and one brand contained only 77 percent of the stated calcium content.[9]

Diet, Supplements, and Chelated Supplements

In general, calcium supplements perform to a lesser degree than dietary sources of calcium in providing many of the health benefits linked to higher calcium intake. This is partly attributed to the fact that dietary sources of calcium supply additional nutrients with health-promoting activities. It is reported that chelated forms of calcium supplements are easier to absorb as the chelation process protects the calcium from oxalates and phytates that may bind with the calcium in the intestines. However, these are more expensive supplements and only increase calcium absorption up to 10 percent. In people with low dietary intakes of calcium, calcium supplements have a negligible benefit on bone health in the absence of a vitamin D supplement. However, when calcium supplements are taken along with vitamin D, there are many benefits to bone health: peak bone mass is increased in early

9. Ross EA, Szabo NJ, Tebbett IR. Lead Content of Calcium Supplements. JAMA. 2000; 284, 1425–33.

adulthood, BMD is maintained throughout adulthood, the risk of developing osteoporosis is reduced, and the incidence of fractures is decreased in those who already had osteoporosis. Calcium and vitamin D pills do not have to be taken at the same time for effectiveness. But remember that vitamin D has to be activated and in the bloodstream to promote calcium absorption. Thus, it is important to maintain an adequate intake of vitamin D.

The Calcium Debate

A recent study published in the British Medical Journal reported that people who take calcium supplements at doses equal to or greater than 500 milligrams per day in the absence of a vitamin D supplement had a 30 percent greater risk for having a heart attack.[10]

Does this mean that calcium supplements are bad for you? If you look more closely at the study, you will find that 5.8 percent of people (143 people) who took calcium supplements had a heart attack, but so did 5.5 percent of the people (111) people who took the placebo. While this is one study, several other large studies have not shown that calcium supplementation increases the risk for cardiovascular disease. While the debate over this continues in the realm of science, we should focus on the things we do know:

1. There is overwhelming evidence that diets sufficient in calcium prevent osteoporosis and cardiovascular disease.

10. Bolland MJ. et al. Effect of Calcium Supplements on Risk of Myocardial Infarction and Cardiovascular Events: Meta-Analysis. Br Med J. 2010; 341(c3691).

2. People with risk factors for osteoporosis are advised to take calcium supplements if they are unable to get enough calcium in their diet. This includes calcium both from dietary sources and supplements.
3. Consuming more calcium than is recommended is not better for your health and can prove to be detrimental. Consuming too much calcium at any one time, be it from diet or supplements, impairs not only the absorption of calcium itself, but also the absorption of other essential minerals, such as iron and zinc. Since the GI tract can only handle about 500 milligrams of calcium at one time, it is recommended to have split doses of calcium supplements rather than taking a few all at once to get the RDA of calcium.

Dietary Reference Intake for Calcium

The recommended dietary allowances (RDA) for calcium are listed in Table 10.1 "Dietary Reference Intakes for Calcium". The RDA is elevated to 1,300 milligrams per day during adolescence because this is the life stage with accelerated bone growth. Studies have shown that a higher intake of calcium during puberty increases the total amount of bone tissue that accumulates in a person. For women above age fifty and men older than seventy-one, the RDAs are also a bit higher for several reasons including that as we age, calcium absorption in the gut decreases, vitamin D3 activation is reduced, and maintaining adequate blood levels of calcium is important to prevent an acceleration of bone tissue loss (especially during menopause). Currently, the dietary intake of calcium for females above age nine is, on average, below the RDA for calcium. Consuming over 2,500 milligrams per day of calcium may cause adverse effects in some people.

Table 11.1 Dietary Reference Intakes for Calcium

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	200*	–
Infants (6–12 months)	260*	–
Children (1–3 years)	700	2,500
Children (4–8 years)	1,000	2,500
Children (9–13 years)	1,300	2,500
Adolescents (14–18 years)	1,300	2,500
Adults (19–50 years)	1,000	2,500
Adult females (50–71 years)	1,200	2,500
Adults, male & female (> 71 years)	1,200	2,500

* denotes Adequate Intake

Source: Ross AC, Manson JE, et al. The 2011 Report on Dietary Reference Intakes for Calcium and Vitamin D from the Institute of Medicine: What Clinicians Need to Know. J Clin Endocrinol Metab. 2011; 96(1), 53–8. http://www.ncbi.nlm.nih.gov/pubmed/21118827. Accessed October 10, 2017.

Dietary Sources of Calcium

In the typical Canadian diet, calcium is obtained mostly from dairy products, primarily cheese. A slice of cheddar or Swiss cheese contains just over 200 milligrams of calcium. One cup of nonfat milk contains approximately 300 milligrams of calcium, which is about a third of the RDA for calcium for most adults. Foods fortified with calcium such as cereals, soy milk, and orange juice also provide one third or greater of the calcium RDA.

Tools for Change

If you need to increase calcium intake, are a vegan, or have a food allergy to dairy products, it is helpful to know that there are some plant-based foods that are high in calcium. Tofu (made with calcium sulfate), turnip greens, mustard greens, and chinese cabbage are good sources. For a list of non-dairy sources you can find the calcium content for thousands of foods by visiting the USDA National Nutrient Database (http://www.nal.usda.gov/fnic/foodcomp/search/). When obtaining your calcium from a vegan diet, it is important to know that some plant-based foods significantly impair the absorption of calcium. These include spinach, Swiss chard, rhubarb, beets, cashews, and peanuts. With careful planning and good selections, you can ensure that you are getting enough calcium in your diet even if you do not drink milk or consume other dairy products.

Table 11.2 Calcium Content of Various Foods

Food	Serving	Calcium (mg)	Percent Daily Value
Yogurt, low fat	8 oz.	415	42
Mozzarella	1.5 oz.	333	33
Sardines, canned with bones	3 oz.	325	33
Cheddar Cheese	1.5 oz.	307	31
Milk, nonfat	8 oz.	299	30
Soymilk, calcium fortified	8 oz.	299	30
Orange juice, calcium fortified	6 oz.	261	26
Tofu, firm, made with calcium sulfate	½ c.	253	25
Salmon, canned with bones	3 oz.	181	18
Turnip, boiled	½ c.	99	10
Kale, cooked	1 c.	94	9
Vanilla Ice Cream	½ c.	84	8
White bread	1 slice	73	7
Kale, raw	1 c.	24	2
Broccoli, raw	½ c.	21	2

Fact Sheet for Health Professionals: Calcium. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Calcium-HealthProfessional/. Updated November 17, 2016. Accessed November 12, 2017.

Calcium Bioavailability

In the small intestine, calcium absorption primarily takes place in the duodenum (first section of the small intestine) when intakes are low, but calcium is also absorbed passively in the jejunum and ileum (second and third sections of the small intestine), especially when intakes are higher. The body doesn't completely absorb all the calcium in food. Interestingly, the calcium in some vegetables such as kale, brussel sprouts, and bok choy is better absorbed by the body than are dairy products. About 30 percent of calcium is absorbed from milk and other dairy products.

The greatest positive influence on calcium absorption comes from having an adequate intake of vitamin D. People deficient in vitamin D absorb less than 15 percent of calcium from the foods they eat. The hormone estrogen is another factor that enhances calcium bioavailability. Thus, as a woman ages and goes through menopause, during which estrogen levels fall, the amount of calcium absorbed decreases and the risk for bone disease increases. Some fibers, such as inulin, found in jicama, onions, and garlic, also promote calcium intestinal uptake.

Chemicals that bind to calcium decrease its bioavailability. These negative effectors of calcium absorption include the oxalates in certain plants, the tannins in tea, phytates in nuts, seeds, and grains, and some fibers. Oxalates are found in high concentrations in spinach, parsley, cocoa, and beets. In general, the calcium bioavailability is inversely correlated to the oxalate content in foods. High-fiber, low-fat diets also decrease the amount of calcium absorbed, an effect likely related to how fiber and fat influence the amount of time food stays in the gut. Anything that causes diarrhea, including sickness, medications, and certain symptoms related to old age, decreases the transit time of calcium in the gut and therefore decreases calcium absorption. As we get older, stomach acidity sometimes decreases, diarrhea occurs more often, kidney function is impaired, and vitamin D absorption and activation is compromised, all of which contribute to a decrease in calcium bioavailability.

Phosphorus

Phosphorus's Functional Role

Phosphorus is present in our bodies as part of a chemical group called a phosphate group. These phosphate groups are essential as a structural component of cell membranes (as phospholipids), DNA and RNA, energy production (ATP), and regulation of acid-base homeostasis. Phosphorus however is mostly associated with calcium as a part of the mineral structure of bones and teeth. Blood phosphorus levels are not controlled as strictly as calcium so the PTH stimulates renal excretion of phosphate so that it does not accumulate to toxic levels.

Dietary Reference Intakes for Phosphorus

In comparison to calcium, most are not at risk for having a phosphate deficiency. Phosphate is present in many foods popular in the North American diet including meat, fish, dairy products, processed foods, and beverages. Phosphate is added to many foods because it acts as an emulsifying agent, prevents clumping, improves texture and taste, and extends shelf-life. The RDA is 700 milligrams per day. The UL set for phosphorous is 4,000 milligrams per day for adults and 3,000 milligrams per day for people over age seventy.

Table 11.3 Dietary Reference Intakes for Phosphorus

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	100*	–
Infants (6–12 months)	275*	–
Children (1–3 years)	460	3,000
Children (4–8 years)	500	3,000
Children (9–13 years)	1,250	4,000
Adolescents (14–18 years)	1,250	4,000
Adults (19–70 years)	700	4,000
Adults (> 70 years)	700	3,000
* denotes Adequate Intake		

Micronutrient Information Center: Phosphorus. Oregon State University, Linus Pauling Institute. http://lpi.oregonstate.edu/mic/minerals/phosphorus. Updated in July 2013. Accessed October 22, 2017.

Dietary Sources of Phosphorus

Table 11.4 Phosphorus Content of Various Foods

Foods	Serving	Phosphorus (mg)	Percent Daily Value 1000
Salmon	3 oz.	315	32
Yogurt, nonfat	8 oz.	306	31
Turkey, light meat	3 oz.	217	22
Chicken, light meat	3 oz.	135	14
Beef	3 oz.	179	18
Lentils*	½ c.	178	18
Almonds*	1 oz.	136	14
Mozzarella	1 oz.	131	13
Peanuts*	1 oz.	108	11
Whole wheat bread	1 slice	68	7
Egg	1 large	86	9
Carbonated cola drink	12 oz.	41	4
Bread, enriched	1 slice	25	3

Micronutrient Information Center: Phosphorus. Oregon State University, Linus Pauling Institute. http://lpi.oregonstate.edu/mic/minerals/phosphorus. Updated in July 2013. Accessed October 22, 2017.

Sulfur

Sulfur is incorporated into protein structures in the body. Amino acids, methionine and cysteine contain sulfur which are essential for the antioxidant enzyme glutathione peroxidase. Some vitamins like thiamin and biotin also contain sulfur which are important in regulating acidity in the body. Sulfur is a major mineral with no recommended intake or deficiencies when protein needs are met. Sulfur is mostly consumed as a part of dietary proteins and sulfur containing vitamins.

Magnesium

Magnesium's Functional Role

Approximately 60 percent of magnesium in the human body is stored in the skeleton, making up about 1 percent of mineralized bone tissue. Magnesium is not an integral part of the hard mineral crystals, but it does reside on the surface of the crystal and helps maximize bone structure. Observational studies link magnesium deficiency with an increased risk for osteoporosis. A magnesium-deficient diet is associated with decreased levels of parathyroid hormone and the activation of vitamin D, which may lead to an impairment of bone remodeling. A study in nine hundred elderly women and men did show that higher dietary intakes of magnesium correlated to an increased BMD in the hip.[1] Only a few clinical trials have evaluated the effects of magnesium supplements on bone health and their results suggest some modest benefits on BMD.

In addition to participating in bone maintenance, magnesium has several other functions in the body. In every reaction involving the cellular energy molecule, ATP, magnesium is required. More than three hundred enzymatic reactions require magnesium. Magnesium plays a role in the synthesis of DNA and RNA, carbohydrates, and lipids, and is

1. Tucker KL, Hannan MT, et al. Potassium, Magnesium, and Fruit and Vegetable Intakes Are Associated with Greater Bone Mineral Density in Elderly Men and Women. Am J ClinNutr. 1999; 69(4), 727–36. http://www.ajcn.org/cgi/pmidlookup?view=long&pmid=10197575. Accessed October 6, 2017.

essential for nerve conduction and muscle contraction. Another health benefit of magnesium is that it may decrease blood pressure.

Many Canadians do not get the recommended intake of magnesium from their diets. Some observational studies suggest mild magnesium deficiency is linked to increased risk for cardiovascular disease. Signs and symptoms of severe magnesium deficiency may include tremor, muscle spasms, loss of appetite, and nausea.

Dietary Reference Intake and Food Sources for Magnesium

The RDAs for magnesium for adults between ages nineteen and thirty are 400 milligrams per day for males and 310 milligrams per day for females. For adults above age thirty, the RDA increases slightly to 420 milligrams per day for males and 320 milligrams for females.

Table 11.5 Dietary Reference Intakes for Magnesium

Age Group	RDA (mg/day)	UL from non-food sources (mg/day)
Infants (0–6 months)	30*	–
Infants (6–12 months)	75*	–
Children (1–3 years)	80	65
Children (4–8 years)	130	110
Children (9–13 years)	240	350
Adolescents (14–18 years)	410	350
Adults (19–30 years)	400	350
Adults (> 30 years)	420	350
* denotes Adequate Intake		

Source: Dietary Supplement Fact Sheet: Magnesium. National Institutes of Health, Office of Dietary Supplements. http://ods.od.nih.gov/factsheets/Magnesium-HealthProfessional/. Updated July 13, 2009. Accessed November 12, 2017.

Dietary Sources of Magnesium

Magnesium is part of the green pigment, chlorophyll, which is vital for photosynthesis in plants; therefore green leafy vegetables are a good dietary source for magnesium. Magnesium is also found in high concentrations in fish, dairy products, meats, whole grains, and nuts. Additionally chocolate, coffee, and hard water contain a good amount of magnesium. Most people do not fulfill the RDA for magnesium in their diets. Typically, Western diets lean toward a low fish intake and the unbalanced consumption of refined grains versus whole grains.

Table 11.6 Magnesium Content of Various Foods

Food	Serving	Magnesium (mg)	Percent Daily Value
Almonds	1 oz.	80	20
Cashews	1 oz.	74	19
Soymilk	1 c.	61	15
Black beans	½ c.	60	15
Edamame	½ c.	50	13
Bread	2 slices	46	12
Avocado	1 c.	44	11
Brown rice	½ c.	42	11
Yogurt	8 oz.	42	11
Oatmeal, instant	1 packet	36	9
Salmon	3 oz.	26	7
Chicken breasts	3 oz.	22	6
Apple	1 medium	9	2

Source: Dietary Supplement Fact Sheet: Magnesium. National Institutes of Health, Office of Dietary Supplements. http://ods.od.nih.gov/factsheets/Magnesium-HealthProfessional/. Updated July 13, 2009. Accessed November 12, 2017.

Summary of Major Minerals

Table 11.7 A Summary of the Major Minerals

Micronutrient	Sources	Recommended Intakes for adults	Major functions	Deficiency diseases and symptoms	Gr for
Calcium	Yogurt, cheese, sardines, milk, orange juice, turnip	1,000 mg/day	Component of mineralized bone, provides structure and microarchitecture	Increased risk of osteoporosis	Po wo wh int ve
Phosphorus	Salmon, yogurt, turkey, chicken, beef, lentils	700 mg/day	Structural component of bones, cell membrane, DNA and RNA, and ATP	Bone loss, weak bones	Ol alc
Magnesium	Whole grains and legumes, almonds, cashews, hazelnuts, beets, collards, and kelp	420 mg/day	Component of mineralized bone, ATP synthesis and utilization, carbohydrate, lipid, protein, RNA, and DNA synthesis	Tremor, muscle spasms, loss of appetite, nausea	Alc inc kic ga dis
Sulfur	Protein foods	None specified	Structure of some vitamins and amino acids, acid-base balance	None when protein needs are met	No
Sodium	Processed foods, table salt, pork, chicken	< 2,300 mg/ day; ideally 1,500 mg/day	Major positive extracellular ion, nerve transmission, muscle contraction, fluid balance	Muscle cramps	Pe co mu exc sw wi dia
Potassium	Fruits, vegetables, legumes, whole grains, milk	4700 mg/day	Major positive intracellular ion, nerve transmission, muscle contraction, fluid balance	Irregular heartbeat, muscle cramps	Pe co hig pre me wi dia
Chloride	Table salt, processed foods	<3600 mg/day; ideally 2300 mg/day	Major negative extracellular ion, fluid balance	Unlikely	no

CHAPTER 12. TRACE MINERALS

Introduction

Wakame Salad Seaweed Food Cooking by maxpixel.com / CCO

Learning Objectives

By the end of this chapter you will be able to:

- Describe the functional role, intake recommendations and sources of trace minerals

Trace minerals are classified as minerals required in the diet each day in smaller amounts, specifically 100 milligrams or less. These include copper, zinc, selenium, iodine, chromium, fluoride, manganese, molybdenum, and others. Although trace minerals are needed in smaller amounts it is important to remember that a deficiency in a trace mineral can be just as detrimental to your health as a major mineral deficiency. Iodine deficiency is a major concern in countries around the world such as Fiji. In the 1990's, almost 50% of the population had signs of iodine deficiency also known as goiter. To combat this national issue, the government of Fiji banned non-iodized salt and allowed only fortified iodized salt into the country in hopes of increasing the consumption of iodine in people's diets. With this law, and health promotion efforts encouraging the consumption of seafood, great progress has been made in decreasing the prevalence of iodine deficiency in Fiji.[1]

Figure 12.1 The Trace Minerals

1. Micronutrient Deficiencies. Ministry of Health and Medical Services, Shaping Fiji's Health. http://www.health.gov.fj/?page_id=1406. Published 2015. Accessed November 12, 2017.

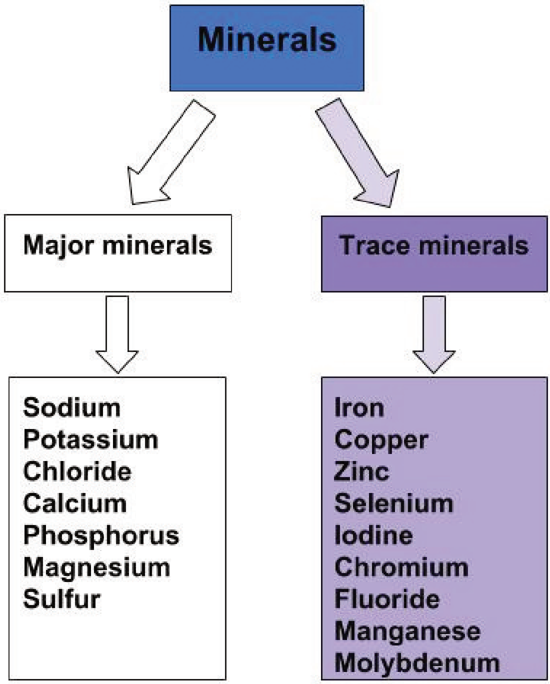
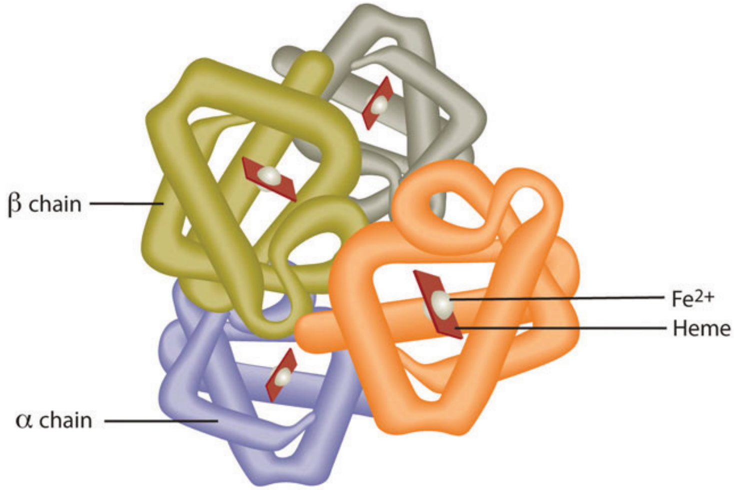


Image by Allison Calabrese / CC BY 4.0

Iron

Red blood cells contain the oxygen-carrier protein hemoglobin. It is composed of four globular peptides, each containing a heme complex. In the center of each heme, lies iron (Figure 12.2). Iron is needed for the production of other iron-containing proteins such as myoglobin. Myoglobin is a protein found in the muscle tissues that enhances the amount of available oxygen for muscle contraction. Iron is also a key component of hundreds of metabolic enzymes. Many of the proteins of the electron-transport chain contain iron–sulfur clusters involved in the transfer of high-energy electrons and ultimately ATP synthesis. Iron is also involved in numerous metabolic reactions that take place mainly in the liver and detoxify harmful substances. Moreover, iron is required for DNA synthesis. The great majority of iron used in the body is that recycled from the continuous breakdown of red blood cells.

Figure 12.2 The Structure of Hemoglobin



Hemoglobin is composed of four peptides. Each contains a heme group with iron in the center.

The iron in hemoglobin binds to oxygen in the capillaries of the lungs and transports it to cells where the oxygen is released. If iron level is low hemoglobin is not synthesized in sufficient amounts and the oxygen-carrying capacity of red blood cells is reduced, resulting in anemia. When iron levels are low in the diet the small intestine more efficiently absorbs iron in an attempt to compensate for the low dietary intake, but this process cannot make up for the excessive loss of iron that occurs with chronic blood loss or low intake. When blood cells are decommissioned for use, the body recycles the iron back to the bone marrow where red blood cells are made. The body stores some iron in the bone marrow, liver, spleen, and skeletal muscle. A relatively small amount of iron is excreted when cells lining the small intestine and skin cells die and in blood loss, such as during menstrual bleeding. The lost iron must be replaced from dietary sources.

The bioavailability of iron is highly dependent on dietary sources. In animal-based foods about 60 percent of iron is bound to hemoglobin, and heme iron is more bioavailable than nonheme iron. The other 40 percent of iron in animal-based foods is nonheme, which is the only iron source in plant-based foods. Some plants contain chemicals (such as phytate, oxalates, tannins, and polyphenols) that inhibit iron absorption. Although, eating fruits and vegetables rich in vitamin C at the same time as iron-containing foods markedly increases iron absorption. A review in the American Journal of Clinical Nutrition reports that in developed countries iron bioavailability from mixed diets ranges between 14 and 18 percent, and that from vegetarian diets ranges between 5 and 12 percent.[1] Vegans are at higher risk for iron deficiency, but

1. Centers for Disease Control and Prevention. “Iron and Iron Deficiency.”

careful meal planning does prevent its development. Iron deficiency is the most common of all micronutrient deficiencies.

Table 12.1 Enhancers and Inhibitors of Iron Absorption

Enhancer	Inhibitor
Meat	Phosphate
Fish	Calcium
Poultry	Tea
Seafood	Coffee
Stomach acid	Colas
	Soy protein
	High doses of minerals (antacids)
	Bran/fiber
	Phytates
	Oxalates
	Polyphenols

Figure 12.3 Iron Absorption, Functions, and Loss

Accessed October 2, 2011. http://www.cdc.gov/nutrition/everyone/basics/vitamins/iron.html.

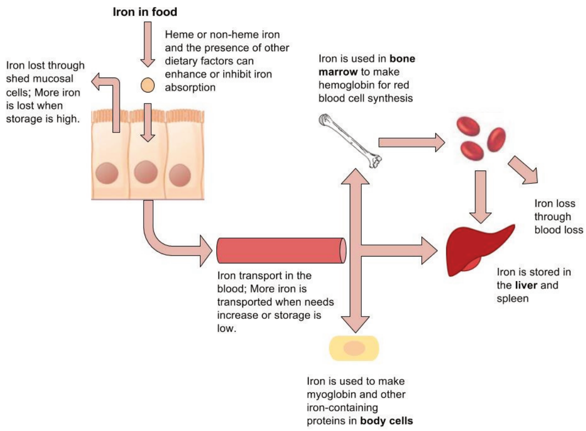


Image by Allison Calabrese / CC BY 4.0

Iron Toxicity

The body excretes little iron and therefore the potential for accumulation in tissues and organs is considerable. Iron accumulation in certain tissues and organs can cause a host of health problems in children and adults including extreme fatigue, arthritis, joint pain, and severe liver and heart toxicity. In children, death has occurred from ingesting as little as 200 mg of iron and therefore it is critical to keep iron supplements out of children's reach. The tolerable upper intake levels of iron is found in Table 12.2 (Table 12.2 "Dietary Reference Intakes for Iron"). Mostly a hereditary disease, hemochromatosis is the result of a genetic mutation that leads to abnormal iron metabolism and an accumulation of iron in certain tissues such as the liver, pancreas, and heart. The signs and symptoms of hemochromatosis are similar to those of iron overload in tissues caused by high dietary intake of iron or other non-genetic metabolic abnormalities, but are often increased in severity.

Dietary Reference Intakes for Iron

Table 12.2 Dietary Reference Intakes for Iron

Age Group	RDA (mg/day)	UL (mg/day)
Infant (0–6 months)	0.27*	40
Infants (6–12 months)	11*	40
Children (1–3 years)	7	40
Children (4–8 years)	10	40
Children (9–13 years)	8	40
Adolescents (14–18 years)	11 (males), 15 (females)	45
Adults (19–50 years)	8 (males), 18 (females)	45
Adults (> 50 years)	8	45
* denotes Adequate Intake		

Dietary Sources of Iron

Table 12.3 Iron Content of Various Foods

Food	Serving	Iron (mg)	Percent Daily Value
Breakfast cereals, fortified	1 serving	18	100
Oysters	3 oz.	8	44
Dark chocolate	3 oz.	7	39
Beef liver	3 oz.	5	28
Lentils	½ c.	3	17
Spinach, boiled	½ c.	3	17
Tofu, firm	½ c.	3	17
Kidney beans	½ c.	2	11
Sardines	3 oz.	2	11

Iron-Deficiency Anemia

Iron-deficiency anemia is a condition that develops from having insufficient iron levels in the body resulting in fewer and smaller red blood cells containing lower amounts of hemoglobin. Regardless of the cause (be it from low dietary intake of iron or via excessive blood loss), iron-deficiency anemia has the following signs and symptoms, which are linked to the essential functions of iron in energy metabolism and blood health:

- Fatigue
- Weakness
- Pale skin
- Shortness of breath
- Dizziness
- Swollen, sore tongue

- Abnormal heart rate

Iron-deficiency anemia is diagnosed from characteristic signs and symptoms and confirmed with simple blood tests that count red blood cells and determine hemoglobin and iron content in blood. Anemia is most often treated with iron supplements and increasing the consumption of foods that are higher in iron. Iron supplements have some adverse side effects including nausea, constipation, diarrhea, vomiting, and abdominal pain. Reducing the dose at first and then gradually increasing to the full dose often minimizes the side effects of iron supplements. Avoiding foods and beverages high in phytates and also tea (which contains tannic acid and polyphenols, both of which impair iron absorption), is important for people who have iron-deficiency anemia. Eating a dietary source of vitamin C at the same time as iron-containing foods improves absorption of nonheme iron in the gut. Additionally, unknown compounds that likely reside in muscle tissue of meat, poultry, and fish increase iron absorption from both heme and nonheme sources.

Iron Deficiency: A Worldwide Nutritional Health Problem

The Centers for Disease Control and Prevention reports that iron deficiency is the most common nutritional deficiency worldwide.[2] The WHO estimates that 80 percent of people are iron deficient and 30 percent of the world population has iron-

2. Iron and Iron Deficiency. Centers for Disease Control and Prevention. http://www.cdc.gov/nutrition/everyone/basics/vitamins/iron.html.Accessed October 2, 2011.

deficiency anemia.[3] The main causes of iron deficiency worldwide are parasitic worm infections in the gut causing excessive blood loss, and malaria, a parasitic disease causing the destruction of red blood cells. In the developed world, iron deficiency is more the result of dietary insufficiency and/or excessive blood loss occurring during menstruation or childbirth.

At-Risk Populations

Infants, children, adolescents, and women are the populations most at risk worldwide for iron-deficiency anemia by all causes. Infants, children, and even teens require more iron because iron is essential for growth. In these populations, iron deficiency (and eventually iron-deficiency anemia) can also cause the following signs and symptoms: poor growth, failure to thrive, and poor performance in school, as well as mental, motor, and behavioral disorders. Women who experience heavy menstrual bleeding or who are pregnant require more iron in the diet. One more high-risk group is the elderly. Both elderly men and women have a high incidence of anemia and the most common causes are dietary iron deficiency and chronic disease such as ulcer, inflammatory diseases, and cancer. Additionally, those who have recently suffered from traumatic blood loss, frequently donate blood, or take excessive antacids for heartburn need more iron in the diet.

3. Anemia. The World Bank. http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTHEALTHNUTRITIONANDPOPULATION/EXTPHAAG/0,,contentMDK:20588506~menuPK:1314803~pagePK:64229817~piPK:64229743 ~theSitePK:672263,00.html. Accessed October 2, 2011.

Preventing Iron-Deficiency Anemia

In young children iron-deficiency anemia can cause significant motor, mental, and behavioral abnormalities that are long-lasting. In the third world, iron-deficiency anemia remains a significant public-health challenge. The World Bank claims that a million deaths occur every year from anemia and that the majority of those occur in Africa and Southeast Asia. The World Bank states five key interventions to combat anemia:[4]

- Provide at-risk groups with iron supplements.
- Fortify staple foods with iron and other micronutrients whose deficiencies are linked with anemia.
- Prevent the spread of malaria and treat the hundreds of millions with the disease.
- Provide insecticide-treated bed netting to prevent parasitic infections.
- Treat parasitic-worm infestations in high-risk populations.

Also, there is ongoing investigation as to whether supplying iron cookware to at-risk populations is effective in preventing and treating iron-deficiency anemia.

4. Anemia. The World Bank. http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTHEALTHNUTRITIONANDPOPULATION/EXTPHAAG/0,,contentMDK:20588506~menuPK:1314803~pagePK:64229817~piPK:64229743 ~theSitePK:672263,00.html. Accessed October 2, 2011.

Copper

Copper, like iron, assists in electron transfer in the electron-transport chain. Furthermore, copper is a cofactor of enzymes essential for iron absorption and transport. The other important function of copper is as an antioxidant. Symptoms of mild to moderate copper deficiency are rare. More severe copper deficiency can cause anemia from the lack of iron mobilization in the body for red blood cell synthesis. Other signs and symptoms include growth retardation in children and neurological problems, because copper is a cofactor for an enzyme that synthesizes myelin, which surrounds many nerves.

Zinc

Zinc is a cofactor for over two hundred enzymes in the human body and plays a direct role in RNA, DNA, and protein synthesis. Zinc also is a cofactor for enzymes involved in energy metabolism. As the result of its prominent roles in anabolic and energy metabolism, a zinc deficiency in infants and children blunts growth. The reliance of growth on adequate dietary zinc was discovered in the early 1960s in the Middle East where adolescent nutritional dwarfism was linked to diets containing high amounts of phytate. Cereal grains and some vegetables contain chemicals, one being phytate, which blocks the absorption of zinc and other minerals in the gut. It is estimated that half of the world's population has a zinc-deficient diet.[1]

This is largely a consequence of the lack of red meat and seafood in the diet and reliance on cereal grains as the main dietary staple. In adults, severe zinc deficiency can cause hair loss, diarrhea, skin sores, loss of appetite, and weight loss. Zinc is a required cofactor for an enzyme that synthesizes the heme portion of hemoglobin and severely deficient zinc diets can result in anemia.

Dietary Reference Intakes for Zinc

Table 12.4 Dietary Reference Intakes for Zinc

1. Prasad, Ananda. "Zinc deficiency." BMJ 2003 February 22; 326(7386): 409–410. doi: 10.1136/bmj.326.7386.409. Accessed October 2, 2011. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1125304/?tool=pmcentrez.

Age Group	RDA (mg/day)	UL (mg/day)
Infant (0–6 months)	2*	4
Infants (6–12 months)	3	5
Children (1–3 years)	3	7
Children (4–8 years)	5	12
Children (9–13 years)	8	23
Adolescents (14–18 years)	11 (males), 9 (females)	34
Adults (19 + years)	11 (males), 8 (females)	40
* denotes Adequate Intake		

Fact Sheet for Health Professionals: Zinc. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Zinc-HealthProfessional/. Updated February 11, 2016. Accessed November 10, 2017.

Dietary Sources of Zinc

Table 12.5 Zinc Content of Various Foods

Food	Serving	Zinc (mg)	Percent Daily Value
Oysters	3 oz.	74	493
Beef, chuck roast	3 oz.	7	47
Crab	3 oz.	6.5	43
Lobster	3 oz.	3.4	23
Pork loin	3 oz.	2.9	19
Baked beans	½ c.	2.9	19
Yogurt, low fat	8 oz.	1.7	11
Oatmeal, instant	1 packet	1.1	7
Almonds	1 oz.	0.9	6

Fact Sheet for Health Professionals: Zinc. National Institute of

Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Zinc-HealthProfessional/. Updated February 11, 2016. Accessed November 10, 2017.

Selenium

Selenium is a cofactor of enzymes that release active thyroid hormone in cells and therefore low levels can cause similar signs and symptoms as iodine deficiency. The other important function of selenium is as an antioxidant.

Selenium Functions and Health Benefits

Around twenty-five known proteins require selenium to function. Some are enzymes involved in detoxifying free radicals and include glutathione peroxidases and thioredoxin reductase. As an integral functioning part of these enzymes, selenium aids in the regeneration of glutathione and oxidized vitamin C. Selenium as part of glutathione peroxidase also protects lipids from free radicals, and, in doing so, spares vitamin E. This is just one example of how antioxidants work together to protect the body against free-radical induced damage. Other functions of selenium-containing proteins include protecting endothelial cells that line tissues, converting the inactive thyroid hormone to the active form in cells, and mediating inflammatory and immune system responses.

Observational studies have demonstrated that selenium deficiency is linked to an increased risk of cancer. A review of forty-nine observational studies published in the May 2011 issue of the Cochrane Database of Systematic Reviews concluded that higher selenium exposure reduces overall cancer incidence by about 34 percent in men and 10 percent in women, but notes these studies had several limitations, including data quality, bias, and large differences among different studies.[1] Additionally, this review states that there is no convincing evidence from six clinical trials that selenium supplements reduce cancer risk.

Because of its role as a lipid protector, selenium has been suspected to prevent cardiovascular disease. In some observational studies, low levels of selenium are associated with a decreased risk of cardiovascular disease. However, other studies have not always confirmed this association and clinical trials are lacking.

Figure 12.4 Selenium's Role in Detoxifying Free Radicals

1. Dennert G, Zwahlen M, et al. Selenium for Preventing Cancer. Cochrane Database of Systematic Reviews. 2011; 5. http://www.ncbi.nlm.nih.gov/pubmed/21563143. Accessed November 22, 2017.

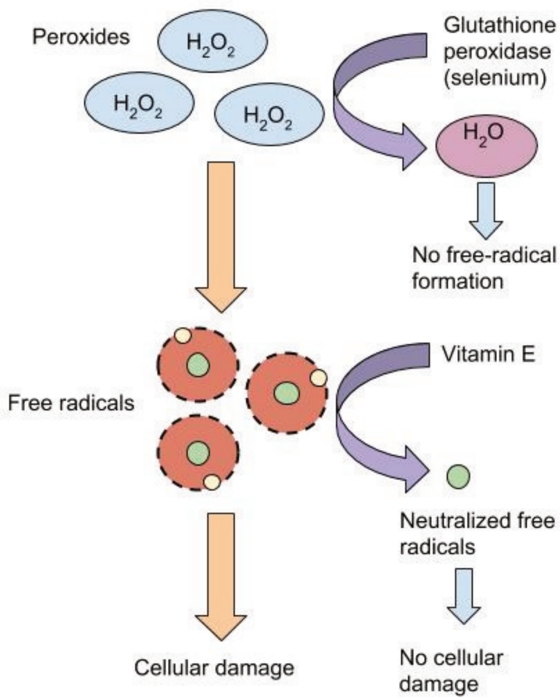


Image by Allison Calabrese / CC BY 4.0

Dietary Reference Intakes for Selenium

The RDAs for selenium are based on the amount required to maximize the activity of glutathione peroxidases found in blood plasma. The RDAs for different age groups are listed in Table 12.6 "Dietary Reference Intakes for Selenium".

Table 12.6 Dietary Reference Intakes for Selenium

Age Group	RDA Males and Females mcg/day	UL
Infants (0–6 months)	15*	45
Infants (7–12 months)	20*	65
Children (1–3 years)	20	90
Children (4–8 years)	30	150
Children (9–13 years)	40	280
Adolescents (14–18 years)	55	400
Adults (> 19 years)	55	400
*denotes Adequate Intake		

Selenium at doses several thousand times the RDA can cause acute toxicity, and when ingested in gram quantities can be fatal. Chronic exposure to foods grown in soils containing high levels of selenium (significantly above the UL) can cause brittle hair and nails, gastrointestinal discomfort, skin rashes, halitosis, fatigue, and irritability. The UL for selenium for adults is 400 micrograms per day.

Dietary Sources of Selenium

Organ meats, muscle meats, and seafood have the highest selenium content. Plants do not require selenium, so the selenium content in fruits and vegetables is usually low. Animals fed grains from selenium-rich soils do contain some selenium. Grains and some nuts contain selenium when grown in selenium-containing soils. See Table 12.7 "Selenium Contents of Various Foods" for the selenium content of various foods.

Table 12.7 Selenium Contents of Various Foods

Food	Serving	Selenium (mcg)	Percent Daily Value
Brazil nuts	1 oz.	544	777
Shrimp	3 oz.	34	49
Crab meat	3 oz.	41	59
Ricotta cheese	1 c.	41	59
Salmon	3 oz.	40	57
Pork	3 oz.	35	50
Ground beef	3 oz.	18	26
Round steak	3 oz.	28.5	41
Beef liver	3 oz.	28	40
Chicken	3 oz.	13	19
Whole-wheat bread	2 slices	23	33
Couscous	1 c.	43	61
Barley, cooked	1 c.	13.5	19
Milk, low-fat	1 c.	8	11
Walnuts, black	1 oz.	5	7

Source: US Department of Agriculture, Agricultural Research Service. 2010. USDA National Nutrient Database for Standard Reference, Release 23. http://www.ars.usda.gov/ba/bhnrc/ndl.

Iodine

Recall the discovery of iodine and its use as a means of preventing goiter, a gross enlargement of the thyroid gland in the neck. Iodine is essential for the synthesis of thyroid hormone, which regulates basal metabolism, growth, and development. Low iodine levels and consequently hypothyroidism has many signs and symptoms including fatigue, sensitivity to cold, constipation, weight gain, depression, and dry, itchy skin and paleness. The development of goiter may often be the most visible sign of chronic iodine deficiency, but the consequences of low levels of thyroid hormone can be severe during infancy, childhood, and adolescence as it affects all stages of growth and development. Thyroid hormone plays a major role in brain development and growth and fetuses and infants with severe iodine deficiency develop a condition known as cretinism, in which physical and neurological impairment can be severe. The World Health Organization (WHO) estimates iodine deficiency affects over two billion people worldwide and it is the number-one cause of preventable brain damage worldwide.[1]

Figure 12.5 Deaths Due to Iodine Deficiency Worldwide in 2012

1. World Health Organization. "Iodine Status Worldwide." Accessed October 2, 2011. http://whqlibdoc.who.int/publications/2004/9241592001.pdf.

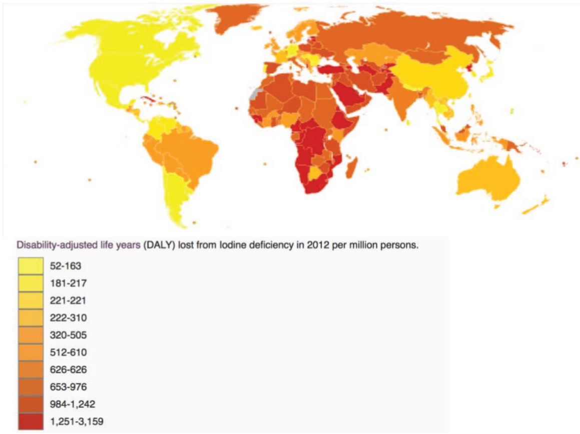


Image by Chris55 / CC BY 4.0

Figure 12.6 Iodine Deficiency: Goiter

A large goiter by Dr. J.S.Bhandari, India / CC BY-SA 3.0

Dietary Reference Intakes for Iodine

Table 12.8 Dietary Reference Intakes for Iodine

Age Group	RDA Males and Females mcg/day	UL
Infants (0–6 months)	110*	
Infants (7–12 months)	130*	
Children (1–3 years)	90	200
Children (4–8 years)	120	300
Children (9–13 years)	150	600
Adolescents (14–18 years)	150	900
Adults (> 19 years)	150	1,100
*denotes Adequate Intake		

Health Professional Fact Sheet: Iodine. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Iodine-HealthProfessional/. Updated June 24, 2011. Accessed November 10, 2017.

Dietary Sources of Iodine

The mineral content of foods is greatly affected by the soil from which it grew, and thus geographic location is the primary determinant of the mineral content of foods. For instance, iodine comes mostly from seawater so the greater the distance from the sea the lesser the iodine content in the soil.

Table 12.9 Iodine Content of Various Foods

Food	Serving	Iodine (mcg)	Percent Daily Value
Seaweed	1 g.	16 to 2,984	11 to 1,989
Cod fish	3 oz.	99	66
Yogurt, low fat	8 oz.	75	50
Iodized salt	1.5 g.	71	47
Milk, reduced fat	8 oz.	56	37
Ice cream, chocolate	½ c.	30	20
Egg	1 large	24	16
Tuna, canned	3 oz.	17	11
Prunes, dried	5 prunes	13	9
Banana	1 medium	3	2

Health Professional Fact Sheet: Iodine. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Iodine-HealthProfessional/. Updated June 24, 2011. Accessed November 10, 2017.

Chromium

The functioning of chromium in the body is less understood than that of most other minerals. It enhances the actions of insulin so plays a role in carbohydrate, fat, and protein metabolism. Currently, the results of scientific studies evaluating the usefulness of chromium supplementation in preventing and treating Type 2 diabetes are largely inconclusive. More research is needed to better determine if chromium is helpful in treating certain chronic diseases and, if so, at what doses. Dietary sources of chromium include nuts, whole grains, and yeast. The recommended intake for chromium is 35 mcg per day for adult males and 25 mcg per day for adult females. There is insufficient evidence to establish an UL for chromium.

Manganese

Manganese is a cofactor for enzymes that are required for carbohydrate and cholesterol metabolism, bone formation, and the synthesis of urea. The recommended intake for manganese is 2.3 mg per day for adult males and 1.8 mg per day for adult females. Manganese deficiency is uncommon. The best food sources for manganese are whole grains, nuts, legumes, and green vegetables.

Molybdenum

Molybdenum also acts as a cofactor that is required for the metabolism of sulfur-containing amino acids, nitrogen-containing compounds found in DNA and RNA, and various other functions. The recommended intake for molybdenum is 46 mcg per day for both adult males and females. The food sources of molybdenum is varies depending on the content in the soil in the specific region.

Fluoride

Fluoride's Functional Role

Fluoride is known mostly as the mineral that combats tooth decay. It assists in tooth and bone development and maintenance. Fluoride combats tooth decay via three mechanisms:

1. Blocking acid formation by bacteria
2. Preventing demineralization of teeth
3. Enhancing remineralization of destroyed enamel

Fluoride is added to drinking water in 45% of communities in Canada. In British Columbia, only 3.7% of the population has access to fluoridated water. Fluoridation of water prevents, on average, 27 percent of cavities in children and between 20 and 40 percent of cavities in adults but it can be expensive.

The optimal fluoride concentration in water to prevent tooth decay ranges between 0.7–1.2 milligrams per liter. Exposure to fluoride at three to five times this concentration before the growth of permanent teeth can cause fluorosis, which is the mottling and discoloring of the teeth.

Figure 12.7 A Severe Case of Fluorosis

Bellingham fluorosis by Editmore / Public Domain

Fluoride's benefits to mineralized tissues of the teeth are well substantiated, but the effects of fluoride on bone are not as well known. Fluoride is currently being researched as a potential treatment for osteoporosis. The data are inconsistent on whether consuming fluoridated water reduces the incidence of osteoporosis and fracture risk. Fluoride does stimulate osteoblast bone building activity, and fluoride therapy in patients with osteoporosis has been shown to increase BMD. In general, it appears that at low doses, fluoride treatment increases BMD in people with osteoporosis and is more effective in increasing bone quality when the intakes of calcium and vitamin D are adequate.

Dietary Reference Intake

The Adequate Intakes (AI) for fluoride, but has not yet developed RDAs. The AIs are based on the doses of fluoride shown to reduce the incidence of cavities, but not cause dental fluorosis. From infancy to adolescence, the AIs for fluoride increase from 0.01 milligrams per day for ages less than six months to 2 milligrams per day for those between the ages of fourteen and eighteen. In adulthood, the AI for males is 4 milligrams per day and for females is 3 milligrams per day. The UL for young children is set at 1.3 and 2.2 milligrams per day for girls and boys, respectively. For adults, the UL is set at 10 milligrams per day.

Table 12.10 Dietary Reference Intakes for Fluoride

Age Group	AI (mg/day)	UL (mg/day)
Infants (0–6 months)	0.01	0.7
Infants (6–12 months)	0.50	0.9
Children (1–3 years)	0.70	1.3
Children (4–8 years)	1.00	2.2
Children (9–13 years)	2.00	10.0
Adolescents (14–18 years)	3.00	10.0
Adult Males (> 19 years)	4.00	10.0
Adult Females (> 19 years)	3.00	10.0

Source: Institute of Medicine. Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride. January 1, 1997. http://www.iom.edu/Reports/1997/Dietary-Reference-Intakes-for-Calcium-Phosphorus-Magnesium-Vitamin-D-and-Fluoride.aspx..

Dietary Sources of Fluoride

Greater than 70 percent of a person's fluoride comes from drinking fluoridated water when they live in a community that fluoridates the drinking water. Other beverages with a high amount of fluoride include teas and grape juice. Solid foods do not contain a large amount of fluoride. Fluoride content in foods depends on whether it was grown in soils and water that contained fluoride or cooked with fluoridated water. Canned meats and fish that contain bones do contain some fluoride.

Table 12.11 Fluoride Content of Various Foods

Food	Serving	Fluoride (mg)	Percent Daily Value*
Fruit Juice	3.5 fl oz.	0.02-2.1	0.7-70
Crab, canned	3.5 oz.	0.21	7
Rice, cooked	3.5 oz.	0.04	1.3
Fish, cooked	3.5 oz.	0.02	0.7
Chicken	3.5 oz.	0.015	0.5
* Current AI used to determine Percent Daily Value			

Micronutrient Information Center: Fluoride. Oregon State University, Linus Pauling Institute. lpi.oregonstate.edu/mic/minerals/fluoride . Updated in April 29, 2015. Accessed October 22, 2017.

Summary of Trace Minerals

Table 12.12 Summary of the Trace Minerals

Micronutrient	Sources	Recommended Intakes for adults	Major Functions	Deficiency diseases and symptoms
Iron	Red meat, egg yolks, dark leafy vegetables, dried fruit, iron-fortified foods	8-18 mg/day	Assists in energy production, DNA synthesis required for red blood cell function	Anemia: fatigue, paleness, faster heart rate
Copper	Nuts, seeds, whole grains, seafood	900 mcg/day	Assists in energy production, iron metabolism	Anemia: fatigue, paleness, faster heart rate
Zinc	oysters, wheat germ, pumpkin seeds, squash,, beans, sesame seeds, tahini, beef, lamb	8-11 mg/day	Assists in energy production, protein, RNA and DNA synthesis; required for hemoglobin synthesis	Growth retardation in children, hair loss, diarrhea, skin sores, loss of appetite, weight loss
Selenium	Meat, seafood, eggs, nuts	55 mcg/day	Essential for thyroid hormone activity	Fatigue, muscle pain, weakness, Keshan disease
Iodine	Iodized salt, seaweed, dairy products	150 mcg/day	Making thyroid hormone, metabolism, growth and development	Goiter, cretinism, other signs and symptoms include fatigue, depression, weight gain, itchy skin, low heart-rate
Chromium		25-35 mcg/day	Assists insulin in carbohydrate, lipid and protein metabolism	abnormal glucose metabolism

Fluoride	Fluoridated water, foods prepared in fluoridated water, seafood	3-4 mg/day	Component of mineralized bone, provides structure and microarchitecture, stimulates new bone growth	Increased risk of dental caries
Manganese	Legumes, nuts, leafy green vegetables	1.8-2.3 mg/day	Glucose synthesis, amino-acid catabolism	Impaired growth, skeletal abnormalities, abnormal glucose metabolism
Molybdenum	Milk, grains, legumes	45 mcg/day	Cofactor for a number of enzymes	Unknown

CHAPTER 13. NUTRITION AND PHYSICAL ACTIVITY

Introduction

Image by Chris McCormack on flickr.com / CC BY-ND 2.0

Learning Objectives

By the end of this chapter you will be able to:

- Describe the physiological changes that occur in response to exercise
- Describe the effects of physical fitness on overall health
- Describe the purpose and applications of nutrition supplements

Becoming and staying physically fit is an important part of achieving optimal health. A well-rounded exercise program is crucial to becoming and remaining healthy. Physical activity improves your health in a number of ways. It promotes weight loss, strengthens muscles and bones, keeps the heart and lungs strong, and helps to protect against chronic disease. There are four essential elements of physical fitness: cardiorespiratory, muscular strength, flexibility, and maintaining a healthful body composition. Some enthusiasts might argue the relative importance of each, but optimal health requires some degree of balance between all four. For example, the Hawaiʻi Ironman is a vigorous race that consists of a 2.4 mile swim, 112 mile bike, and a 26 mile run. All four elements of physical fitness are vital in order to complete each leg of the race. To learn more about the Hawaiʻi Ironman, visit their website at http://www.ironman.com.

Some forms of exercise confer multiple benefits, which can help you to balance the different elements of physical fitness. For example, riding a bicycle for thirty minutes or more not only builds cardiorespiratory endurance, it also improves muscle strength and muscle endurance. Some forms of yoga can also build muscle strength and endurance, along with flexibility. However, addressing fitness standards in all four categories generally requires incorporating a range of activities into your regular routine. If you exercise regularly, your body will begin to change and you will notice that you are able to continue your activity longer. This is due to the overload principle that our bodies will adapt to with continuous repetition. For example, if you run a mile everyday for a week, in a few weeks you would be able to run further and likely faster.

The Essential Elements of Physical Fitness

Cardiorespiratory Endurance

Cardiorespiratory endurance is enhanced by aerobic training which involves activities that increase your heart rate and breathing such as walking, jogging, or biking. Building cardiorespiratory endurance through aerobic exercise is an excellent way to maintain a healthy weight. Working on this element of physical fitness also improves your circulatory system. It boosts your ability to supply the body's cells with oxygen and nutrients, and to remove carbon dioxide and metabolic waste. Aerobic exercise is continuous exercise (lasting more than 2 minutes) that can range from low to high levels of intensity. In addition, aerobic exercise increases heart and breathing rates to meet increased demands for oxygen in working muscles. Regular, moderate aerobic activity, about thirty minutes at a time for five days per week, trains the body to deliver oxygen more efficiently, which strengthens the heart and lungs, and reduces the risk of cardiovascular disease.[1] Strengthening your heart muscle and increasing the blood volume pumped each heartbeat will lead to a lower resting

1. The American Heart Association Recommendations for Physical Activity in Adults. American Heart Association. Heart.org. http://www.heart.org/HEARTORG/HealthyLiving/PhysicalActivity/FitnessBasics/American-Heart-Association-Recommendations-for-Physical-Activity-Infographic_UCM_450754_SubHomePage.jsp. Accessed March 10, 2018.

heart rate for healthy individuals. Aerobic exercise increases the ability of muscles to use oxygen for energy metabolism therefore creating ATP.

Aerobic capacity, or VO_2 is the most common standard for evaluating cardiorespiratory endurance. VO_2 max is your maximal oxygen uptake, and the VO_2 max test measures the amount of oxygen (in relation to body weight) that you can use per minute. A test subject usually walks or runs on a treadmill or rides a stationary bicycle while the volume and oxygen content of exhaled air is measured to determine oxygen consumption as exercise intensity increases. At some point, the amount of oxygen consumed no longer increases despite an increase in exercise intensity. This value of oxygen consumption is referred to as VO_2 max, 'V' meaning volume, and 'max' meaning the maximum amount of oxygen (O2) an individual is capable of utilizing. The higher the number, the more oxygen you can consume, and the faster or longer you can walk, run, bike, or swim, among other aerobic activities. VO_2 max can increase over time with training.[2]

Figure 13.1 VO_2 Max Test

2. Ed Eyestone. How to Improve Your VO_2 Max. RunnersWorld.com. http://www.runnersworld.com/article/0,7120,s6-238-244--12408-0,00.html. Published January 9, 2008.

Image by Cosmed / CC BY-SA 3.0

Muscle Strength

Muscle strength is developed and maintained by weight or resistance training that often is called anaerobic exercise. Anaerobic exercise consists of short duration, high intensity movements that rely on immediately available energy sources and require little or no oxygen during the activity. This type of high intensity training is used to build muscle strength by short, high intensity activities. Building muscle mass is not just crucial for athletes and bodybuilders—building muscle strength and endurance is important for children, seniors, and everyone in between. The support that your muscles provide allows you to work, play, and live more efficiently. Strength training involves the use of resistance machines, resistance bands, free weights, or other tools. However, you do not need to pay for a gym membership or expensive equipment to strengthen your muscles. Homemade weights, such as plastic bottles filled with sand, can work just as well. You can also use your own body weight and do push-ups, leg squats, abdominal crunches, and other exercises to build your muscles. If strength training is performed at least twice a week, it can help to improve muscle strength and to increase bone strength. Strength training can also help you to maintain muscle mass during a weight-loss program.[3]

Flexibility

Flexibility is the range of motion available to your joints. Yoga, tai chi, Pilates, and stretching exercises work to improve this element of fitness. Stretching not only improves your range of motion, it also promotes better posture, and helps you perform activities that can require greater flexibility, such as chores around the house. In addition to working on flexibility, older adults should include balance exercises in their regular routine. Balance tends to deteriorate with age, which can result in falls and fractures.[4]

Body Composition

Body composition is the proportion of fat and fat-free mass (which includes bones, muscles and organs) in your body. A healthy and physically fit individual has a greater proportion of

3. American College of Sports Medicine. Resistance Training for Health and Fitness. Acsm.org. https://www.acsm.org/docs/brochures/resistance-training.pdf. Accessed March 11, 2018.
4. Fitness Training: Elements of a Well-Rounded Routine. MayoClinic.com. http://www.mayoclinic.com/health/fitness-training/HQ01305. Updated August 10, 2017.

muscle and smaller proportion of fat than an unfit individual of the same weight. Although habitual physical activity can promote a more healthful body composition, other factors like age, gender, genetics, and diet contribute to an individual's body composition. Women have a higher healthy fat percentage than men. For adult women, a healthy amount of body fat ranges from 20 to 32 percent. Adult males on the other hand range from 10 to 22 percent of body fat.[5]

Metabolic Fitness

Being fit also includes metabolic fitness. It relates to the number of calories you require to survive and the number of calories you burn during physical activity. Recall that metabolism is the sum of all chemical reactions that occur in the human body to conduct life's processes. Some are catabolic reactions that break down nutrients to supply the body with cellular energy. The rate at which a person burns calories depends on body composition, gender, age, nutritional status, physical activity, and genetics.

Increasing your daily activity and shedding excess body fat helps to improve metabolic fitness. Physical activity also makes weight management easier because it increases energy needs and lean body mass. During moderate to vigorous activity, energy expenditure raises well above the resting rate. With continuous exercise over time, regular exercise increases lean body mass as well. At rest, lean tissues use more energy than

5. Measuring and Evaluating Body Composition. ACSM.org. http://www.acsm.org/public-information/articles/2016/10/07/measuring-and-evaluating-body-composition

fat tissue therefore increasing basal metabolism. The combination of increased energy output, energy expenditure and basal needs over a long period of time can have a major impact on total energy expenditure (see Figure 16.2 “The Effect of Physical Activity on Energy Expenditure”). The more energy you expend, the more foods you are able to consume while maintaining a healthy weight. Any improvement to metabolic fitness is beneficial and means a decrease in the risk for developing diabetes, or other chronic conditions.

One measurement of metabolic fitness is basal metabolic rate, or BMR, which is a measurement of the amount of energy required for the body to maintain its basic functions while at rest, i.e. breathing, heart beats, liver and kidney function, and so on. On average, BMR accounts for between 50 and 70 percent of a person’s total daily energy expenditure. Different factors can affect the BMR. For example, a slender person who is tall has more body surface area and therefore has a higher RMR relative to their body mass (weight). Also, muscle utilizes more energy at rest than fat, so a person with more muscle mass has a higher BMR.

A second measurement of metabolic fitness is the number of calories burned during physical activity. The amount of calories burned depends on how much oxygen is delivered to tissues, and how efficiently metabolic reactions consume oxygen and, therefore, expend calories. One of the best estimates of energy expenditure during exercise is how much oxygen a person consumes. Recall that VO2 max is a measure of the maximum cardiorespiratory capacity to deliver oxygen to the body, especially to working muscles during exercise.. Greater VO2 max is indicative of better cardiovascular fitness. In contrast to RMR, VO2 max increases significantly with exercise training due to training adaptations that increase the body’s ability to deliver oxygen to working tissues and an increased capacity of muscles to take up and utilize oxygen.

Figure 13.2 The Effect of Physical Activity on Energy Expenditure

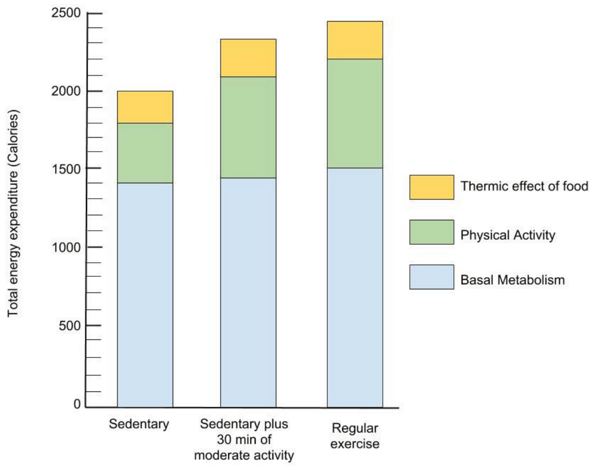


Image by Allison Calabrese / CC BY 4.0

Physical Activity Recommendations

The Canadian Society for Exercise Physiology (CSEP) and Participaction have outlined guidelines for activity for all age groups. Adults should get at least 150 minutes of moderate-intensity aerobic physical activity or 75 minutes of vigorous-intensity aerobic physical activity each week. In addition to aerobic physical activity, it is recommended that adults do muscle strengthening activities on each major muscle group two or three times each week. Adults also are recommended to do flexibility exercises at least two to three times a week to improve range of motion. To learn more about these guidelines visit the CSEP website at https://csepguidelines.ca/ .

The Benefits of Physical Activity

Regular physical activity is one of the best things you can do to achieve optimal health. Individuals who are physically active for about seven hours per week lower the risk of dying early by 40 percent compared to those who are active for less than thirty minutes per week.[1] Improving your overall fitness involves sticking with an exercise program on a regular basis. If you are nervous or unsure about becoming more active, the good news is that moderate-intensity activity, such as brisk walking, is safe for most people. Also, the health advantages of becoming active far outweigh the risks. Physical activity not only helps to maintain your weight, it also provides a wealth of benefits—physical, mental, and emotional.

Physical Benefits

Getting the recommended amount of physical activity each week, about 150 minutes of moderate, aerobic exercise, such as power walking or bicycling, does not require joining a gym, or taking expensive, complicated classes. If you can't commit to a formal workout four to five days per week, you can become more active in simple ways—by taking the stairs instead of the elevator, by walking more instead of driving, by going out

1. Physical Activity and Health: The Benefits of Physical Activity. CDC.org. http://www.cdc.gov/physicalactivity/everyone/health/index.html. Last updated February 16, 2011.

dancing with your friends, or by doing your household chores at a faster pace. It is not necessary to perform at the level of a professional dancer or athlete, or to work out for several hours every day, to see real gains from exercise. Even slightly increased activity can lead to physical benefits, such as:

- Longer life. A regular exercise program can reduce your risk of dying early from heart disease, certain cancers, and other leading causes of death.
- Healthier weight. Exercise, along with a healthy, balanced eating plan, can help you lose extra weight, maintain weight loss, or prevent excessive weight gain.
- Cardiovascular disease prevention. Being active boosts HDL cholesterol and decreases unhealthy triglycerides, which reduces the risk of cardiovascular diseases.
- Management of chronic conditions. A regular routine can help to prevent or manage a wide range of conditions and concerns, such as metabolic syndrome, type 2 diabetes, depression, arthritis, and certain types of cancer.
- Energy boosts. Regular physical activity can improve muscle tone and strength and provide a boost to your cardiovascular system. When the heart and lungs work more efficiently, you have more energy.
- Strong bones. Research shows that aerobic activity and strength training can slow the loss of bone density that typically accompanies aging.

Mental and Emotional Benefits

The benefits of an exercise program are not just physical, they are mental and emotional as well. Anyone who has gone for a walk to clear their head knows the mental benefits of exercise firsthand. Also, you do not have to be a marathoner on a "runner's high" to enjoy the emotional benefits of becoming active. The mental and emotional benefits of physical activity include:

- Mood improvement. Aerobic activity, strength-training, and more contemplative activities such as yoga, all help break cycles of worry, absorption, and distraction, effectively draining tension from the body.
- Reduced risk of depression, or limited symptoms of it. Some people have called exercise "nature's antidepressant," and studies have shown that physical activity reduces the risk of and helps people cope with the symptoms of depression.
- Cognitive skills retention. Regular physical activity can help people maintain thinking, learning, and judgement as they age.
- Better sleep. A good night's sleep is essential for clear thinking, and regular exercise promotes healthy, sound sleep. It can also help you fall asleep faster and deepen your rest.

Changing to a More Active Lifestyle

A physically active lifestyle yields so many health benefits that it is recommended for everyone. Change is not always easy, but even small changes such as taking the stairs instead of the elevator, or parking farther away from a store to add a bit more walking into your day can lead to a more active lifestyle and set you on the road to optimal health. When people go one step further by walking or biking on a regular basis, or becoming active by growing and maintaining a garden, they do more than promote their own health—they safeguard the health of the planet, too.

As you change to a more active lifestyle, select an activity that you can integrate into your schedule smoothly, so you can maintain it. For example, instead of making time to get coffee with friends, you might suggest a walk, rollerblading, or going for a swim in the campus pool. Also, find an activity that you will be motivated to do. Some people decide to participate in team sports, such as local soccer or softball leagues, because they enjoy being active with others or like knowing that a team relies on them. Others prefer to take a class, such as spinning or yoga, that is led by an instructor who will motivate them. Still others prefer more solitary pursuits, such as taking a jog alone in their neighborhood. No matter what your preference, you are more likely to stick to a workout program if you enjoy it.

Fuel Sources

The human body uses carbohydrate, fat and protein in food and from body stores as energy. These essential nutrients are needed regardless of the intensity of activity you are doing. If you are lying down reading a book or running the Vancouver Marathon, these macronutrients are always needed in the body. However, in order for these nutrients to be used as fuel for the body, their energy must be transferred into the high energy molecule known as Adenosine Triphosphate (ATP). ATP is the body's immediate fuel source of energy that can be generated either with the presences of oxygen known as aerobic metabolism or without the presence of oxygen by anaerobic metabolism. The type of metabolism that is predominately used during physical activity is determined by the availability of oxygen and how much carbohydrate, fat, and protein are used.

Anaerobic and Aerobic Metabolism

Anaerobic metabolism occurs in the cytosol of the muscle cells. As seen in Figure 13.3 "Anaerobic versus Aerobic Metabolism", a small amount of ATP is produced in the cytosol without the presence of oxygen. Anaerobic metabolism uses glucose as its only source of fuel and produces pyruvate and lactic acid. Pyruvate can then be used as fuel for aerobic metabolism. Aerobic metabolism takes place in the mitochondria of the cell and is able to use carbohydrates, protein or fat as its fuel source. Aerobic metabolism is a much slower process than anaerobic metabolism but produces majority of the ATP.

Figure 13.3 Anaerobic versus Aerobic Metabolism

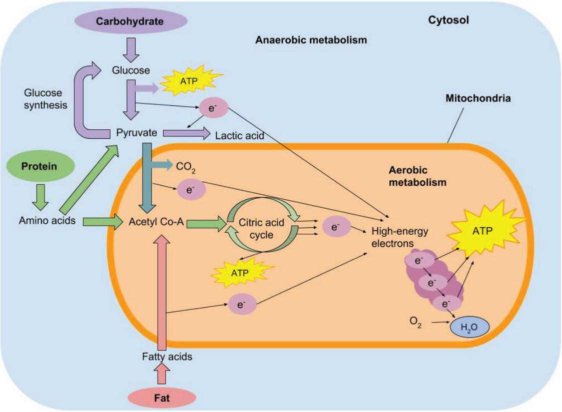


Image by Allison Calabrese / CC BY 4.0

Physical Activity Duration and Fuel Use

The respiratory system plays a vital role in the uptake and delivery of oxygen to muscle cells throughout the body. Oxygen is inhaled by the lungs and transferred from the lungs to the blood where the cardiovascular system circulates the oxygen-rich blood to the muscles. The oxygen is then taken up by the muscles and can be used to generate ATP. When the body is at rest, the heart and lungs are able to supply the muscles with adequate amounts of oxygen to meet the aerobic metabolism energy needs. However, during physical activity your muscles energy and oxygen needs are increased. In order to provide more oxygen to the muscle cells, your heart rate and breathing rate will increase. The amount of oxygen that is delivered to the tissues via the cardiovascular and respiratory systems during exercise depend on the duration, intensity and physical conditioning of the individual.

During the first few steps of exercise, your muscles are the first to respond to the change in activity level. Your lungs and heart however do not react as quickly and during those beginning steps they do not begin to increase the delivery of oxygen. In order for our bodies to get the energy that is needed in these beginning steps, the muscles rely on a small amount of ATP that is stored in resting muscles. The stored ATP is able to provide energy for only a few seconds before it is depleted. Once the stored ATP is just about used up, the body resorts to another high-energy molecule known as creatine phosphate to convert ADP (adenosine diphosphate) to ATP. After about 10 seconds, the stored creatine phosphate in the muscle cells are also depleted as well.

About 15 seconds into exercise, the stored ATP and creatine phosphate are used up in the muscles. The heart and lungs have still not adapted to the increase need of oxygen so the muscles must begin to produce ATP by anaerobic metabolism (without oxygen). Anaerobic metabolism can produce ATP at a rapid pace but only uses glucose as its fuel source. The glucose is obtained from the blood of muscle glycogen. At around 30 seconds, anaerobic pathways are operating at their full capacity but because the availability of glucose is limited, it cannot continue for a long period of time.

As your exercise reaches two to three minutes, your heart rate and breathing rate have increased to supply more oxygen to your muscles. Aerobic metabolism is the most efficient way of producing ATP by producing 18 times more ATP for each molecule of glucose than anaerobic metabolism. Although the primary source of ATP in aerobic metabolism is carbohydrates, fatty acids and protein can also be used as fuel to generate ATP.

Figure 13.4 The Effect of Exercise Duration on Energy Systems

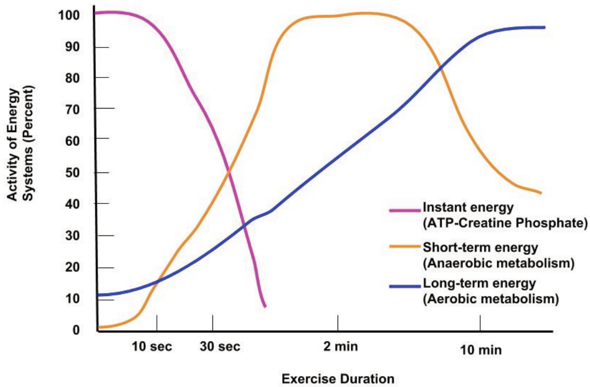


Image by Allison Calabrese / CC BY 4.0

The fuel sources for anaerobic and aerobic metabolism will change depending on the amount of nutrients available and the type of metabolism. Glucose may come from blood glucose (which is from dietary carbohydrates or liver glycogen and glucose synthesis) or muscle glycogen. Glucose is the primary energy source for both anaerobic and aerobic metabolism. Fatty acids are stored as triglycerides in muscles but about 90% of stored energy is found in adipose tissue. As low to moderate intensity exercise continues using aerobic metabolism, fatty acids become the predominant fuel source for the exercising muscles. Although protein is not considered a major energy source, small amounts of amino acids are used while resting or doing an activity. The amount of amino acids used for energy metabolism increase if the total energy intake from your diet does not meet the nutrient needs or if you are involved in long endurance exercises. When amino acids are broken down removing the nitrogen-containing amino acid, that remaining carbon molecule can be broken down into ATP via aerobic metabolism or used to make glucose. When exercise continues for many hours, amino acid use will increase as an energy source and for glucose synthesis.

Figure 13.5 Fuel Sources for Anaerobic and Aerobic Metabolism

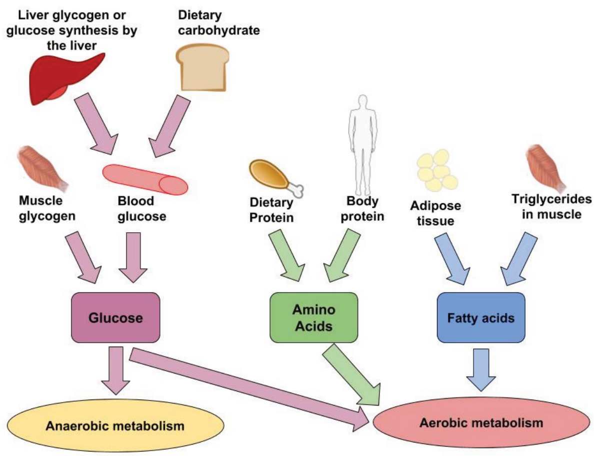


Image by Allison Calabrese / CC BY 4.0

Physical Activity Intensity and Fuel Use

The exercise intensity determines the contribution of the type of fuel source used for ATP production(see Figure 16.4 "The Effect of Exercise Intensity on Fuel Sources"). Both anaerobic and aerobic metabolism combine during exercise to ensure that the muscles are equipped with enough ATP to carry out the demands placed on them. The amount of contribution from each type of metabolism will depend on the intensity of an activity. When low-intensity activities are performed, aerobic metabolism is used to supply enough ATP to muscles. However, during high-intensity activities more ATP is needed so the muscles must rely on both anaerobic and aerobic metabolism to meet the body's demands.

During low-intensity activities, the body will use aerobic metabolism over anaerobic metabolism because it is more efficient by producing larger amounts of ATP. Fatty acids are the primary energy source during low-intensity activity. With fat reserves in the body being almost unlimited, low-intensity activities are able to continue for a long time. Along with fatty acids, a small amount of glucose is used as well. Glucose differs from fatty acids where glycogen storages can be depleted. As glycogen stores are depleted, fatigue will eventually set in.

Figure 13.6 The Effect of Exercise Intensity on Fuel Sources

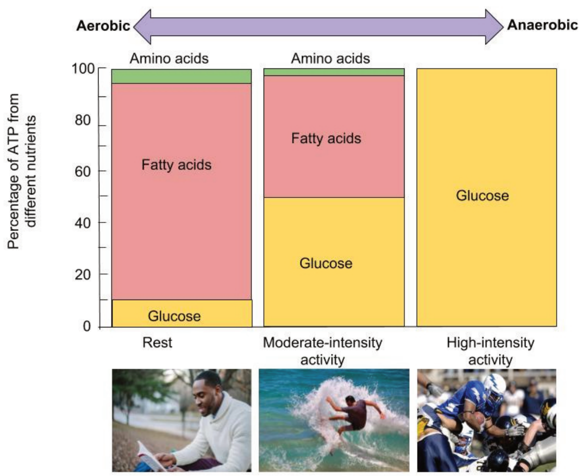


Image by Allison Calabrese / CC BY 4.0

The Fat-Burning Zone

The fat-burning zone is a low intensity aerobic activity that keeps your heart rate between 60 and 69% of your maximum heart rate. The cardio zone on the other hand is a high intensity aerobic activity that keeps the heart rate between about 70 to 85% of your maximum heart rate. So which zone do you burn the most fat in? Technically, your body burns a higher percentage of of calories from fat during a low intensity aerobic activity but there's more to it than just that. When you begin a low intensity activity, about 50% of the calories burned comes from fat whereas in the cardio zone only 40% come froms fat. However, when looking at the actual numbers of calories burned, higher intensity activity burns just as much fat and a much greater total calories overall.

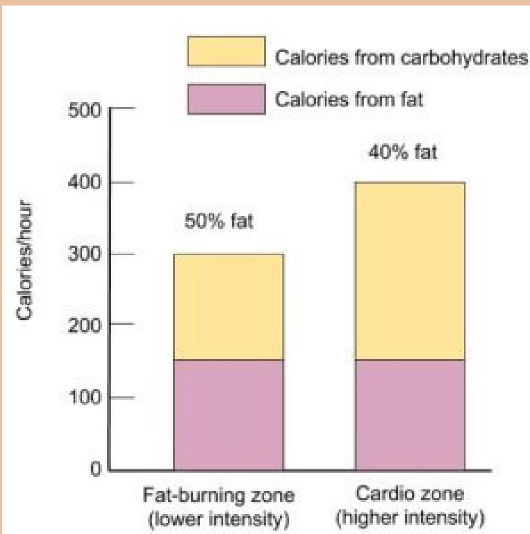


Image by Allison Calabrese / CC BY 4.0

“Hitting the Wall” or “Bonking”

If you are familiar with endurance sports, you may have heard of “hitting the wall” or “bonking.” These colloquial terms refer to the extreme fatigue that sets in after about 120 minutes of performing an endurance sport, such as marathon running or long-distance cycling. The physiology underlying “hitting the wall” means that muscles have used up all their stored glycogen and are therefore dependent on other nutrients to support their energy needs. Fatty acids are transported from fat-storing cells to the muscle to rectify the nutrient deficit. However, fatty acids take more time to convert to energy than glucose, thus decreasing performance levels. To avoid “hitting the wall” or “bonking,” endurance athletes load up on carbohydrates for a few days before the event, known as carbohydrate loading. This will maximize an athlete’s amount of glycogen stored in their liver and muscle tissues. It is important not to assume that carbohydrate loading works for everyone. Without accompanied endurance training you will not increase the amount of stored glucose. If you plan on running a five-mile race for fun with your friend and decide to eat a large amount of carbohydrates in the form of a big spaghetti dinner the night before, the excess carbohydrates will be stored as fat. Therefore, if you are not an endurance athlete exercising for more than 90 minutes, carbohydrate loading will provide no benefit, and can even have some disadvantages. Another way for athletes to avoid “hitting the wall” is to consume carbohydrate-containing drinks and foods during an endurance event. In fact, throughout the Tour de France—a twenty-two-day, twenty-four-hundred-mile race—the average cyclist consumes greater than 60 grams of carbohydrates per hour.

Sports Nutrition

Nutrient Needs for Athletes

Nutrition is essential to your performance during all types of exercise. The foods consumed in your diet are used to provide the body with enough energy to fuel an activity regardless of the intensity of activity. Athletes have different nutritional needs to support the vigorous level they compete and practice at.

Energy Needs

To determine an athletes nutritional needs, it is important to revisit the concept of energy metabolism. Energy intake is the foundation of an athlete's diet because it supports optimal body functions, determines the amount of intake of macronutrients and micronutrients, and assists in the maintaining of body composition. Energy needs for athletes increase depending on their energy expenditure. The energy expended during physical activity are contingent on the intensity, duration, and frequency of the exercise. Competitive athletes may need 3,000 to over 5,000 calories daily compared to a typical inactive individual who needs about 2,000 calories per day. Energy needs are also affected by an individual's gender, age, and weight. Weight-bearing exercises, such as running, burn more calories per hour than non-weight bearing exercises, such as swimming. Weight-bearing exercises requires your body to move against gravity which requires more energy. Men are also able to burn more calories than women for the same activity because they have more muscle mass which requires more energy to support and move around.[1]

Body weight and composition can have a tremendous impact on exercise performance. Body weight and composition are considered the focal points of physique for athletes because they are the able to be manipulated the most. Energy intake can play a role in manipulating the physiques for athletes. For individuals competing in sports such as football and weight lifting, having a large amount of muscle mass and increased body weight may be beneficial. This can be obtained through a combination of increased energy intake, and protein. Although certain physiques are more advantageous for specific sports, it is important to remember that a single and rigid "optimal" body composition is not recommended for any group of athletes.[2]

Macronutrient Needs

The composition of macronutrients in the diet is a key factor in maximizing performance for athletes. Carbohydrates are an important fuel source for the brain and muscle during exercise. Carbohydrate storage in the liver and muscle cells are relatively limited and therefore it is important for athletes to consume

1. Nutrition and Athletic Performance. American College of Sports Medicine.Medicine & Science in Sports & Exercise. 2016; 48(3), 543- 568. https://journals.lww.com/acsm-msse/Fulltext/2016/03000/Nutrition_and_Athletic_Performance.25.aspx. Accessed March 17, 2018.
2. Nutrition and Athletic Performance. American College of Sports Medicine.Medicine & Science in Sports & Exercise. 2016; 48(3), 543- 568. https://journals.lww.com/acsm-msse/Fulltext/2016/03000/Nutrition_and_Athletic_Performance.25.aspx. Accessed March 17, 2018.

enough carbohydrates from their diet. Carbohydrate needs should increase about 3-10 g/kg/day depending on the type of training or competition.[3] See Table 16.1 "Daily Needs for Carbohydrate Fuel" for carbohydrate needs for athletes depending on the intensity of the exercise.

Table 13.1 Daily Needs for Carbohydrate Fuel

Activity Level	Example of Exercise	Increase of Carbohydrate (g/kg of athlete's body weight/ day)
Light	Low intensity or skill based activities	3-5
Moderate	Moderate exercise program (about 1 hour per day)	5-7
High	Endurance program (about 1-3 hours per day of moderate to high intensity exercise)	6-10
Very High	Extreme commitment (4-5 hours per day of moderate to high intensity exercise)	8-12

Source: Nutrition and Athletic Performance. American College of Sports Medicine.Medicine & Science in Sports & Exercise. 2016; 48(3), 543- 568. https://journals.lww.com/acsm-msse/Fulltext/2016/03000/Nutrition_and_Athletic_Performance.25.aspx. Accessed March 17, 2018.

Fat is a necessary component of a healthy diet to provide energy, essential fatty acids and to facilitate the absorption of fat-soluble vitamins. Athletes are recommended to consume the same amount of fat in the diet as the general population,

3. Nutrition and Athletic Performance. American College of Sports Medicine.Medicine & Science in Sports & Exercise. 2016; 48(3), 543- 568. https://journals.lww.com/acsm-msse/Fulltext/2016/03000/Nutrition_and_Athletic_Performance.25.aspx. Accessed March 17, 2018.

20-35% of their energy intake. Although these recommendations are in accordance with public health guidelines, athletes should individualize their needs based on their training level and body composition goals. Athletes who choose to excessively restrict their fat intake in an effort to lose body weight or improve body composition should ensure they are still getting the minimum recommended amount of fat. Fat intakes below 20% of energy intake will reduce the intake of fat-soluble vitamins and essential fatty acids, especially omega 3's.[4]

Although protein accounts for only about 5% of energy expended, dietary protein is necessary to support metabolic reactions (that generate ATP), and to help muscles with maintenance, growth, and repair. During exercise, these metabolic reactions for generating ATP rely heavily on proteins such as enzymes and transport proteins. It is recommended that athletes consume 1.2 to 2.0 g/kg/day of proteins in order to support these functions. Higher intakes may also be needed for short periods of intense training or when reducing energy intake.[5] See Table 13.2 "Recommended Protein Intakes for Athletes" below for a better representation of protein needs depending on extent of training and dietary sources.

Table 13.2 The Recommended Protein Intakes for Individuals

4. Nutrition and Athletic Performance. American College of Sports Medicine.Medicine & Science in Sports & Exercise. 2016; 48(3), 543- 568. https://journals.lww.com/acsm-msse/Fulltext/2016/03000/Nutrition_and_Athletic_Performance.25.aspx. Accessed March 17, 2018.
5. Nutrition and Athletic Performance. American College of Sports Medicine.Medicine & Science in Sports & Exercise. 2016; 48(3), 543- 568. https://journals.lww.com/acsm-msse/Fulltext/2016/03000/Nutrition_and_Athletic_Performance.25.aspx. Accessed March 17, 2018.

Group	Protein Intake (g/kg body weight)
Most adults	0.8
Endurance athletes	1.2 to 1.4
Vegetarian endurance athletes	1.3 to 1.5
Strength athletes	1.6 to 1.7
Vegetarian strength athletes	1.7 to 1.8

Source: Dietary Reference Intakes, 2002 ACSM/ADA/Dietitians of Canada Position Statement: Nutrition & Athletic Performance, 2001. Accessed March 17, 2018.

It is important to consume adequate amounts of protein and to understand that the quality of the protein consumed affects the amount needed. High protein foods such as meats, dairy, and eggs contain all of the essential amino acids in relative amounts that most efficiently meet the body's needs for growth, maintenance and repair of muscles. Vegetarian diets contain protein that has lower digestibility and amino acid patterns that do not match human needs as closely as most animal proteins. To compensate for this as well as the fact that plant food protein sources also contain higher amounts of fiber, higher protein intakes are recommended for vegetarian athletes. (See Table 13.2 "The Recommended Protein Intakes for Individuals")

Micronutrient Needs

Vitamins and minerals are essential for energy metabolism, the delivery of oxygen, protection against oxidative damage, and the repair of body structures. When exercise increases, the amount of many vitamins and minerals needed are also increased due to the excess loss in nutrients. Currently, there is not special micronutrient recommendations made for athletes but most athletes will meet their needs by consuming a balanced diet that meets their energy needs. Because the energy needs of athletes increase, they often consume extra vitamins and minerals. The major micronutrients of concern for athletes include iron, calcium, vitamin D, and some antioxidants.[6]

Common Nutrient Deficiencies for Athletes

Energy deficiency

For athletes, consuming sufficient amounts of calories to support their energy expenditure is vital to maintain health and body functions. When the energy intake for athletes does not meet the high demands of exercise, a syndrome referred to as relative deficiency in sport (RED-S) occurs. RED-S has a negative effect on performance and health in both male and female athletes as shown in Table 13.7 "Relative Energy Deficiency in Sport Effects". Athletes in sports with weight classes, such as wrestling, may put their health at risk by rapid weight loss in order to hit a specific weight for a match. These athletes are vulnerable to eating disorders due to sporadic dieting (several of which will restrict energy intake). The long term effects of these practices can not only impair performance but also have serious repercussions such as heart

6. Nutrition and Athletic Performance. American College of Sports Medicine.Medicine & Science in Sports & Exercise. 2016; 48(3), 543- 568. https://journals.lww.com/acsm-msse/Fulltext/2016/03000/Nutrition_and_Athletic_Performance.25.aspx. Accessed March 17, 2018.

and kidney function, temperature regulation and electrolyte balance problems.

Figure 13.7 Relative Energy Deficiency in Sport Effects

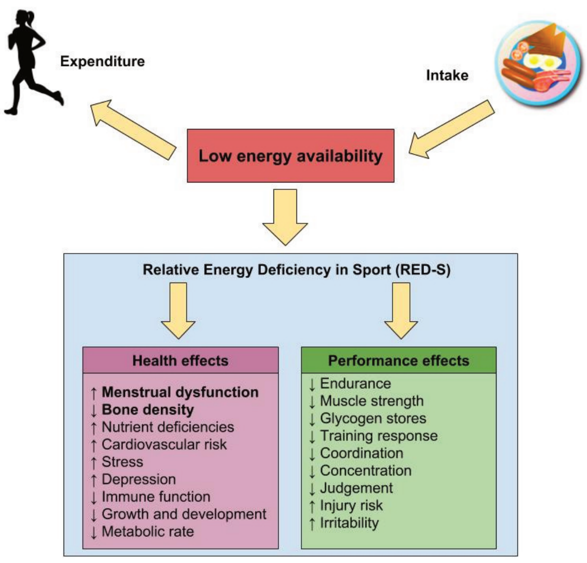


Image by Allison Calabrese / CC BY 4.0

Of the RED-S consequences that occur from an energy intake deficiency, the two health effects that are of the greatest concern to female athletes are menstrual dysfunction and decreased bone density. Menstrual dysfunction and low bone density symptoms of RED-S can create hormonal imbalances that are described in "Figure 13.8 The Female Athlete Triad". In today's society, there is increasing pressure to be extremely thin that some females take exercise too far. The low energy intakes will lead to the female athlete triad that causes bone loss, stoppage of menstrual periods, and eating disorders.[7]

7. The Female Athlete Triad. American College of Sports Medicine. http://www.acsm.org/public-information/articles/2016/10/07/the-

Figure 13.8 The Female Athlete Triad

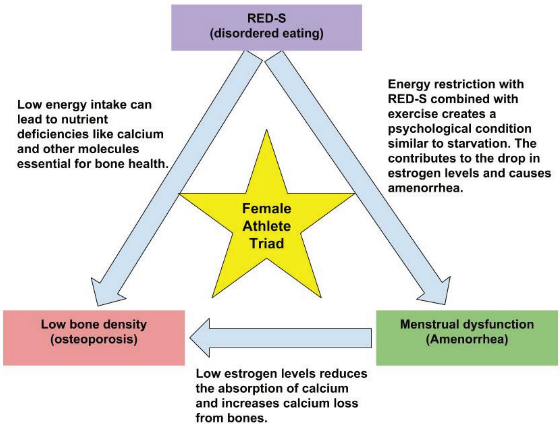


Image by Allison Calabrese / CC BY 4.0

Iron

Iron deficiency is very common in athletes. During exercise, iron-containing proteins like hemoglobin and myoglobin are needed in great amounts. An iron deficiency can impair muscle function to limit work capacity leading to compromised training performance. Some athletes in intense training may have an increase in iron losses through sweat, urine, and feces. Iron losses are greater in females than males due to the iron lost in blood every menstrual cycle. Female athletes, distance runners and vegetarians are at the greatest risk for developing iron deficiency.[8] See Table 13.3 "The

female-athlete-triad. Published October 7, 2016. Accessed March 16, 2018.

8. Beard J, Tobin B. Iron Status and Exercise. The American Journal of Clinical Nutrition. 2000; 72(2), 594S–597S. https://academic.oup.com/ajcn/article/72/2/594S/4729672. Accessed March 16, 2018.

Potential Iron Loss in Endurance Athletes" for the potential amounts of iron loss each day in male and female athletes. An increased recommendation for both genders are shown below. These recommendations are based on the assumption that iron has a 10% absorption efficiency. As noted above, women athletes have a greater iron loss due to menstruation and therefore must increase their dietary needs more than male athletes.

Table 13.3 The Potential Iron Loss in Endurance Athletes

Approximate Daily Iron Losses in Endurance Athletes (mg/day)and Increased Dietary Need		
	Male	Female
Sedentary	1	1.5
Athlete	1.8	2.5
*Increase dietary needs	8	10
*Assumes 10% absorption efficiency		

Source: Weaver CM, Rajaram S.Exercise and iron status. J Nutr. 1992 Mar;122(3 Suppl):782-7. https://www.ncbi.nlm.nih.gov/pubmed/1542048. Accessed March 23, 2018.

Sports anemia, which is different from iron deficiency anemia is an adaptation to training for athletes. Excessive training causes the blood volume to expand in order to increase the amount of oxygen delivered to the muscles. During sports anemia, the synthesis of red blood cells lags behind the increase in blood volume which results in a decreased percentage of blood volume that is red blood cells. The total amount of red blood cells remains the same or may increase slightly to continue the transport of oxygen. Eventually as training progresses, the amount of red blood cells will increase to catch up with the total blood volume.

Vitamin D and Calcium

Vitamin D regulates the calcium and phosphorus absorption and metabolism and plays a key role in maintaining optimal bone health. There is also growing evidence that vitamin D is important for other aspect of athletic performance such as injury prevention, rehabilitation, and muscle metabolism. Individuals who primarily practice indoors are at a larger risk for a vitamin D deficiency and should ensure they are consuming foods high in vitamin D to maintain sufficient vitamin D status.[9]

Calcium is especially important for the growth, maintenance, and repair of bone tissue. Low calcium intake occurs in athletes with RED-S, menstrual dysfunction, and those who avoid dairy products. A diet inadequate in calcium increases the risk for low bone mineral density which ultimately leads to stress fractures.

Antioxidant nutrients

Antioxidant nutrients play an important role in protecting cell membranes from oxidative damage. During exercise, the amount of oxygen used by the muscles increases and can produce free radicals which causes an increase in antioxidant systems in the the body. These antioxidant systems rely on the dietary antioxidants such as beta-carotene, vitamin C, vitamin

9. Nutrition and Athletic Performance. American College of Sports Medicine.Medicine & Science in Sports & Exercise. 2016; 48(3), 543- 568. https://journals.lww.com/acsm-msse/Fulltext/2016/03000/Nutrition_and_Athletic_Performance.25.aspx. Accessed March 17, 2018.

E, and selenium that can be obtained through a nutrient dense diet.

Water and Electrolyte Needs

During exercise, being appropriately hydrated contributes to performance. Water is needed to cool the body, transport oxygen and nutrients, and remove waste products from the muscles. Water needs are increased during exercise due to the extra water losses through evaporation and sweat. Dehydration can occur when there is inadequate water levels in the body and can be very hazardous to the health of an individual. As the severity of dehydration increases, the exercise performance of an individual will begin to decline (see Figure 13.9 "Dehydration Effect on Exercise Performance"). It is important to continue to consume water before, during and after exercise to avoid dehydration as much as possible.

Figure 13.9 Dehydration Effect on Exercise Performance

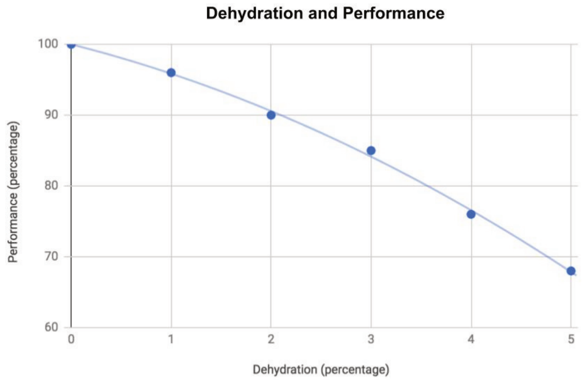


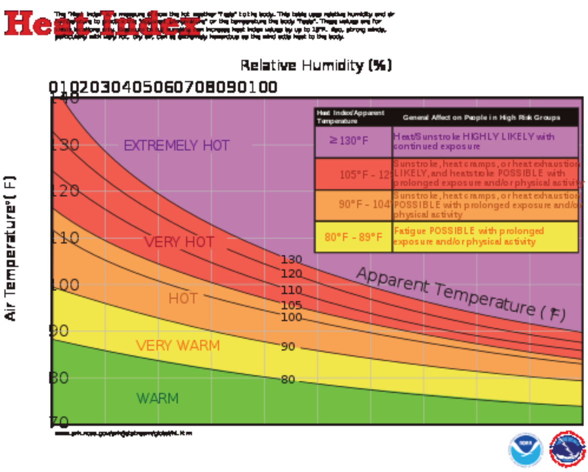
Image by Allison Calabrese / CC BY 4.0

During exercise, thirst is not a reliable short term indicator of the body's needs as it typically is not enough to replace the water loss. Even with the constant replenishing of water throughout an exercise, it may not be possible to drink enough water to compensate for the losses. Dehydration occurs when the total loss of water is so significant that the total blood volume decreases which leads to the reduction of oxygen and nutrients transported to the muscle cells. A decreased blood volume also reduces the blood flow to the skin and the production of sweat which can increase the body temperature. As a result, the risk of heat related illnesses increases.

Heat cramps are one of the heat related illnesses that can occur during or after exercise. Heat cramps are involuntary muscle spasms that usually involve the muscle being exercised, which causes by an imbalance of electrolytes, usually sodium. Heat exhaustion is caused the the loss of water decreasing the blood volume so much that it is not possible to cool the body as well as provide oxygen and nutrients to the active muscles. Symptoms that arise from heat exhaustion may include low blood pressure, disorientation, profuse sweating, and fainting. Heat exhaustion can progress further if exercise continues into a heat stroke. A heat stroke is the most serious form of heat related illnesses that can occur. During a heat stroke, the internal body temperature rises above 105℉ which causes the brain's temperature-regulatory center to shut down. When the brain's temperature regulatory center shuts down, an individual is unable to sweat regardless of their internal body temperature rising. Other symptoms that arise are dry skin, extreme confusion, and unconsciousness. A heat stroke requires immediate medical attention.

The external temperature during exercise can also play a role in the risk of heat related illnesses. As the external temperature increases, it becomes more difficult for the body to dissipate heat. As humidity also increases, the body is unable to cool itself through evaporation. The Heat Index is a measure of how hot the body feels when humidity is added to the air temperature (see Figure 13.10 "The Heat Index").

Figure 13.10 The Heat Index



"Heat Index" by National Weather Service, Southern Region Headquarters / Public Domain

Hyponatremia

Sweating during exercise helps our bodies to stay cool. Sweat consists of mostly water but it also causes losses of sodium, potassium, calcium and magnesium. During most exercises, the amount of sodium lost is very small.Drinking water after completing an exercise will replenish the sodium in the body. However, during long endurance exercises such as a marathon or triathlon, sodium losses are larger and must be replenished as well. If water is replenished without sodium the sodium already in the body will become diluted. These low levels of sodium in the blood will cause a condition known as hyponatremia (see Figure 13.11 "The Effect of Exercise on Sodium Levels"). When sodium levels in the blood are decreased, water moves into the cell through osmosis which causes swelling. Accumulation of fluid in the lungs and the brain can cause serious life threatening conditions such as a seizure, coma and death.

In order to avoid hyponatremia, athletes should increase their consumption of sodium in the days leading up to an event and consume sodium-containing sports drinks during their race or game. The early signs of hyponatremia include nausea, muscle cramps, disorientation, and slurred speech. To learn more about the sports drinks that can optimize your performance, refer back to Chapter 3, Water and Electrolytes.

Figure 13.11 The Effect of Exercise on Sodium Levels

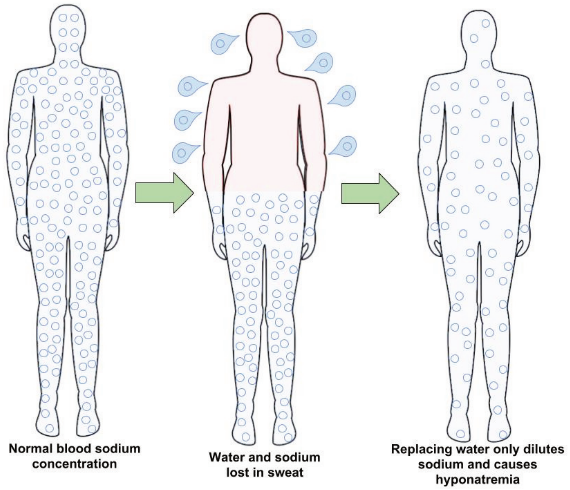


Image by Allison Calabrese / CC BY 4.0

Food Supplements and Food Replacements

Current trends also include the use of supplementation to promote health and wellness. Vitamins, minerals, herbal remedies, and supplements of all kinds constitute big business and many of their advertising claims suggest that optimal health and eternal youth are just a pill away. Dietary supplements can be macronutrient (amino acids, proteins, essential fatty acids), micronutrient (vitamins and minerals that promote healthy body functions), probiotic (beneficial bacteria such as the kind found in the intestines), and herbally (often target a specific body part, such as bones) based.

Some public health officials recommend a daily multivitamin due to the poor diet of most North Americans. The following people may benefit from taking daily vitamin and mineral supplements:[1]

- Women who are pregnant or breastfeeding
- Premenopausal women who may need extra calcium and iron
- Older adults
- People with health issues that affect their ability to eat
- Vegetarians, vegans, and others avoiding certain food groups

However, before you begin using dietary supplementation,

1. Nutrition and Athletic Performance. American College of Sports Medicine.Medicine & Science in Sports & Exercise. 2016; 48(3), 543- 568. https://journals.lww.com/acsm-msse/Fulltext/2016/03000/Nutrition_and_Athletic_Performance.25.aspx. Accessed March 17, 2018.

consider that the word supplement denotes something being added. Vitamins, minerals, and other assorted remedies should be considered as extras. They are add-ons—not replacements—for a healthy diet. As food naturally contains nutrients in its proper package, remember that food should always be your primary source of nutrients. When considering taking supplements, it is important to recognize possible drawbacks that are specific to each kind:[2]

- Micronutrient Supplements. Some vitamins and minerals are toxic at high doses. Therefore, it is vital to adhere to the Tolerable Upper Intake Levels (UL) so as not to consume too much of any vitamin. For example, too much vitamin A is toxic to the liver. Symptoms of vitamin A toxicity can include tinnitus (ringing in the ears), blurred vision, hair loss, and skin rash. Too much niacin can cause a peptic ulcer, hyperglycemia, dizziness, and gout.
- Herbal Supplements. Some herbs cause side effects, such as heart palpitations and high blood pressure, and must be taken very carefully. Also, some herbs have contraindications with certain medicines. For example, Valerian and St. John's Wort negatively interact with certain prescription medications, most notably antidepressants. Additionally, there is a real risk of overdosing on herbs because they do not come with warning labels or package inserts.
- Amino Acid Supplements. Certain amino acid supplements, which are often taken by bodybuilders among others, can increase the risk of consuming too

2. Choosing a Vitamin and Mineral Supplement—Topic Overview. WebMD.com. http://www.webmd.com/food-recipes/tc/choosing-a-vitamin -and-mineral-supplement-topic-overview. Last revised March 11, 2018.

much protein. An occasional amino acid drink in the place of a meal is not a problem. However, problems may arise if you add the supplement to your existing diet. Most Americans receive two to three times the amount of protein required on a daily basis from their existing diets—taking amino acid supplements just adds to the excess. Also, certain amino acids share the same transport systems in the absorption process; therefore, a concentrated excess of one amino acid obtained from a supplement may increase the probability of decreased absorption of another amino acid that uses the same transport system. This could lead to deficiency in the competing amino acid.

Supplement Claims and Restrictions

Health Canada regulates supplements, but it treats them like food rather than pharmaceuticals. The phrase caveat emptor means "buyer beware," and it is important to keep the term in mind when considering supplementation. Just because a product is "natural" does not mean it can't be harmful or dangerous, particularly if used inappropriately. The following are helpful questions to explore before deciding to take a supplement:

- Does the scientific community understand how this supplement works and are all its effects well known?
- Is there proof that the supplement actually performs in the manner that it claims?
- Does this supplement interact with food or medication?
- Is taking this supplement necessary for my health?
- Is the supplement affordable?
- Is the supplement safe and free from contaminants?

Lastly, please remember that a supplement is only as good as the diet that accompanies it. We cannot overstate the importance of eating a healthy, well-balanced diet designed to provide all of the necessary nutrients. Food contains many more beneficial substances, such as phytochemicals and fiber, that promote good health and cannot be duplicated with a pill or a regimen of supplements. Therefore, vitamins and other dietary supplements should never be a substitute for food. Nutrients should always be derived from food first.

Appendix A: Comparison of Dietary Reference Intake Values (for adult men and women) and Daily Values for Micronutrients with the Tolerable Upper Intake Levels (UL), Safe Upper Levels (SUL), and Guidance Levels

This table compares the typical levels of recommended daily nutrient intake (RDA and AI), Tolerable Upper Intake Levels (ULs) and the United Kingdom's Safe Upper Levels (SULs). The Recommended Dietary Allowance (RDA) and Adequate Intake (AI) values are considered to be levels of nutrient intake that meet or exceed the needs of practically all healthy people. The Daily Value amounts, that are currently used as reference values on food and supplement labels, are similar to the RDA/AI values, but differ in some cases. UL values are the amounts that are considered to be the maximum safe level of intake from food and supplements combined. SUL values are the maximum level of intake of a nutrient from dietary supplements that can be considered to be reasonably safe.

How much is too much?

Comparison of Dietary Reference Intake Values (for adult men and women) and Daily Values for Micronutrients with the Tolerable Upper Intake Levels (UL),[a],[c] Safe Upper Levels (SUL),[d] and Guidance Levels[d]

Nutrient	RDA/ AI[b] (men / women) ages 31-50	Daily Value (Food Labels)	UL[c]	SUL or Guidance Level[d]	Selected Potential Effects of Excess Intake
Vitamin A (mcg)	900 / 700	1500 (5000 IU)	3000	1500** (5000 IU)	Liver damage, bone & joint pain, dry skin, loss of hair, headache, vomiting
beta-Carotene (mg)	–	–	–	7 (11,655 IU)	Increased risk of lung cancer in smokers and those heavily exposed to asbestos
Vitamin D (mcg)	15 (600 IU)	10 (400 IU)	100	25 (1000 IU)	Calcification of brain, arteries, increased blood calcium, loss of appetite, nausea
Vitamin E (mg)	15	20 (30 IU)	1000	540 (800 IU)	Deficient blood clotting
Vitamin K (mcg)	120 / 90*	80	–	1000**	Red blood cell damage/anemia; liver damage
Thiamin (B1) (mg)	1.2 / 1.1	1.5	–	100**	Headache, nausea, irritability, insomnia, rapid pulse, weakness (7000+ mg dose)
Riboflavin (B2) (mg)	1.3 / 1.1	1.7	–	40**	Generally considered harmless; yellow discoloration of urine
Niacin (mg)	16 / 14	20	35	500**	Liver damage, flushing, nausea, gastrointestinal problems
Vitamin B6 (mg)	1.3	2	100	10	Neurological problems, numbness and pain in limbs
Vitamin B12 (mcg)	2.4	6	–	2000**	

Folic acid (mcg)	400	400	1000	1000**	Masks B12 deficiency (which can cause neurological problems)
Pantothenic acid (mg)	5*	10	–	200**	Diarrhea & gastrointestinal disturbance (10,000+ mg/day)
Biotin (mcg)	30*	300	–	900**	No reports of toxicity from oral ingestion
Choline (mcg)	550/ 425*	–	3500	–	Fishy body odor (trimethylaminuria), hepatotoxicity
Vitamin C (mg)	90 / 75	60	2000	1000**	Nausea, diarrhea, kidney stones
Boron (mg)	–	–	20	9.6	Adverse effects on male and female reproductive system
Calcium (mg)	1000	1000	2500	1500**	Nausea, constipation, kidney stones
Chloride (mg)	2300*	3400	3600	–	Increased blood pressure in salt-sensitive individuals (when consumed as sodium chloride)
Chromium (mcg)	35/25*	120	–	10,000**	Potential adverse effects on liver and kidneys; picolinate form possibly mutagenic
Cobalt (mg)	–	–	–	1.4**	Cardiotoxic effects; not appropriate in a dietary supplement except as vitamin B-12
Copper (mcg)	900	2000	10000	10000	Gastrointestinal distress, liver damage

Fluoride (mg)	4 / 3*	–	10	–	Bone, kidney, muscle, and nerve damage; supplement with professional guidance
Germanium	–	–	–	zero**	Kidney toxin; should not be in a dietary supplement
Iodine (mcg)	150	150	1100	500**	Elevated thyroid hormone concentration
Iron (mg)	8 / 18	18	45	17**	Gastrointestinal distress, increased risk of heart disease, oxidative stress
Magnesium (mg)	420 / 320	400	350[e]	400**	Diarrhea
Manganese (mg)	2.3 / 1.8*	2	11	4**	Neurotoxicity
Molybdenum (mcg)	45	75	2000	zero**	Gout-like symptom; joint pains; increased uric acid
Nickel (mcg)	–	–	1000	260**	Increased sensitivity of skin reaction to nickel in jewelry
Phosphorus (mg)	700	1000	4000	250**	Alteration of parathyroid hormone levels; reduced bone mineral density
Potassium (mg)	4700*	3500	–	3700**	Gastrointestinal damage
Selenium (mcg)	55	70	400	450	Nausea, diarrhea, fatigue, hair and nail loss
Silicon (mg)	–	–	–	700	Low toxicity; possibility of kidney stones

Sodium (mg)	1500*	2400	2300	–	Increased blood pressure in salt-sensitive individuals (when consumed as sodium chloride)
Vanadium (mg)	–	–	1.8	zero	Gastrointestinal irritation; fatigue
Zinc (mg)	11 / 8	15	40	25	Impaired immune function, low HDL-cholesterol

[a]Food and Nutrition Board, Institute of Medicine (U.S.). Dietary Reference Intakes Tables.

[b](RDA) = Recommended Dietary Allowance, AI = Adequate Intake, indicated with *

[c]UL = Tolerable Upper Intake Level (from food & supplements combined)

[d]SUL = Safe Upper Levels; SULs and Guidance Levels (indicated by **) set by the Expert Group on Vitamins and Minerals of the Food Standards Agency, United Kingdom. These are intended to be levels of daily intake of nutrients in dietary supplements that potentially susceptible individuals could take daily on a life-long basis without medical supervision in reasonable safety. When the evidence base was considered inadequate to set a SUL, Guidance Levels were set based on limited data. SULs and Guidance Levels tend to be conservative and it is possible that, for some vitamins and minerals, greater amounts could be consumed for short periods without risk to health. The values presented are for a 60 kg (132 lb) adult. Consult the full publication for values expressed per kg body weight. This FSA publication, Safe Upper Levels for Vitamins and Minerals, is available at: http://www.foodstandards.gov.uk/multimedia/pdfs/vitmin2003.pdf

[e]The UL for magnesium represents intake specifically from pharmacological agents and/or dietary supplements in addition to dietary intake.