Principles of Human Nutrition

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Principles of Human Nutrition has been developed for a Nutrition 101 course with no prerequisites, by faculty of South Puget Sound Community College in Olympia, WA.

This textbook includes material from several different sources. References to specific sources are given where possible. The bulk of the text is adapted from the following two open resource textbooks:

- Jellum, Lisa; Hitzeman, Jason; Knauss, Mark; Henderson, Sharryse; Harnden, Tom; Elsberry, Cynthia; and Ford, Greg, "Principles of Nutrition Textbook, Second Edition" (2018). *Nursing and Health Sciences Open Textbooks*. 5. https://oer.galileo.usg.edu/health-textbooks/5
- Fialkowski Revilla, Marie Kainoa; Titchenal, Alan; Calabrese, Allison; Gibby, Cheryl; and Meinke, Billy, *Human Nutrition*. University of Hawai'i at Mānoa. http://pressbooks.oer.hawaii.edu/humannutrition/

CHAPTER I

CHAPTER 1: NUTRITION AND YOU

Food is one of the basic necessities of life. Around the world, every person alive needs to consume food in one form or another. We need food to form the building blocks from which we're made. We need food to give us energy to carry out daily activities. We need food to help our muscles, bones, heart, brain, skin, and every other part of our body do their jobs. As you read through this textbook, you'll come to a deep understanding of what food actually is and why it's essential for life.

Sections:

Chapter from *Principles of Nutrition* by Jellum, et al. Acknowledgements therein:

- Adapted from: Zimmerman and Snow. "An Introduction to Nutrition" v. 1.0. Accessed on December 4, 2017. https://2012books.lardbucket.org/books/an-introduction-to-nutrition
- Also includes selected sections from: Lindshield, B. L. Kansas State University Human Nutrition (FNDH 400) Flexbook. Accessed on December 4, 2017. goo.gl/vOAnR

Section 1.5 adapted from Fialkowski Revilla et al., *Human Nutrition.*

1.0 Introduction

As we get started on our journey into the world of health and **nutrition**, our first focus will be to demonstrate that **nutritional science** is an evolving field of study, continually being updated and supported by research, studies, and trials.

Let's begin with a story: the story of **peptic ulcers** and ***H. pylori***.

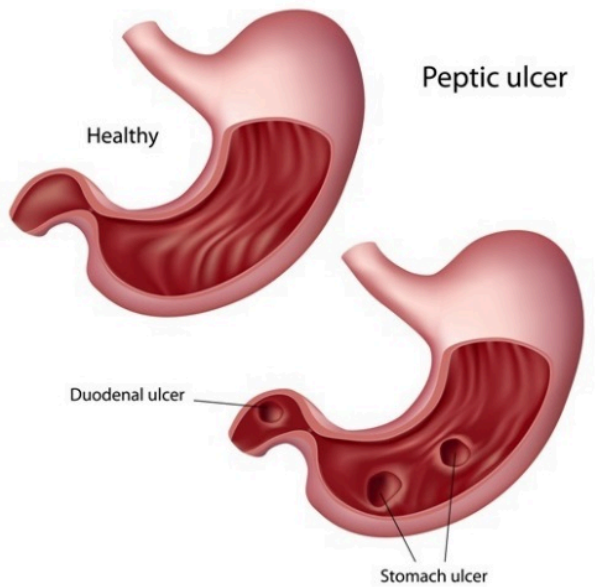

Figure 1.01 *Peptic ulcer Image source*

Peptic ulcers are painful sores in the gastrointestinal tract. Symptoms of peptic ulcers include abdominal pain, nausea, loss of appetite, and weight loss. The cure for this ailment took some time for scientists to figure out. If your grandfather complained to his doctor of symptoms of peptic ulcer, he was probably told to avoid spicy foods, alcohol, and coffee, and to manage his stress. In the early twentieth century, the medical community thought peptic ulcers were caused by what you ate and drank, and by stress.

In 1915, Dr. Bertram W. Sippy devised the "Sippy diet" for treating peptic ulcers. Dr. Sippy advised patients to drink small amounts of cream and milk every hour in order to neutralize stomach acid. Ultimately, the Sippy diet did not cure peptic ulcers and in the latter 1960s, scientists discovered the diet was associated with a significant increase in **heart disease** due to its high saturated fat content.

In the 1980s, Australian physicians Barry Marshall and Robin Warren proposed a radical hypothesis — that the cause of ulcers was bacteria that could survive in the acidic environment of the stomach and small intestine.[1] They met with significant opposition to their hypothesis but they persisted with their research. Their research led to an understanding that the spiral shape of the bacterium *Helicobacter pylori* (*H. pylori*) allows it to penetrate the stomach's mucous lining, where it secretes an **enzyme** that generates substances to neutralize the stomach's acidity. This weakens the stomach's protective mucous, making the tissue more susceptible to the damaging effects of acid, leading to the development of sores and ulcers. *H. pylori* also prompt the stomach to produce even more acid, further damaging the stomach lining.

In 1994, the National Institutes of Health held a conference on the cause of peptic ulcers. There was scientific consensus that *H. pylori* cause most peptic ulcers and that patients should be treated with antibiotics.

In 1996, the **Food and Drug Administration (FDA)** approved the first antibiotic that could be used to treat patients with peptic ulcers. Nevertheless, the link between *H. pylori* and peptic ulcers was not sufficiently communicated to health-care providers. In fact, 75 percent of patients with peptic ulcers in the late 1990s were still being prescribed antacid medications and advised to change their diet and reduce their stress.

In 1997, the **Centers for Disease Control and Prevention (CDC)**, alongside other public health organizations, began an intensive educational campaign to convince the public and health-care providers that peptic ulcers are a curable condition requiring treatment with antibiotics. Today, if you go to your primary physician you will be given the option of taking an antibiotic to eradicate *H. pylori* from your gut.

The *H. pylori* discovery was made recently, overturning a theory applied in our own time. The demystification of disease requires the continuous forward march of science, overturning old, traditional theories and discovering new, more effective ways to treat disease and promote health. In 2005, Marshall and Warren were awarded the prestigious Nobel Prize in medicine for their discovery that many stomach ulcers are caused by *H. pylori*.

A primary goal of this text is to provide you with information backed by nutritional science, and with a variety of resources that use scientific evidence to optimize health and prevent disease. In this chapter, you will see that there are many conditions and deadly diseases that can be prevented by good nutrition. You will also discover the many other determinants of health and disease, how the powerful tool of scientific investigation is used to design dietary guidelines, and recommendations that will promote health and prevent disease.

“The most exciting phrase to hear in science, the one that heralds new discoveries, is not ‘Eureka!’ but ‘That’s funny…’”

– Isaac Asimov (January 2, 1920–April 6, 1992)

Notes

1. Marshall and Warren. “Ulcers — The Culprit Is H. Pylori!” National Institutes of Health, Office of Science Education. Accessed on November 10, 2011. http://science.education.nih.gov/home2.nsf/Educational+ResourcesResource+FormatsOnline+Resources+High+School/928BAB9A176A71B585256CCD00634489 [inactive]

1.1 Defining Nutrition, Health, and Disease

Your View of Food

Americans are bombarded with television programs that show where to find the best dinners, pizzas, and cakes, and the restaurants that serve the biggest and juiciest burgers. Other programs feature chefs battling to prepare meals, and the top places to burst your belly from consuming atomic chicken wings and deli sandwiches longer than a foot. There are also shows that feature bizarre foods from cultures around the world. How do you use the information from popular network food shows to build a nutritious meal? You don't — these shows are for entertainment. The construction of a nutritious meal requires learning about which foods are healthy and which foods are not, how foods and **nutrients** function in your body, and how to use scientific resources. This text is designed to provide you with the information necessary to make sound nutritional choices that will optimize health and help prevent **disease**.

Figure 1.11 *How do you fill your plate? ©Shutterstock*

The word nutrition first appeared in 1551 and comes from the Latin word *nutrire*, which means, "to nourish." Today, we define **nutrition** as the sum of all processes involved in how **organisms** obtain nutrients, metabolize them, and use them to support all of life's processes. **Nutritional science** is the investigation of how an organism is nourished, and incorporates the study of how nourishment affects personal health, population health, and planetary health. Nutritional science covers a wide spectrum of disciplines. As a result, nutritional scientists can specialize in particular aspects of nutrition such as biology, physiology, immunology, biochemistry, education, psychology, **sustainability**, and sociology.

Without adequate nutrition, the human body does not function optimally, and severe nutritional inadequacy can lead to disease and even death. The typical American diet is lacking in many ways, from not containing the proper amounts of essential nutrients, to being too speedily consumed, to being only meagerly satisfying. Dietitians are nutrition professionals who integrate their knowledge of nutritional science into helping people achieve a healthy diet and develop good dietary habits. The Academy of Nutrition and Dietetics (AND) is the largest organization of nutrition professionals worldwide and dietitians registered with the AND are committed to helping Americans eat well and live healthier lives. To learn more from the AND's nutritional advice, visit http://www.eatright.org.

Nutrition, Health, and Disease

Your ability to wake up, to think clearly, to communicate, to hope, to dream, to go to school, to gain knowledge, to go to work, to earn a living, and to do all of the things that you like to do are dependent upon one factor—your health. Good health means you are able to function normally and work hard to achieve your goals in life. In 1946, the World Health Organization (WHO) defined **health** as "a state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity."[1]

This definition was adopted into the WHO constitution in 1948 and has not been amended since. A triangle is often used to depict the equal influences of physical, mental, and social well- being on health (**Figure 1.12**).

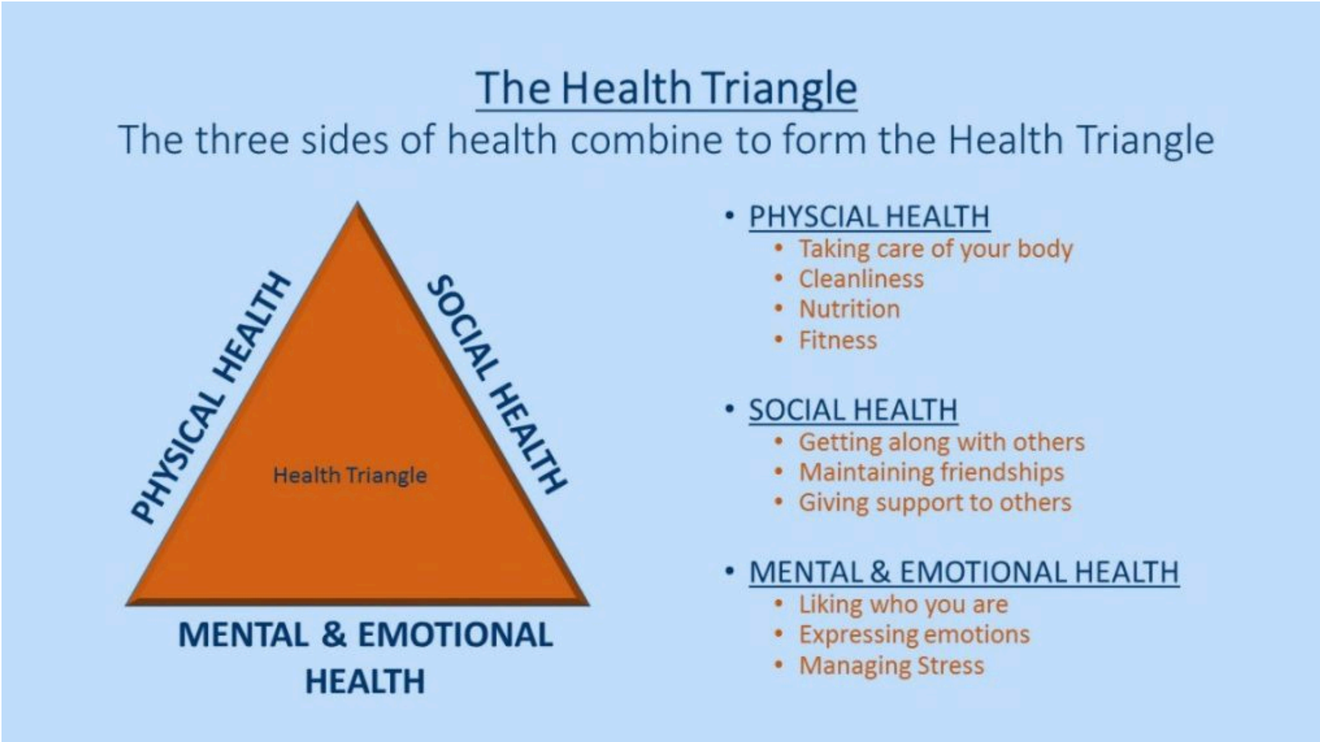

Figure 1.12 *The Health Triangle.*

Disease is defined as any abnormal condition affecting the health of an organism, and is characterized by specific signs and symptoms. Signs refer to identifying characteristics of a disease such as swelling, weight loss, or fever. Symptoms are the features of a disease recognized by a patient and/or their doctor. Symptoms can include nausea, fatigue, irritability, and pain. Diseases are broadly categorized as resulting from pathogens (i.e., bacteria, viruses, fungi, and parasites), deficiencies, genetics, and physiological dysfunction. Diseases that primarily affect physical health are those that impair body structure (as is the case with **osteoporosis**), or functioning (as is the case with cardiovascular disease). The most effective and affordable method of preventing chronic disease starts with optimal nutrition.

The foods we eat affect all three aspects of our health. For example, a teen with Type 2 diabetes (a disease brought on in part by poor diet) is first diagnosed by physical signs and symptoms such as increased urination, thirstiness, and unexplained weight loss. However, research has also found that teens with Type 2 diabetes often experience bullying or other social difficulties, affecting their mental and social well-being. Type 2 diabetes is just one example of a physiological disease that affects all aspects of health—physical, mental, and social.

Public Health and Disease Prevention

In 1894, the first congressional funds were appropriated to the **US Department of Agriculture (USDA)** for the study of the relationship between nutrition and human health. Dr. Wilbur Olin Atwater was appointed as the Chief of Nutrition Investigations and is recognized as the "Father of Nutrition Science" in America.[2]

Under his guidance, the USDA released the first bulletin to the American public that contained information on the amounts of fat, **carbohydrates**, proteins, and food energy in various foods. Nutritional science advanced considerably in these early years, but it took until 1980 for the USDA and the US Department of Health and Human Services (HHS) to jointly release the first edition of *Nutrition and Your Health: Dietary Guidelines for Americans*.

Although wide distribution of dietary guidelines did not come about until the 1980s, many historical events that demonstrated the importance of diet to health preceded their release. Assessments of the American diet in the 1930s led President Franklin D. Roosevelt to declare in his inaugural address on January 20, 1937, "I see one-third of our nation is ill-housed, ill-clad, and ill-nourished." From the time of Atwater until the onset of the Great Depression nutritional scientists had discovered many of the **vitamins** and **minerals** essential for the functioning of the human body. Their work and the acknowledgement by President Roosevelt of the nutritional inadequacy of the American diet evoked a united response between scientists and government leading to the enrichment of flour, the development of **school lunch programs**, and advancements of nutritional education in this country.

In the latter part of the twentieth century nutritional scientists, public health organizations, and the American public increasingly recognized that eating too much of certain foods is linked to chronic diseases. We now know that diet-related conditions and diseases include hypertension (high blood pressure), **obesity**, Type 2 diabetes, cardiovascular disease, some cancers, and osteoporosis. These diet-related conditions and diseases are some of the biggest killers of Americans. The HHS reports that unhealthy diets and inactivity cause between 310,000 and 580,000 deaths every single year.[3]

According to the USDA, eating healthier could save Americans over $70 billion per year and this does not include the cost of obesity, which is estimated to cost a further $117 billion per year. Unfortunately, despite the fact that the prevalence of these diseases can be decreased by healthier diets and increased physical activity, the **CDC** reports that the federal government spends one thousand times more to treat disease than to prevent it ($1,390 versus $1.21 per person each year).[4]

In 2010, the new edition of the dietary guidelines identified obesity as the number one nutritional-related health problem in the United States and established strategies to combat its incidence and health consequences in the American population. A 2008 study in the journal *Obesity* reported that if current trends are not changed, 100 percent of Americans will be overweight or obese in 2048![5]

In 2011, the US federal government released a new multimedia tool that aims to help Americans choose healthier foods from the five food groups (grains, vegetables, fruits, dairy, and proteins). The tool, called "Choose MyPlate," (Figure 1.13) is available at choosemyplate.gov. Whether at home or on-the-go, MyPlate can help you find a healthy eating style that works for you. (Watch the video below for more information.)

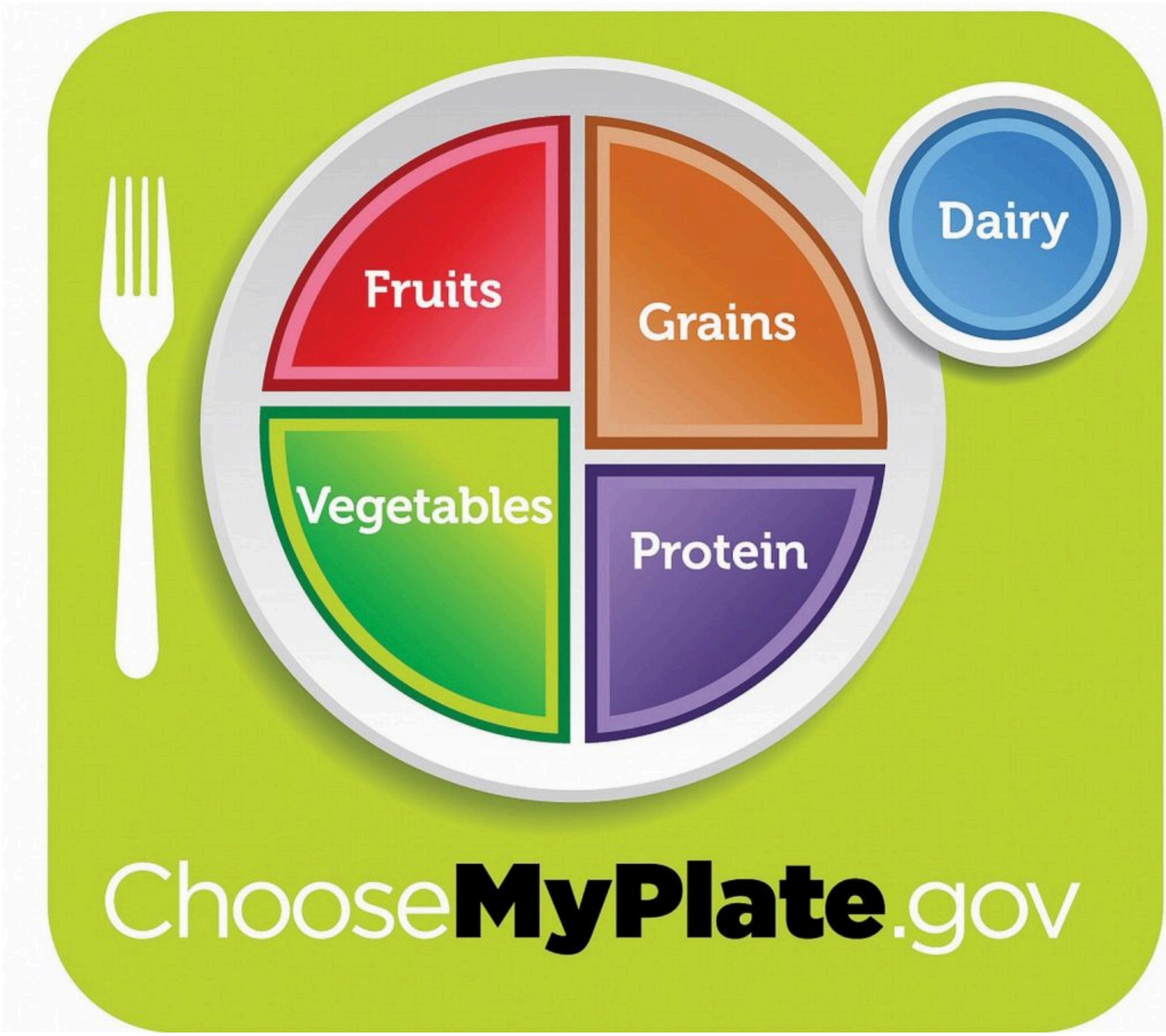

Figure 1.13 *The Federal Government's New and Improved Tool of Nutritional Communication*

Video Link: My Plate, My Wins

The U.S. Department of Agriculture's Center for Nutrition Policy and Promotion introduces the "MyPlate, MyWins" video series that shows how small changes to what you eat and drink add up.

Notes

1. World Health Organization. Preamble to the *Constitution of the World Health Organization* as adopted by the International Health Conference, New York, June 19–July 22, 1946. https://www.who.int/about/governance/constitution
2. Combs, G.F. "Celebration of the Past: Nutrition at USDA." *J Nutr* 124, no. 9 supplement (1994): 1728S–32S. https://doi.org/10.1093/jn/124.suppl_9.1728S
3. Center for Science in the Public Interest. "Nutrition Policy." Accessed March 1, 2012. http://www.cspinet.org/nutritionpolicy/nutrition_policy.html#disease
4. Combs, G.F. "Celebration of the Past: Nutrition at USDA." *J Nutr* 124, no. 9 supplement (1994): 1728S–32S. https://doi.org/10.1093/jn/124.suppl_9.1728S
5. Wang Y, et al. "Will All Americans Become Overweight or Obese? Estimating the Progression and Cost of the US Obesity Epidemic." *Obesity* 10, no. 16 (October 2008): 2323–30. https://doi.org/10.1038/oby.2008.351

1.2 What Are Nutrients?

What's in Food?

The foods we eat contain **nutrients**. Nutrients are substances the body needs to stay healthy. Essential nutrients are substances we must consume to stay healthy. For example, vitamin D is not an essential nutrient as the body makes enough when exposed to sunlight. In the Northwest, however, during Fall and Winter we typically don't get enough sunlight exposure to produce vitamin D and we must get it from our diet. This is the point at which a nutrient becomes essential, when we must consume it for good health.

Nutrients are used to produce energy, 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 (Figure 1.21). These are carbohydrates, lipids, proteins, water, vitamins, and minerals. Foods also contain non-nutrients that may be harmful (such as cholesterol, dyes, and preservatives) or beneficial (such as antioxidants). Non-nutrient substances in food will be further explored in later chapters.

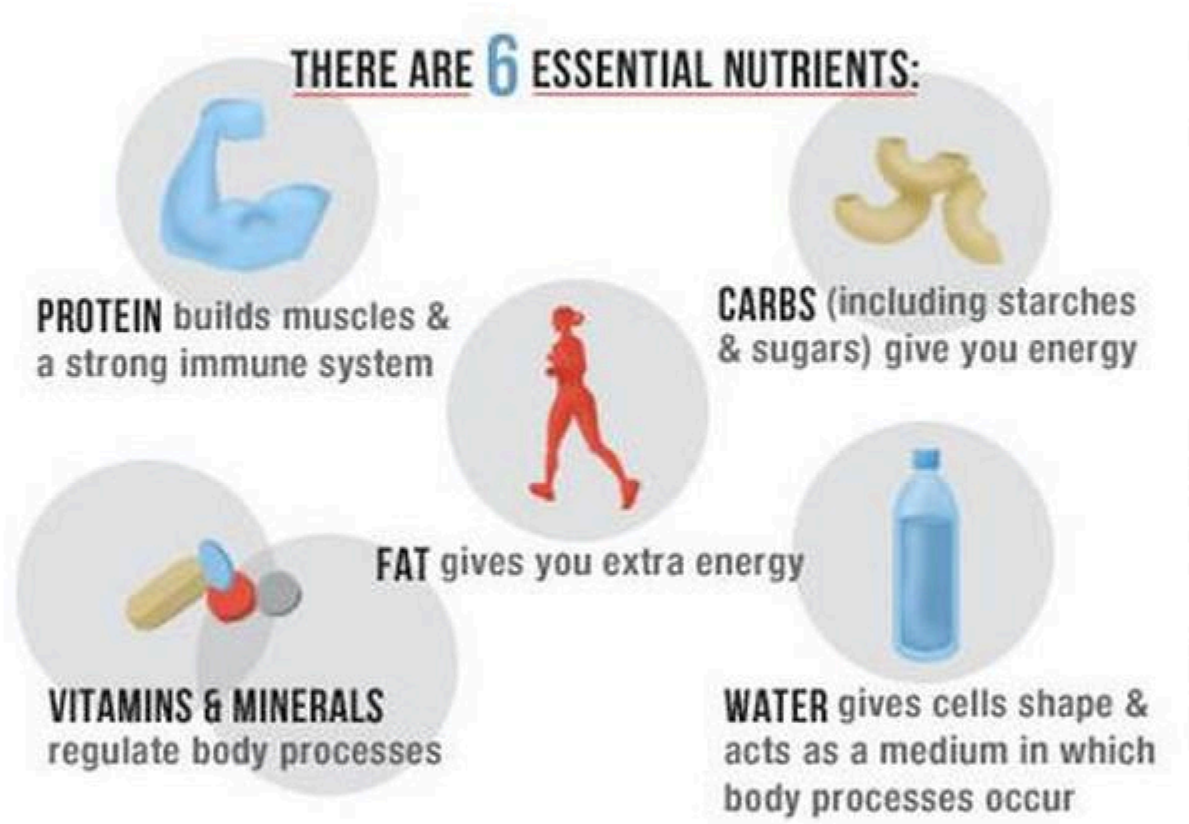

Figure 1.21 *The Six Essential Nutrients. Image Source*

MACRONUTRIENTS

Nutrients that are needed in large amounts are called **macronutrients**. There are three classes of macronutrients: carbohydrates, lipids, and proteins (Figure 1.22). 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.

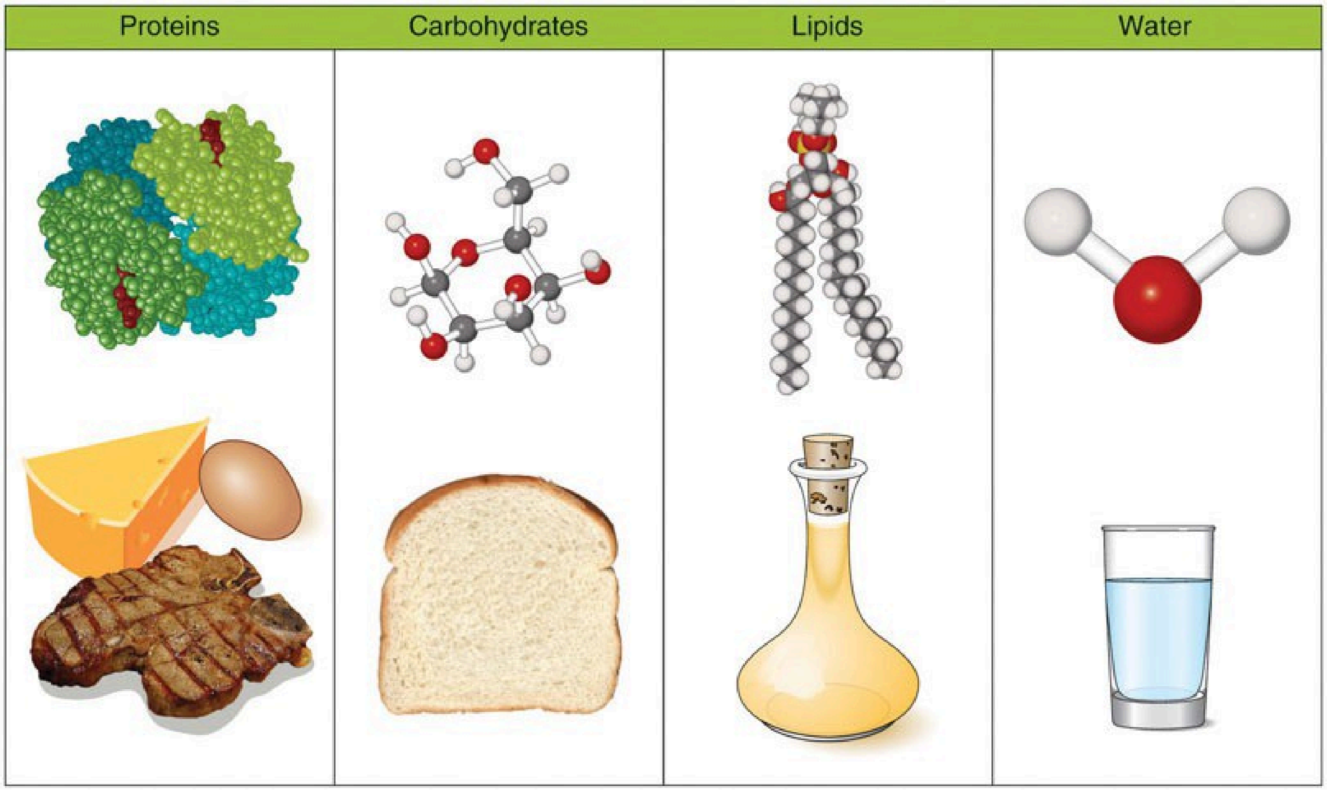

Figure 1.22 *The Macronutrients: Carbohydrates, Lipids, Protein, and Water.*

Carbohydrates

Carbohydrates are molecules composed of carbon, hydrogen, and oxygen in a 1:2:1 ratio. 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.

When you consume carbohydrates, the amount of sugar (glucose) in your blood increases. Carbohydrates are broadly classified into two forms based on how they affect your blood sugar: **fast-releasing carbohydrates**, often called simple sugars, and slow-releasing carbohydrates.

Fast-releasing carbohydrates cause a rapid rise in blood sugar, followed by a drop. This pattern of blood sugar may be associated with diabetes and cardiovascular disease and may cause you to feel hungry more quickly. Fast-releasing carbohydrates are found in refined grains and foods/drinks with added sugar. Structurally, these carbohydrates consist of one or two basic units, which is why they can be called simple sugars. 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.

Slow-releasing carbohydrates raise your blood sugar but the effect is slower, spread out over time. These carbohydrates are long chains of simple sugars that can be branched or unbranched. During **digestion**, the body breaks down all slow-releasing 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 slow-releasing carbohydrate, but it cannot be broken down in the human body and passes through the digestive tract undigested unless the bacteria that inhabit the gut break it down.

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 starches. Glycogen and starches are slow-releasing 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 predominately in butter, oils, meats, dairy products, nuts, and seeds, and in many processed foods. The three main types of lipids are **triglycerides (triacylglycerol)**, **phospholipids**, and **sterols**. The main job of lipids is to 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 cell membranes, surround and protect **organs**, aid in temperature regulation, and regulate many other functions in the body.

Proteins

Molecules composed of chains of amino acid subunits are called **proteins**. Amino acids in turn, are simple subunits composed of carbon, oxygen, hydrogen, and nitrogen. The food sources of proteins are 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. 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.

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. According to the "rule of threes," a generalization supported by survival experts, a person can survive three minutes without oxygen, three days without water, and three weeks without food. 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 1.21 "Minerals and Their Major Functions" and Table 1.22 "Vitamins and Their Major Functions" for a complete list and their major functions). In contrast to the macronutrients, the micronutrients are not directly used for making energy, but they assist in the process as being part 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 roles in the body.

Minerals

Minerals are solid inorganic substances that form crystals and are classified depending on how much of them we need. **Trace minerals** such as zinc, iron, or iodine are only required in a few milligrams or less per day. While major minerals such as calcium, sodium, and potassium are required in hundreds of milligrams per day. 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**.

Table 1.21 Minerals and Their Major Functions

MAJOR MINERALS	MAJOR FUNCTION
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 MINERALS	**MAJOR FUNCTIONS**
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 and iron metabolism
Manganese	Coenzyme

Vitamins

Unlike minerals, vitamins are all organic compounds. The thirteen vitamins are categorized as either **water-soluble** or **fat-soluble**. The water-soluble vitamins are vitamin C and all the B vitamins. 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. Vitamin deficiencies can cause severe health problems. For example, a deficiency in niacin causes **pellagra**. Until scientists found out that better diets relieved the signs and symptoms of pellagra, many people with the disease ended up in insane asylums awaiting death (watch the video link below). Other vitamins were also found to prevent certain disorders and diseases such as scurvy (vitamin C), night blindness (vitamin A), and **rickets** (vitamin D).

Video Link: Pellagra

This video provides a brief history of Dr. Joseph Goldberger's discovery that pellagra was a diet-related disease.

Table 1.22 Vitamins and Their Major Functions

WATER-SOLUBLE VITAMINS	**MAJOR FUNCTIONS**
B1 (thiamine)	Coenzyme, energy metabolism assistance
B2 (riboflavin)	Coenzyme, energy metabolism assistance
B3 (niacin)	Coenzyme, energy metabolism assistance
B5 (pantothenic acid)	Coenzyme, energy metabolism assistance
B6 (pyroxidine)	Coenzyme, amino acid synthesis assistance
B7 (biotin)	Coenzyme
B9 (folate)	Coenzyme, essential for growth
B12 (cobalamin)	Coenzyme, red blood cell synthesis
C	Collagen synthesis, antioxidant
FAT-SOLUBLE VITAMINS	**MAJOR FUNCTIONS**
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

Food Energy

Food energy is measured in kilocalories (kcals), commonly referred to as Calories. This terminology is technically incorrect, but is used so commonly that we will refer to them as calories throughout the course. A kilocalorie is the amount of energy needed to raise 1 kilogram of water 1 degree Celsius. A food's kilocalories are determined by putting the food into a **bomb calorimeter** and determining the energy output (energy = heat produced). The link below is to a video of a bomb calorimeter showing how one is used.

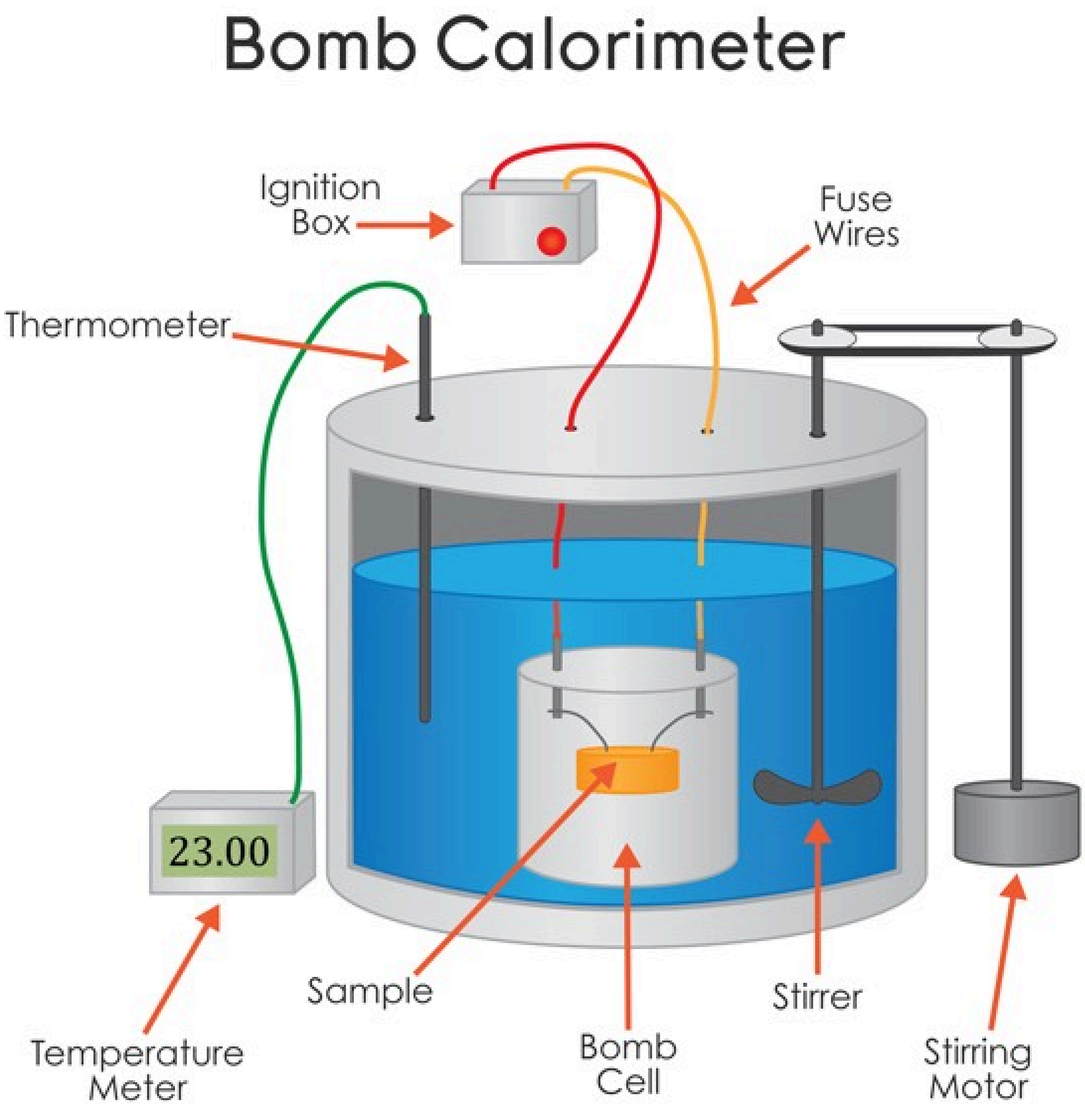

Figure 1.23 *Bomb calorimeter ©Science Media Group*

Video Link: Bomb Calorimeter Measuring Energy in Food Digestion

This video shows how a bomb calorimeter is used to measure the energy in food

Among the nutrients, the amount of kilocalories per gram that each provide are shown below, along with the nutrients that do not provide energy.

Energy (kcal/g)	**No Energy**
Carbohydrates (4 kcal/g)	Vitamins
Protein (4 kcal/g)	Minerals
Lipids (9 kcal/g)	Water

As can be seen, only carbohydrates, proteins, and lipids provide energy. However, there is another energy source in the diet that is not a nutrient: alcohol. Just to re-emphasize, alcohol is NOT a nutrient! However, it does provide energy. In fact, alcohol provides seven kilocalories per gram.

Image source

Phytochemicals, Zoochemicals, and Functional Foods

Beyond macronutrients and micronutrients, there is a lot of interest in non-nutritive compounds found in foods that may be either beneficial or detrimental to health.

Phytochemicals

Phytochemicals are compounds in plants (phyto) that are believed to provide health benefits beyond the traditional nutrients. One example is lycopene in tomatoes, which is thought to potentially decrease the risk of some cancers (in particular prostate cancer). Diets rich in fruits and vegetables have been associated with decreased risk of chronic diseases. Many fruits and vegetables are rich in phytochemicals, leading some to hypothesize that phytochemicals are responsible for the decreased risk of chronic diseases. The role that phytochemicals play in health is still in the early stages of research, relative to other areas of nutrition such as micronutrients. The Linus Pauling Institute has a website containing good information on phytochemicals if you are interested in learning more about them (web link below).

Image source

Web Link: Linus Pauling Institute: Phytochemicals

Zoochemicals

Zoochemicals are the animal equivalent of phytochemicals in plants. They are compounds in animals that are believed to provide health benefits beyond the traditional nutrients that food contains. Hopefully the name is pretty easy to remember because you can find animals at a zoo. Some compounds can be both phytochemicals and zoochemicals. An example of compounds that can be classified as both are the yellow **carotenoids** lutein and zeaxanthin. Kale, spinach, and corn contain phytochemicals and are good sources of lutein and zeaxanthin. Whereas egg yolks contain zoochemicals and are also a good source of these carotenoids.

Functional Foods

There are a number of definitions of functional foods. Functional foods are generally understood to be a food, or a food ingredient, that may provide a health benefit beyond the traditional nutrients (macro and micronutrients) it contains. Functional foods are often a rich source of a phytochemical or zoochemical, or contain more of a certain nutrient than a normal food.

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 many of the nutrients relative to the amount of calories they provide. Nutrient-dense foods are the opposite of "empty-calorie" foods, such as carbonated sugary drinks, or sweet and buttery pastries, which contain a high number of calories and very few nutrients. Food quality is additionally associated with its taste, texture, appearance, microbial content, and how much consumers like it.

Food: A Better Source of Nutrients

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. While vitamins, multivitamins, and supplements are a $20 billion industry in this country and more than 50 percent of Americans purchase and use them daily, there is no consistent evidence that they are better than food in promoting health and preventing disease. Dr. Marian Neuhouser, associate of the Fred Hutchinson Cancer Research Center in Seattle, says that "…scientific data are lacking on the long-term health benefits of supplements. To our surprise, we found that multivitamins did not lower the risk of the most common cancers and also had no impact on heart disease."[1]

Notes

1. Woodward, K. “Multivitamins Each Day Will Not Keep Common Cancers Away; Largest Study of Its Kind Provides Definitive Evidence that Multivitamins Will Not Reduce Risk of Cancer or Heart Disease in Postmenopausal Women.” Fred Hutchinson Cancer Research Center. *Center News* 16 (February 2009). https://www.fredhutch.org/en/news/center-news/2009/02/multivitamins-common-cancers.html

1.3 The Role of Nutritional Science

How to Determine the Health Effects of Food and Nutrients

Similar to the method by which a police detective finally charges a criminal with a crime, 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 on whether the food suspect fits the claim. This organized process of inquiry used in forensic science, nutritional science, and every other science is called the **scientific method** (Figure 1.31).

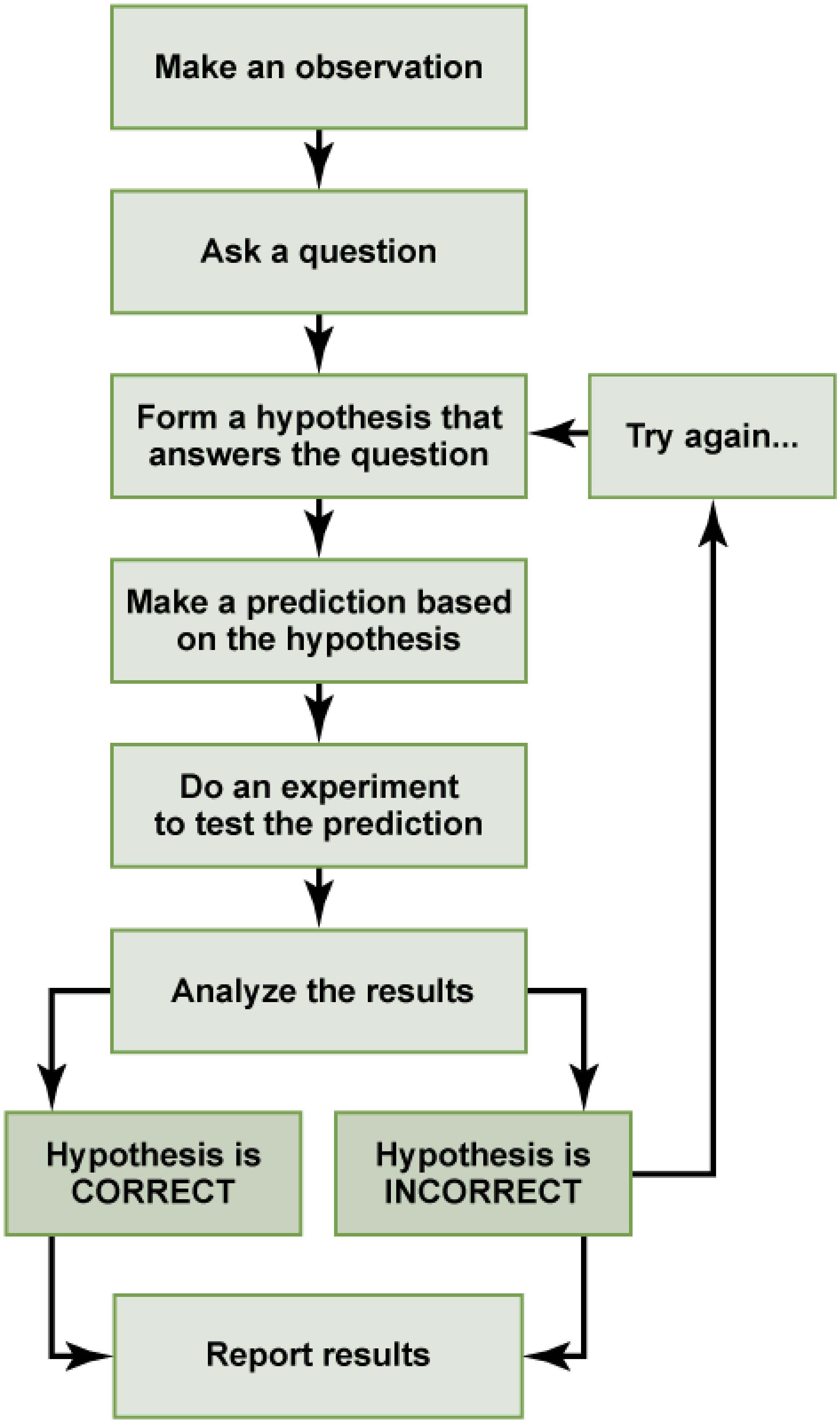

Figure 1.31 *The basic steps of the scientific method. Image Source*

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.[1]

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

Figure 1.32 *Goiter Image source*

- **Hypothesis.** In 1813, Swiss physician Jean-Francois Coindet hypothesized that the seaweed contained iodine and he could use just iodine instead of seaweed to treat his patients.
- **Experimental test.** Coindet administered iodine tincture orally to his patients with goiter.
- **Interpret results.** Coindet's iodine treatment was successful.
- **Gathering more evidence.** Many other physicians contributed to the research on iodine deficiency and goiter.
- **Hypothesis.** French chemist Chatin proposed that the low iodine content in food and

water of certain areas far away from the ocean were 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 children with goiter 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-aged children demonstrated goiter. 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.
- **Results.** This study conducted on over four-thousand school-aged children found that iodized salt prevented goiter.
- **Conclusions.** Seven other studies similar to Marine's were conducted in Italy and Switzerland that 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 percent 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.

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.

The Food and Nutrition Board of the Institute of Medicine, a nonprofit, nongovernmental organization, constructs its nutrient recommendations (i.e., **Dietary Reference Intakes**, or DRI) using an evidence-based approach to nutrition. The same approach is used by the USDA and HHS, which are departments of the US federal government. The USDA and HHS websites are great tools for discovering ways to optimize health; however, it is important to gather nutrition information from multiple resources, as there are often differences in opinion among various scientists and public health organizations. While the new ***Dietary Guidelines***, published in 2010, have been well-received by some, there are nongovernmental public health organizations that are convinced that some pieces of the guidelines may be influenced by lobbying groups and/or the food industry. For example, the Harvard School of Public Health (HSPH) feels the government falls short by being "too lax on refined grains".[2]

The guidelines recommend getting at least *half* of grains from whole grains but according to the HSPH this still leaves too much consumption of refined grains. For a list of reliable sources that advocate good nutrition to promote health and prevent disease using evidence-based science (see Table 1.31 "Web Resources for Nutrition and Health"). In later chapters, we will further discuss distinguishing criteria that will enable you to wade through misleading nutrition information and instead gather your information from reputable, credible websites and organizations. Throughout the course, you are also required to cite credible websites and organizations in your discussion posts.

Table 1.31 Web Resources for Nutrition and Health

US GOVERNMENTAL WEBSITES	
US Department of Agriculture	https://www.usda.gov/topics/food-and-nutrition
USDA Center for Nutrition Policy and Promotion	https://www.fns.usda.gov/cnpp
US Department of Health and Human Services	http://www.hhs.gov/
Centers for Disease Control and Prevention	http://www.cdc.gov/
Food and Drug Administration	http://www.fda.gov/
Healthy People	http://www.healthypeople.gov/2020/default.aspx
Office of Disease Prevention and Health Promotion	https://health.gov/
INTERNATIONAL WEBSITES	
World Health Organization	https://www.who.int/nutrition/en/
Food and Agricultural Organization of the United Nations	http://www.fao.org/
Health Canada	http://www.hc-sc.gc.ca/
NON-GOVERNMENTAL WEBSITES	
Harvard School of Public Health	https://hsph.harvard.edu/nutritionsource
Mayo Clinic	http://www.mayoclinic.com/
Linus Pauling Institute	http://lpi.oregonstate.edu/
American Society for Nutrition	http://www.nutrition.org/
American Medical Association	http://www.ama-assn.org/
American Diabetes Association	http://www.diabetes.org/
The Academy of Nutrition and Dietetics	http://www.eatright.org/

National Academy of Medicine	http://www.nam.edu
Dietitians of Canada	http://www.dietitians.ca/

Types of Scientific Studies

There are many types of scientific studies that can be used to provide supporting evidence for a particular hypothesis. The various types of studies include epidemiological studies, interventional clinical trials, and randomized clinical interventional trials.

Epidemiological studies are observational studies and are often the front-line studies for public health. The CDC defines epidemiological studies as scientific investigations that define frequency, distribution, and patterns of health events in a population. Thus, these studies describe the occurrence and patterns of health events over time. The goal of an epidemiological study is to find factors associated with an increased risk for a health event, though these sometimes remain elusive. An example of an epidemiological study is the Framingham Heart Study, a project of the National Heart, Lung and Blood Institute and Boston University that has been ongoing since 1948. This study first examined the physical health and lifestyles of 5,209 men and women from the city of Framingham, Massachusetts and has now incorporated data from the children and grandchildren of the original participants. One of the seminal findings of this ambitious study was that higher cholesterol levels in the blood are a risk factor for heart disease.[3]

Epidemiological studies are a cornerstone for examining and evaluating public health and some of their advantages are that they can lead to the discovery of disease patterns and risk factors for diseases, and they can be used to predict future healthcare needs and provide information for the design of disease prevention strategies for entire populations. Some shortcomings of epidemiological studies are that investigators cannot control environments and lifestyles, a specific group of people studied may not be an accurate depiction of an entire population, and these types of scientific studies cannot directly determine if one variable causes another.

Interventional clinical trial studies are scientific investigations in which a variable is changed between groups of people. When well done, this type of study allows one to determine causal relationships. An example of an interventional clinical trial study is the Dietary Approaches to Stop **Hypertension** (DASH) trial published in the April 1997 issue of *The New England Journal of Medicine*. In this study, 459 people were randomly assigned to three different groups; one was put on an average American control diet, a second was put on a diet rich in fruits and vegetables, and the third was put on a combination diet rich in fruits, vegetables, and low-fat dairy products with reduced saturated and total fat intake. The groups remained on the diets for eight weeks. Blood pressures were measured before starting the diets and after eight weeks. Results of the study showed that the group on the combination diet had significantly lower blood pressure at the end of eight weeks than those who consumed the control diet. The authors concluded that the combination diet is an effective nutritional approach to treat high blood pressure.[4] The attributes of high-quality clinical interventional trial studies are:

- include a control group, which does not receive the intervention, to which you can compare the people who receive the tested intervention;
- randomized into the group or intervention group, meaning a given subject has an equal chance of ending up in either the control group or the intervention group. This is done to ensure that any possible confounding variables are likely to be evenly distributed between the control and the intervention groups;
- include a sufficient number of participants.

Randomized clinical interventional trial studies are powerful tools to provide supporting evidence for a particular relationship and are considered the "gold standard" of scientific studies. A randomized clinical interventional trial is a study in which 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. However, from their limitations it is clear that epidemiological studies complement interventional clinical trial studies and both are necessary to construct strong foundations of scientific evidence for **health promotion** and disease prevention.

Other scientific studies used to provide supporting evidence for a hypothesis include laboratory studies conducted on animals or cells. An advantage of this type of study is that they typically do not cost as much as human studies and they require less time to conduct. Other advantages are that researchers have more control over the environment and the number of confounding variables can be significantly reduced. Moreover, animal and cell studies provide a way to study relationships at the molecular level and are also helpful in determining the exact mechanism by which a specific nutrient causes a change in health. The disadvantage of these types of studies are that researchers are not working with whole humans and thus the results may not be relevant. Nevertheless, well-conducted animal and cell studies that can be repeated by multiple researchers and obtain the same conclusion are definitely helpful in building the evidence to support a scientific hypothesis.

Table 1.32 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.

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 it is important to know where a scientific study was conducted and who provided the money. Indeed, just as an air quality study paid for by a tobacco company diminishes its value in the minds of readers, so does one on red meat performed at a laboratory funded by a national beef association. Science can also be contentious even amongst experts that don't have any conflicting financial interests. Contentious science is actually a good thing as it forces researchers to be of high integrity, well-educated, well-trained, and dedicated (watch video below). It also instigates public health policy makers to seek out multiple sources of evidence in order to support a new policy. Agreement involving many experts across multiple scientific disciplines is necessary for recommending dietary changes to improve health and prevent disease. Although a somewhat slow process, it is better for our health to allow the evidence to accumulate before incorporating some change in our diet.

Video Link: Boosting Vitamin D: Not Enough Or Too Much?

The Experts Debate: This webcast from March 29, 2011 demonstrates how science is always evolving and how debate among nutrition science experts influences policy decisions.

Evolving Nutritional Science

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 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. Eventually this field will progress so that a person's diet can be tailored to their genetics. Thus, your DNA will determine your optimal diet.

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 may also delve into the field of nutritional genetics and download your gene expression profiles to a database that analyzes yours against millions of others.

Notes

1. Zimmerman, M.B. "Research on Iodine Deficiency and Goiter in the 19th and Early 20th Centuries." *J Nutr* 138, no. 11 (November 2008): 2060–63. https://doi.org/10.1093/jn/138.11.2060
2. The Harvard School of Public Health. "New US Dietary Guidelines: Progress, Not Perfection." 2012. The President and Fellows of Harvard College. https://www.hsph.harvard.edu/nutritionsource/2011/01/31/new-u-s-dietary-guidelines-2010-progress-not-perfection
3. The Framingham Heart Study, a project of the National Heart, Lung, and Blood Institute and Boston University. "History of the Framingham Heart Study." c 2012 Framingham Heart Study. https://framinghamheartstudy.org/fhs-about/history
4. Appel, L. J., et al. "A Clinical Trial of the Effects of Dietary Patterns on Blood Pressure.," *N Engl J Med* 336 (April 1997): 1117–24. http://www.nejm.org/doi/full/10.1056/NEJM199704173361601

1.4 Health Factors and Their Impact

In addition to nutrition, health is affected by genetics, the environment, life cycle, and lifestyle. These factors are referred to as "determinants" of health and they all interact with each other. For example, family income influences the food choices available and the quantity and quality of food that can be purchased, which of course affects nutrition. Except for nutrition and lifestyle, these factors can be difficult or impossible to change.

Genetics

Everyone starts out in life with the genes handed down to them from the families of their mother and father. **Genes** are responsible for your many traits as an individual and are defined as the sequences of DNA that code for all the proteins in your body. The expression of different genes can determine the color of your hair, skin, and eyes, and even if you are more likely to be fat or thin and if you have an increased risk for a certain disease. The sequence of DNA that makes up your genes determines your genetic makeup, also called your **genome**, which is inherited from your mother and father. In 2003, the Human Genome Project was completed and now the entire sequence of DNA in humans is known. It consists of about three billion individual units and contains between twenty-five and thirty thousand genes. The human genome that was sequenced was taken from a small population of donors and is used as a reference DNA sequence for the entire population. Each of us has a similar but unique DNA sequence. Only identical twins and cloned animals have the exact same DNA sequence.

Now that we understand the map of the human genome, let us enter the fields of nutrigenomics and epigenetics. Recall that **nutrigenomics** is an emerging scientific discipline aimed at defining healthy genes and not-so healthy genes and how nutrients affect them.

Epigenetics is another rapidly advancing scientific field in which researchers study how your behaviors and environment can change the way your genes work. Epigenetics is the study of how exposure to certain chemicals or situations can cause your cells to turn genes "on" and "off," changing how your cells function without changing the actual sequence of DNA. Scientists are discovering that nutrients are one factor that can affect epigenetics. Researchers at the Genetic Science Learning Center at the University of Utah conducted an experiment in which some pregnant mice were fed a diet containing folate, choline, vitamin B12, and betaine, and other pregnant mice were fed a diet that did not contain these nutrients and chemicals. Both groups of pregnant mice were also fed bisphenol A, a chemical in plastic, which alters DNA by inhibiting a specific chemical reaction. The mice born from the mother fed the supplemented diet were brown, thin, and healthy. The mice born from the mother fed the unsupplemented diet were yellow, fat, and unhealthy. This is a dramatic example of how nutrients change not the sequence of DNA, but which genes are expressed.

These two mice look different, but have identical DNA sequences. Thus, not only do the things you eat determine your health but so do the things your mother ate during **pregnancy**.

Moreover, other studies have demonstrated what your dad ate—and what your grandmother ate while she was pregnant with your mother!—also can affect your gene expression and, consequently, your health. Does this make it OK for you to blame your mother and father for all of your shortcomings? No. Genetics are important in determining your health, but they are certainly not the only determinant.

The Life Cycle

The **life cycle** of human beings originates from a fertilized egg, which develops into a **fetus** that is eventually born as a baby. A baby develops into a child, transitions through the wonderful phase of adolescence, becomes an adult, and then advances into old age and eventually death (Figure 1.41 "The Life Cycle: The Forward March to Old Age and Ultimately Death"). The current average life expectancy in America is approaching eighty.

Figure 1.41 *The Life Cycle: The Forward March to Old Age and Ultimately Death. © Shutterstock*

A person's stage of life influences their health and nutritional requirements. For example, when you are an adolescent, your bones grow quickly. More calcium, a bone-building nutrient, is required in the diet during this life stage than at other ages. As you get older, the aging process affects how your body functions. One effect of aging, apparently earlier in women than in men, is the deterioration of bone tissue. As a result, women over age fifty-one need more calcium in their diet than younger adult women. Another life-cycle stage, pregnancy, requires several adjustments to nutrition compared to non-pregnant women. It is recommended that a pregnant woman consume more protein than a non-pregnant woman to support growth and development, and to consume more of some vitamins, such as folate, to prevent certain birth defects. The USDA provides information on healthy diets for many different stages of the life cycle on their website. Healthy aging requires eating a diet that matches one's life stages to support the body's specific physiological requirements. What else is known to help a person age slowly and gracefully? Diets high in vegetables and fruits are associated with increased longevity and a decreased risk of many diseases.

Environment

Your environment has a large influence on your health, genetics, life cycle, and lifestyle. Scientists say that the majority of your expressed traits are a product of your genes and environment, of which nutrition is a component. An example of this interaction can be observed in people who have the rare genetic disorder, **phenylketonuria (PKU)** (Figure 1.42).

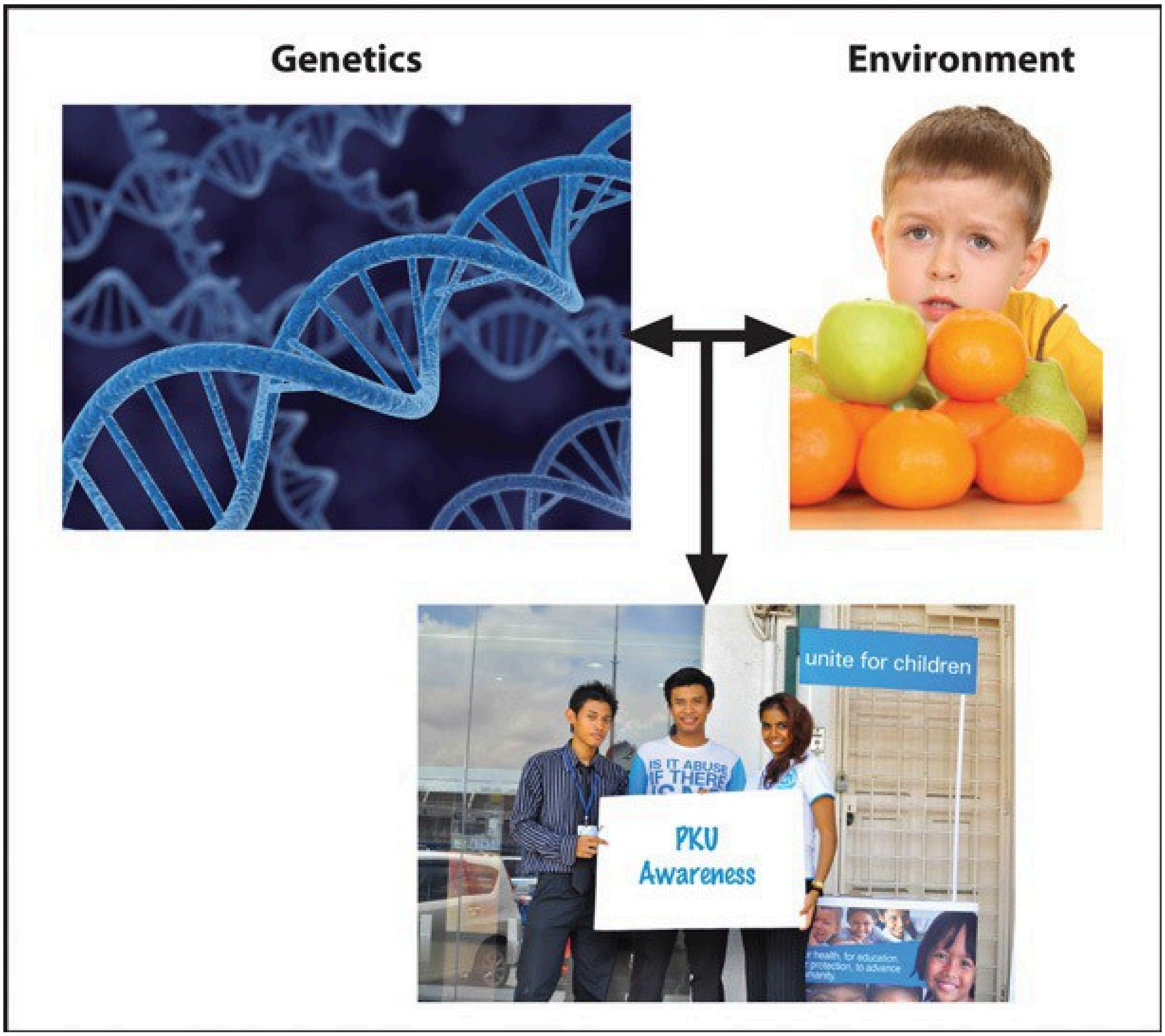

Figure 1.42 *The interplay of genetics and environment. Image 1 Source Image 2 Source ©Shutterstock*

The clinical signs of PKU are mental retardation, brain damage, and seizures and are caused by the build-up of the amino acid phenylalanine and its metabolites (breakdown products produced during **metabolism**) in the body. The high level of phenylalanine in a person who has PKU is the result of a change in the gene that encodes for an enzyme that converts phenylalanine into the amino acid tyrosine. This genetic change, called a mutation, causes the enzyme to not function properly. In this country and many others, all newborn babies are screened for PKU in order to diagnose and treat the disease before the development of mental retardation and brain damage. Once diagnosed, PKU is treated by strict adherence to a diet low in phenylalanine, consisting mostly of fruits, vegetables, and grains. Adhering to this diet for life allows an individual with PKU to lead a normal life without suffering the consequences of brain damage, mental retardation, or seizures. In the example of PKU, the consequences of a genetic mutation are modified by diet. Thus, a person's genes can make them more susceptible to a particular disease, or cause a disease, and their environment can decrease or increase the progression and severity of the condition.

Socioeconomic Status

Multiple aspects of a person's environment can affect nutrition, which in turn affects health. One of the best environmental predictors of a population's health is socioeconomic status. **Socioeconomic status** is a measurement made up of three variables: income, occupation, and education. Socioeconomic status affects nutrition by influencing what foods you can afford and consequently, food choice and food quality. Nutrition and health are generally better in populations that have higher incomes, better jobs, and more education. On the other hand, the burden of disease is highest in the most disadvantaged populations. A commentary in the *Journal of the American Medical Association* reports that the lower life expectancy of populations of lower socioeconomic status is largely attributable to increased death from heart disease. The American Heart Association states that having a healthy diet is one of the best weapons to fight heart disease and it is therefore essential that all socioeconomic status groups have access to high-quality, nutrient-dense foods. The disparities in nutrition and health in America are directly related to the disparity in socioeconomic status.[1]

Other dimensions that affect health disparity are race, ethnic group, sex, sexual identity, age, disability, and geographic location. The federal government recognizes the issue of inequitable health among Americans and one of the overarching goals of Healthy

People 2020, a large program managed by the HHS, is to "Achieve health equity, eliminate disparities, and improve the health of all groups." To work toward this monumental goal, the HHS is actively tracking disease patterns, chronic conditions, and death rates among the many different types of people that live in the United States.

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 of 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 at restaurants. 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 Level

In 2008, the HHS released the *Physical Activity Guidelines for Americans* (see link below). The HHS states, "Being physically active is one of the most important steps that Americans of all ages can take to improve their health. The 2008 *Physical Activity Guidelines for Americans* provides science-based guidance to help Americans aged six and older improve their health through appropriate physical activity." The guidelines recommend exercise programs for people in many different stages of their lifecycle including for pregnant women and for adults and children who have disabilities. The HHS reports that 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. New guidelines are expected to be released in 2018.

Web Link: 2008 *Physical Activity Guidelines for Americans*

Recreational Drug Use

Recreational drug use, which includes tobacco smoking and alcohol consumption along with narcotic and other illegal drug use, has a large impact on health. Smoking cigarettes causes lung cancer, eleven other types of cancer, heart disease, and several other disorders or diseases that markedly decrease quality of life and increase mortality. In the United States, smoking causes more than four hundred thousand deaths every single year, which is far more than deaths associated with any other lifestyle component.[2] Also according to the CDC, excessive alcohol intake causes an estimated seventy-five thousand deaths per year.[3]

Staying away from excessive alcohol intake lowers blood pressure, the risk from injury, heart disease, stroke, liver problems, and some types of cancer. Abstaining from alcohol also aids in weight loss and increases the money in your wallet. While heavy drinking of alcoholic beverages is associated with several bad health effects, 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. The HHS defines drinking in moderation 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 and is a prominent problem in the United States. The health effects of drug abuse can be far-reaching including increased risk for stroke, heart disease, cancer, lung disease, and liver disease.

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 diet or exercise. At least 10 percent of Americans have chronic insomnia. 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.[4] Harvard's Women's Health Watch notes six reasons to get enough sleep: Sleep promotes healthy brain function, while lack of sleep can cause weight gain and increase appetite, decrease safety (falling asleep while driving), make a person moody and irritable, decrease health of the cardiovascular system and prevent the immune system from functioning well.[5]

Video Link: Healthy Sleep Tips

Nutrition, Genetics, Environment, and Lifestyle Interact to Affect Health

The Pima Indians who inhabit parts of southern Arizona and the Pima Indians that live across the border in Mexico are genetically and culturally similar, but there are vast differences in the health of these two populations. In America, the Pima Indians have the highest rate of obesity and Type 2 diabetes compared to any other ethnic group. However, the Pima Indians who live in Mexico do not share these same health problems because of a complex interplay between nutrition, genetics, environment, and lifestyle. Over one hundred years ago, the Pima Indians were farmers, hunters, and gatherers and their diets consisted of about 70 percent carbohydrate, 15 percent protein, and 10 to 15 percent fat. Typical of the lives of farmers, hunters, and gatherers a century ago, they lived through times of feast and times of famine.

The geneticist James Neel proposed in 1962 that the Pima Indians carried a "thrifty gene" that makes them very efficient at storing fat during times of plenty so they do not starve when food is scarce. After World War II, the Pima Indians in America either went back to reservations in southern Arizona or moved to the cities for work. They rapidly adopted the American diet and lifestyle and consumed high-fat, processed foods, and refined grains and were more sedentary than their counterparts in Mexico, who retained their more traditional diet and lifestyle. Today, the typical American Pima Indian diet obtains more than 40 percent of calories from fat. The "thrifty gene" in the American Pima Indian population increased their susceptibility to the consequences of the high-fat

American diet and sedentary lifestyle because they were genetically better at storing fat than others. The story of the Pima Indians and the difference between the health of their populations in America and Mexico demonstrates the interactions between nutrition, genetics, environment, and lifestyle. Indeed, preliminary studies suggest that when American Pima Indians switch back to the diets of their ancestors and consume beans, corn, grains, and greens and other low-fat, high-fiber plant foods, the benefits are weight loss and reduced risk of chronic disease. The health status of American Pima Indians is considered “a canary in the coal mine,” meaning they provide a warning to the American people (Figure 1.43).

Although the health consequences of the American diet and lifestyle in Pima Indians appeared rapidly in their population, all Americans that partake in the current trends of American diet and lifestyle are at risk. On the lighter side (literally!), the new studies that show changing back to more traditional diets markedly improved the health of the American Pima Indians suggest that all Americans can reduce their risk for diet-related diseases even when their genetic susceptibility for these diseases is high.

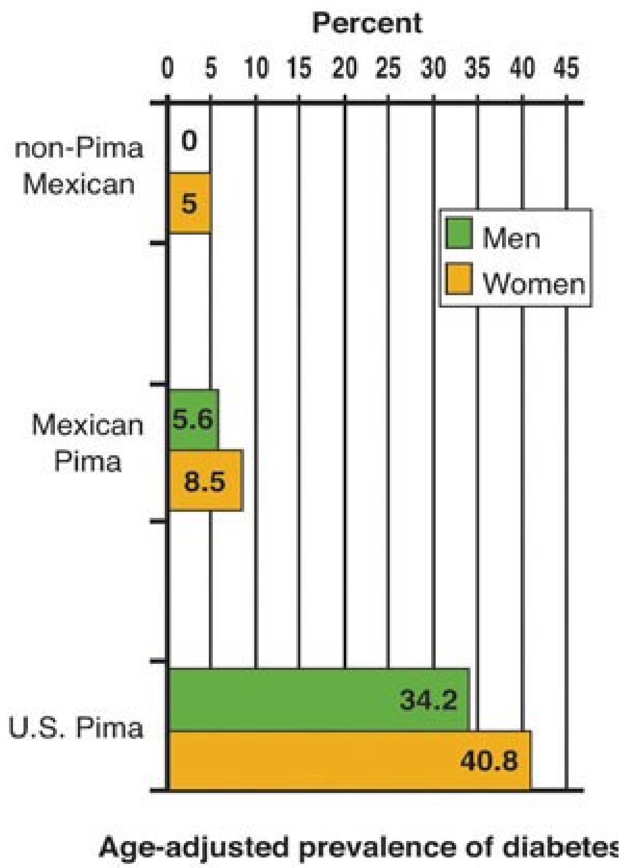

Figure 1.43 *The Interplay of Nutrition, Genetics, Environment, and Lifestyle Affects Health. Pima Indians living in America are genetically similar to those who live in Mexico, but differences in their nutrition, environment, and lifestyle changes their health. Source: paleobioticslab.com [inactive]*

Personal Choice: The Challenge of Choosing Foods

From visiting websites about traditional foods of different cultures and ethnic groups, you may have noticed that a few more things 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. 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 body, mind, and soul. 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, people from New England like to combine pork and sauerkraut as a way to eat their way to luck. Several hundred miles away in the southern United States, people eat Hoppin' John, a favorite local dish made with black-eyed peas and pork, while fish is the "lucky" food of choice for Japanese Americans. National food traditions are carried to other countries when people immigrate. American cuisine would not be what it is today without the contributions of Italian, Chinese, Mexican, and other immigrants.

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 peoples' 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 is 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 Midwestern US states 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 can purchase cheap and fast pizzas or opt for high-end versions at fancy restaurants.
- **Health concerns.** Some people have significant food allergies, to lactose or 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 pounds.
- **Emotions.** There is a wide range in how emotional issues affect eating habits. When faced with a great deal of stress, some people tend to overeat, while others find it hard to eat at all.
- **Green food/Sustainability choices.** Based on a growing understanding of diet as a public and personal issue, more and more people are starting to make food choices based on their environmental impact. Realizing that their food choices help shape the world, many individuals are opting for a vegetarian diet, or, if they do eat animal products, striving to find the most “cruelty-free” options possible. Purchasing local and organic food products and items grown through sustainable products also helps shrink the size of one’s dietary footprint.

Notes

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2. Centers for Disease Control and Prevention. "Smoking and Tobacco Use." Last updated March 21, 2011. http://www.cdc.gov/tobacco/data_statistics/fact_sheets/health_effects/tobacco_related_mortality/index.htm
3. Centers for Disease Control and Prevention. "Alcohol and Drug Use." Last updated June 7, 2012. http://www.cdc.gov/healthyyouth/alcoholdrug/
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1.5 Nutrition Assessment

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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, Anthropometry Procedures Manual (revised January 2004) from the National Health and Nutrition Examination Survey can be viewed here: NHANES Anthropometry Procedures Manual.

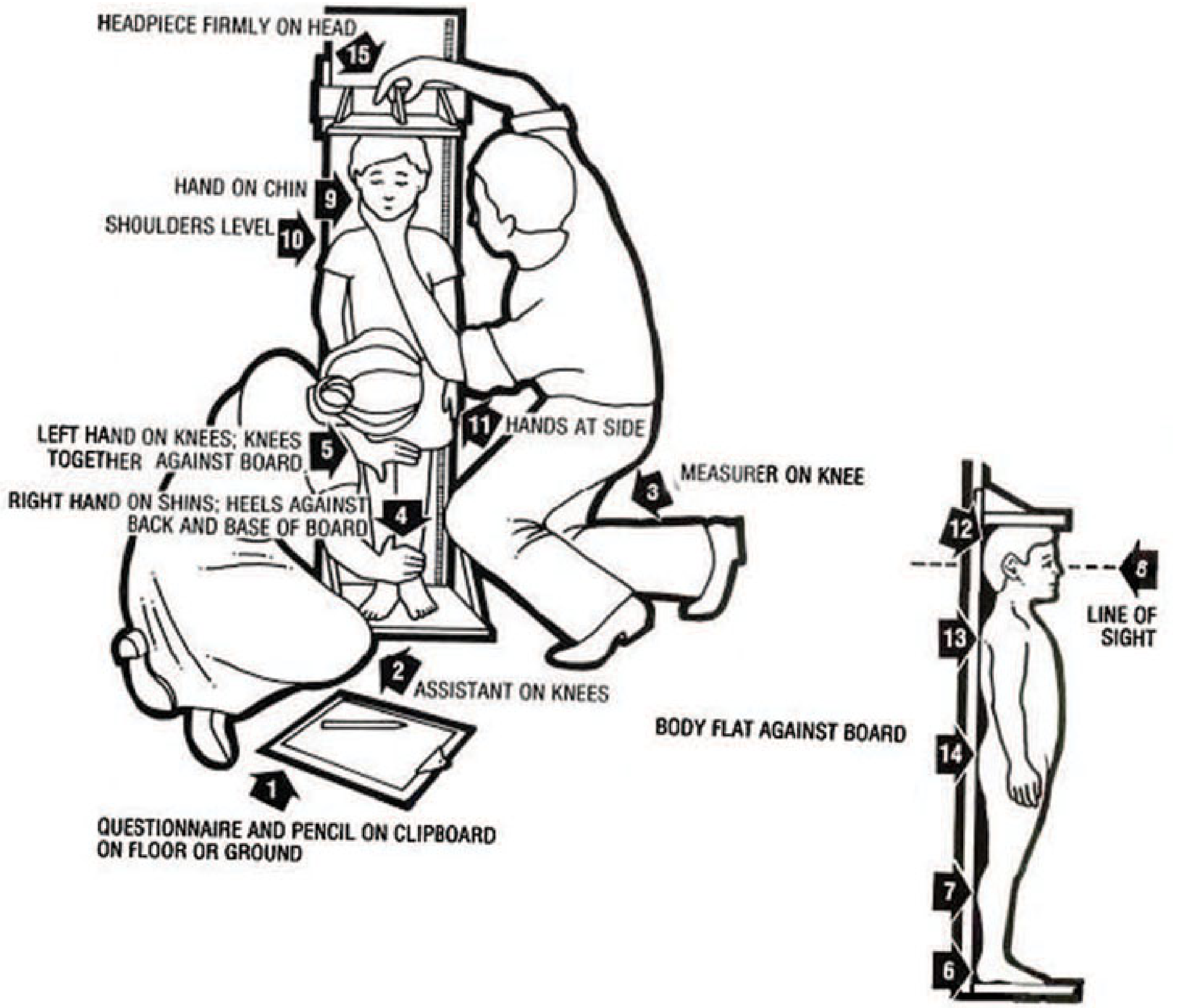


Figure 1.51 *Measuring Height. Source: UNICEF, 1986, How to weigh and measure children: assessing the nutrition status of young children*

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 1.52** 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.

Family Medical History

Because genetics play a large role in defining your health, it is a good idea to take the time to learn some of the diseases and conditions that may affect you. To do this, you need to record your family's medical history. Start by simply drawing a chart that details your immediate family and relatives. Many families have this and you may have a good start already. The next time you attend a family event start filling in the blanks. What did people die from? What country did Grandpa come from? While this may be a more interesting project historically, it can also provide you with a practical tool to determine what diseases you might be more susceptible.

This will allow you to make better dietary and lifestyle changes early on to help prevent a disease from being handed down from your family to you. It is good to compile your information from multiple relatives.

Lifestyle Assessment

A lifestyle assessment includes evaluating your personal habits, level of fitness, emotional health, sleep patterns, and work-life balance. Many diseases are preventable by simply staying away from certain lifestyles. Don't smoke, don't drink excessively, and don't do recreational drugs. Instead, make sure you exercise. Find out how much to exercise by reading the 2008 *Physical Activity Guidelines for Americans*. There is a wealth of scientific evidence that increased physical activity promotes health, prevents disease, and is a mood enhancer. Emotional health is often hard to talk about; however, a person's quality of life is highly affected by emotional stability.

Finding balance between work and life is a difficult and continuous process involving keeping track of your time, taking advantage of job flexibility options, saying no, and finding support when you need it. Work-life balance can influence what you eat too.

CHAPTER II

CHAPTER 2: ACHIEVING A HEALTHY DIET

In chapter 1, we began to discuss the components of a healthy diet. In chapter 2, we'll discuss basic principles for making healthy food choices and introduce several tools that can be used to craft a healthy diet: the dietary guidelines, the daily reference intakes, and nutrition labels.

Sections:

Chapter from *Principles of Nutrition* by Jellum, et al. Acknowledgements therein:

- Adapted from: Zimmerman and Snow. "An Introduction to Nutrition" v. 1.0. Accessed on December 4, 2017. https://2012books.lardbucket.org/books/an-introduction-to-nutrition/

2.0 Introduction

Let's talk about a toolkit for a healthy diet. Long before the dietary toolkit full of acronyms such as DRI, RDA, EAR, and UL, daily standards were created with the single goal of keeping workers alive and toiling in the factories and workhouses of the early Industrial Revolution. In the late nineteenth century, powerhouse tycoons operated without fear of legal consequences and paid their workers as little as possible in order to maximize their own profits. Workers could barely afford housing, and depended on what their bosses fed them at the workhouses to fend off starvation.

Figure 2.01 *Without programs like food stamps, workers and military personnel often had to accept whatever food their employers gave to them. © Shutterstock*

Living conditions in those days show that the term "starvation wages" was not just a figure of speech. Here is a typical day's menu:

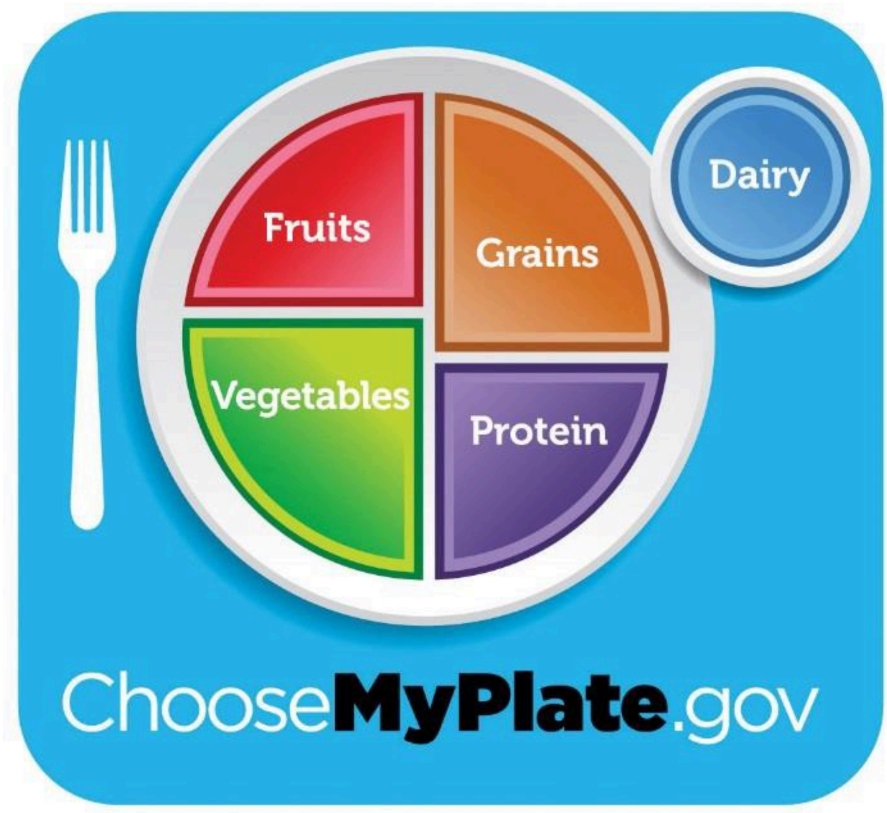
- **Breakfast.** 1 pint porridge, one 6-ounce piece of bread.
- **Lunch.** Beef broth one day, boiled pork and potatoes the next.
- **Dinner.** 1 pint porridge, one 6-ounce piece of bread.

As public awareness about these working conditions grew, so did public indignation. Experts were eventually called upon to create the first dietary guidelines, which were designed only to provide a typical individual with what they needed to survive each day, and no more. It was not until World War I that the British Royal Society first made recommendations about the **nutrients** people needed to be healthy, as opposed to merely surviving. They included ideas we now take for granted, such as making fruit and vegetables part of the diet and giving milk to children. Since then, most governments have established their own dietary standards. Food is a precious commodity, like energy, and controlling the way it is distributed confers power.

Sometimes this power is used to influence other countries, as when the United States withholds food aid from countries with regimes of which it disapproves. Governments can also use their power over food to support their most fragile citizens with food relief programs, such as the **Supplemental Nutrition Assistance Program (SNAP)** and the **Women, Infants, and Children Supplemental Food Program (WIC)**.

The US government has also established dietary standards to help citizens follow a healthy diet. The first of these were the Recommended Daily Allowances (RDAs), published in 1943 because of the widespread food shortages caused by World War II. During the war, the government rationed sugar, butter, milk, cheese, eggs, coffee, and canned goods. Limited transportation made it hard to distribute fruits and vegetables. To solve this problem, the government encouraged citizens to plant "victory gardens" to produce their own fruits and vegetables. More than twenty million people began planting gardens in backyards, empty lots, and on rooftops. Neighbors pooled their resources and formed cooperatives, planting in the name of patriotism.

Today in the United States, there are various measures used to maintain access to nutritious, safe, and sufficient food to the citizenry. Many of these dietary guidelines are provided by the government, and are found at the **Food and Drug Administration's (FDA)** new website, ChooseMyPlate.gov. We call this collection of guidelines the "dietary toolkit."



Source: US Department of Agriculture.

The government works to provide citizens with information, guidance, and access to healthy foods. How will you decide which information to follow? What are the elements of a healthy diet, and how do you figure out ways to incorporate them into your personal diet plan? The dietary toolkit can be likened to a mechanics toolkit, with every tool designed for a specific task(s). Likewise, there are many tools in the dietary toolkit that can help you build, fix, or maintain your diet for good health. In this chapter, you will learn about many of the tools available to you.

Today, the US government sets dietary guidelines that provide evidence-based nutrition information designed to improve the health of the population.

2.1 A Healthy Philosophy toward Food

"Tell me what you eat, and I will tell you what you are" wrote the French lawyer and politician, Antheime Brillat-Savarin in his book, *Physiologie du Gout, ou Meditations de Gastronomie Transcendante*, in 1826. Almost one hundred years later, nutritionist Victor Lindlahr wrote in an ad in 1923, "Ninety percent of the diseases known to man are caused by cheap foodstuffs. You are what you eat." Today, we know this phrase simply as, "You are what you eat."[1]

Good nutrition equates to receiving enough (but not too much) of the **macronutrients** (proteins, carbohydrates, fats, and water) and **micronutrients** (vitamins and minerals) so that the body can stay healthy, grow properly, and work effectively. The phrase "you are what you eat" refers to the fact that your body will respond to the food it receives, either good or bad. Processed, sugary, high-fat, and excessively salted foods leave the body tired and unable to perform effectively. By contrast, eating fresh, natural whole foods fuels the body by providing what it needs to produce energy, promote metabolic activity, prevent micronutrient deficiencies, ward off chronic disease, and to promote a sense of overall health and well-being.

Figure 2.11 *Nutrition provides the nutrients the body needs to perform all activities, from taking a breath to strenuous athletic activity. © Dreamstime*

Table 2.11 Why Nutrition Is Important to Health

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.

Undernutrition, Overnutrition, and Malnutrition

For many, the word "malnutrition" produces an image of a child in a third-world country with a bloated belly, and skinny arms and legs. However, this image alone is not an accurate representation of the state of malnutrition. For example, someone who is 150 pounds overweight can also be malnourished. **Malnutrition** refers to one not receiving *proper* nutrition and does not distinguish between the consequences of *too many* nutrients or the *lack* of nutrients, both of which impair overall health. **Undernutrition** is characterized by a lack of nutrients and insufficient energy supply, whereas **overnutrition** is characterized by excessive nutrient and energy intake. Overnutrition can result in obesity, a growing global health threat. **Obesity** is the condition of having excess accumulation of body fat. In some individuals, obesity may contribute to developing type 2 diabetes, heart disease, and hypertension.

Although not as prevalent in America as it is in developing countries, undernutrition is not uncommon and affects many subpopulations, including the elderly, those with certain diseases, and those in poverty. Many people who live with diseases either have no appetite or may not be able to digest food properly. Some medical causes of malnutrition include cancer, **inflammatory bowel disease**, AIDS, Alzheimer's disease, illnesses or conditions that cause chronic pain, psychiatric illnesses, such as **anorexia nervosa**, or as a result of side effects from medications. Overnutrition is an epidemic in the United States and is known to be a risk factor for many diseases, including Type 2 diabetes, cardiovascular disease, inflammatory disorders (such as rheumatoid arthritis), and cancer.

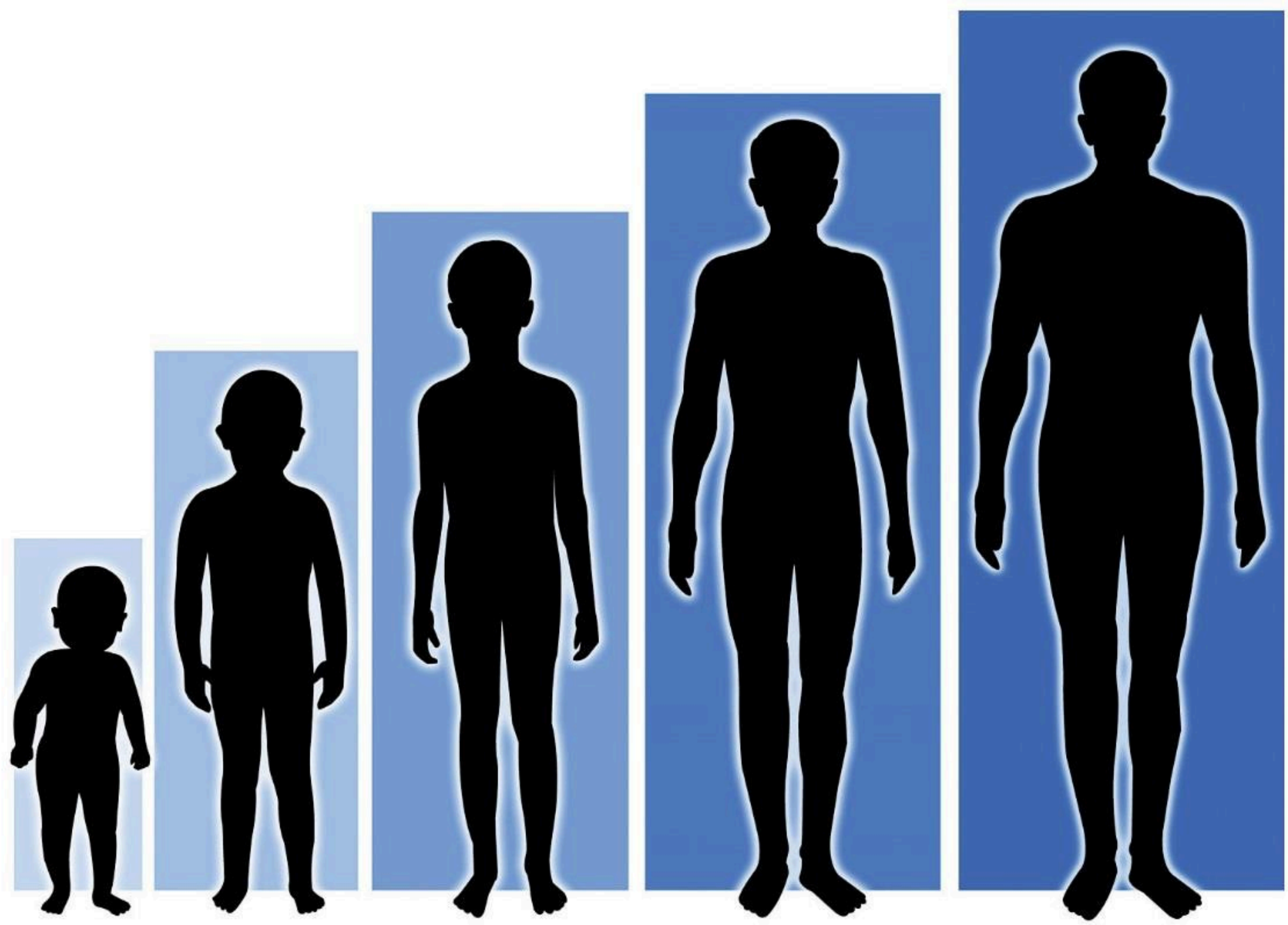


Figure 2.12 *Proper growth throughout the life stages depends upon proper nutrition. © Dreamstime*

Growth and Development

From birth to adulthood, nutrients fuel proper growth and function of all body **cells**, tissue, and systems. Without proper amounts of nutrients, growth and development are stunted. Some nutrient deficiencies manifest right away, but sometimes the effects of undernutrition are not seen until later in life. For example, if children do not consume proper amounts of calcium and vitamin D, **peak bone mass** will be reduced compared to what it would be had adequate amounts of these nutrients been consumed. When adults enter old age without adequate bone mass, they are more susceptible to **osteoporosis**, putting them at risk for bone fractures.

Therefore, it is vital to build bone strength through proper nutrition during youth because it cannot be done in later life.[2]

The Healing Process

With all wounds, from a paper cut to major surgery, the body must heal itself. Healing is facilitated through proper nutrition[3], while malnutrition inhibits and complicates this vital process.

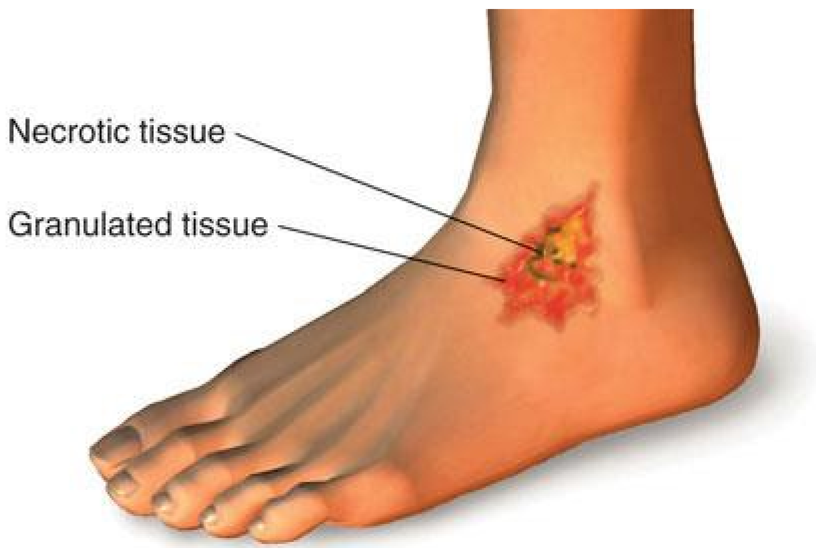


Figure 2.13 *Healing, a critical function of a healthy body, is facilitated by adequate nutrition.*

The following nutrients are important for proper healing:

- **Vitamin A.** Helps to enable the epithelial tissue (the thin outer layer of the body and the lining that protects your **organs**) and bone cells form.
- **Vitamin C.** Helps form collagen, an important protein in many body **tissues**.
- **Protein.** Facilitates tissue formation.
- **Fats.** Play a key role in the formation and function of cell membranes.
- **Carbohydrates.** Fuel cellular activity, supplying needed energy to support the inflammatory response that promotes healing.

Now that we have discussed the importance of proper nutrition for your body to perform normal tissue growth, repair, and maintenance, we will discuss ways of achieving a healthy diet.

Notes

1. Phrase Finder. Accessed July 6, 2011. http://www.phrases.org.uk/meanings/you%20are%20what%20you%20eat.html
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2.2 Principles of a Healthy Diet

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:

- A diet must be **adequate**, by providing sufficient amounts of each essential nutrient, as well as fiber and **calories**.
- A **balanced diet** results when you do not consume one nutrient at the expense of another, but rather get appropriate amounts of all nutrients.
- **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.
- **Moderation** means not eating to the extremes, neither too much nor too little.
- **Variety** refers to consuming different foods from within each of the food groups on a regular basis.

A healthy diet is one that favors whole foods. As an alternative to modern processed foods, a healthy diet focuses on "real" fresh whole foods that have been sustaining people throughout the millenniums. 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, high cholesterol, 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 a diet that provides all of the nutrients your body needs, including vitamins, minerals, healthy fats, fiber, and calories. **Nutrient-dense** foods are an important part of an adequate diet. These foods contain many essential nutrients per calorie, and so they can help you get an adequate amount of essential nutrients without going over the amount of calories you need. Nutrient-dense foods are the opposite of "**empty-**

calorie" foods. If your diet has a lot of empty-calorie foods in it, you may go well above your calorie budget and still not have an adequate diet. 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 maintenance of a healthy weight, while simultaneously providing all necessary nutrients.

Table 2.21 The Smart Choice: Nutrient-Dense Food Alternatives[1]

Instead of…	**Replace with…**
Sweetened fruit yogurt	Plain fat-free yogurt with fresh fruit
Whole milk	Low-fat or fat-free milk
Cheese	Low-fat or reduced-fat cheese
Bacon or sausage	Canadian bacon or lean ham
Sweetened cereals	Minimally sweetened cereals with fresh fruit
Apple or berry pie	Fresh apple or berries
Deep-fried French fries	Oven-baked French fries or sweet potato baked fries
Fried vegetables	Steamed or roasted vegetables
Sugary sweetened soft drinks	Seltzer mixed with 100 percent fruit juice
Recipes that call for sugar	Experiment with reducing amount of sugar and adding spices (cinnamon, nutmeg, etc…)

Figure 2.21 *With careful planning, a balanced diet providing optimal nutrition can be achieved and maintained. ©Shutterstock*

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 a vital nutrient, an overabundance of it can contribute to congestive heart failure and chronic kidney disease. Remember, everything must be consumed in the proper amounts.

MODERATION

Eat in moderation. Moderation is crucial for optimal health and survival. Burgers, French fries, cake, and ice cream 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 have too much of an impact on overall health. If this is done once per month, it will have even less of an impact upon overall health. It is important to remember that eating is, in part, about enjoyment and indulging with a spirit of moderation. This fits within a healthy diet.

CALORIE CONTROL

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 weight gain. In order to lose weight, 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.

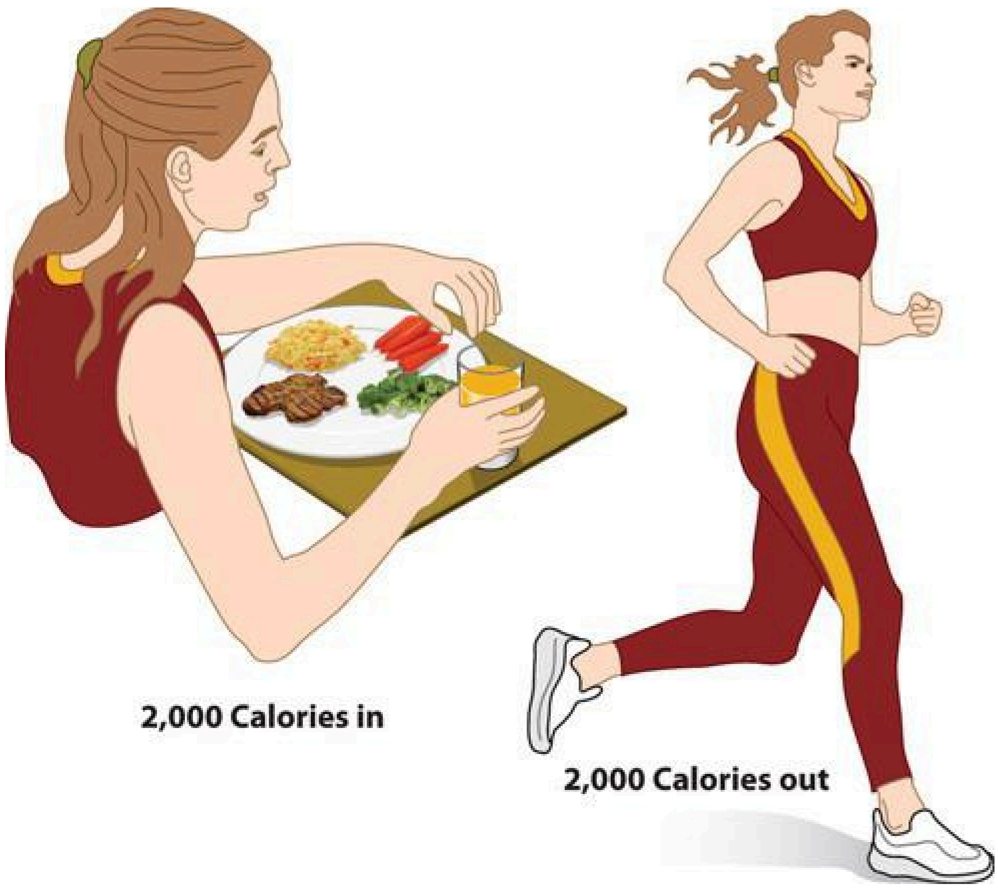

***Figure 2.22** The number of calories consumed should always match the number of calories being expended by the body to maintain a healthy weight. ©Networkgraphics*

VARIETY

Figure 2.23 *Scientific evidence confirms that a diet full of fresh whole foods reduces the risks for developing chronic disease and helps maintain a healthy weight. ©Dreamstime*

Variety involves eating different foods from all the food groups. Eating a varied diet helps to ensure that you receive all the nutrients necessary for a healthy diet. 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 afford you lasting health benefits.

Table 2.22 Food Choices for a Healthful Diet[2]

Grain	**Whole-grain products**: brown rice, quinoa, barley, buckwheat, millet, wild rice, oats, rye berries, sorghum, bulgur, kasha, farrow, wheat berries, corn, amaranth, spelt
Vegetable	**Dark green:** broccoli, collards, kale, romaine lettuce, spinach, turnip greens, watercress
	Red and orange: Acorn squash, butternut squash, carrots, pumpkin, red peppers, sweet potatoes
	Beans and peas: Black beans, black-eyed peas, chickpeas, kidney beans, lentils, navy beans, pinto beans, soybeans, split peas, white beans
	Starchy: Cassava, green bananas, green peas, green lima beans, plantains, potatoes, taro, water chestnuts
	Other vegetables: Asparagus, avocado, bean sprouts, beets, Brussels sprouts, cabbage, cauliflower, celery, eggplant, green beans, green peppers, mushrooms, okra, onions, parsnips
Fruit	apples, apricots, bananas
	Berries: strawberries, blueberries, raspberries, cherries, grapefruit, kiwi fruit, lemons, limes, mangoes
	Melons: cantaloupe, honey dew, watermelon
	Other fruits: nectarines, oranges, peaches, pears, papaya, pineapple, plums, prunes
Dairy	all fluid milk (fat free, low-fat, reduced-fat, whole milk, lactose-free), fortified soy milk, yogurt
	Hard natural cheeses: cheddar, mozzarella, Swiss, parmesan
	Soft cheeses: ricotta, cottage cheese
Protein	**Meats:** beef, ham, lamb, pork, veal
	Poultry: chicken, goose, turkey, duck
	Eggs
	Beans and peas: (see vegetable section)
	Nuts and seeds: almonds, cashews, hazelnuts, peanuts, pecans, pistachios, pumpkin seeds, sesame seeds, sunflower seeds, walnuts
	Seafood: catfish, cod, flounder, haddock, halibut, herring, mackerel, pollock, porgy, salmon, sea bass, snapper, swordfish, trout, tuna
	Shellfish: scallops, mussels, crab, lobster

Notes

1. Source: US Department of Agriculture. “Food Groups.” http://www.choosemyplate.gov/food-groups/.
2. Source: Adapted from https://www.myplate.gov/eat-healthy/protein-foods.

2.3 Understanding the Bigger Picture of Dietary Guidelines

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The first US dietary recommendations were set by the National Academy of Sciences in 1941. The **recommended dietary allowances (RDA)** were first established out of concern that America's overseas World War II troops were not consuming enough daily nutrients to maintain good health. The first Food and Nutrition Board was created in 1941, and in the same year set recommendations for the adequate intakes of caloric energy and eight essential nutrients. These were disseminated to officials responsible for food relief for armed forces and civilians supporting the war effort. Since 1980, the **dietary guidelines** have been reevaluated and updated every five years by the advisory committees of the **US Department of Agriculture (USDA)** and the US Department of Health and Human Services (HHS). The guidelines are continually revised to keep up with new scientific evidence-based conclusions on the importance of nutritional adequacy and physical activity to overall health.

While dietary recommendations set prior to 1980 focused only on preventing nutrient inadequacy, the current dietary guidelines have the additional goals of promoting health, reducing chronic disease, and decreasing the prevalence of overweight and obesity.

Establishing Human Nutrient Requirements for Worldwide Application

The United Nations (UN) and the World Health Organization (WHO) work together to establish human nutrient requirements that apply worldwide. The WHO's Department of Nutrition for Health and Development, in collaboration with the Food and Agriculture Organization of the United Nations (FAO), continually reviews new research and information from around the world on human nutrient requirements and recommended nutrient intakes. This is a vast and never-ending task, given the large number of essential human nutrients. These nutrients include protein, energy, carbohydrates, fats and lipids, a range of vitamins, and a host of minerals and trace elements.

Many countries rely on WHO and FAO to establish and disseminate this information, which they adopt as part of their national dietary allowances. Others use it as a base for their standards. The establishment of human nutrient requirements is the common foundation for all countries to develop food-based dietary guidelines for their populations.

Establishing requirements means that the public health and clinical significance of intake levels – both deficiency and excess – and associated disease patterns for each nutrient, need to be thoroughly reviewed for all age groups. Every ten to fifteen years, enough research is completed and new evidence accumulated to warrant WHO and FAO undertaking a revision of at least the major nutrient requirements and recommended intakes.[1]

Why Are Guidelines Needed?

Instituting nation-wide standard policies provides consistency across organizations and allows health-care workers, nutrition educators, school boards, and eldercare facilities to improve **nutrition** and subsequently the health of their respective populations. At the same time, the goal of the Dietary Guidelines is to provide informative guidelines that will help any interested person in obtaining optimal nutritional balance and health. The seventh edition of the Dietary Guidelines was released in 2010 and focused mainly on combating the obesity epidemic. Former USDA secretary Tom Vilsack said, "The bottom line is that most Americans need to trim their waistlines to reduce the risk of developing diet-related chronic disease. Improving our eating habits is not only good for every individual and family, but also for our country." The 2015 Dietary Guidelines focus on eating patterns, which may be predictive of overall health status and disease risk. The Dietary Guidelines were formulated by the Food and Nutrition Board of the Institute of Medicine (IOM), which has recently changed their name to the National Academy of Medicine (NAM). These guidelines are from the review of thousands of scientific journal articles by a consensus panel consisting of more than two thousand nutrition experts with the overall mission of improving the health of the nation[2].

Major Themes of the 2015 Dietary Guidelines[3]

Consume a healthy eating pattern that accounts for all foods and beverages within an appropriate calorie level. A healthy eating pattern 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, 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
- A limited amount of healthy oils

A healthy eating pattern limits:

- Saturated fats and trans fats, added sugars, and sodium
- Cholesterol, in order to limit saturated fats.

Previously, the recommendation for cholesterol was less than 300 mg/day of cholesterol for the general public, and less than 200 mg/day for those with cardiovascular disease risk. The 2015 Dietary Guidelines recommends consuming as little dietary cholesterol as possible rather than quantifying it because someone consuming a diet according to the recommendations would consume around 100-300 mg daily and because dietary cholesterol does not impact blood cholesterol levels as much as previously believed. The reason for consuming as little cholesterol as possible is because many (but not all) foods that have cholesterol also have saturated fat.

Key Recommendations that are quantitative are provided for several components of the diet that should be limited. These components are of particular public health concern in the United States, and the specified limits can help individuals achieve healthy eating patterns within calorie limits:

- Consume less than 10 percent of calories per day from added sugars
- Consume less than 10 percent of calories per day from saturated fats

- Consume less than 2,300 milligrams (mg) per day of sodium

If alcohol is consumed, it should be consumed in moderation—up to one drink per day for women and up to two drinks per day for men—and only by adults of legal drinking age.

High consumptions of certain foods, such as those high in saturated or trans fat, sodium, added sugars, and refined grains may contribute to the increased incidence of chronic disease. Additionally, excessive consumption of these foods replaces the intake of more nutrient-dense foods.

The average person consumes 3,400 milligrams of sodium per day, mostly in the form of table salt. The Dietary Guidelines recommend that Americans reduce their daily sodium intake to less than 2,300 milligrams. If you are over the age of fifty-one, are African American, or have cardiovascular risk factors, such as high blood pressure or diabetes, sodium intake should be reduced even further to 1,500 milligrams. The Dietary Guidelines also recommend that less than 10 percent of calories come from saturated fat, and that fat calories should be obtained by eating foods high in unsaturated fatty acids. The Dietary Guidelines stress the importance of limiting the consumption of foods with refined grains and added sugars, and introduce the new term, SoFAS, which is an acronym for solid fats and added sugars, both of which should be consumed in moderation in a healthy diet[4].

Notes

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2. Johnson TD. Online Only: New Dietary Guidelines Call for Less Salt, Fewer Calories, More Exercise. Nation's Health. March 2011; 41(2), E6. http://thenationshealth.aphapublications.org/content/41/2/E6.full. Accessed November 22, 2017. Key Recommendations: Components of Healthy Living Patterns. Dietary Guidelines 2015-2020. https://health.gov/dietaryguidelines/2015/guidelines/chapter-1/key-recommendations/. Published 2015. Accessed November 22, 2017.
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4. Nelson, J. and K. Zeratsky. Dietary Guidelines Connect SoFAS and Weight Gain. Mayo Clinic, Nutrition-Wise (blog). http://www.mayoclinic.com/health/dietary-guidelines/MY01417. [inactive] Published August 25, 2010. Accessed November 22, 2017.

2.4 National Goals for Nutrition and Health: Healthy People 2030

Video Link: Healthy People 2030

Every ten years, the U.S. Department of Health and Human Services has used public health data to establish a set of objectives and tools aimed towards improving the health and well-being of all Americans. Healthy People 2030, launched in 2020, is the fifth iteration of this program and has been updated to include new health concerns, such as vaping and Covid-19.

Similar to the Dietary Guidelines, the Healthy People program has been established to promote longer lives free of preventable disease, disability, injury, and premature death. The stated mission of Healthy People 2030 is "to promote, strengthen, and evaluate the nation's efforts to improve the health and well-being of all people." The goals of the program are based on the following foundational principles:[1]

- The health and well-being of all people and communities is essential to a thriving, equitable society.
- Promoting health and well-being and preventing disease are linked efforts that encompass physical, mental, and social health dimensions.
- Investing to achieve the full potential for health and well-being for all provides valuable benefits to society.
- Achieving health and well-being requires eliminating health disparities, achieving health equity, and attaining health literacy.
- Healthy physical, social, and economic environments strengthen the potential to achieve health and well-being.
- Promoting and achieving health and well-being nationwide is a shared responsibility that is distributed across the national, state, tribal, and community levels, including the public, private, and not-for-profit sectors.
- Working to attain the full potential for health and well-being of the population is a component of decision-making and policy formulation across all sectors.

The Healthy People program takes into consideration the circumstances in which people are born, live, work, and age. It also reflects the conditions that shape their circumstances such as money, power, and resources at the local, national, and global levels. Social determinants of health are primarily accountable for the lack of fair health opportunities and the unjust differences in health status that exist within and between countries.[2] The social determinants of health included in Healthy People 2030 include: economic stability, education access and quality, health care access and quality, neighborhood and built environment, and social and community context. To learn more about these social determinants of health, visit the following website: https://health.gov/healthypeople/objectives-and-data/social-determinants-health or view the "Determinants of Health" video link below.

Helping People Make Healthy Choices

It is not just ourselves, the food industry, and federal government that shape our choices of food and physical activity, but also our sex, genetics, disabilities, income, religion, culture, education, lifestyle, age, and environment. All of these factors must be addressed by organizations and individuals that seek to make changes in dietary habits. The socioeconomic model incorporates all of these factors and is used by health-promoting organizations, such as the USDA and the HHS to determine multiple avenues through which to promote healthy eating patterns, to increase levels of physical activity, and to reduce the risk of chronic disease for all Americans. Lower economic prosperity influences diet specifically by lowering food quality, decreasing food choices, and decreasing access to enough food. As a result of the 2008 financial crisis in America the number of people who struggle to have enough to eat was rising and approaching fifty million. In response to these numbers, then-USDA Secretary Tom Vilsack said, "These numbers are a wake-up call…for us to get very serious about food security and **hunger**, about nutrition and food safety in this country."[3]

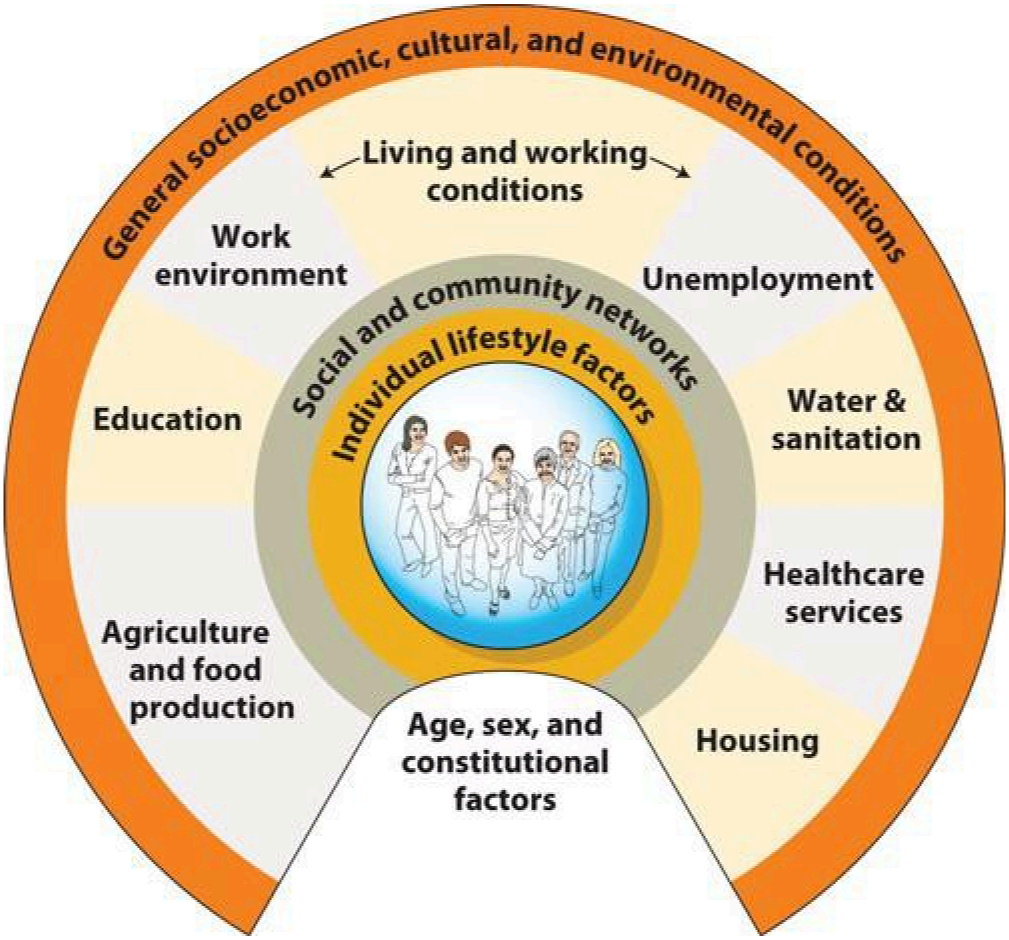

Figure 2.41 *The socioeconomic model helps organizations and the government to plan and promote effective healthy-eating programs tailored to specific populations. ©Networkgraphics*

Video Link: Healthy People 2020 – Determinants of Health

Goals for Nutrition and Weight Status

While Healthy People 2030 has many goals and objectives, we are going to focus on the two goals related to nutrition and weight status. They are to promote health and reduce the risk of developing chronic diseases by encouraging Americans to consume healthful diets and to achieve and maintain healthy body weights. Specific objectives of Healthy People 2030 are based on solid scientific research into what behaviors and programs improve individual health and well-being. Emphasis is on modifying individual behavior patterns and habits, and having policies and environments that will support these behaviors in various settings, such as schools, work, and local community-based organizations.

Figure 2.42 *One of the ways that Healthy People 2030 strives to promote good health and nutrition is by bringing together multiple agencies and groups dedicated to achieving the Healthy People 2030 nationwide objectives. ©Shutterstock*

Healthy People 2030 has defined the following broad, overarching goals:[4]

- Attain healthy, thriving lives and well-being free of preventable disease, disability, injury, and premature death.
- Eliminate health disparities, achieve health equity, and attain health literacy to improve the health and well-being of all.
- Create social, physical, and economic environments that promote attaining the full potential for health and well-being for all.
- Promote healthy development, healthy behaviors, and well-being across all life stages.
- Engage leadership, key constituents, and the public across multiple sectors to take action and design policies that improve the health and well-being of all.

Figure 2.43 *Consuming nutrient-dense foods and limiting portion sizes of food will contribute to weight management. Avoiding excessive amounts of anything allows room for many food types in the diet. ©Dreamstime*

The program has identified the following key nutrition-related recommendations:

- Consume a variety of nutrient-dense foods within and across the food groups, especially whole grains, fruits, vegetables, low-fat or fat-free milk or milk products, and lean meats and other protein sources
- Limit the intake of saturated fat and trans fats, cholesterol, added sugars, sodium (salt), and alcohol
- Limit caloric intake to meet caloric needs.[5]

Tools for Change

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.

Benefits of Following the Healthy People 2020 Goals

Nutrition and weight status are important to children's growth and development. In addition, healthy eating habits will decrease risks for developing chronic health conditions such as obesity, malnutrition, anemia, cardiovascular disease, high blood pressure, dyslipidemia (poor lipid profiles), Type 2 diabetes, osteoporosis, dental disease, constipation, **diverticular disease**, and certain types of **cancer**.[6]

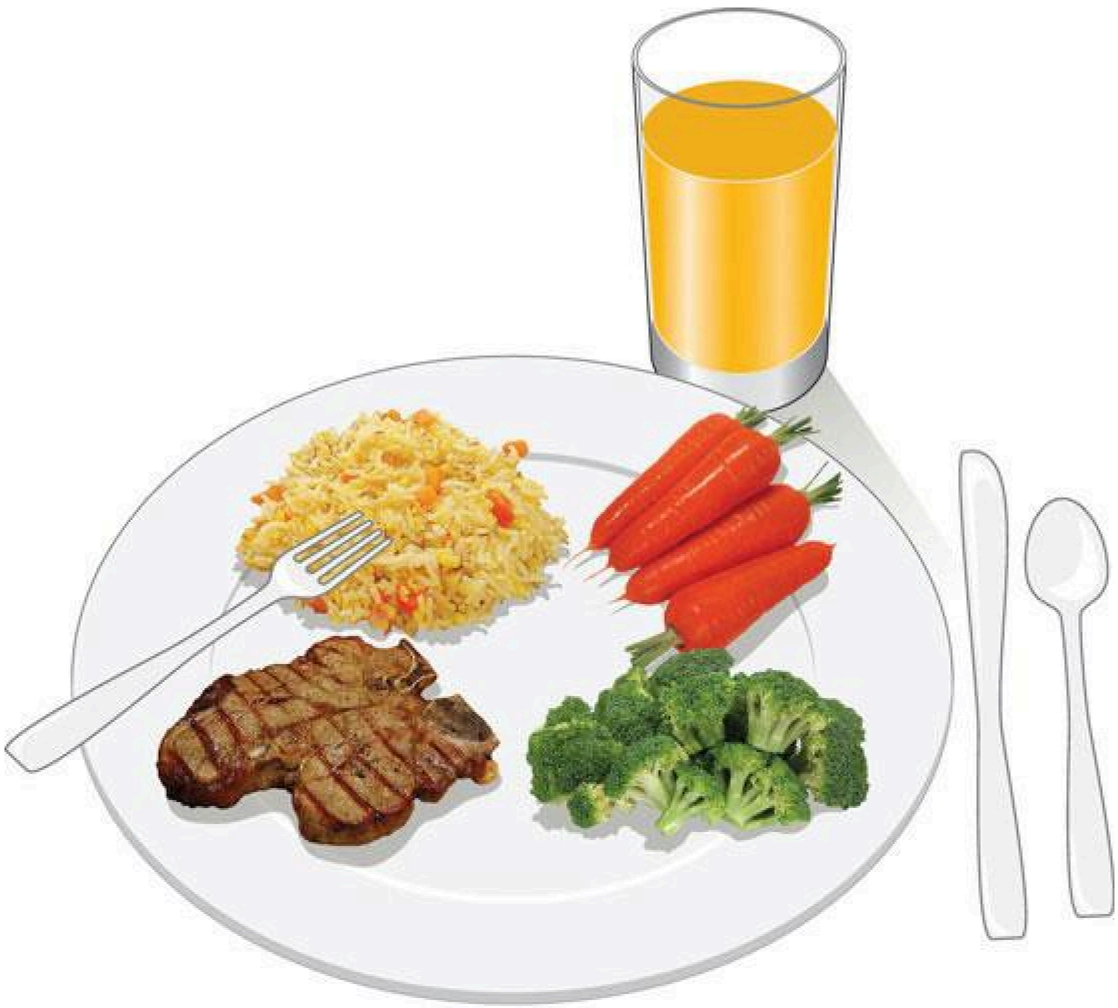

Figure 2.44 *Following the Dietary Guidelines will promote nutrition, weight loss, and weight maintenance as well as the reduction of chronic disease. © Networkgraphics*

Meeting the recommended intake for energy needs by adopting a balanced eating regimen as promoted by the USDA's My Food Plate tool will assist people in losing and maintaining weight and in improving overall health.

Objectives Related to the Healthy People 2030 Goals

Some of the objectives related to nutrition include: reducing food insecurity; increasing consumption of fruits, vegetables, and whole grains; and decreasing consumption of saturated fats and added sugars. Other objectives focus on specific micronutrients, such as increasing potassium and vitamin D consumption, decreasing sodium consumption, and reducing iron deficiency. Healthy People 2030 also focuses on preventing diseases related to nutrition and obesity, such as type 2 diabetes and cardiovascular disease. If you'd like to explore the other goals and objectives of this program, you can go to the following website: https://health.gov/healthypeople/objectives-and-data/browse-objectives.

Seven out of every ten deaths in the United States are caused by chronic diseases, such as heart disease, cancer, and diabetes, and three-quarters of the country's health spending goes toward the cost of treating these diseases. Helping people lose weight, maintain a healthy weight, and prevent chronic disease by improving dietary habits requires providing education about food and nutrition, assuring access to healthier food options, and promoting the desire and ability to become physically active. Some of the Healthy People 2030 program's specific related objectives are discussed below.

- **Improve health, fitness, and quality of life through daily physical activity.**[7] The Healthy People 2030 objectives for physical activity are based on the *Physical Activity Guidelines for Americans*, and reflect the strong scientific evidence supporting the benefits of physical activity. More than 80 percent of the current US population, from youth to adults, is not meeting these guidelines. Healthy People 2030 aims to increase the number of people of all ages who do both aerobic and muscle-strengthening activity. Other specific objectives include increasing the use of walking or bikes to get places, increasing participation in sports, and decreasing screen time for children and adolescents. The program also aims to increase institutional support for physical activity by increasing physical activity in child care centers, physical education in schools, and increase offerings of employee physical activity programs at workplaces. Understanding that personal, social, economic, and environmental barriers to physical activity all have a part in determining a population's physical activity level, is an important part of being able to provide interventions that foster physical activity. Consistent physical activity is necessary for preventing chronic disease, improving bone health, decreasing body fat, and preventing an early death.

- **Improve health by promoting healthy eating and making nutritious foods available.**[8] Improving healthy eating includes ensuring that everyone has access to healthy foods and that people make healthy choices for what they eat. Healthy People 2030 defines food insecurity as "the disruption of food intake or eating patterns because of lack of money and other resources."[9] Approximately 11 percent of households in the U.S. were food insecure in 2018.[10] Healthy People 2030 aims to reduce food insecurity, with a particular emphasis on children. Part of the plan for improving access to food includes increasing participation in **school breakfast** and summer food service programs. Specific objectives related to making healthy food choices include increasing consumption of fruits, vegetables, and whole grains; and decreasing consumption of saturated fats and added sugars. Other objectives focus on specific micronutrients, such as increasing consumption of potassium, calcium, and vitamin D; decreasing sodium consumption; and reducing iron deficiency. Healthy People also aims to increase breastfeeding of infants, reduce the availability of unhealthy foods and drinks in schools, and increase the number of employee nutrition programs offered at worksites.
- **Reduce overweight and obesity by helping people eat healthy and get physical activity.**[11] In addition to the physical activity and healthy eating objectives discussed above, one of the goals of Healthy People 2030 is to reduce obesity in children, adolescents, and adults. The program aims to increase the proportion of individuals who are at a healthy weight before becoming pregnant, to reduce negative outcomes associated with being overweight or underweight during **pregnancy**. Healthy People 2030 also focuses on preventing diseases related to nutrition and obesity, such as type 2 diabetes and cardiovascular disease.

Figure 2.45 *Healthy children will lead to a healthy adult population with less disease, lower healthcare costs, and increased longevity. © Shutterstock*

If you would like to look through all objectives related to Healthy People 2030, including those that are not directly related to nutrition, go to the website: https://health.gov/healthypeople/objectives-and-data/browse-objectives. You can read through objectives related to specific health concerns, populations, settings, and social determinants of health.

Notes

1. US Department of Health and Human Services. "Healthy People 2030 Framework." https://health.gov/healthypeople/about/healthy-people-2030-framework
2. World Health Organization. "Social Determinants of Health." © 2012. http://www.who.int/social_determinants/en/.
3. Amy Goldstein, "Hunger a Growing Problem in America, USDA Reports," *Washington Post*, 17

November 2009. http://www.washingtonpost.com/wp-dyn/content/article/2009/11/16/AR2009111601598.html.

4. https://health.gov/healthypeople/about/healthy-people-2030-framework
5. US Department of Health and Human Services. “Nutrition and Weight Status.” HealthyPeople.gov. Last updated May 1, 2012. http://healthypeople.gov/2020/topicsobjectives2020/overview.aspx?topicid=29
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10. https://health.gov/healthypeople/objectives-and-data/browse-objectives/nutrition-and-healthy-eating/reduce-household-food-insecurity-and-hunger-nws-01
11. https://health.gov/healthypeople/objectives-and-data/browse-objectives/overweight-and-obesity

2.5 Recommendations for Optimal Health

For many years, the US government has been encouraging Americans to develop healthful dietary habits. In 1992, the food pyramid was introduced, and in 2005 it was updated. This was the symbol of healthy eating patterns for all Americans. However, some felt it was difficult to understand, so in 2011, the pyramid was replaced with ChooseMyPlate.

The ChooseMyPlate program uses a tailored approach to give people the needed information to help design a healthy diet. The plate is divided according to the amount of food and nutrients you should consume for each meal. Each food group is identified with a different color, showing the food variety that all plates must have. Aside from educating people about the type of food that is best to support optimal health, the new food plan offers the advice that it is okay to enjoy food, just eat less of it.[1]

Video Link: Introducing the New Food Icon: MyPlate

Building a Healthy Plate: Choose Nutrient-Rich Foods

Planning a healthy diet using the MyPlate approach is not difficult. According to the icon, half of your plate should have fruits and vegetables, one-quarter should have whole grains, and one- quarter should have protein. Dairy products should be low-fat or non-fat. The ideal diet gives you the most nutrients within the fewest calories. This means choosing nutrient-rich foods.

Fill half of your plate with red, orange, and dark green vegetables and fruits, such as kale, collard greens, tomatoes, sweet potatoes, broccoli, apples, oranges, grapes, bananas, blueberries, and strawberries in main and side dishes. Vary your choices to get the benefit of as many different vegetables and fruits as you can. You may choose to drink fruit juice as a replacement for eating fruit. (As long as the juice is 100 percent fruit juice and only half your fruit intake is replaced with juice, this is an acceptable exchange.) For snacks, eat fruits, vegetables, or unsalted nuts.

Fill a quarter of your plate with whole grains such as 100 percent whole-grain cereals, breads, crackers, rice, and pasta. Half of your daily grain intake should be whole grains. Read the ingredients list on food labels carefully to determine if a food is comprised of whole grains.

Identify which vegetables and fruits are in season and local to your area. By consuming in- season, local foods you cut down on transportation costs (emission and financial) and you are likely to get fresher produce. You also support your local farms by purchasing their produce.

Figure 2.51 *Make sure at least half of your daily grain intake comes from whole-grain foods. © Shutterstock*

Select a variety of protein foods to improve nutrient intake and promote health benefits. Each week, be sure to include a nice array of protein sources in your diet, such as nuts, seeds, beans, legumes, poultry, soy, and seafood. The recommended consumption amount for seafood for adults is two 4-ounce servings per week. When choosing meat, select lean cuts. Be conscious to prepare meats using little or no added saturated fat, such as butter.

Figure 2.52 *Remember to vary your selections of protein. Lentils contain good amounts of protein and make great meals. Try using lentils or beans as a meat substitute each week. ©Thinkstock*

If you enjoy drinking milk or eating milk products, such as cheese and yogurt, choose low-fat or nonfat products. Low-fat and nonfat products contain the same amount of calcium and other essential nutrients as whole-milk products, but with much less fat and calories. Calcium, an important mineral for your body, is also available in lactose-free and fortified soy beverage and rice beverage products. You can also get calcium in vegetables and other fortified foods and beverages.

Oils are essential for your diet as they contain valuable essential fatty acids, but the type you choose and the amount you consume is important. Be sure the oil is plant-based rather than based on animal fat. You can also get oils from many types of fish, as well as avocados, and unsalted nuts and seeds. Although oils are essential for health, they do contain about 120 calories per tablespoon. It is vital to balance oil consumption with total caloric intake. The **Nutrition Facts label** provides the information to help you make healthful decisions.

In short, substituting vegetables and fruit in place of unhealthy foods is a good way to make a nutrient-poor diet healthy again. Vegetables are full of nutrients and antioxidants that help promote good health and reduce the risk for developing chronic diseases such as stroke, heart disease, high blood pressure, Type 2 diabetes, and certain types of cancer. Regularly eating fresh fruits and vegetables will boost your overall health profile.

Discretionary Calories

When following a balanced, healthful diet with many nutrient-dense foods, you may consume enough of your daily nutrients before you reach your daily calorie limit. The remaining calories are discretionary (to be used according to your best judgment). To find out your discretionary calorie allowance, add up all the calories you consumed to achieve the recommended nutrient intakes and then subtract this number from your recommended daily caloric allowance. For example, someone who has a recommended 2,000-calorie per day diet may eat enough nutrient-dense foods to meet requirements after consuming only 1,814 calories. The remaining 186 calories are discretionary. These calories may be obtained from eating an additional piece of fruit, adding another teaspoon of olive oil on a salad or butter on a piece of bread, adding sugar or honey to cereal, or consuming an alcoholic beverage.[2]

The amount of discretionary calories increases with physical activity level and decreases with age. For most physically active adults, the discretionary calorie allowance is, at most, 15 percent of the recommended caloric intake. By consuming nutrient-dense foods, you afford yourself a discretionary calorie allowance.

Table 2.51 Sample Menu Plan Containing 2,000 Calories

Meal	Calories	Total Meal/Snack Calories
Breakfast		
1 scrambled egg	92	
with sliced mushrooms and spinach	7	
½ whole-wheat muffin	67	
1 tsp. margarine-like spread	15	
1 orange	65	
8 oz. low-sodium tomato juice	53	299
Snack		
6 oz. fat-free flavored yogurt	100	
with ½ c. raspberries	32	132
Lunch		
1 sandwich on pumpernickel bread	160	
with smoked turkey deli meat,	30	
4 slices tomato	14	
2 lettuce leaves	3	
1 tsp. mustard	3	
1 oz. baked potato chips	110	
½ c. blueberries, with 1 tsp. sugar	57	
8 oz. fat-free milk	90	467
Snack		
1 banana	105	
7 reduced-fat high-fiber crackers	120	225
Dinner		
1 c. Greek salad (tomatoes, cucumbers, feta)	150	
with 5 Greek olives,	45	
with 1.5 tsp. olive oil	60	

Meal	Calories	Total Meal/Snack Calories
3 oz. grilled chicken breast	150	
½ c. steamed asparagus	20	
with 1 tsp. olive oil,	40	
with 1 tsp. sesame seeds	18	
½ c. cooked wild rice	83	
with ½ c. chopped kale	18	
1 whole-wheat dinner roll	4	
with 1 tsp. almond butter	33	691
Total calories from all meals and snacks = 1,814	**Discretionary calorie allowance: 186**	

Healthy Eating Index

To assess whether the American diet is conforming to the 2010 *Dietary Guidelines*, the Center for Nutrition Policy and Promotion (CNPP), a division of the USDA, uses a standardized tool called the **Healthy Eating Index (HEI)**.[3] The first HEI was developed in 1995 and revised in 2006.

This tool is a simple scoring system of dietary components. The data for scoring diets is taken from national surveys of particular population subgroups, such as children from low-income families or Americans over the age of sixty-five. Diets are broken down into several food categories including milk, whole fruits, dark green and orange vegetables, whole grains, and saturated fat, and then a score is given based on the amount consumed. For example, a score of ten is given if a 2,000-kilocalorie diet includes greater than 2.6 cups of milk per day. If less than 10 percent of total calories in a diet are from saturated fat, a score of eight is given. All of the scores are added up from the different food categories and the diets are given a HEI score. Using this standardized diet-assessment tool at different times, every ten years for instance, the CNPP can determine if the eating habits of certain groups of the American population are getting better or worse. The HEI tool provides the federal government with information to make policy changes to better the diets of American people. For more information on the HEI, visit this website: https://www.fns.usda.gov/resource/healthy-eating-index-hei.

Notes

1. US Department of Agriculture. Accessed July 22, 2012. http://www.choosemyplate.gov/.
2. US Department of Agriculture. "MyPyramid Education Framework." Accessed July 22, 2012. http://www.choosemyplate.gov
3. US Department of Agriculture. "Healthy Eating Index." Last modified March 14, 2012. https://www.fns.usda.gov/resource/healthy-eating-index-hei.

2.6 Understanding Dietary Reference Intakes

Dietary Reference Intakes (DRI) are the recommendation levels for specific nutrients and consist of a number of different types of recommendations. The link below takes you to the tables that many people commonly associate with the DRIs, but the DRIs are more than just numbers in a table.

Web Link: DRI Summary Tables

The Dietary Guidelines discussed in section 2.3 provide **qualitative** advice to the public about diet and chronic disease prevention and maintaining health. The Dietary Reference Intakes provide **quantitative** advice to professionals about amounts of nutrients or food components that are found in a healthy diet.

Dietary 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] DRIs are important not only to help the average person determine whether their intake of a particular nutrient is **adequate**, they are also used by health-care professionals and policy makers to determine nutritional recommendations for special groups of people who may need help reaching nutritional goals. This includes people who are participating in programs such as the Special Supplemental Food Program for Women, Infants, and Children. The DRI is not appropriate for people who are ill or malnourished, even if they were healthy previously.

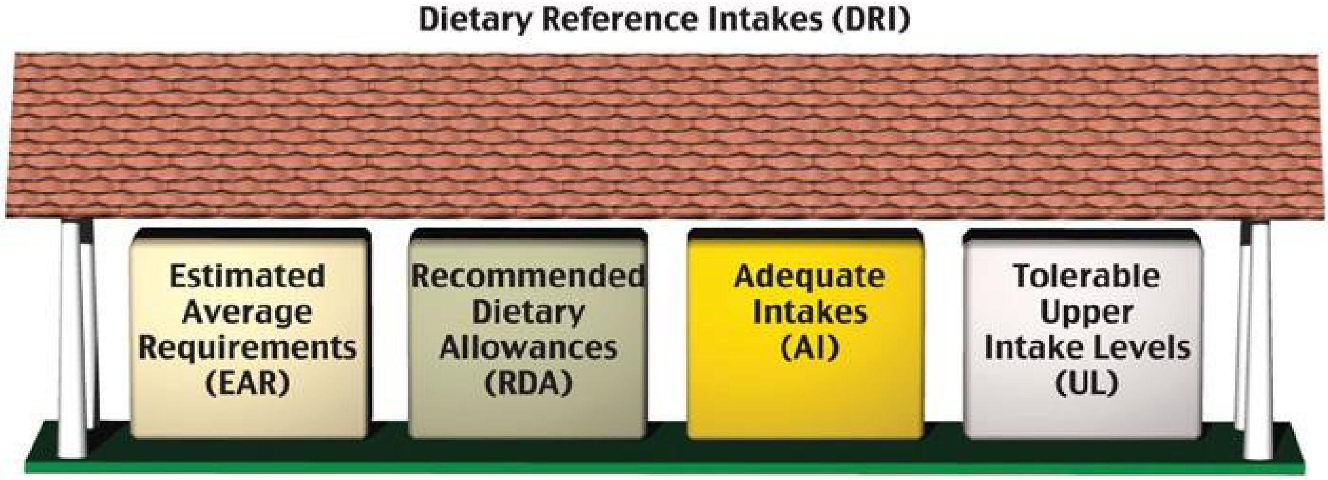

Figure 2.61 *The DRIs include all four reference values. ©Networkgraphics*

Determining Dietary Reference Intakes

Each DRI value is derived in a different way.

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

Recommended Daily Allowances. 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 the RDA meets 97 to 98 % of the populations' needs, 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.

Adequate Intake. 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.

Tolerable Upper Intake Levels. 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.

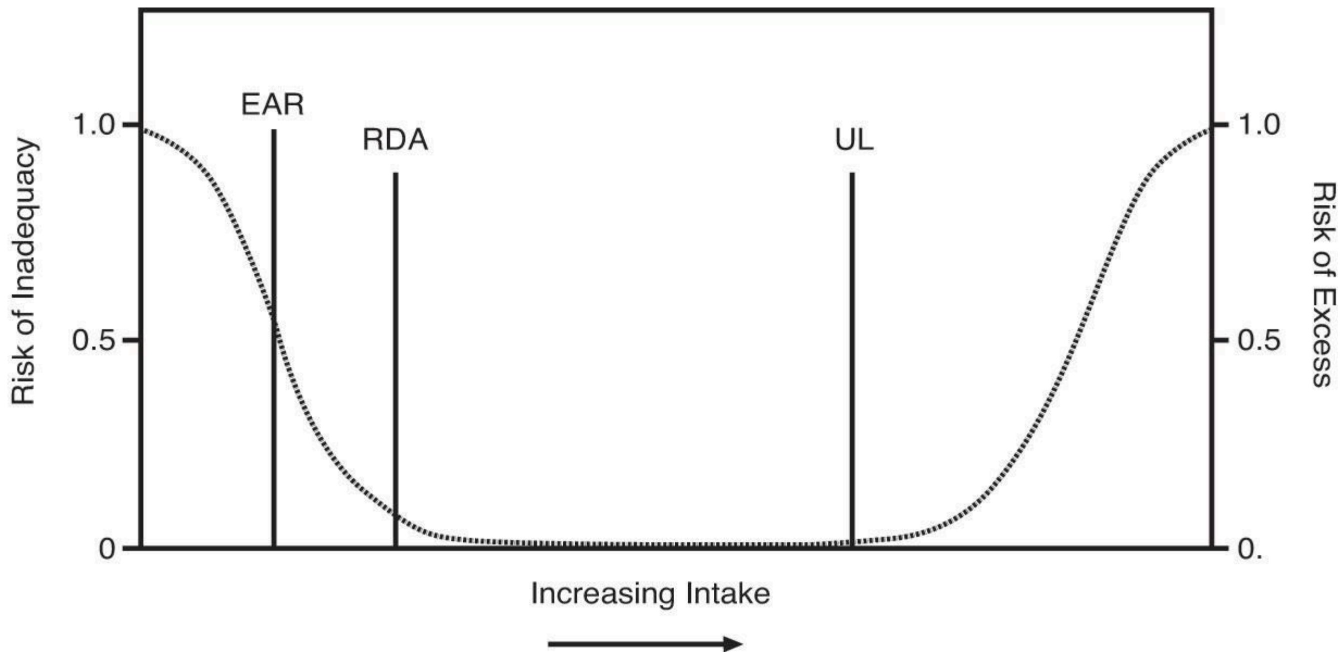

Figure 2.62 *DRI Graph, showing relationship of EAR, RDA, and UL to risk of inadequacy or excess of a micronutrient. Credit: Institute of Medicine. © 2012 National Academy of Sciences. All Rights Reserved. http://www.nam.edu*

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.

Other Quantitative Dietary Recommendations

Acceptable Macronutrient Distribution Ranges

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. People who do not reach the AMDRs for their target group increase their risk of developing health complications.

Table 2.61 AMDR Values for Adults[2]

Nutrient	Value (percentage of Calories)
Fat	20.0–35.0
Carbohydrate	45.0–65.0
Protein	10.0–35.0
Polyunsaturated fatty acids	5.0–10.0
Linolenic acid	0.6–1.2

Estimated Energy Requirement

Estimated Energy Requirement (EER) is the estimated number of calories needed to maintain caloric balance. Using weight as a reference, this means you are taking in no more calories, and also no fewer calories, than are needed to maintain that exact weight. To gain weight, you'd need to consume more than your EER, and to lose weight you'd need to consume less than your EER. Unlike some of the other DRIs, EER is individual-specific and is based on calculations that take into account multiple variables, including an individual's energy intake, energy expenditure, age, sex, weight, height, and physical activity level[3]. We'll discuss EER more in chapter 9, when we talk about energy balance.

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. In addition, the values are meant to assess and plan average intake over time; that is, you do not need to meet these recommendations every single day—meeting them on average over several days is sufficient.

Requirements vs. Recommendations

It's important to understand that the DRIs are set to protect the health of a whole population. A single individual's dietary needs may be higher or lower than the DRI. This is why the DRIs are *recommendations*, not requirements. 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.

Nevertheless, if you are consuming the RDA (or AI) for a nutrient, on average, you can be reasonably sure (97-98% sure) that you're getting an adequate amount of that nutrient.

Notes

1. Health Canada. "Using the Dietary Reference Intakes." https://www.canada.ca/en/health-canada/services/food-nutrition/healthy-eating/dietary-reference-intakes/using-dietary-reference-intakes.html
2. 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. (Washington, DC: National Academies Press, 2002).
3. Gerrior, S., Juan, W., & Peter, B. 2006. An Easy Approach to Calculating Estimated Energy Requirements. *Preventing Chronic Disease*, 3(4), A129

2.7 Discovering Nutrition Facts

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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 the United States, the Nutrition Labeling and Education Act passed in 1990 and came into effect in 1994. In Canada, mandatory labeling came into effect in 2005. As a result, all packaged foods sold in the United States and 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.

In May, 2016 a new Nutrition Facts label for packaged foods was announced. This label reflects new scientific information and will make it easier for consumers to make informed food choices. Some of the changes made to the label include:

- Increased type size for "Calories," "servings per container," and "Serving size"
- Bolded type for the number of calories and the "Serving size"
- Actual amounts of vitamin D, calcium, iron, and potassium (in addition to the **Daily Value** amounts) are required to be listed. Vitamins A and C are now voluntary.
- Improved footnote to better explain the Daily Value
- "Added sugars" in grams and percent Daily Value are required to be listed due to scientific data the impact of added sugars on caloric intake
- "Total Fat," "Saturated Fat," "Trans Fat," "Cholesterol," "Total Carbohydrates" are still required on the label
- "Calories from fat" has been removed because the type of fat is important
- Updated values for sodium, dietary fiber, and vitamin D (which are all required on the label) based on newer scientific research
- Updated serving sizes that reflect how much consumers are more likely eating today
- Some packages with serving sizes between one and two are required to be labelled

as one serving since most consumers will likely eat it in one sitting

- Dual columns for certain products that are larger than a single serving but could be consumed in one sitting will indicate “per serving” and “per package” amounts
- The compliance date for manufacturers to adopt the new label is July 26, 2018. Manufacturers with less than $10 million in annual food sales will have until 2019.

Reading the Label

The first part of the Nutrition Facts panel gives you information on the serving size and how many servings are in the container. For example, a label on a box of crackers might tell you that twenty crackers equals one serving and that the whole box contains 10 servings. All other values listed thereafter, from the calories to the dietary fiber, are based on this one serving, so you need to know how many servings you will be eating. 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 food label in Figure 2.71 “Reading the Nutrition Label,” the percent DV of calcium for one serving is 25 percent, which means that one serving of this food (frozen lasagna) provides 25 percent of the daily recommended calcium intake. Since the DV for calcium is 1,300 milligrams, the food producer determined the percent DV for calcium by taking the calcium content in milligrams in each serving, and dividing it by 1,300 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 frozen lasagna, look at the percent DV for fat, which is 12 percent, and subtract it from 100 percent. To know this amount in grams of fat, you can look up the recommended daily value of fat in Table 2.71 and multiply the percentage by the maximum amount of fat recommended per day in the Daily Value. 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.

Along with the updated nutrition label, the FDA calculated new Daily Values for many nutrients, based on updated nutrition research. For some nutrients, such as calcium, fiber, and total fat, the recommended amount was increased. For other nutrients, such as sodium and the B vitamins, the recommended daily value was decreased. If you'd like to know more about these changes you can visit the following website: **Daily Value on the New Nutrition and Supplement Facts Labels**.

Table 2.71 Daily Values Based on a Caloric Intake of 2,000 Calories (For Adults and Children Four or More Years of Age), updated[1]

Food Component	Daily Value (DV)
Total Fat	78 grams (g)
Saturated Fat	20 g
Cholesterol	300 milligrams (mg)
Sodium	2,300 mg
Potassium	4,700 mg
Total Carbohydrate	275 g
Dietary Fiber	28 g
Protein	50 g
Vitamin A	900 micrograms (µg) RAE (retinol activity equivalents)
Vitamin C	90 mg
Calcium	1,300 mg
Iron	18 mg
Vitamin D	20 µg
Vitamin E	15 mg alpha-tocopherol
Vitamin K	120 µg
Thiamin	1.2 mg
Riboflavin	1.3 mg
Niacin	16 mg NE (niacin equivalents)
Vitamin B6	1.7 mg
Folate	400 µg DFE (dietary folate equivalents)
Vitamin B12	2.4 µg
Biotin	30 µg
Pantothenic acid	5 mg
Phosphorus	1,250 mg
Iodine	150 µg
Magnesium	420 mg
Zinc	11 mg

Selenium	55 µg
Copper	0.9 mg
Manganese	2.3 mg
Chromium	35 µg
Molybdenum	45 µg
Chloride	2,300 mg

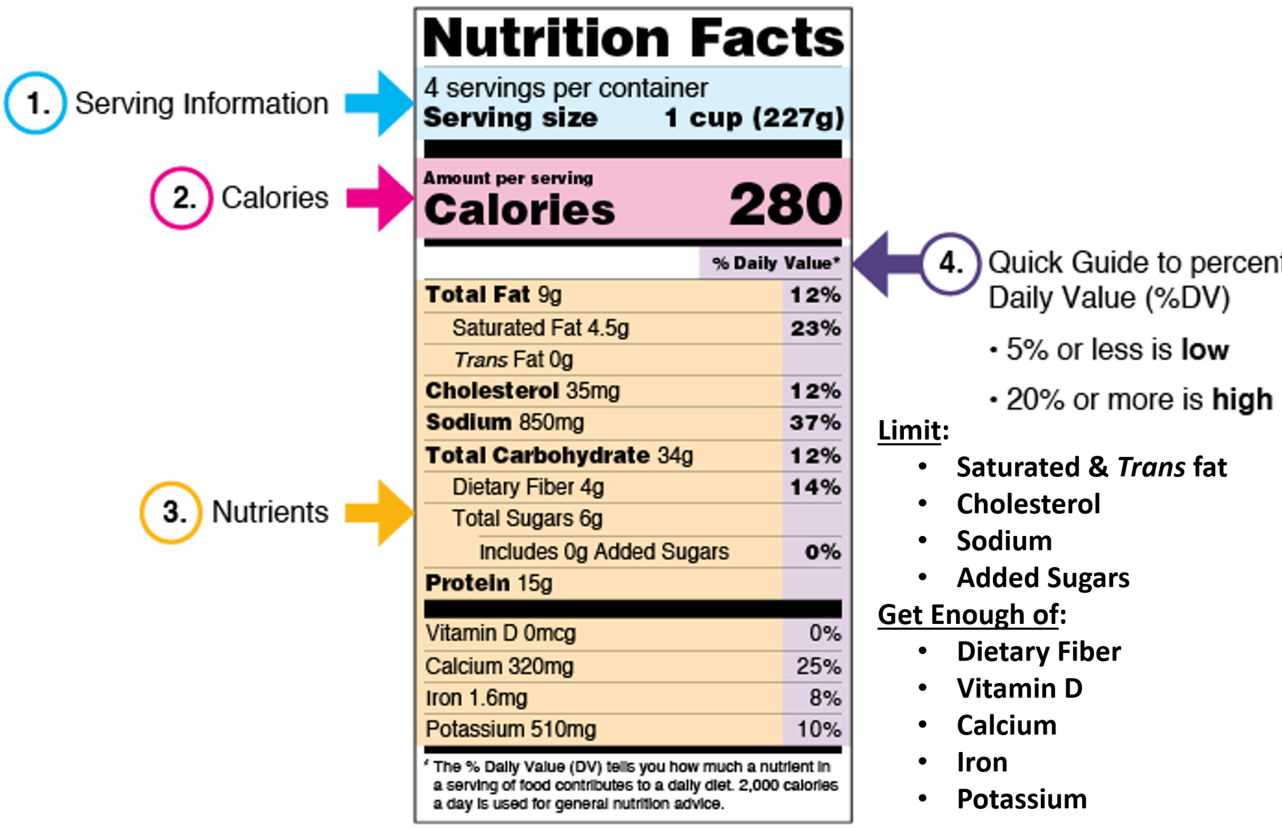

***Figure 2.71** Reading the Nutrition Label. A sample label for frozen lasagna. Source: How to Understand and Use the Nutrition Facts Panel. FDA. Updated March 2020. Accessed September 8, 2021.*

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 websites:

Web Links:

Interactive Nutrition Facts Label

Ingredient List

New Format for Nutrition Facts

The figures below summarize changes to the nutrition label that were finalized by the Food and Drug Administration (FDA) in 2016. As of 2021, all food manufacturers are required to use the new format. The FDA and companies are still working on compliance, so when you're looking for Nutrition Facts at the grocery store, you may occasionally still see the older version of the label. [2]

Figure 2.72 *The New Nutrition Facts Label*

Figure 2.73 *Food Serving Sizes*

There are other types of information that are required by law to appear somewhere on the consumer packaging. They include[3]:

- Name and address of the manufacturer, packager, or distributor
- Statement of identity, what the product actually is
- Net contents of the package: weight, volume, measure, or numerical count
- Ingredients, listed in descending order by weight

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.

According to the 2010 health and diet survey released by the FDA, 54 percent of first-time buyers of a product will check the food label and will use this information to evaluate fat, calorie, vitamin, and sodium content[4]. The survey also notes that more Americans are using food labels and are showing an increased awareness of the connection between diet and health. Having reliable food labels is a top priority of the FDA, which has a new initiative to prepare guidelines for the food industry to construct "front of package" labeling that will make it even easier for Americans to choose healthy foods. Stay tuned for the newest on food labeling by visiting the FDA website: http://www.fda.gov/Food/LabelingNutrition/default.htm.

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[5]. See Table 2.72 "Common Label Terms Defined" for some examples.

Table 2.72 Common Label Terms Defined[6]

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

Health Claims

Often we hear news of a particular nutrient or food product that contributes to our health or may prevent disease. A health claim is a statement that links a particular food with a reduced risk of developing disease. As such, health claims such as "reduces heart disease," must be evaluated by the FDA before it may appear on packaging. Prior to the passage of the NLEA products that made such claims were categorized as drugs and not food. All health claims must be substantiated by scientific evidence in order for it to be approved and put on a food label. To avoid having companies making false claims, laws also regulate how health claims are presented on food packaging. In addition to the claim being backed up by scientific evidence, it may never claim to cure or treat the disease. For a detailed list of approved health claims, and to learn more about this process, visit the websites below:

Web Links:

Health Claims that Meet the Significant Scientific Agreement Standard

Q&A on Health Claims in Food Labeling

Qualified Health Claims

While health claims must be backed up by hard scientific evidence, qualified health claims have supportive evidence, which is not as definitive as with health claims. The evidence may suggest that the food or nutrient is beneficial. Wording for this type of claim may look like this: "Consuming EPA and DHA combined may help lower blood pressure in the general population and reduce the risk of **hypertension**. However, FDA has concluded that the evidence is inconsistent and inconclusive. One serving of [name of food] provides [X] grams of EPA and DHA.[7]

Structure/Function Claims

Some companies claim that certain foods and nutrients have benefits for health even though no scientific evidence exists. In these cases, food labels are permitted to claim that you may benefit from the food because it may boost your immune system, for example. There may not be claims of diagnosis, cures, treatment, or disease prevention, and there must be a disclaimer that the FDA has not evaluated the claim[8].

Allergy Warnings

Food manufacturers are required by the FDA to list on their packages if the product contains any of the eight most common ingredients that cause food **allergies**. These eight common allergens are as follows: milk, eggs, peanuts, tree nuts, fish, shellfish, soy, and wheat. (More information on these allergens will be discussed in Chapter 9 "Energy Balance and Body Weight".) The FDA does not require warnings that cross contamination may occur during packaging, however most manufacturers include this advisory as a courtesy. For instance, you may notice a label that states, "This product is manufactured in a factory that also processes peanuts." If you have food allergies, it is best to avoid products that may have been contaminated with the allergen.

Notes

1. Source: FDA, https://www.fda.gov/food/new-nutrition-facts-label/daily-value-new-nutrition-and-supplement-facts-labels
2. https://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm385663.htm

3. Food Labeling. US Food and Drug Administration. https://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm385663.htm#highlights. Updated November 11, 2017. Accessed November 22, 2017.
4. Consumer Research on Labeling, Nutrition, Diet and Health. US Food and Drug Administration. https://www.fda.gov/food/foodscienceresearch/consumerbehaviorresearch/ucm275987.htm.Updated November 17, 2017.
5. Nutrient Content Claims. US Food and Drug Administration. https://www.fda.gov/food/ingredientspackaginglabeling/labelingnutrition/ucm2006880.htm. [inactive]Updated December 9, 2014. Accessed December 10, 2017.
6. Source: Food Labeling Guide. US Food and Drug Administration. http://www.fda.gov. Updated February 10, 2012. Accessed November 28, 2017.
7. FDA Announces New Qualified Health Claims for EPA and DHA Omega-3 Consumption and the Risk of Hypertension and Coronary Heart Disease. US Food and Drug Administration. https://www.fda.gov/food/cfsan-constituent-updates/fda-announces-new-qualified-health-claims-epa-and-dha-omega-3-consumption-and-risk-hypertension-and. Published June 19, 2019. Accessed August 31, 2020.
8. Claims That Can Be Made for Conventional Foods and Dietary Supplements. US Food and Drug Administration. https://www.fda.gov/food/food-labeling-nutrition/label-claims-conventional-foods-and-dietary-supplements. Updated September 2003. Accessed November 28,2017.

2.8 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.

The food industry makes following the 2010 *Dietary Guidelines* a challenge. In many restaurants and eating establishments, portion sizes have increased, use of fats and sugars has 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.

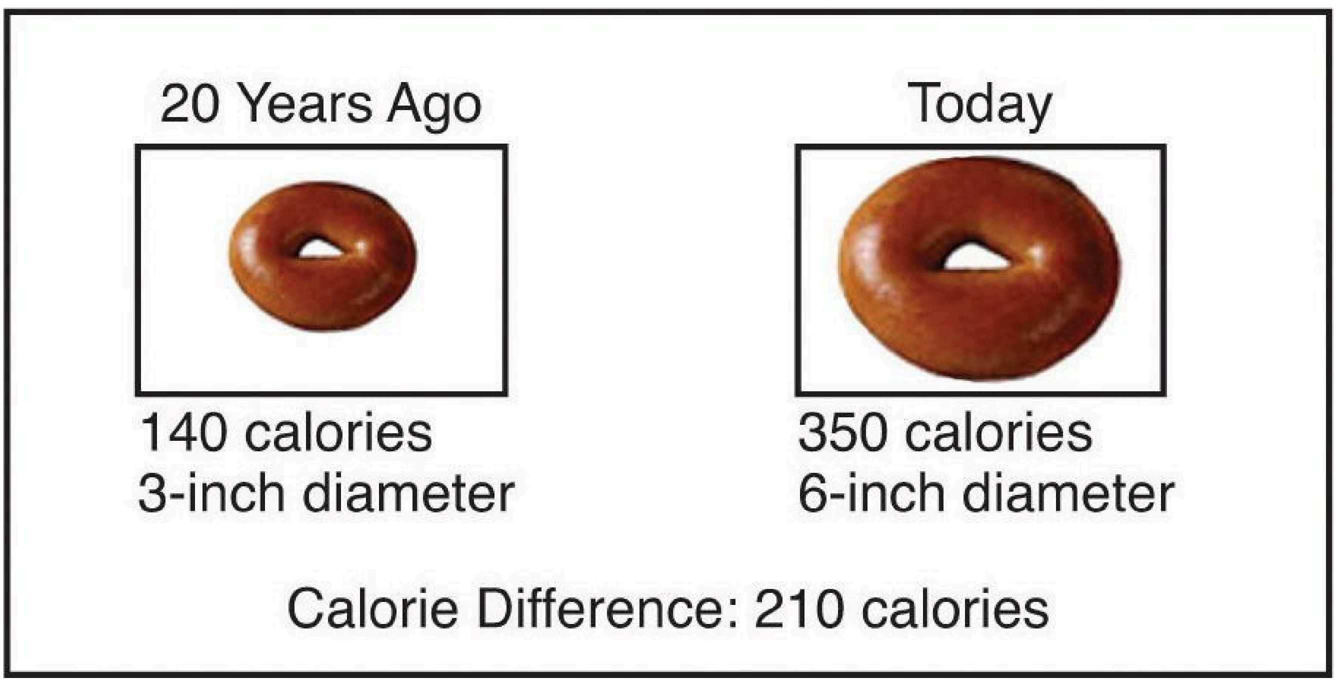

Figure 2.81 *As food sizes and servings increase, it is important to limit the portions of food consumed on a regular basis.*

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. See Table 2.81 "Determining Food Portions" for some examples.

Table 2.81 Determining Food Portions[1]

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

MyPlate Planner

Estimating portions can be done using the **MyPlate** Planner. Recall that the MyPlate symbol is divided according to how much of each food group should be included with each meal. Note the MyPlate Planner Methods of Use:

- Fill half of your plate with vegetables such as carrots, broccoli, salad, and fruit.
- Fill one-quarter of your plate with lean meat, chicken, or fish (about 3 ounces)
- Fill one-quarter of your plate with a whole grain such as ⅓ cup rice
- Choose one serving of dairy
- Add margarine or oil for preparation or addition at the table

Eating Interval and Portion Size

If you wait many hours between meals, there is a good chance you will overeat. If overeating at meals is something you struggle with, 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.

Notes

1. American Cancer Society. "Controlling Portion Sizes." Last revised January 12, 2012. http://www.cancer.org/Healthy/EatHealthyGetActive/TakeControlofYourWeight/controlling-portion-sizes

2.9 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. There are a few websites that can be consistently relied upon for accurate material that is updated regularly.

Figure 2.91 *Right information or wrong information? How can you know? ©Shutterstock*

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.

- The scientific study under discussion should be published in a peer-reviewed journal, such as the *Journal of the International Society of Sports Nutrition*. Question studies that come from less trustworthy sources (such as non peer-reviewed journals or websites) or that are not published.
- 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?
- 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.
- 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 gives you more confidence in it.
- Peer-reviewed articles deliver a broad perspective and are inclusive of findings of many studies on the exact same subject.
- 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:

- Who sponsors the website?
- Are names and credentials disclosed?
- Is an editorial board identified?
- Does the site contain links to other credible informational websites? 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?
- How often is the website updated?
- Are you being sold something at this website?
- Does the website charge a fee?

Trustworthy Sources

Now let us consider some reputable organizations and websites from which you can obtain valid nutrition information.

Organizations Active in Nutrition Policy and Research

- **US Department of Agriculture Food and Nutrition Information Center.** The USDA site https://www.nal.usda.gov/fnic has more than twenty-five hundred links to dietary, nutrition, diet and disease, weight and obesity, food-safety and food-labeling, packaging, dietary supplement and consumer questions sites. Using this interactive site, you can find tips and resources on how to eat a healthy diet, my Foodapedia, and a food planner, among other sections.
- **The Academy of Nutrition and Dietetics (AND).** The AND promotes scientific evidenced- based, research-supported food and nutrition related information on its website, http://www.eatright.org. It is focused on informing the public about recent scientific discoveries and studies, weight-loss concerns, food safety topics, nutrition issues, and disease prevention.
- **Department of Health and Human Services.** The HHS website, HealthFinder.gov, provides credible information about healthful lifestyles and the latest in health news. A variety of online tools are available to assist with food-planning, weight maintenance, physical activity, and dietary goals. You can also find healthful tips for all age groups, tips for preventing disease, and on daily health issues in general.
- **Centers for Disease Control and Prevention.** The Centers for Disease Control and Prevention (http://www.cdc.gov) distributes an online newsletter called *CDC Vital Signs*. This newsletter is a valid and credible source for up-to-date public health information and data regarding food, nutrition, cholesterol, high blood pressure,

obesity, teenage drinking, and tobacco usage.

- **Dietitians of Canada.** Dietitians of Canada, http://www.dietitians.ca/, is the national professional association for dietitians. It provides trusted nutrition information to Canadians and health professionals.
- **Health Canada.** Health Canada, http://www.hc-sc.gc.ca/index-eng.php, is the Federal department that helps Canadians improve their health. Its website also provides information about health-related legislation.

CHAPTER III

CHAPTER 3: NUTRIENTS IN THE BODY

You probably do not think too much about what actually happens to the food you eat after you eat it. This chapter will describe in depth how what you eat is digested. We'll start with an introduction to some basic biology of the body, and then take an in-depth tour through the digestive tract and its workings.

Sections:

Section 3.1: from Fialkowski Revilla, et al. *Human Nutrition*

Sections 3.2-3.7: from Jellum et al. *Principles of Nutrition*

3.1 Basic Biology, Anatomy, and Physiology

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In order to understand how our digestive system works, you first must understand a bit about the most basic unit of our bodies: the cell.

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. 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 3.11 "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.

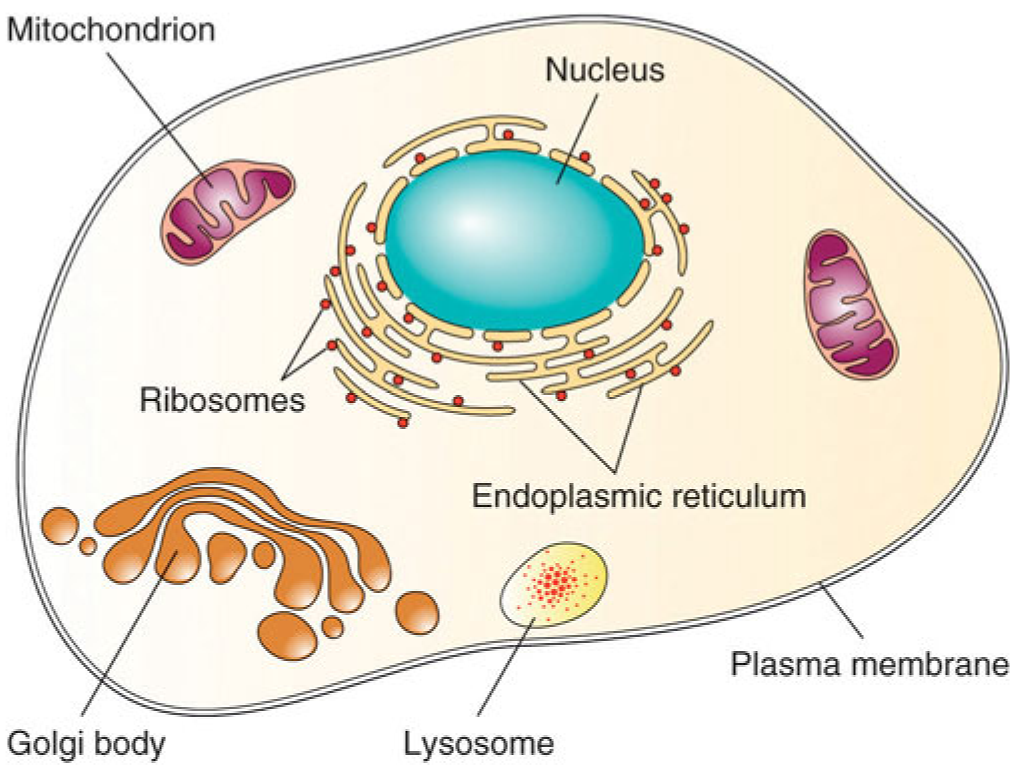

Figure 3.11 *The Cell Structure. The cell is structurally and functionally complex.*

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 3.12 "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 3.11 "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.

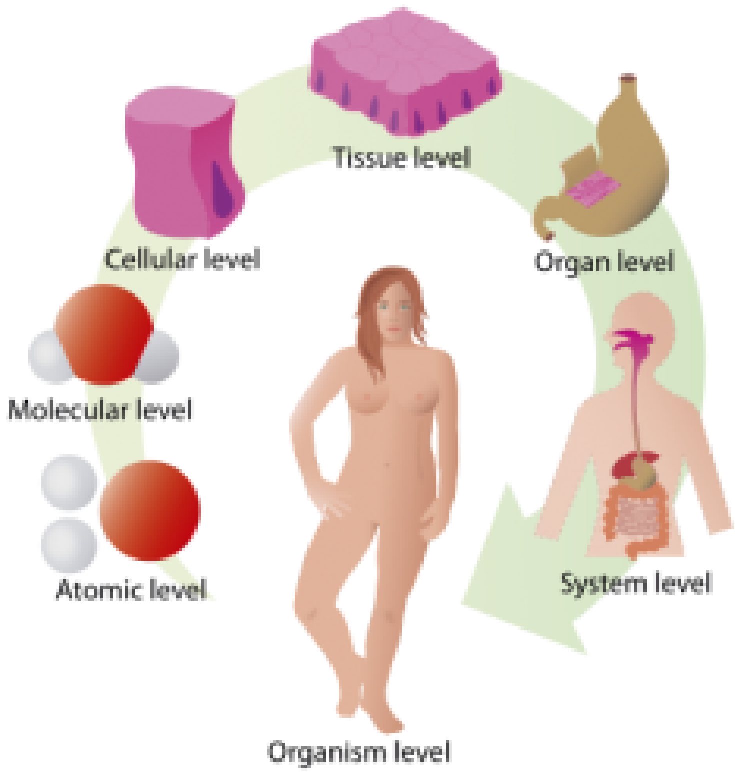

Figure 3.12 Organization of Life. "Organization Levels of Human Body" by Laia Martinez / CC BY-SA 4.0

Table 3.11 The 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
Lymphatic & 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

3.2 Digestive System Overview

A grain of rice is probably one of the smallest pieces of food you ever put in your mouth. But even that is about 250 times longer than one of your cells. So, how can your cells possibly use that grain of rice?

This is the first problem that your digestive system must solve if it's going to keep you supplied with essential nutrients.

The digestive system faces two major problems:

1. **Accessing nutrients.** The digestive system must break large food particles down into individual molecules that can be used by your cells. This process of breaking down food into its component parts is called **digestion**. Both chemical and mechanical break down occur in the digestive tract.
2. **Circulating nutrients to all the cells of the body.** It's not enough to have nutrients in your digestive tract; they must get to all the other cells of your body, too! **Absorption** is the process of getting nutrients from the digestive tract into the blood. Once in the blood, nutrients are transported throughout the body, to all of your cells.

Activities of the Digestive System

Digestion and absorption are the two main functions of the digestive system, but there are a lot of other activities involved that all work towards getting nutrients out of the food we eat and into our bloodstream:

Activities of the Digestive System

Ingestion: Intake of food (mouth)
Propulsion: Movement of food through GI tract
Mixing: Mixing food with digestive juices
Mechanical Digestion: Mechanical breakdown of food
Chemical Digestion: Enzymatic breakdown of food
Absorption: Uptake of nutrients from GI tract to blood or lymph
Defecation: Elimination of solid, indigestible waste

Propulsion

Propulsion is the act of moving something forward; in this case, moving food through the digestive tract. There are two main processes involved in propulsion: **swallowing** and **peristalsis**.

We're all familiar with swallowing. It's a voluntary movement that sends food out the back of our mouth and into the esophagus. Technically, swallowing is a reflex that we trigger by moving food to the back of our mouth with our tongues. Next time you're eating, I dare you to try to swallow without using your tongue.

Peristalsis refers to the waves of involuntary muscle contractions that move food through the lower digestive tract. Once food gets down to the lower esophagus, the walls of your digestive tract contract in a rolling wave that propels food through the stomach, small intestine, and large intestine. It's a bit like squeezing a baseball through a tube sock. When you squeeze the walls of the sock together, it pushes the baseball forward. Peristalsis is an involuntary motion, you can't consciously control it.

Mixing

It's vital to mix the foods you eat with the digestive juices. The digestive juices are the fluids secreted into your digestive tract that contain the digestive **enzymes**. Your tongue mixes food with saliva in your mouth. Your stomach, a very muscular organ, churns and pounds food intensively, turning the mushy ball of chewed food and saliva that you swallow into a creamy paste. In the small intestine, contractions occur that squeeze the contents of the intestine, mixing this paste with pancreatic juices and **bile** in a process called **segmentation.**

Mechanical and Chemical Digestion

There are two types of digestion in the body; mechanical and chemical. **Mechanical digestion** involves physically breaking food down into smaller pieces, usually through muscle contractions. The best example of this is chewing.

Chemical digestion uses digestive enzymes to break large food molecules into smaller nutrient molecules. This generally involves the breaking of chemical bonds.

The Digestive Tract

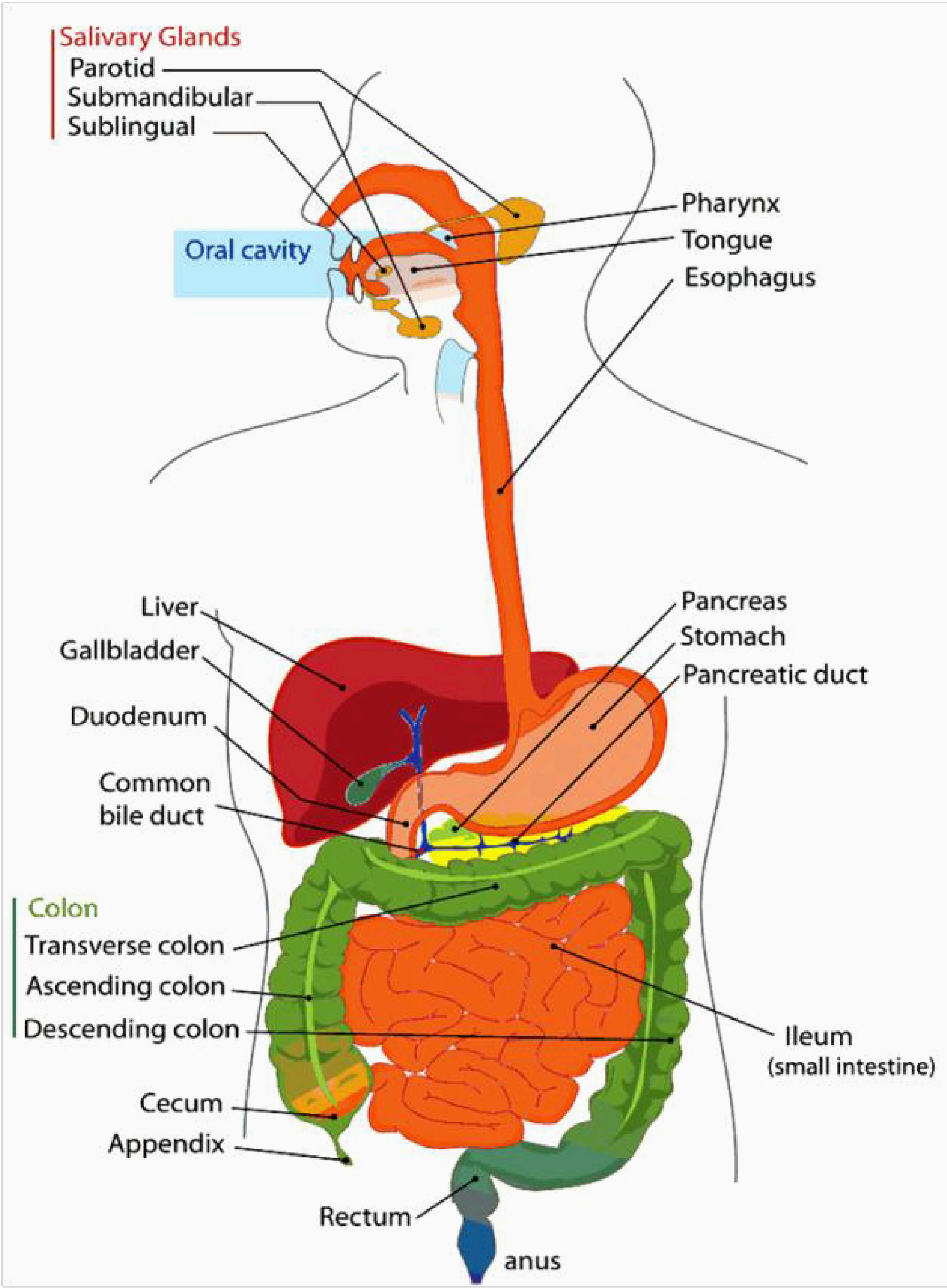

Figure 3.21 *A number of organs are involved in digestion, which collectively are referred to as the digestive system. Image source*

Video: Enzymes and Digestion

The **gastrointestinal (GI or digestive) tract**, the passageway through which our food travels, is a "tube within a tube." The trunk of our body is the outer tube and the GI tract is the interior tube, as shown below. Thus, even though the GI tract is within the body, the actual interior of the tract is technically outside of the body. This is because the contents have to be absorbed into the body. If it's not absorbed, it will be excreted and never enter the body itself. It's as if you never consumed it.

The organs that form the gastrointestinal tract (e.g., mouth, esophagus, stomach, small intestine, large intestine (aka colon), rectum, and anus) come into direct contact with the food or digestive contents.

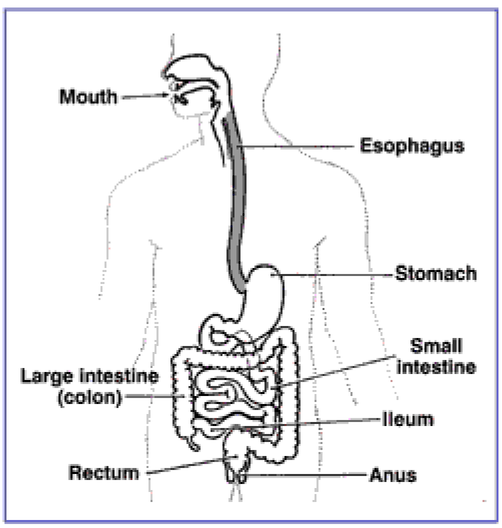

Figure 3.22 *The gastrointestinal or digestive tract. Image source*

The journey through the gastrointestinal tract starts in the mouth and ends in the anus as shown below:

Mouth –> Esophagus –> Stomach –> Small Intestine –> Large Intestine –> Rectum –> Anus

Sphincters

Sphincters are muscular openings that separate one compartment of the digestive tract from the next. These openings act as one-way valves. As a mass of food moves along, the sphincter closes behind it, ensuring that the food keeps moving forward through the digestive tract.

There are five sphincters in the digestive tract:

- **Upper esophageal sphincter:** Between the pharynx and esophagus
- **Lower esophageal (or gastroesophageal) sphincter:** Between the esophagus and stomach
- **Pyloric sphincter:** Between the stomach and the small intestine
- **Ileocecal valve:** Between the small intestine and the large intestine
- **Anus:** Between your digestive tract and the outside world

Accessory Organs

In addition to the GI tract, there are a number of **accessory organs** (e.g. **salivary glands**, pancreas, **gallbladder**, and liver) that play an integral role in digestion. The accessory organs do not come directly in contact with food or digestive contents, but still play a crucial role in the digestive process.

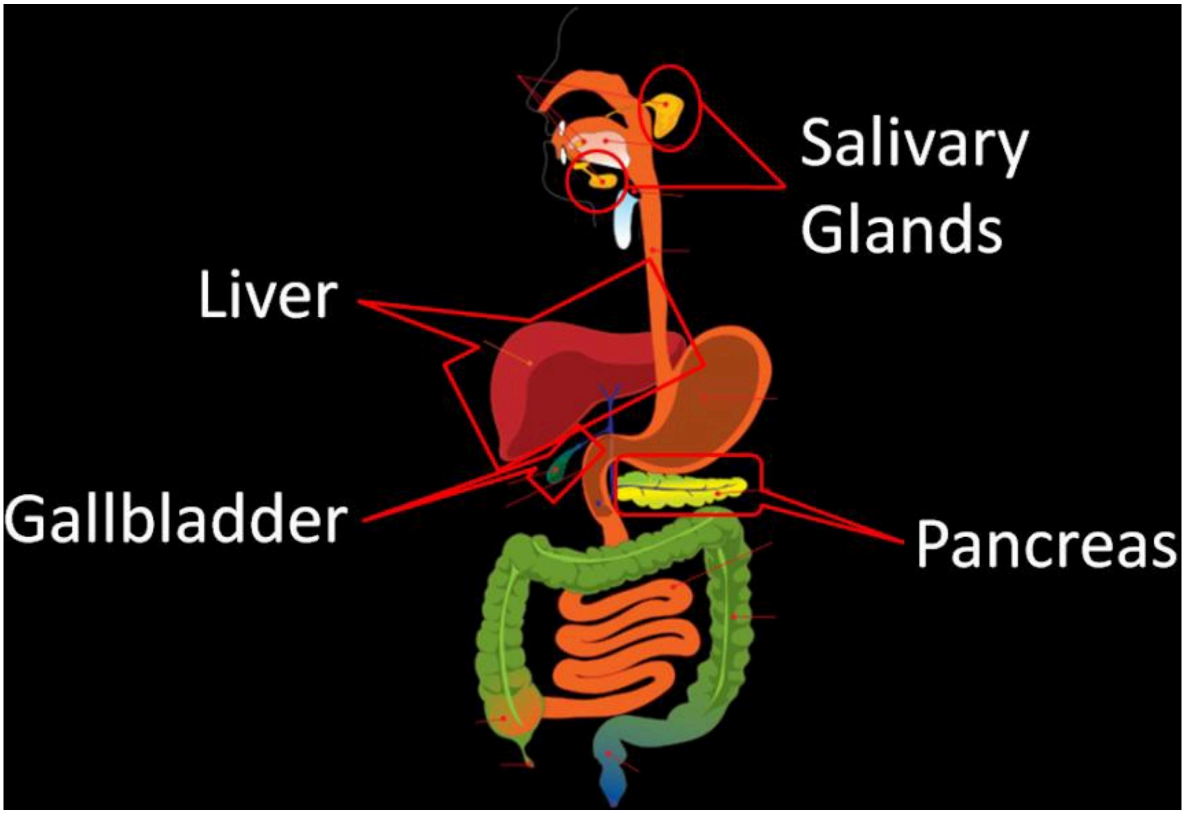

Figure 3.23 *Digestion accessory organs. Image source*

Digestive Enzymes

In addition to the digestive and accessory organs, there are a number of enzymes that are involved in digestion. We will go through each one in detail later, but this table should help give an overview of which enzymes are active at each location of the GI tract.

Table 3.21 Digestive enzymes

Location	Enzymes
Mouth	Salivary amylase Lingual lipase
Stomach	Pepsin
Small Intestine	Pancreatic amylase, Brush border disaccharidases Pancreatic lipase, Phospholipase A_2, Cholesterol esterase Proteases, Brush border peptidases

Sometimes the name of a digestive enzyme helps you remember what type of nutrient it acts on. For example, *lipases* break down *lipids*, *proteases* break down *proteins*, and *disaccharidases* break down *disaccharides*.

3.3 Mouth to the Stomach

Digestion begins in the mouth, both mechanically and chemically. Mechanical digestion in the mouth consists of mastication, or the chewing and grinding of food into smaller pieces. The salivary glands release saliva, mucus, and three enzymes: **salivary amylase**, **lingual lipase**, and **lysozyme**.

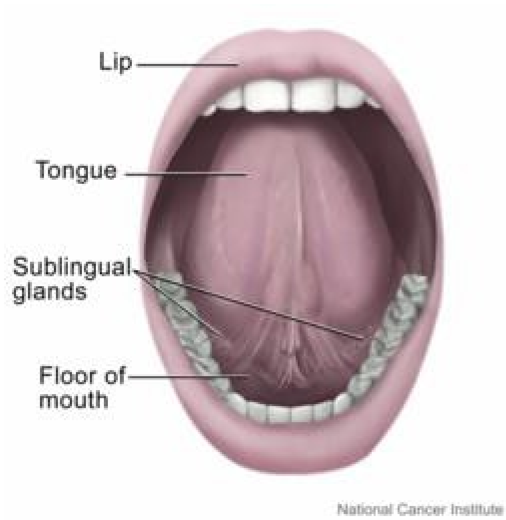

Figure 3.31 *The mouth. Credit: Alan Hoofring, Image source*

Salivary amylase cleaves the glycosidic bonds in the starch molecules, amylose and amylopectin. Overall however, this enzyme accounts for a minor amount of **carbohydrate** digestion.

Lysozyme helps break down bacteria cell walls to prevent a possible infection. Another enzyme, lingual lipase, is also released in the mouth. Although it is released in the mouth, it is most active in the stomach where it preferentially cleaves short-chain fatty acids. Lingual lipase has a small role in digestion in adults, but may be important for infants to help break down **triglycerides** in breast milk[1].

Swallowing (a.k.a Deglutition)

Now that the food has been thoroughly chewed and formed into a bolus (a small rounded mass of chewed food), it can proceed down the throat to the next stop in digestion. It will move down the pharynx where it reaches a "fork in the road", with the larynx as one road and the esophagus as the other. The esophagus road leads to the stomach; this is the direction that food should go (see Figure 3.32). The other road, through the larynx, leads to the trachea and ultimately the lungs. This is definitely not where you want your food or drink going, as this is the pathway for the air you breathe.

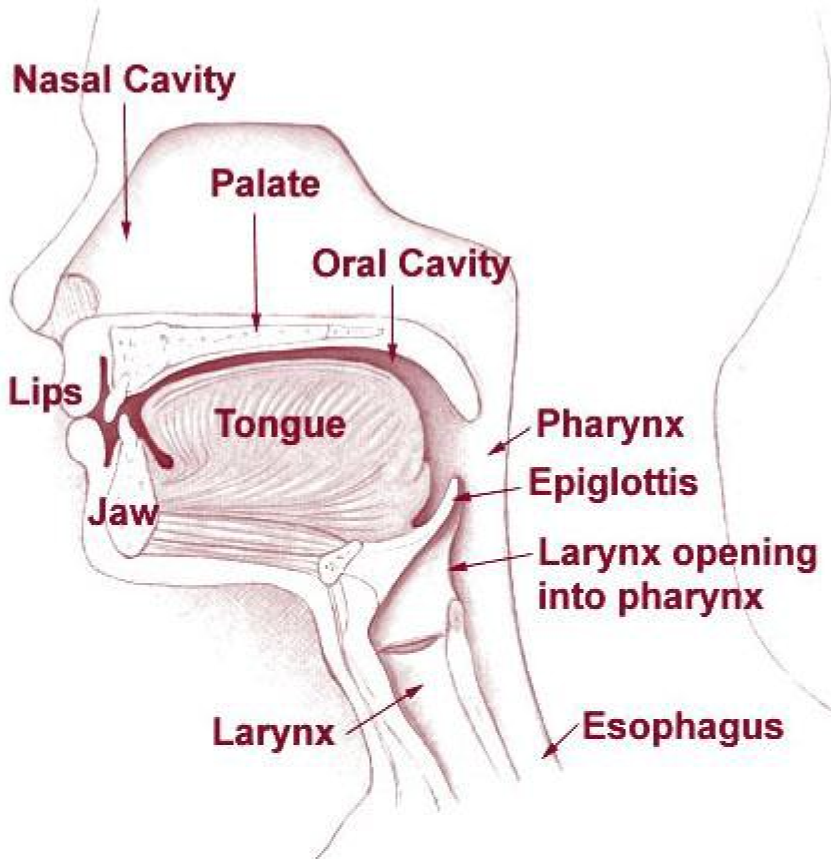

Figure 3.32 *Cross section of face. The epiglottis covers larynx to prevent food and drink from entering the lungs. Image source*

Fortunately, our body was designed in such a way that a small flap, called the epiglottis, covers the opening to the trachea during swallowing. It directs the food down the correct road as shown below.

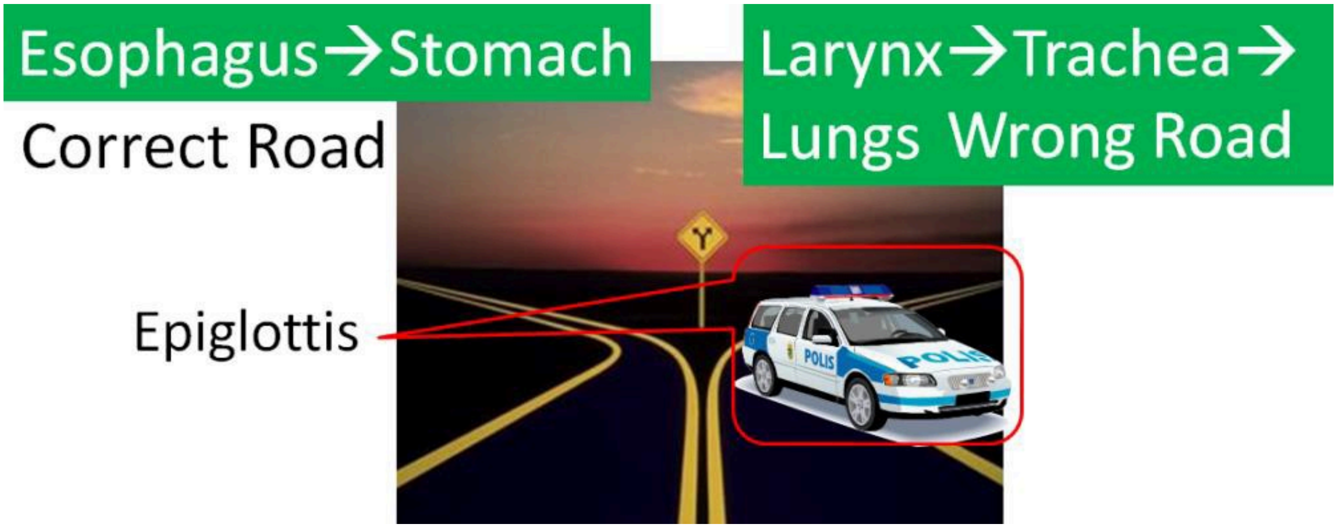

***Figure* 3.33** *Epiglottis is like a traffic cop guiding food down the correct digestion road.*

Esophagus

Before being correctly guided into the esophagus, the bolus of food will travel through the upper esophageal sphincter. Sphincters are circular muscles that are found throughout the gastrointestinal tract that essentially serve as gates between the different sections. Once in the esophagus, wave-like muscular movements, known as **peristalsis**, occur, as shown in the stomach at the link below. Peristalsis occurs throughout the digestive tract with the purpose of moving food along the tract.

Video Links:

Peristalsis Animation

Peristaltic Wave in the Stomach

At the end of the esophagus, the bolus will encounter the lower esophageal sphincter, also known as the cardiac sphincter due to its proximity to the heart. This sphincter keeps the harmful acids of the stomach out of the esophagus. However, in many people this sphincter is leaky, which allows stomach acid to reflux, or creep up, the esophagus. Stomach acid is very acidic (has a low pH). The ruler below will give you an idea of just how acidic the stomach is. Notice that the pH of gastric (term used to describe the stomach) fluid is lower (more acidic) than any of the listed items besides battery acid.

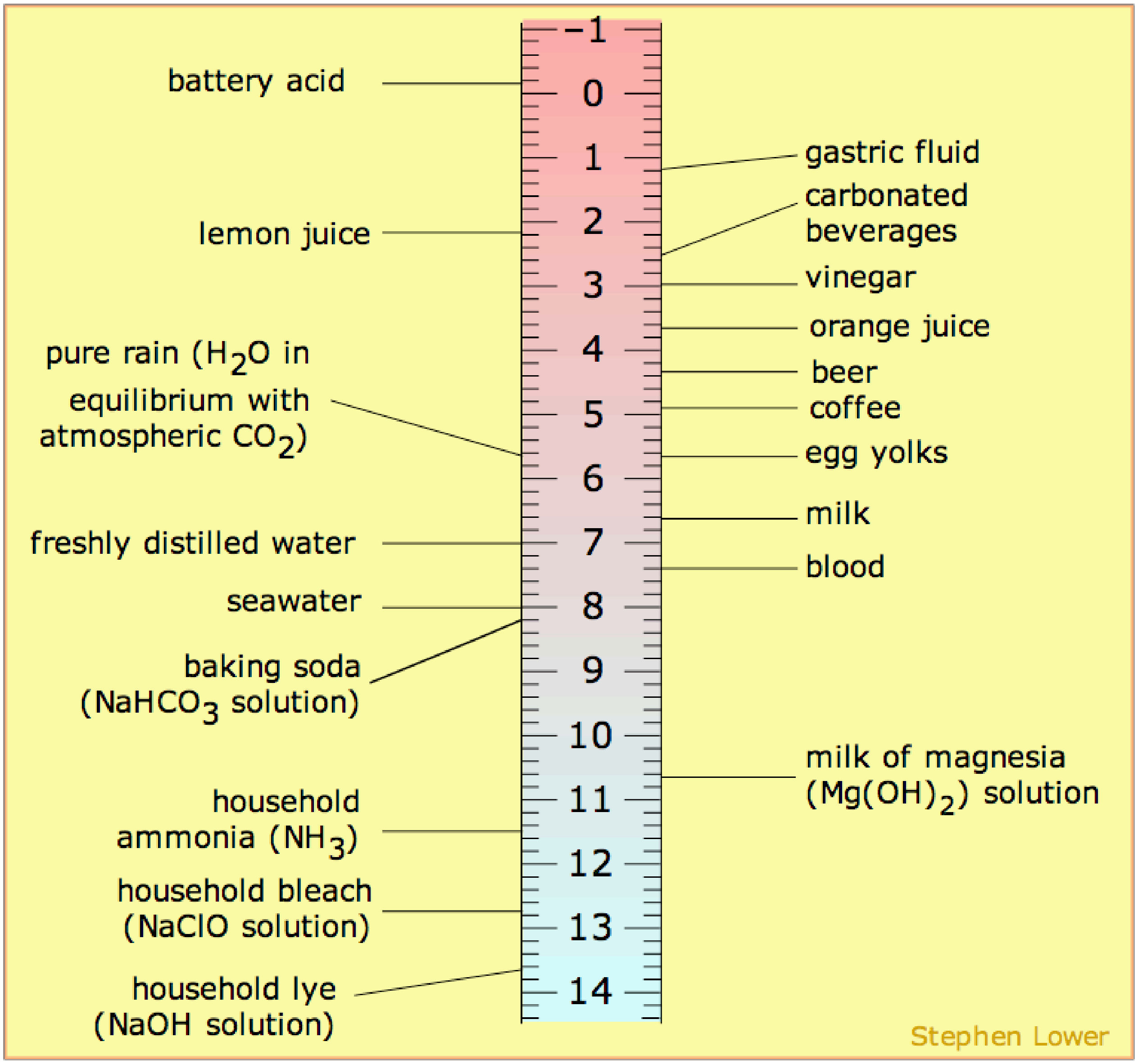

Figure 3.34 *pH of some common items Image Source*

The leaking of the very acidic gastric contents results in a burning sensation commonly referred to as "heartburn." If this occurs more than twice per week and is severe, the person may have **gastroesophageal reflux disease (GERD)**. The following videos explain more about these conditions.

Video Links:

Acid Reflux (1:28)

GERD 101 (0.55)

Table 3.31 Review of Chemical Digestion in the Mouth

Macronutrient	Enzyme Action
Carbohydrates	Salivary amylase cleaves glycosidic bonds
Lipids	Lingual lipase begins digestion of triglycerides
Protein	None

Notes

1. Shils ME, Shike M, Ross AC, Caballero B, Cousins RJ, editors. (2006) *Modern Nutrition in Health and Disease*. Baltimore, MD: Lippincott Williams & Wilkins.

3.4 Stomach

After going through the lower esophageal **sphincter**, food enters the stomach. Our stomach is involved in both chemical and mechanical digestion. Mechanical digestion occurs as the stomach churns and grinds food into a semisolid substance called **chyme** (partially digested food).

There are four main regions in the **stomach**: the cardia, fundus, body, and pylorus (see Figure 3.41 below). The **cardia** (or cardiac region) is the point where the esophagus connects to the stomach and through which food passes into the stomach. Located inferior to the diaphragm, above and to the left of the cardia, is the dome-shaped **fundus**. Below the fundus is the **body**, the main part of the stomach. The funnel-shaped **pylorus** connects the stomach to the duodenum. The wider end of the funnel, the **pyloric antrum**, connects to the body of the stomach. The narrower end is called the **pyloric canal**, which connects to the duodenum. The smooth muscle **pyloric sphincter** is located at this latter point of connection and controls stomach emptying. In the absence of food, the stomach deflates inward, and its mucosa and submucosa fall into a large fold called a **rugae**[1]. These rugae increase the surface area inside the stomach, which aids the digestive process.

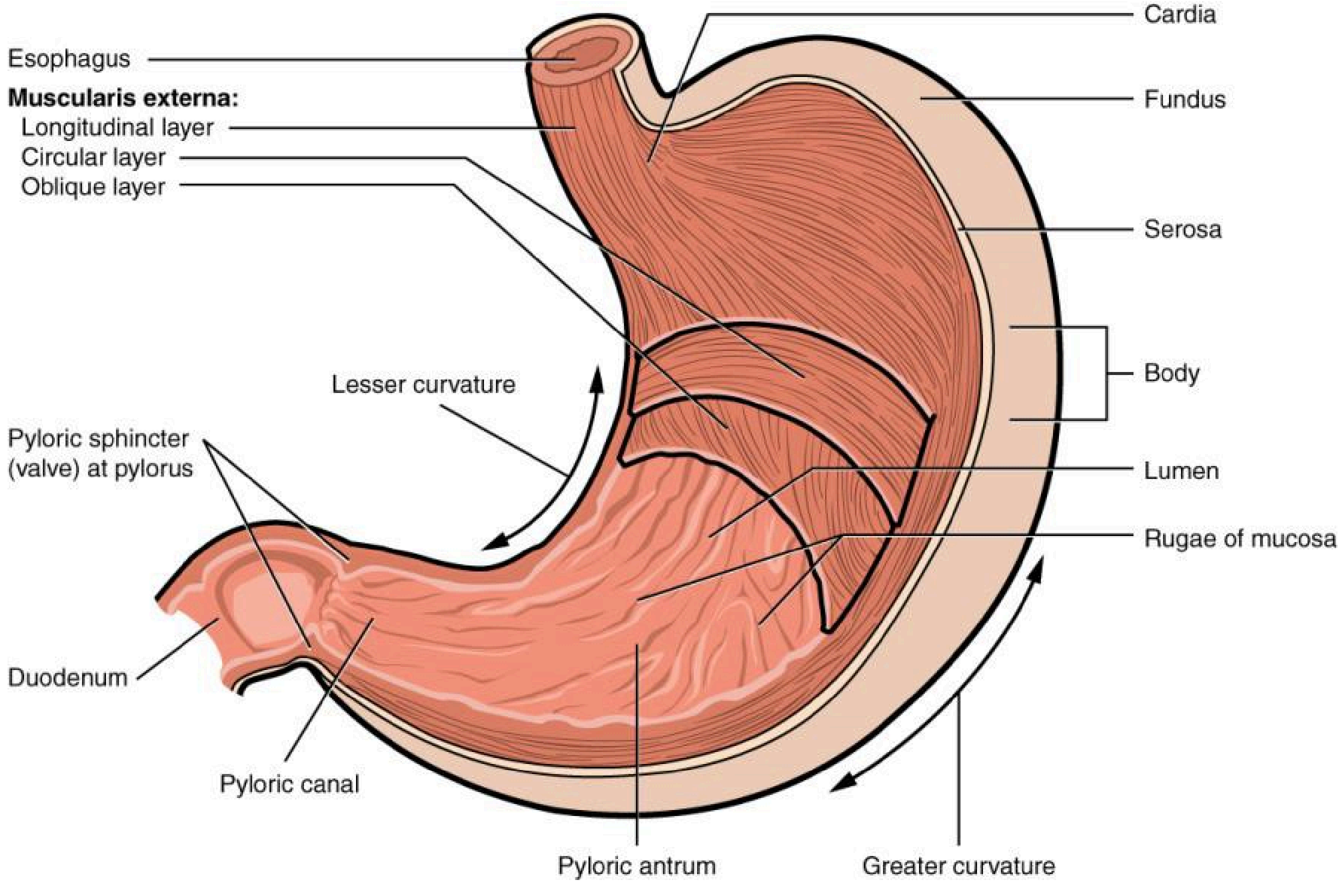

Figure 3.41 *The stomach has four major regions: the cardia, fundus, body, and pylorus. The addition of an inner oblique smooth muscle layer gives the muscularis the ability to vigorously churn and mix food. Image source*

The lining of the stomach is made up of four different layers of tissue. For the purposes of this discussion, we will focus on only the innermost layer. The **mucosa** is the innermost layer of the stomach (closest to stomach cavity) as shown in the figure below.

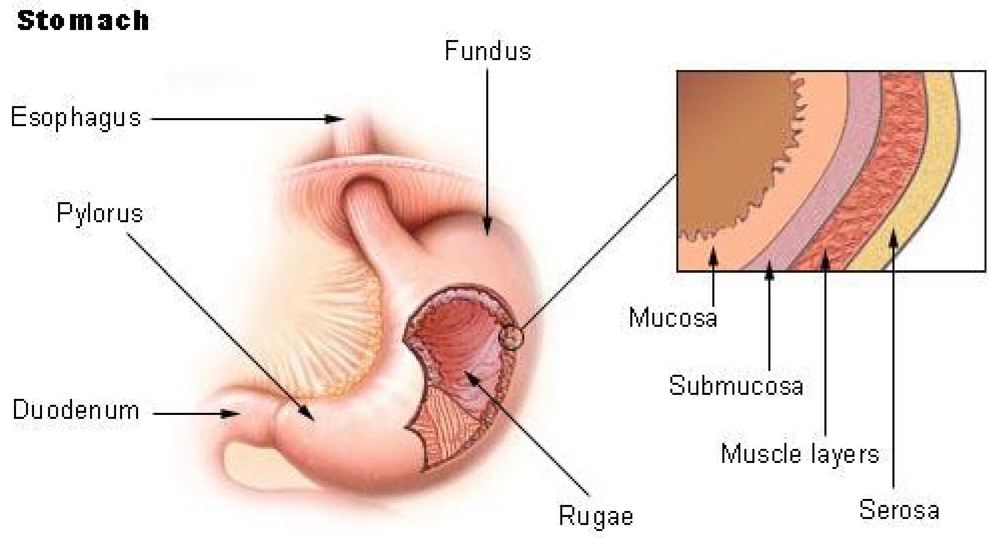

Figure 3.42 *The anatomy of the stomach Image source*

The mucosa is not a flat surface. Instead, its surface is lined by gastric pits, as shown in Figure 3.43 below.

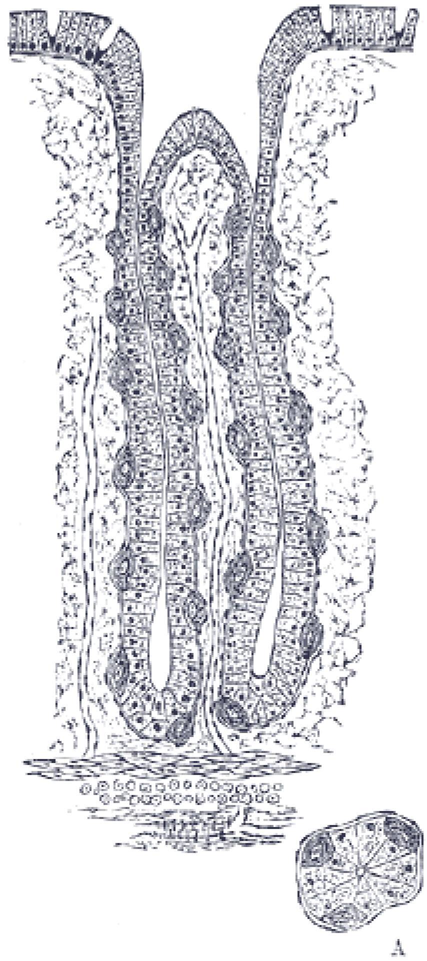

Figure 3.43 *Gastric pits Image Source*

Gastric pits are indentations in the stomach's surface that are lined by four different types of cells (see Figure 3.44 for names and locations).

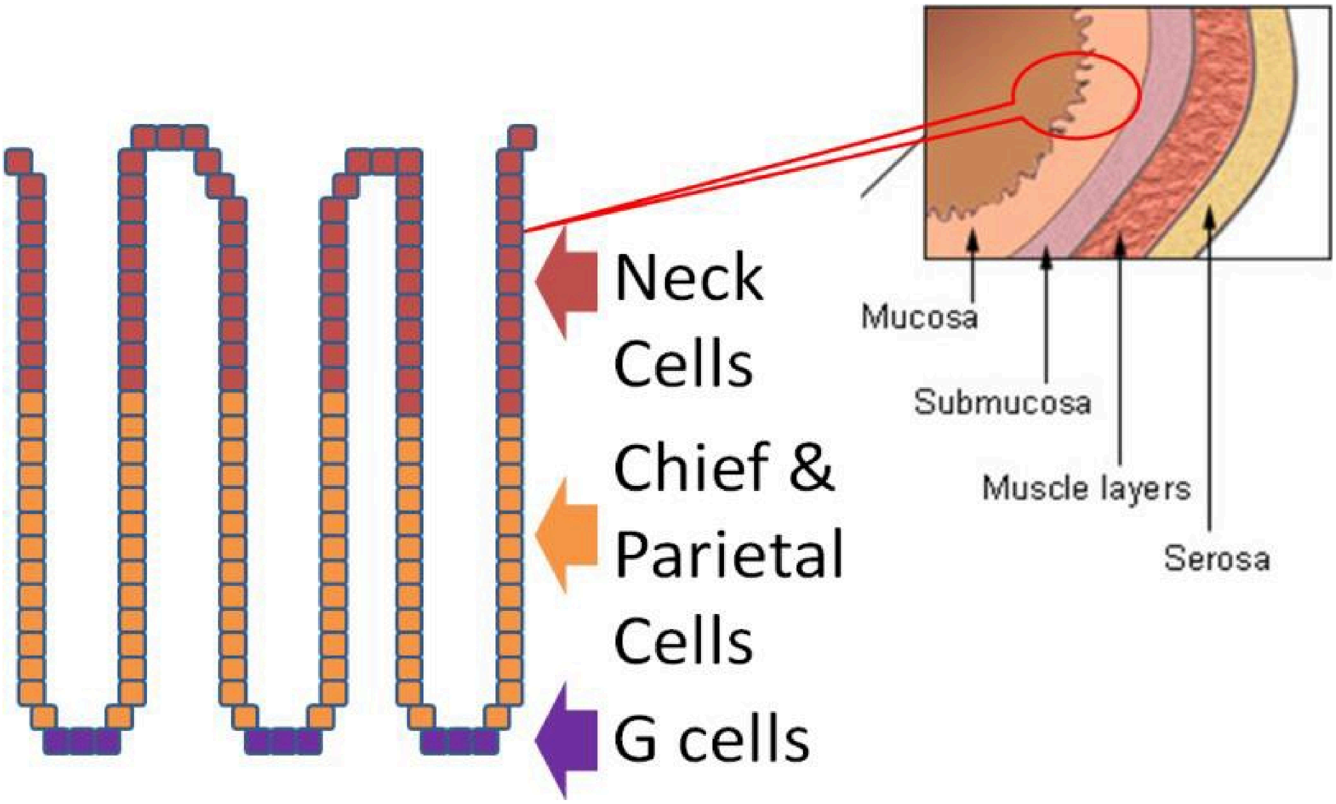

Figure 3.44 *Blowup of mucosa to show the structure of gastric pits. Image Source*

The following video is a nice introduction to gastric pits and talks about chief and parietal cells that are covered in more detail below.

Video: Gastric Pits (0:56)

At the bottom of the gastric pit are the gastric enteroendocrine cells (G cells) that secrete the **hormone** gastrin. **Gastrin** stimulates the parietal and chief cells that are found above the G cells. The chief cells secrete the pepsinogen. **Pepsinogen** is the inactive precursor that must be altered to form the active enzyme, pepsin. The parietal cells secrete hydrochloric acid (HCl), which lowers the pH of the gastric juice (water + enzymes + acid). The HCl also inactivates salivary amylase and catalyzes the conversion of the inactive pepsinogen to its active form, known as **pepsin**. Finally, at the top of the pits are the neck cells (specialized goblet cells) that secrete mucus to prevent the gastric juice from digesting or damaging the stomach mucosa[2]. The table below summarizes the actions of the different cells in the gastric pits.

Table 3.41 Cells involved in the digestive processes in the stomach

Type of Cell	Secrete
Neck (Goblet)	Mucus
Chief	Pepsinogen
Parietal	HCl (hydrochloric acid)
G cells	Gastrin

The figure below shows the action of all these different secretions in the stomach.

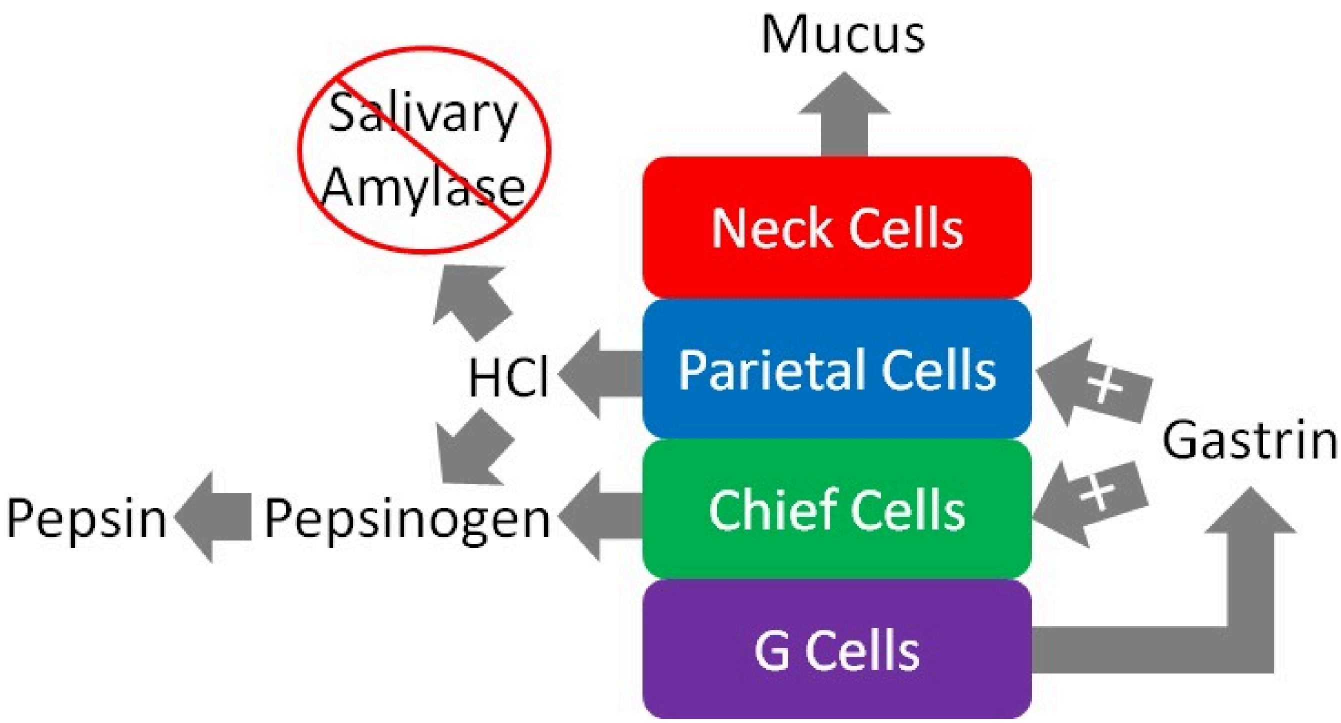

Figure 3.45 *The action of gastric secretions in the stomach*

To reiterate, the figure above illustrates that the neck cells of the gastric pits secrete mucus to protect the mucosa of the stomach from essentially digesting itself. Gastrin from the G cells stimulates the parietal and chief cells to secrete HCl and enzymes, respectively.

The HCl in the stomach denatures salivary amylase and other proteins by breaking down the structure and, thus, the function of it. HCl also converts pepsinogen to the active enzyme pepsin. Pepsin is a protease, meaning that it cleaves the **peptide bonds** in proteins. It breaks down the proteins in food into individual peptides (shorter segments of **amino acids**).

The chyme will then leave the stomach in small amounts and enter the small intestine via the pyloric sphincter (shown below). Full emptying of the stomach takes about 2-4 hours.

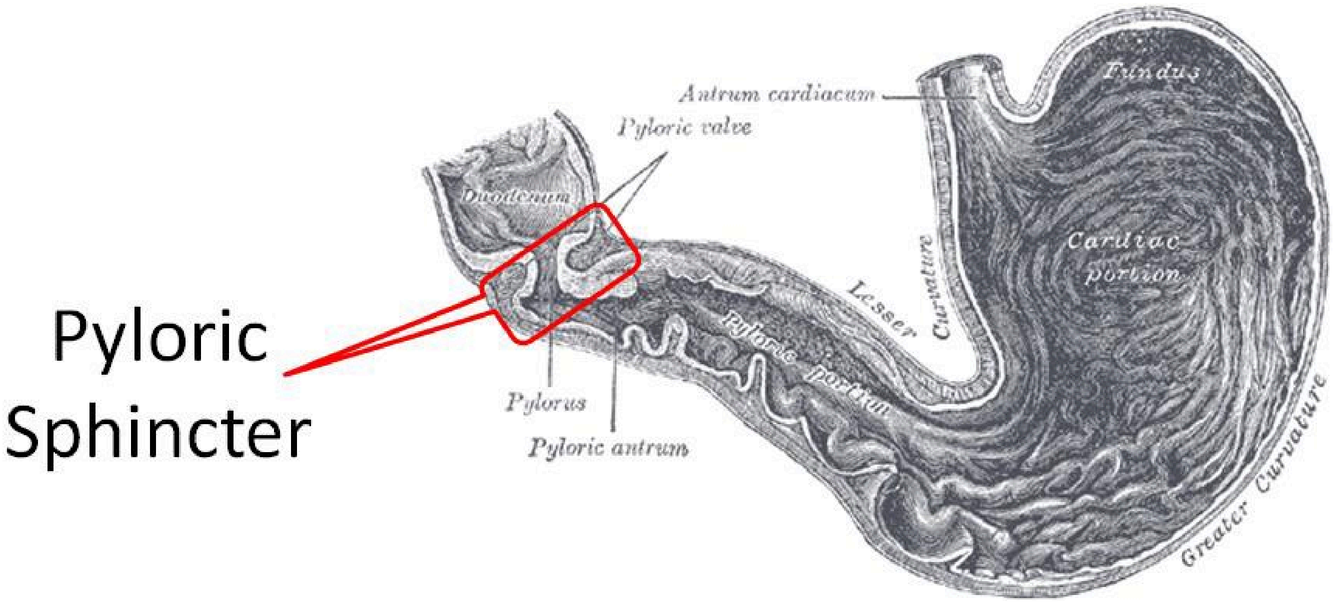

Figure 3.46 *Cross section of the stomach showing the pyloric sphincter. Image source*

Table 3.42 Summary of chemical digestion in the stomach

Chemical or Enzyme	Action
Gastrin	Stimulates chief cells to release pepsinogen Stimulates parietal cells to release HCl
HCl	Denatures salivary amylase Denatures proteins Facilitates the conversion of pepsinogen to pepsin
Pepsin	Cleaves proteins to peptides

Notes

1. OpenStax, Anatomy & Physiology. OpenStax CNX. Aug 1, 2017 http://cnx.org/contents/14fb4ad7-39a1-4eee-ab6e-3ef2482e3e22@8.108
2. Gropper SS, Smith JL, Groff JL. (2008) *Advanced Nutrition and Human Metabolism*. Belmont, CA: Wadsworth Publishing

3.5 Small Intestine

The small intestine is the primary site of digestion. It is divided into three sections: the duodenum, jejunum, and ileum (shown below). After leaving the stomach, the first part of the small intestine that chyme will encounter is the duodenum.

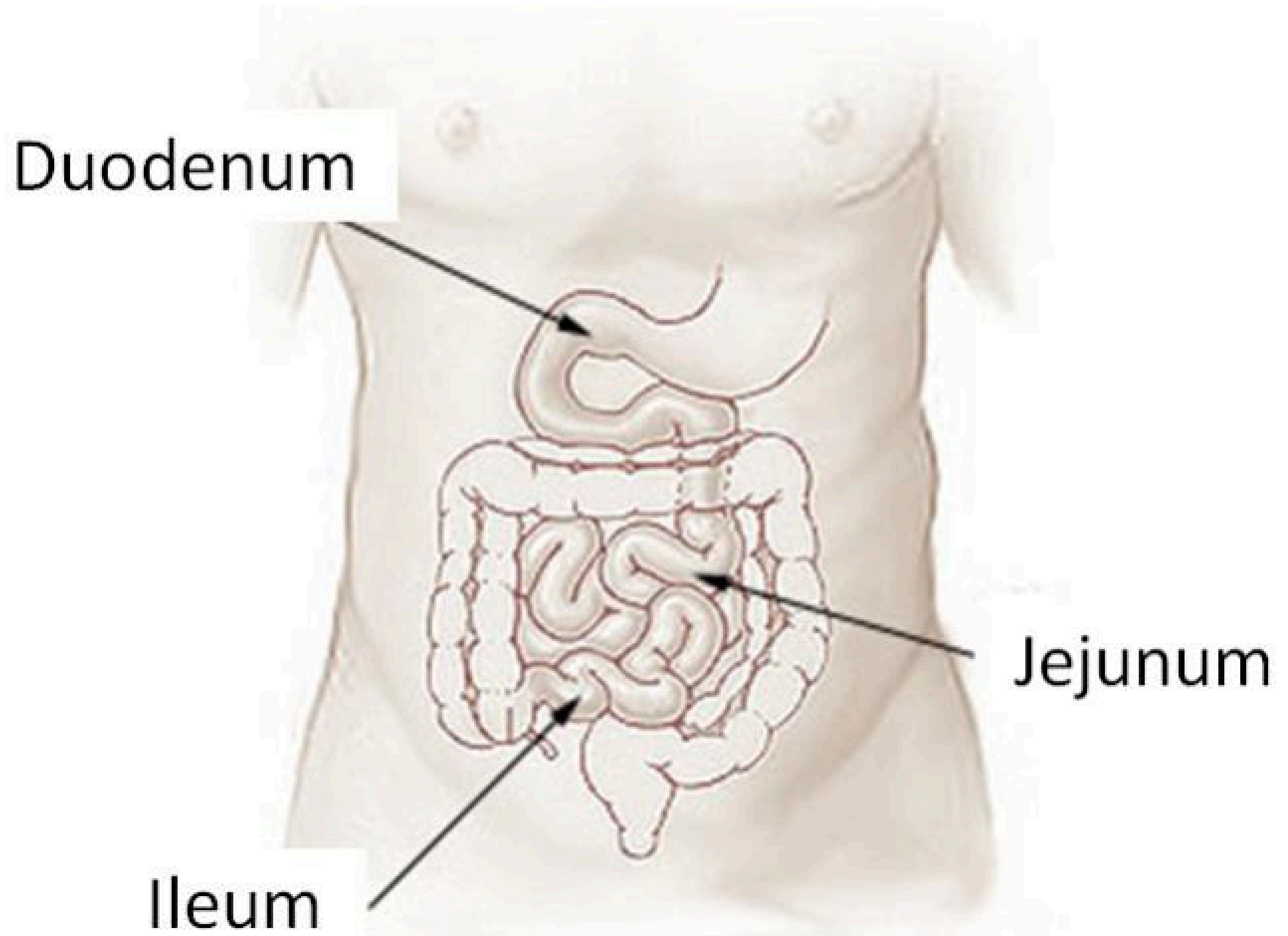

Figure 3.51 *Three sections of the small intestine. Image source*

The small intestine consists of many layers, which can be seen in the cross section in Figure 3.52 below.

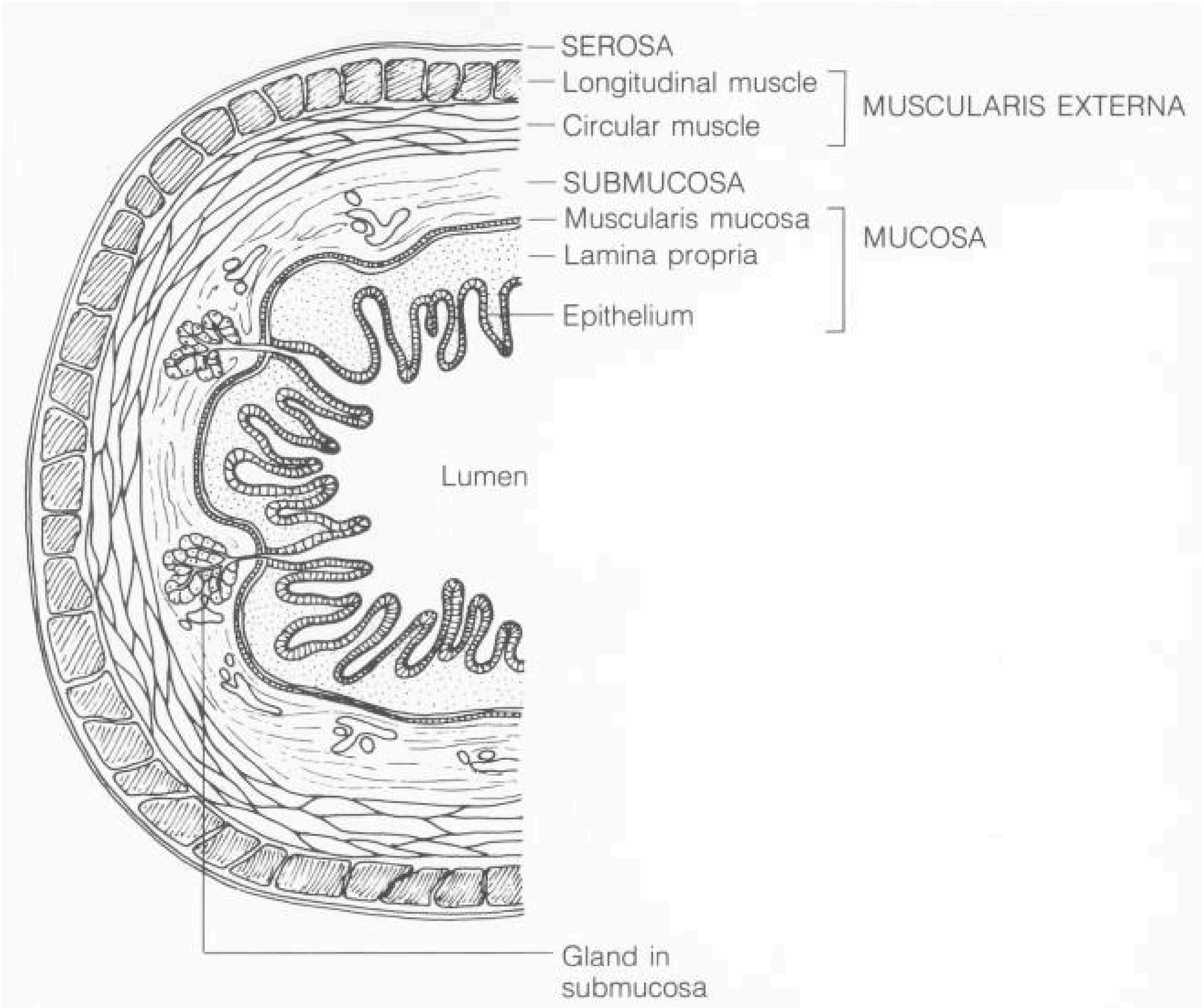

Figure 3.52 *Cross section of the small intestine. Image Source*

Examining these layers more closely, we are going to focus on the lining of the small intestine, known as the epithelium (see Figure 3.52 above), which comes into contact with the chyme and is responsible for absorption. The lumen is the name of the cavity that is considered "outside the body" that chyme moves through.

The organization of the small intestine is in such a way that it contains circular folds and finger- like projections known as villi. The folds and villi are shown in the next few figures.

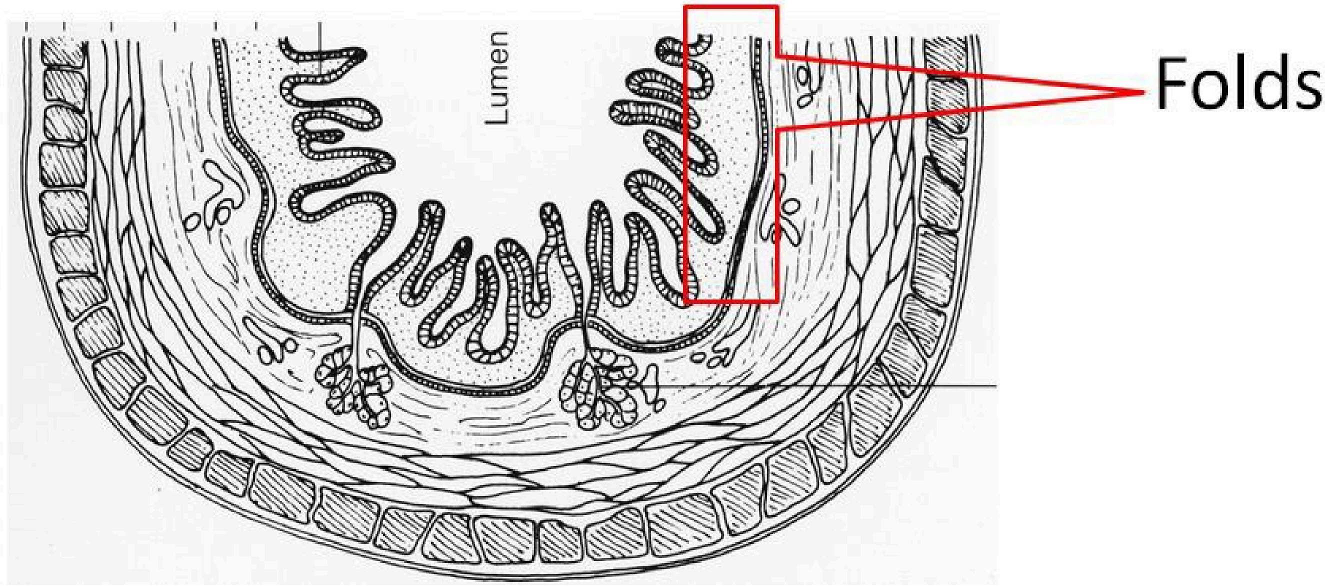

Figure 3.53 *Folds in the small intestine. Image Source*

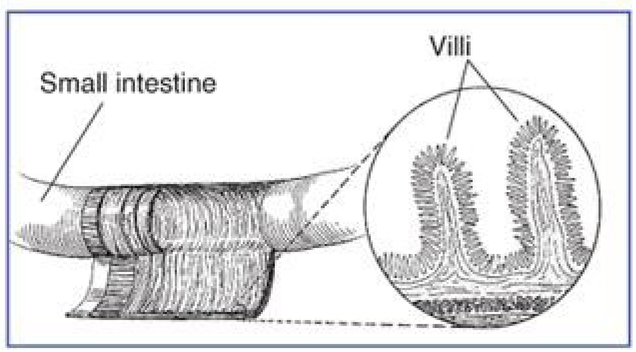

Figure 3.54 *Villi in the small intestine. Image source*

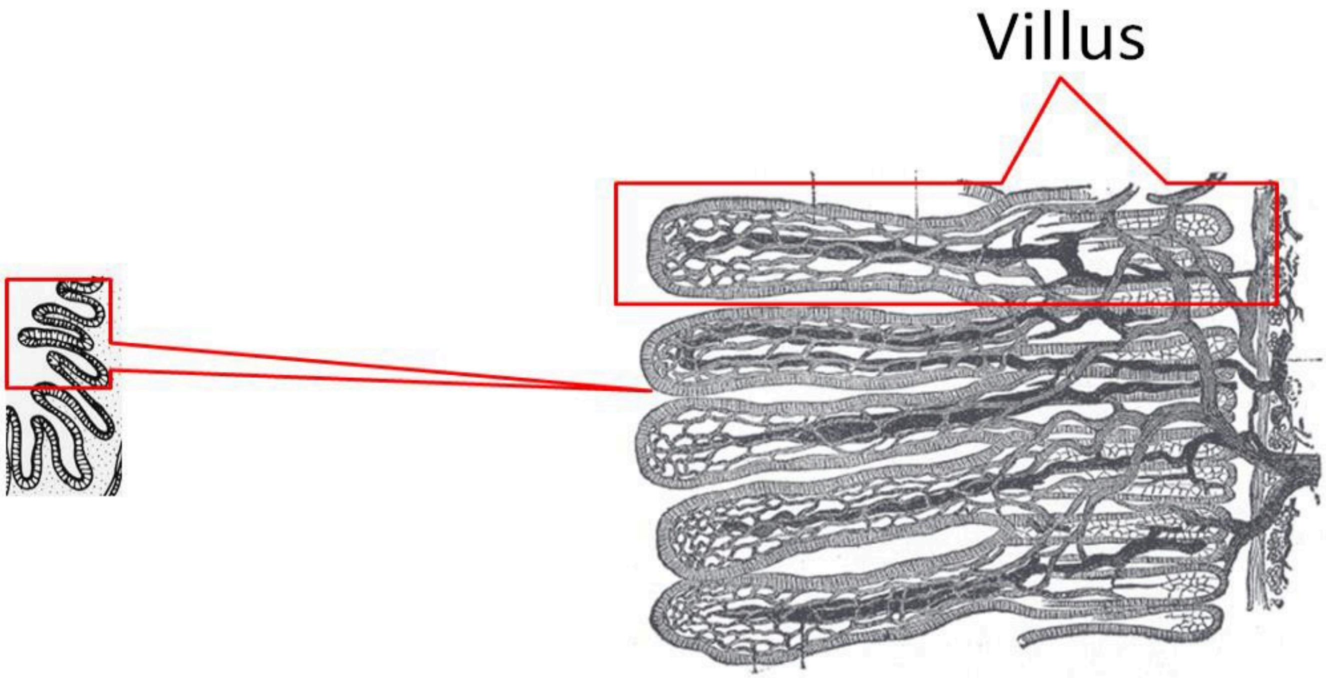

Figure 3.55 *Villi line the surface of the small intestine. Image 1 source Image 2 source*

If we were to zoom in even closer, we would be able to see that enterocytes (small intestine absorptive cells; a.k.a brush border cells) line villi as shown below. This layer is referred to as the mucosa, and is composed primarily of simple columnar epithelium.

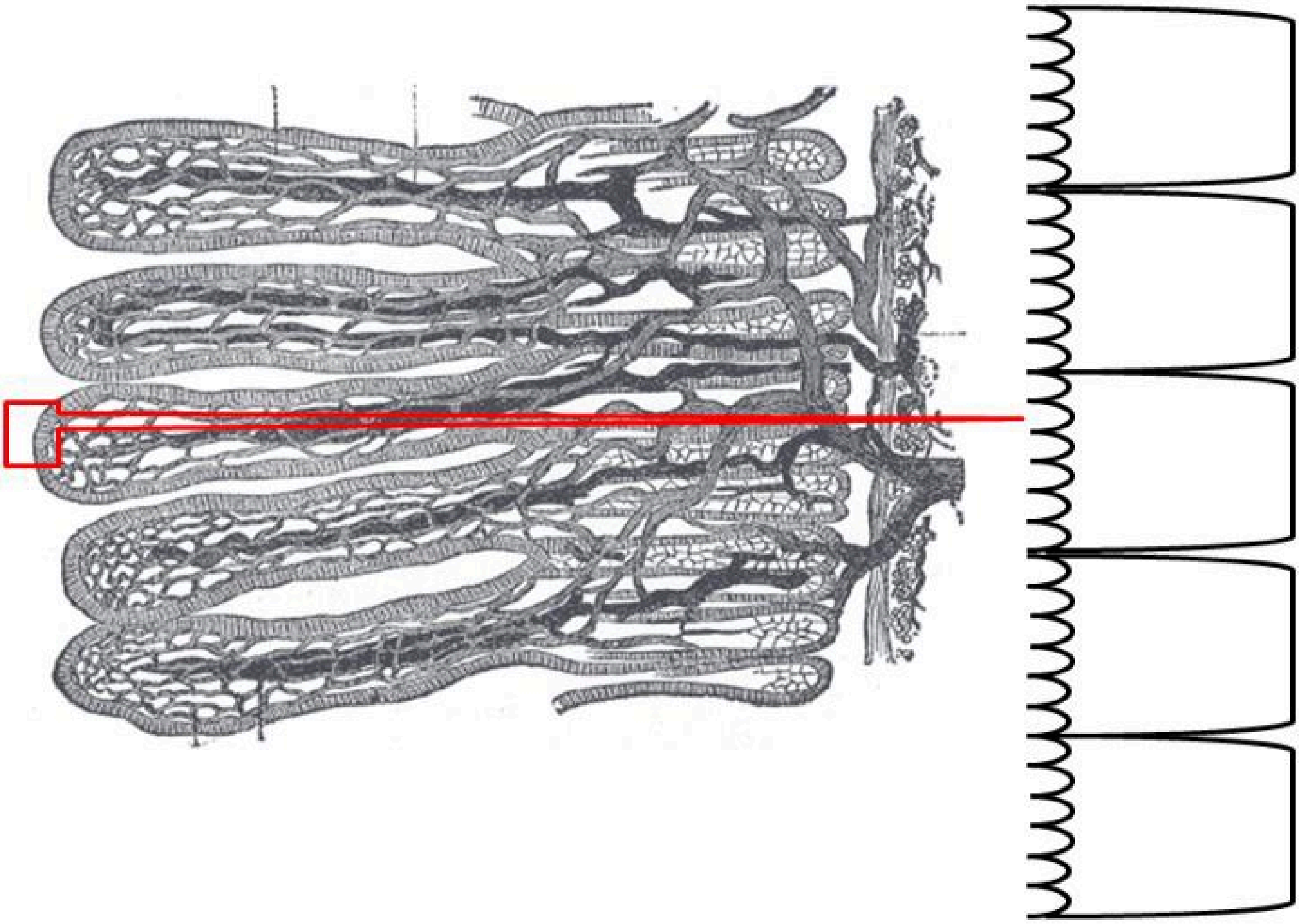

Figure 3.56 *Enterocytes line villi. Image source*

The side, or membrane, of the enterocyte that faces the lumen is not smooth either. It is lined with **microvilli**, and is known as the brush border membrane, as shown below.

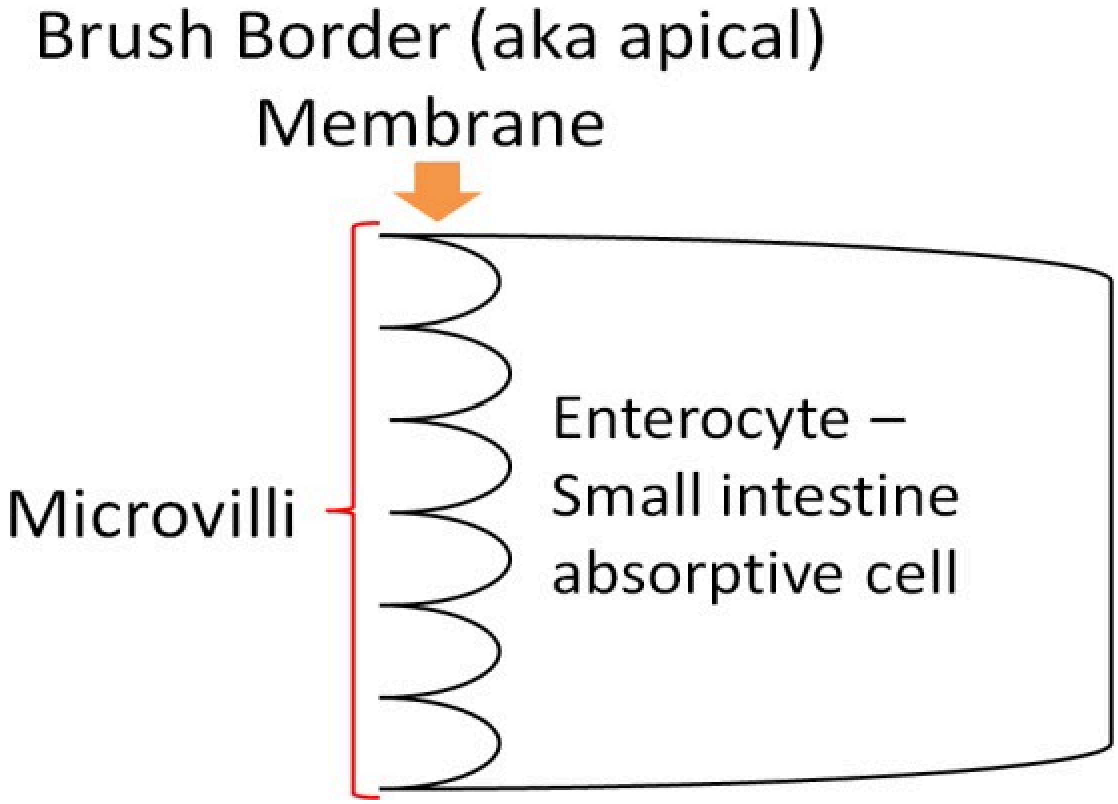

***Figure* 3.57** *Enterocyte, or small intestinal absorptive cell is lined with microvilli. This lined surface is referred to as the brush border membrane.*

Together these features (folds + villi + microvilli) increase the surface area ~600 times versus if it was a smooth tube[1]. (Note: the symbol ~ is used in place of the word "approximately." You will see it used other places in this text as well.) More surface area leads to more contact between the chyme and the enterocytes, and thus, increased absorption.

Finally, the surface of the cells on the microvilli are covered with proteins, which helps to catch a molecule-thin layer of water within itself. This layer, called the "unstirred water layer," has a number of functions in absorption of nutrients, and will have a direct impact on fat absorption as we will see later[2].

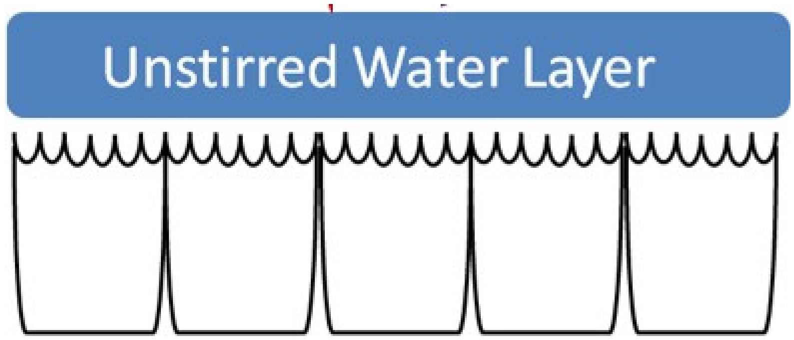

Figure 3.58 *Unstirred water layer*

Notes

1. Byrd-Bredbenner C, Moe G, Beshgetoor D, Berning J. (2009) *Wardlaw's Perspectives in Nutrition.* New York, NY: McGraw-Hill.
2. http://www.newworldencyclopedia.org/entry/Small_intestine

3.6 The Large Intestine

We have now reached a fork in the digestive road. We could follow the uptake of the digested compounds into the enterocyte or we could finish following what has escaped digestion and is going to continue into the large intestine. Obviously from the title of this section we are going to do the latter. As we learned previously, fiber is a crude term for what has survived digestion and has reached the large intestine.

Figure 3.61 *The fork in the road between finishing digestion in the colon and absorption into the enterocyte*

The ileocecal valve is the sphincter between the ileum (hence *ileo*– in ileocecal valve), and the large intestine. This name should make more sense as we go through the anatomy of the large intestine.

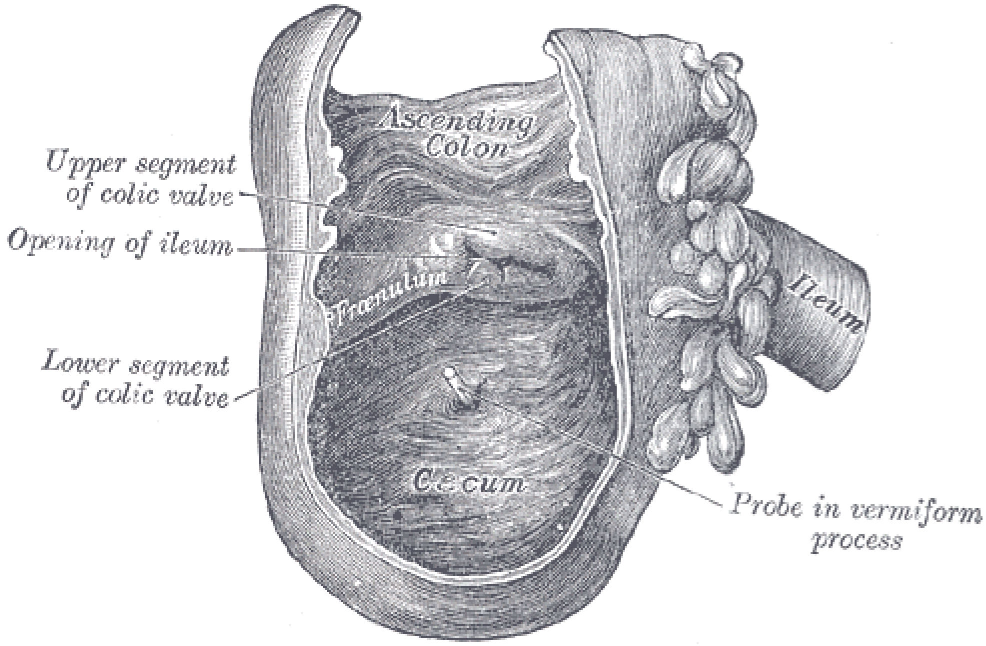

Figure 3.62 *The ileocecal valve. Image source*

The large intestine consists of the colon, the rectum, and the anus. The colon can be further divided into the cecum (hence the –*cecal* in ileocecal valve), ascending colon, transverse colon, descending colon, and sigmoid colon as shown below.

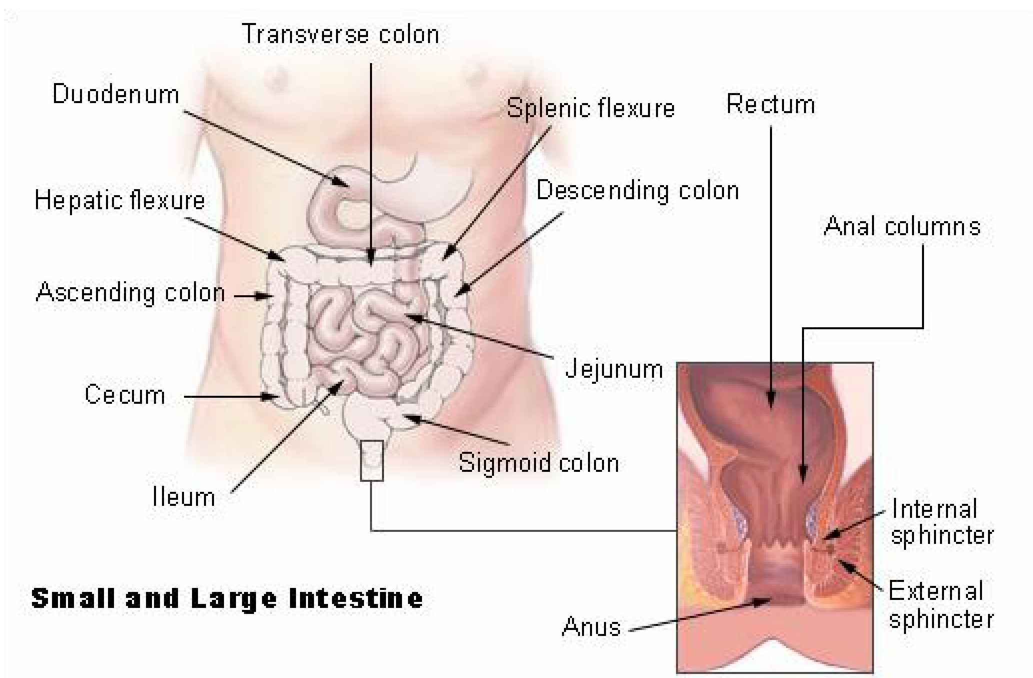

Figure 3.63 *Anatomy of the large intestine and rectum. Image source*

The large intestine is responsible for absorbing the remaining water and electrolytes (sodium, potassium, and chloride) in chyme. By removing water, the unabsorbed chyme is converted into a more solid form (feces) which is then excreted via **defecation**. The large intestine contains large amounts of microorganisms like those shown in the figure below.

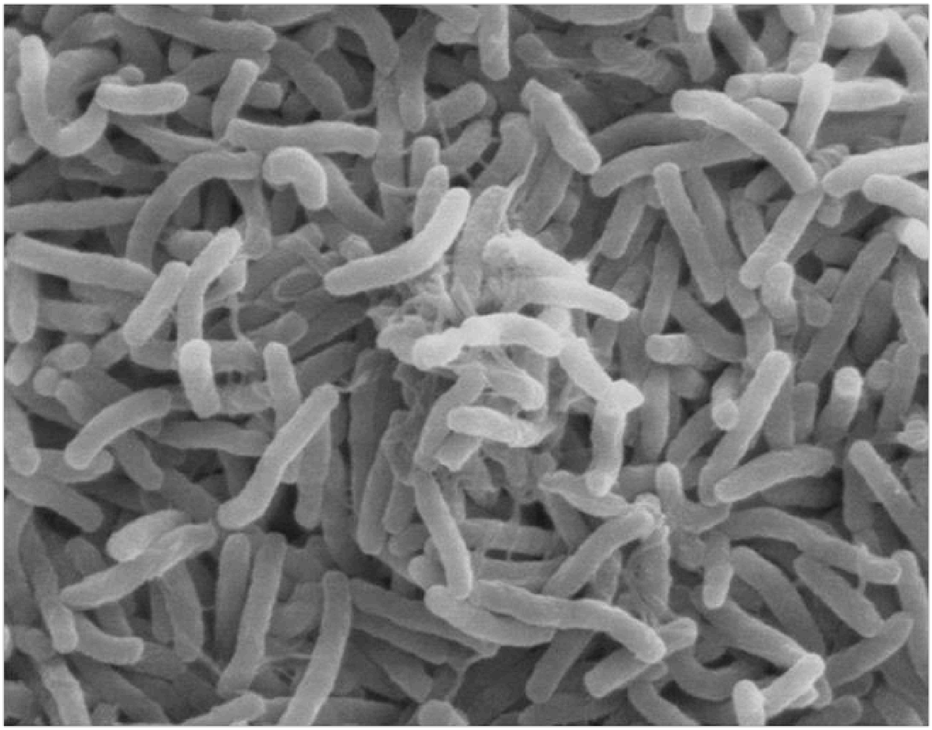

Figure 3.64 *Magnified image of bacteria. Image source*

The large intestine can also be referred to as the gut. There are a large number of microorganisms found throughout the gastrointestinal tract that collectively are referred to by a variety of names: flora, microflora, biota, or microbiota. Technically, microbiota is the preferred term because flora means "pertaining to plants". There are 10 times more microorganisms in the gastrointestinal tract than cells in the whole human body[1]. As can be seen in the figure below, the density of microorganisms increases as you move down the digestive tract.[2] The number of microorganisms is reported in "colony-forming units (cfu)" per milliliter (cfu/mL). One cfu is approximately one bacterium.

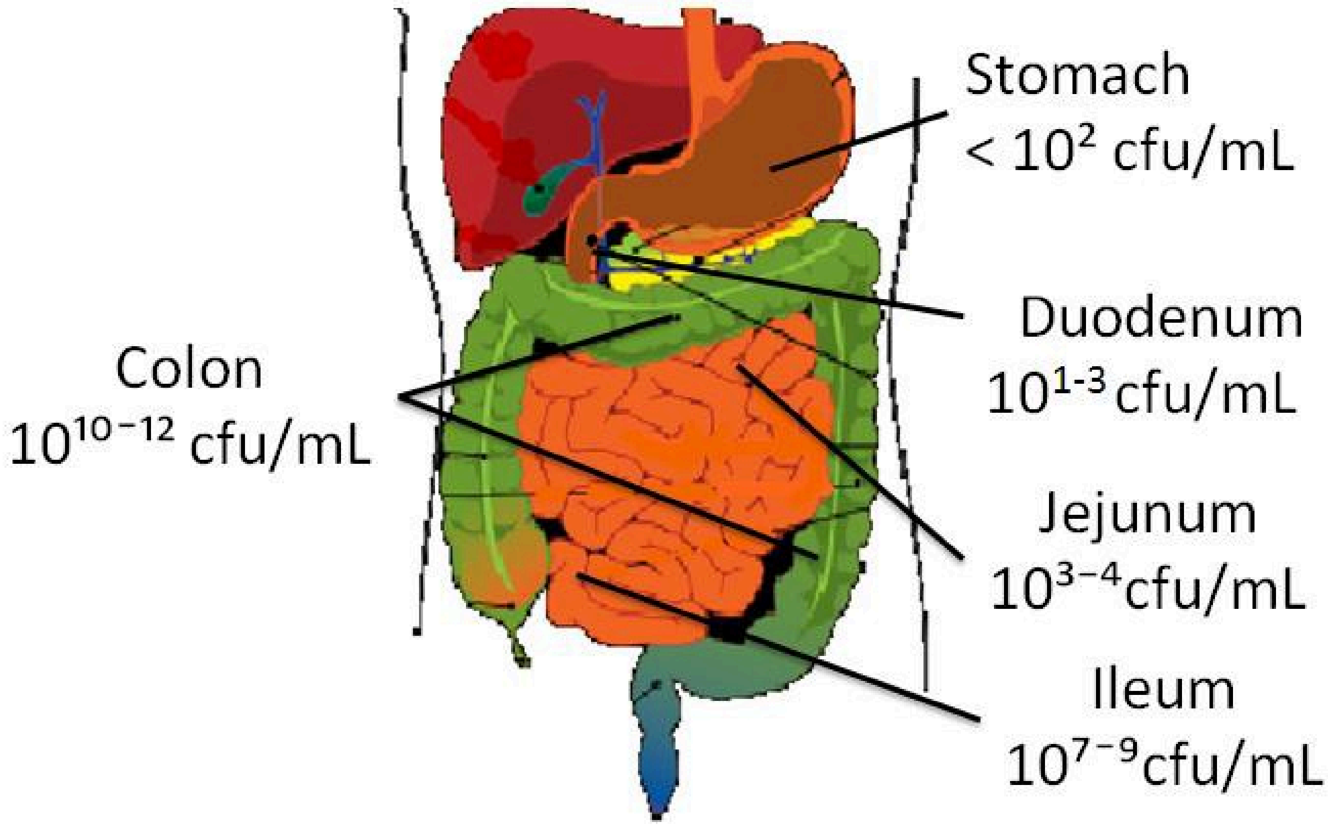

Figure 3.65 *Relative amounts of bacteria in selected locations of the GI tract. cfu/ml = colony forming unit, a measure of the number of live microorganisms in 1 milliliter of digestive sample Image source (adapted)*

As described in the fiber sections, there are two different fates for fiber once it reaches the large intestine. The fermentable, viscous fiber is fermented by bacteria. **Fermentation** is the **metabolism** of compounds by the microorganisms in the gut. An example of fermentation is the utilization of the **oligosaccharides** raffinose and stachyose by microorganisms that results in the production of gas, which can lead to flatulence. Additionally, some bile acids are fermented by microorganisms to form secondary bile acids that can be reabsorbed. These secondary bile acids represent approximately 20% of the total bile acids in our body. Fermentable fibers can also be used to form short-chain fatty acids that can then be absorbed and used by the body.

Conversely, the non-fermentable, non-viscous fiber is not really altered and will be a component of feces, that is then excreted through the rectum and anus via defecation. This process involves both an internal and external sphincter that are shown in Figure 3.63 above.

Probiotics & Prebiotics

Recently there has been increased attention given to the potential of a person's microbiota to impact health. This is because there are beneficial and non-beneficial bacteria inhabiting our gastrointestinal tracts. Thus, theoretically, if you can increase the beneficial, or decrease the non-beneficial bacteria, there may be improved health outcomes. In response to this, probiotics and prebiotics have been identified/developed. A **probiotic** is a live microorganism that is consumed, and colonizes in the body as shown in Figure 3.66.

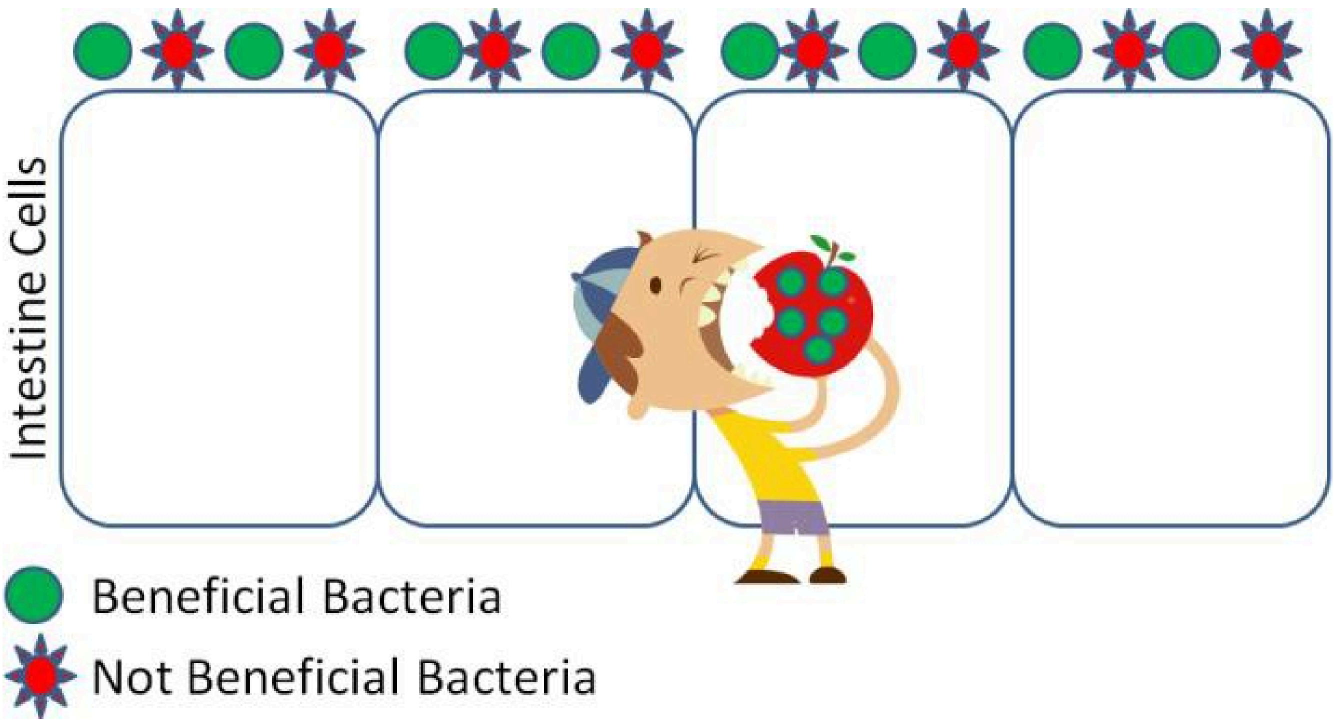

Figure 3.66 *Probiotics: the consumption of the bacteria itself*

A **prebiotic** is a non-digestible food component that selectively stimulates the growth of beneficial intestinal bacteria. It can be used as food for intestinal bacteria because it is not broken down in the small intestine. An example of a prebiotic is inulin (this is not the same as, or related to, the hormone **insulin** that you may be familiar with), which is shown in the figure below.

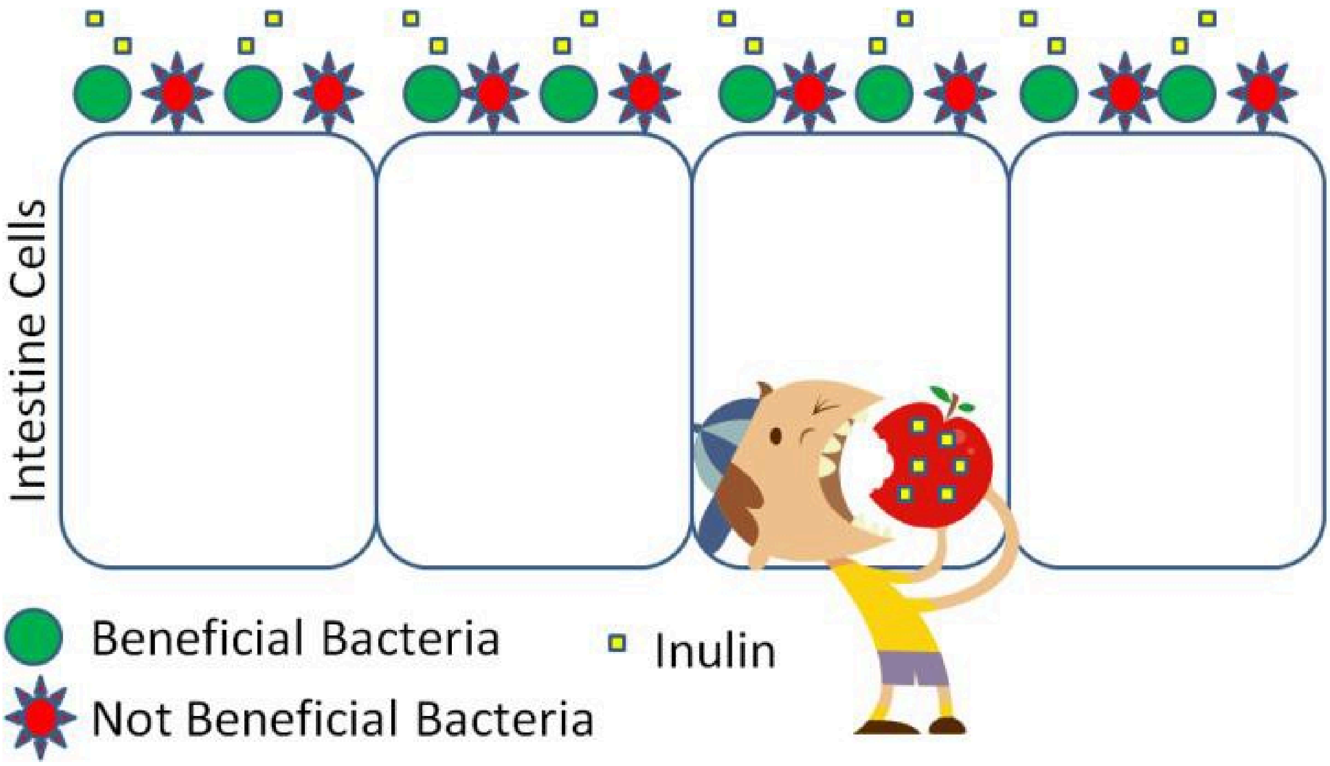

Figure 3.67 *Prebiotics: Consumption of an indigestible molecule that can be used by bacteria in your digestive tract. Inulin is a common example of a prebiotic.*

The net result is the same for both prebiotics and probiotics, an improvement in the beneficial/non-beneficial bacteria ratio.

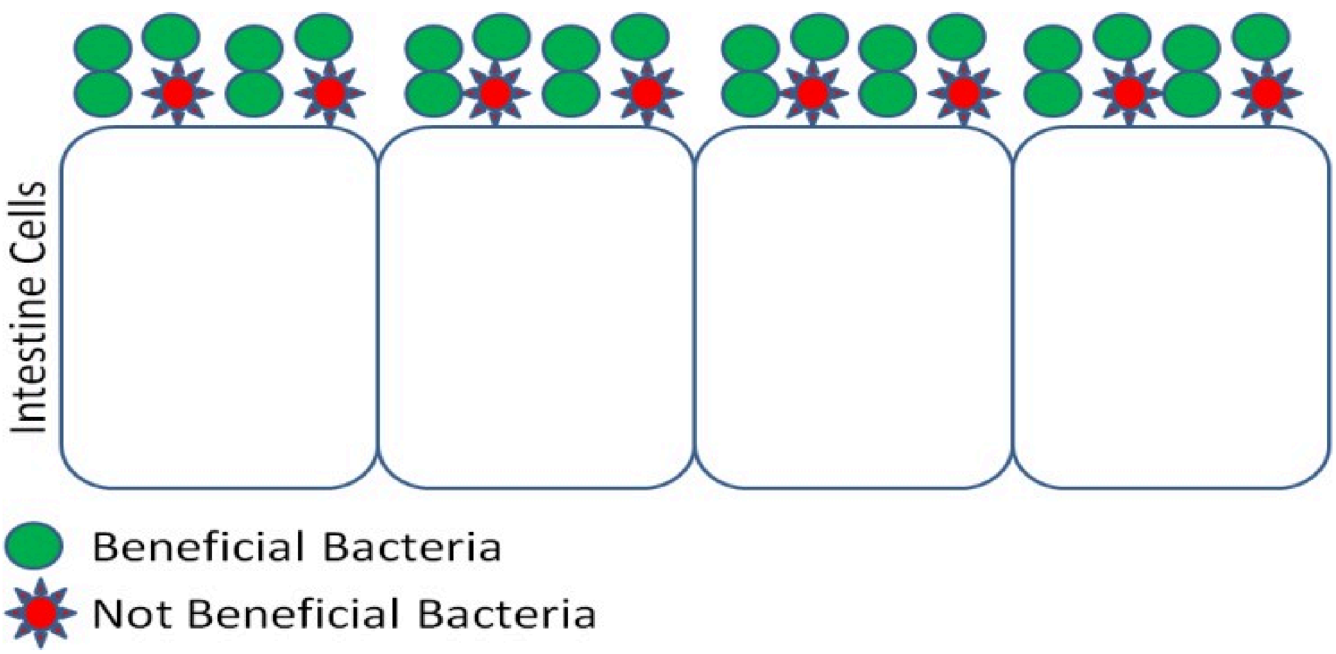

Figure 3.68 *An effective prebiotic or probiotic should result in an increase in the beneficial bacteria*

The following video does a nice job of explaining and illustrating how probiotics work. The National Center for Complementary and Integrative Health (NCCIH) website is a good source of information if you have further questions on the topic.

Video Link: Probiotics (3:40)

Web Link: NCCIH: Probiotics

Some common examples of probiotic foods are sauerkraut, kimchi, kefir, and yogurts containing live cultures. If you're wondering if your yogurt contains live cultures, check the label. Look for "live culture" or "active culture".

It should be notes that the claims companies have made about their probiotic products have come under scrutiny. Dannon settled with the US Federal Trade Commission to drop claims that its probiotic products will help prevent colds or alleviate digestive problems, as seen in the top link below. General Mills also settled a lawsuit that accused them of a falsely advertising the digestive benefits of Yo-Plus, a product it no longer sells, as seen in the second link.

Web Links:

New Campaign Markets Activia to Wider Audience

General Mills Settles Yo-Plus Lawsuit

Some examples of prebiotics include the previously mentioned inulin, fructose-containing oligosaccharides and **polysaccharides**, and resistant starch. These are found in a number of foods including onions, leaks, sprouted whole grains, seeds, and berries.[3]

Resistant starch is so named because it is a starch that is resistant to digestion. As a result, it arrives in the colon to be fermented.

Notes

1. Guarner F, Malagelada J. (2003) Gut flora in health and disease. *The Lancet* 361(9356): 512. DOI:10.1016/S0140-6736(03)12489-0
2. DiBaise J, Zhang H, Crowell M, Krajmalnik-Brown R, Decker, et al. (2008) Gut microbiota and its possible relationship with obesity. *Mayo Clin Proc* 83(4): 460. DOI:10.4065/83.4.460
3. Gut Health 101: Top Prebiotic and Probiotic Foods https://www.betternutrition.com/checkout/prebiotic-probiotic-foods-lists

3.7 Digestive Hormones, Accessory Organs, and Secretions

Before we go into the digestive details of specific **macronutrients**, it is important that you have a basic understanding of the anatomy and physiology of the following digestion **accessory organs**: pancreas, liver, and gallbladder. Digestion accessory organs assist in digestion, but are not part of the gastrointestinal tract. How are these organs involved?

Upon entering the **duodenum**, the chyme causes the release of two hormones from the small intestine: secretin and **cholecystokinin (CCK)** in response to acid and fat, respectively. These hormones have multiple effects on different **tissues**. In the pancreas, secretin stimulates the secretion of bicarbonate (HCO_3), while CCK stimulates the secretion of digestive enzymes. The bicarbonate and digestive enzymes released together are collectively known as pancreatic juice, which travels to the small intestine, as shown below.

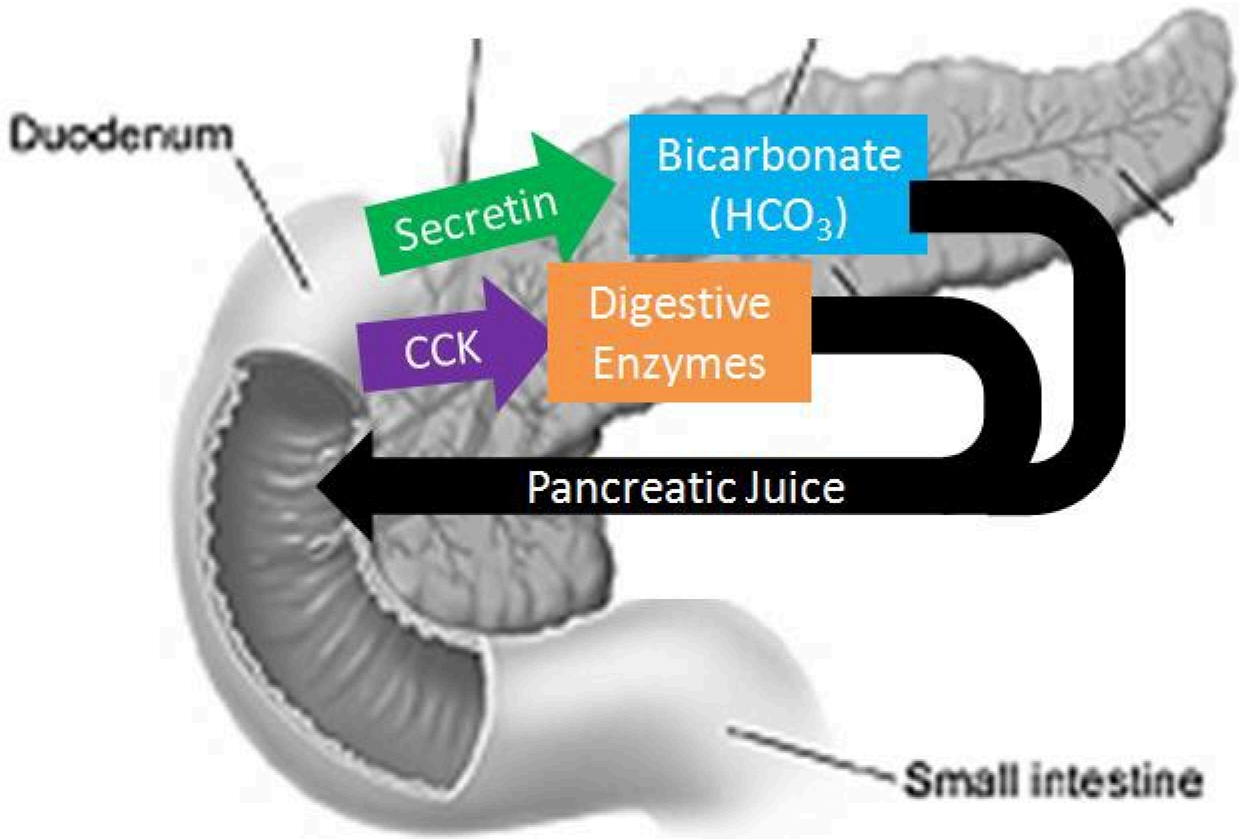

Figure 3.71 *The hormones secretin and CCK stimulate the pancreas to secrete pancreatic juice. Image source (adapted)*

In addition, CCK also stimulates the contraction of the gallbladder causing the secretion of stored **bile** into the duodenum.

Pancreas

The pancreas is found behind the stomach and just above the transverse colon (part of the large intestine discussed later in this chapter). It is a tadpole-shaped organ consisting of a head, body, and tail. It is a unique organ containing both endocrine and exocrine portions. The smaller, endocrine (hormone-producing) portions contain alpha, beta, delta, and PP cells that secrete the hormones **glucagon**, **insulin**, somatostatin, and pancreatic polypeptide respectively. These cells are clustered in groups known as pancreatic islets (traditionally referred to as the Islets of Langerhans). However, the vast majority of the pancreas is made up of grape-like clusters of exocrine cells known as acini (singular = acinus). The cells composing each acinus are known as acinar cells. These acinar cells are responsible for producing enzyme-rich pancreatic juice. Pancreatic juice is released into small ducts that continually merge to form a large main pancreatic duct which delivers pancreatic juice from the pancreas to the duodenum, merging with the common bile duct (from the liver & gallbladder) along the way. The release of pancreatic juice, and bile, is controlled by the hepatopancreatic sphincter. The following video does a nice job of showing and explaining the function of the different pancreatic cells.

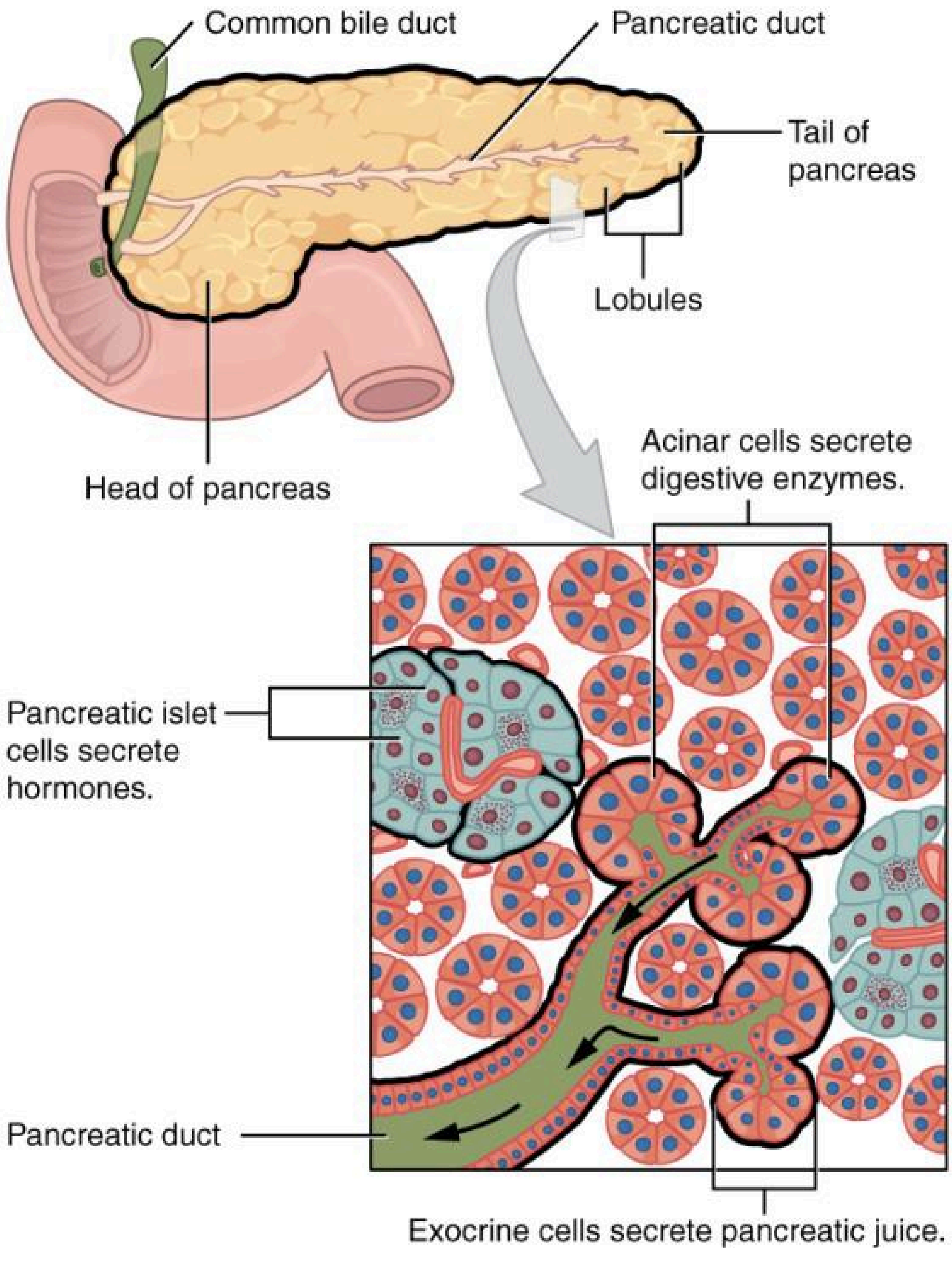

Figure 3.72 *The pancreas has a head, a body, and a tail. It delivers pancreatic juice to the duodenum through the pancreatic duct. Credit: OpenStax, Anatomy & Physiology. OpenStax CNX. Aug 1, 2017 http://cnx.org/contents/14fb4ad7-39a1-4eee-ab6e-3ef2482e3e22@8.108*

Video Link: **Video Link:** The Pancreas *Watch the first 53 seconds.*

In addition to pancreatic hormones and enzymes, the pancreas releases bicarbonate. Bicarbonate is a base (high pH) meaning that it can help neutralize an acid (such as gastric juice.) You can find sodium bicarbonate ($NaHCO_3$, baking soda) on the ruler below to get an idea of its pH.

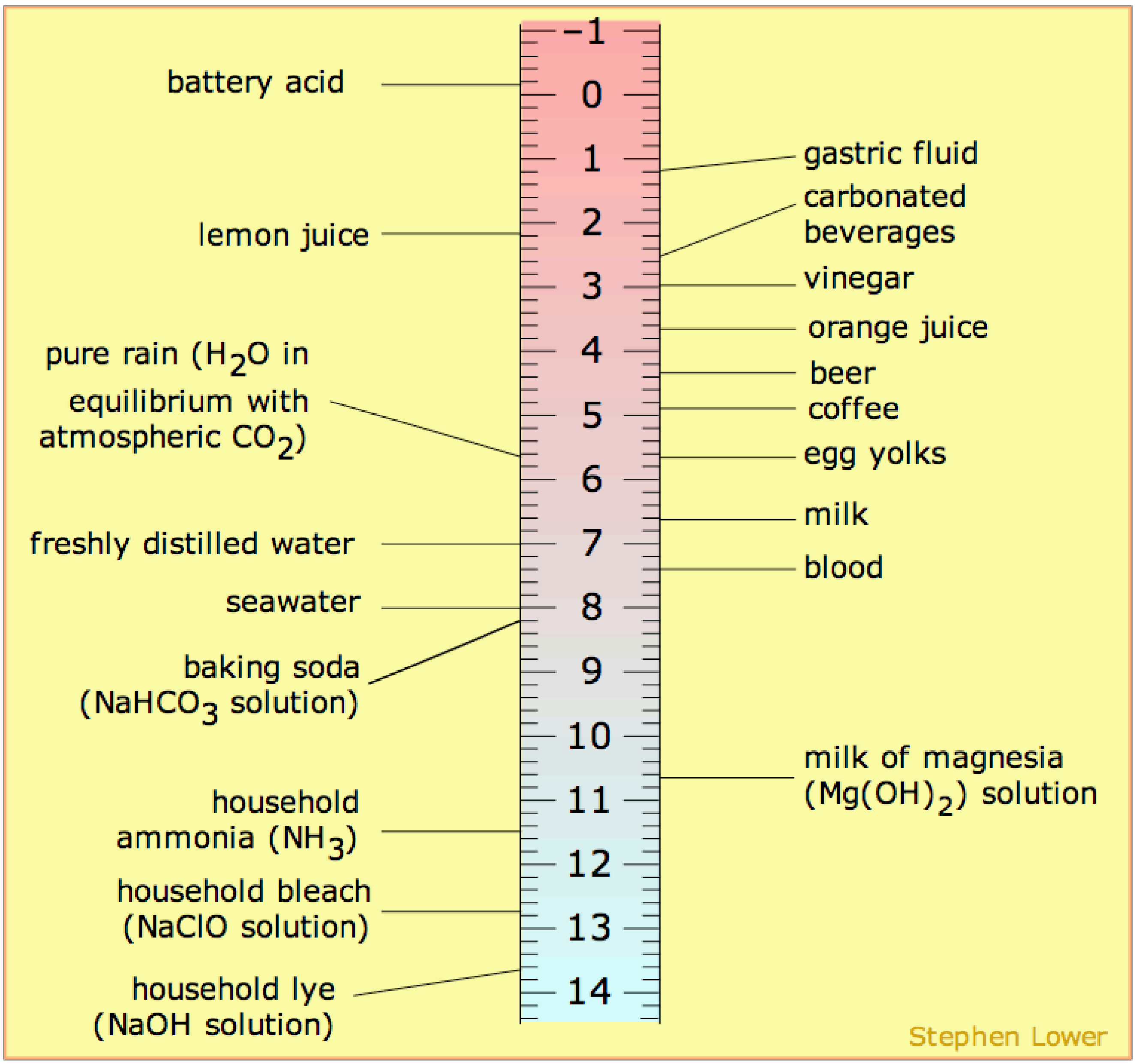

***Figure 3.73** pH of some common items. Image source*

The main digestive enzymes in pancreatic juice are listed in the table below.

Table 3.71 Enzymes in pancreatic juice

Enzyme	Macronutrients Digested
Pancreatic amylase	Carbohydrates
Proteases	Protein
Pancreatic Lipase	Lipids
Phospholipase A_2	Lipids
Cholesterol Esterase	Lipids

Liver

The liver is the largest internal, and the most metabolically active, organ in the body. The figure below shows the liver and the other accessory organs position relative to the stomach.

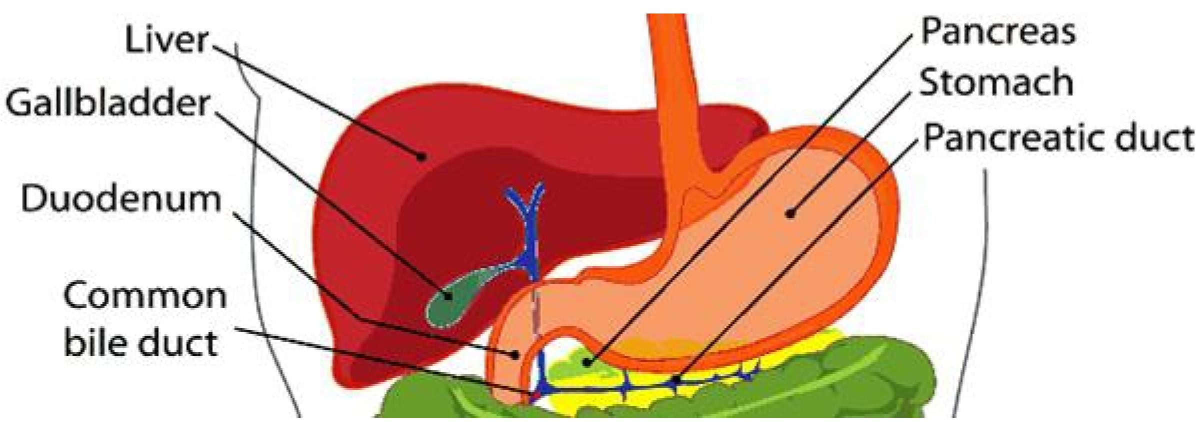

Figure 3.74 *Location of digestion accessory organs relative to the stomach. Image source*

The liver is made up two major types of cells. The primary liver cells are **hepatocytes**, which carry out most of the liver's functions. Hepatic is another term for liver. For example, if you are going to refer to liver concentrations of a certain nutrient, these are often reported as hepatic concentrations. The other major cell type is the hepatic stellate (also known as Ito) cells. These are fat storing cells in the liver.

The liver's major role in digestion is to produce **bile**. This is a greenish-yellow fluid that is composed primarily of bile acids, but also contains cholesterol, **phospholipids**, and the pigments bilirubin and biliverdin. Bile acids are synthesized from cholesterol. The two primary bile acids are chenodeoxycholic acid and cholic acid. In the same way that fatty acids are found in the form of salts, these bile acids can also be found as salts. Because of this, these bile salts are often seen in texts with an (-*ate*) ending (chenodeoxycholate and cholate) indicating they are in the salt form.

Bile acids, much like phospholipids, have both hydrophobic and hydrophilic portions. This makes them excellent **emulsifiers** that are instrumental in fat digestion. Bile is then transported to the gallbladder.

Gallbladder

The gallbladder is a small, sac-like organ found just off the liver (see Figure 3.74 above). Its primary function is to store and concentrate bile made by the liver. The bile is then transported to the duodenum through the common bile duct.

Why do we need bile?

Bile is important because fat is hydrophobic, but the environment in the lumen of the small intestine is watery. In addition, there is an unstirred water layer that fat must cross to reach the **enterocytes** in order to be absorbed.

Figure 3.75 *Fat is not happy alone in the watery environment of the small intestine.*

Triglycerides naturally form large triglyceride droplets to keep the interaction with the watery environment to a minimum. Picture the large droplets of cooking oil that form when you add it to water. This is inefficient for digestion, because enzymes cannot access the interior of the droplet. Bile acts as an emulsifier, or detergent. It, along with phospholipids, breaks the large triglyceride droplets into smaller triglyceride droplets that increase the surface area accessible for triglyceride digestive enzymes, as shown below.

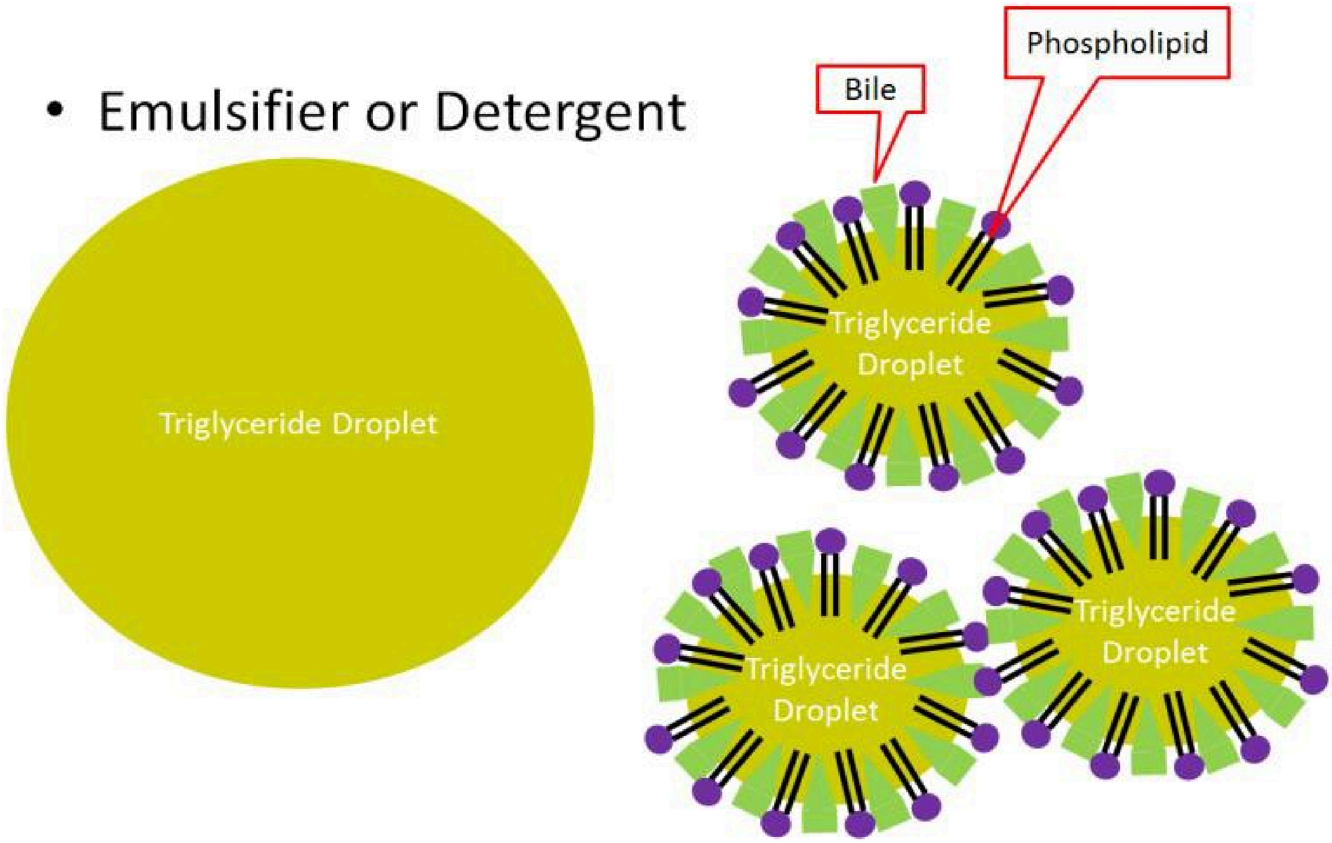

***Figure 3.76** Bile acids and phospholipids facilitate the production of smaller triglyceride droplets.*

Secretin and CCK also control the production and secretion of bile. Secretin stimulates the flow of bile from the liver to the gallbladder. CCK stimulates the gallbladder to contract, causing bile to be secreted into the duodenum, as shown in Figure 3.77.

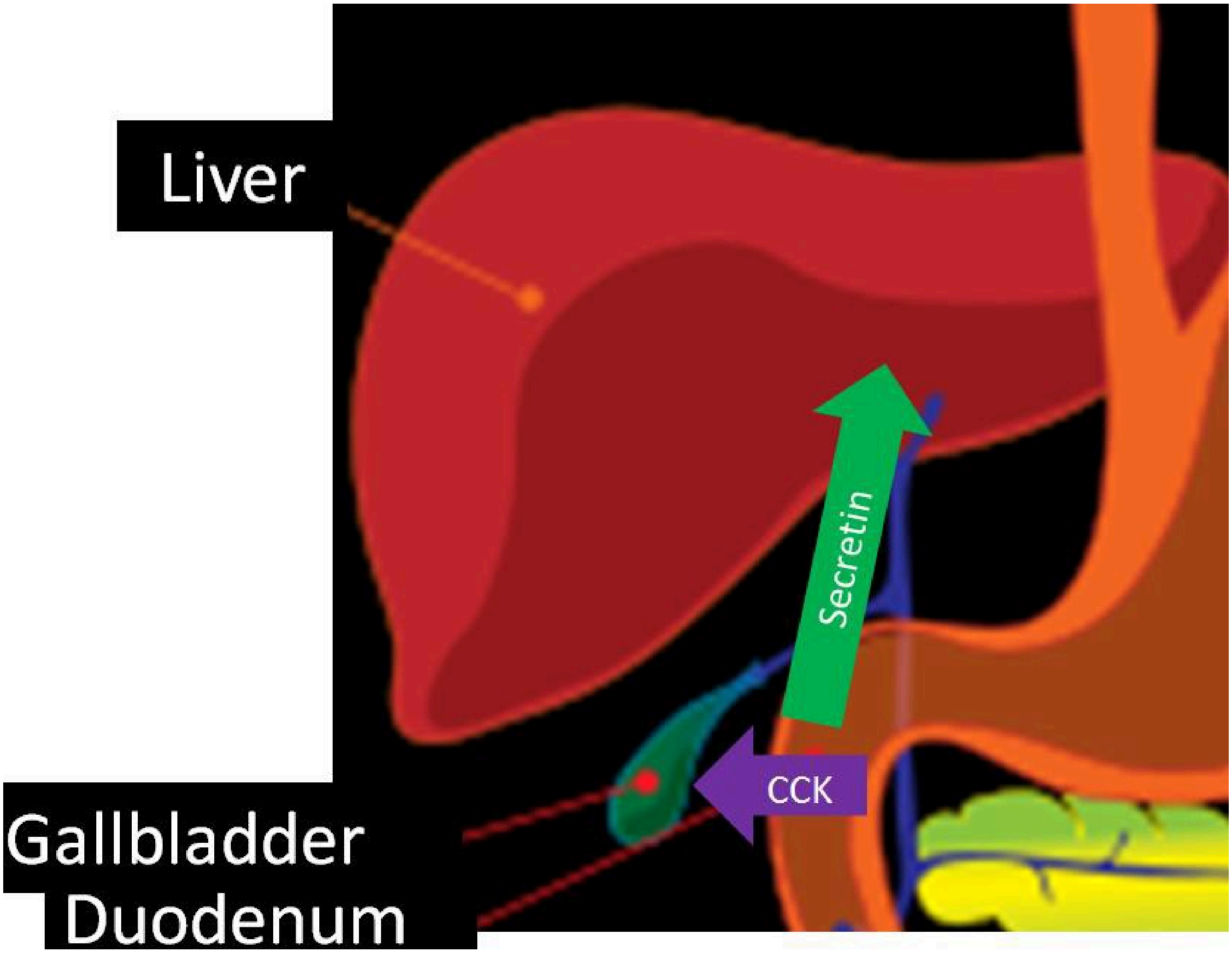

Figure 3.77 *Secretion stimulates bile flow from liver; CCK stimulates the gallbladder to contract. Image source*

3.8 Absorption and Circulation Overview

The term absorption can have a number of different meanings. In nutrition, **absorption** means that a compound is taken in from the lumen of the digestive tract into the bloodstream for circulation throughout the body. This process is sometimes divided into two steps: uptake (compounds being moved from the lumen into the **enterocyte**) and absorption (a compound being moved from the enterocyte to the bloodstream). Under most circumstances, compounds that are taken up into the enterocytes will then be absorbed into the bloodstream.

What's Actually Absorbed

We know that digestion breaks large macronutrient molecules into smaller molecules. It is these smaller molecules that are absorbed into the bloodstream. The figure below shows what is actually taken up into the enterocyte. We will go into more detail about how these small molecules are made when we discuss digestion of specific macronutrients in chapters 5, 6, and 7.

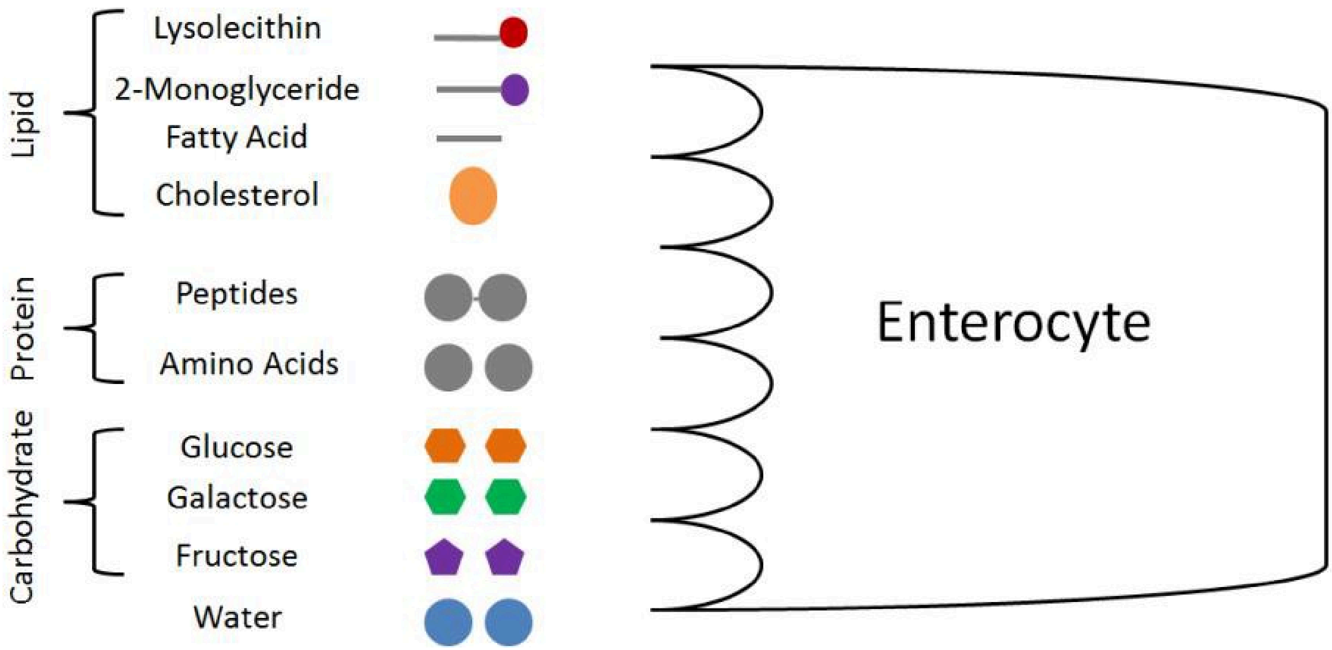

***Figure 3.81** The macronutrient uptake lineup*

From lipids, we have lysolecithin (from phospholipids), 2-monoglyceride (from triglycerides), fatty acids, and cholesterol. From protein, there are small peptides (di- and tripeptides) and **amino acids**. From carbohydrates, only the **monosaccharides** glucose, galactose, and fructose will be taken up. The other macronutrient, water, has not been discussed so far because it does not undergo digestion.

Vitamins and **minerals** are also taken up through enterocytes.

The Plasma Membrane

In order to be taken up by the enterocytes, these compounds must now cross the cell (plasma) membrane, which is a **phospholipid bilayer**. In the cell membrane, the **hydrophilic heads** of the phospholipids point into the lumen of the GI tract, as well as towards the interior of the cell, while the **hydrophobic tails** are on the interior of the plasma membrane. This is depicted in the diagram below.

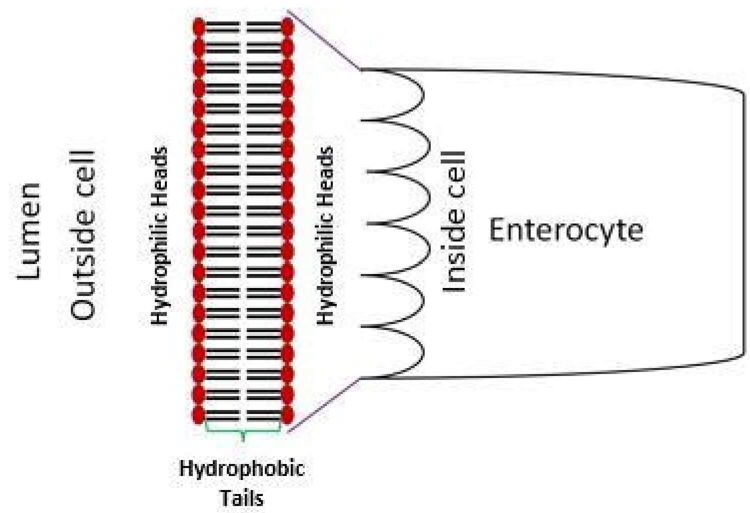

Figure 3.82 *Plasma membrane of a cell*

In addition to phospholipids, the cell membrane also contains proteins, cholesterol, and carbohydrates in addition to the phospholipids. Membrane proteins, such as channels, pumps, pores, and carriers are important for the transport of some compounds across the cell membrane. Figure 3.83 and two videos below do a nice job of illustrating the components of the cell membrane.

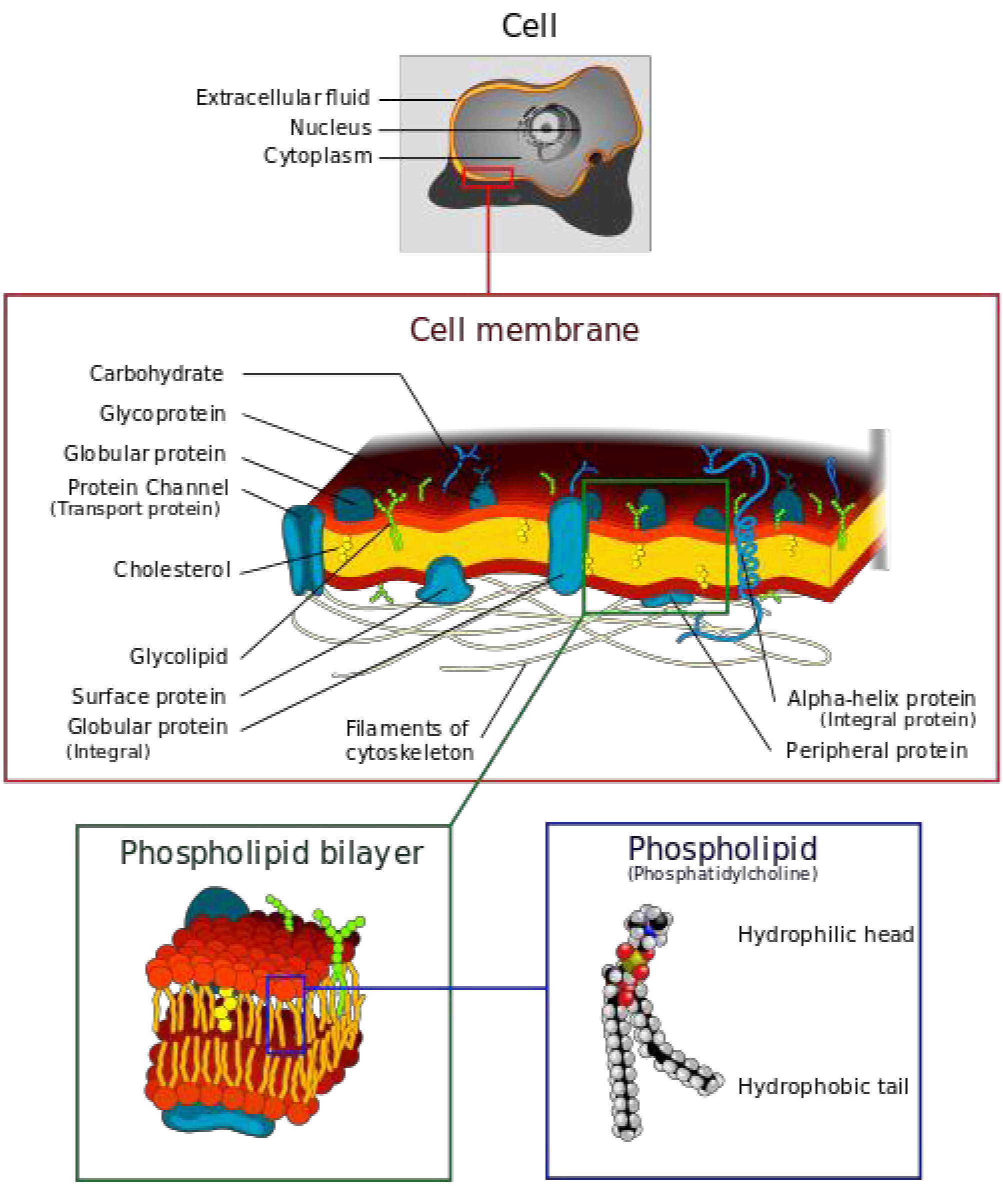

***Figure* 3.83** *Cell membrane. Image source*

Video Links:

Cell Membrane (1:27)

Voyage Inside the Cell: Membrane (1:23)

Transport Across the Plasma Membrane

There are a number of different transport mechanisms utilized by your body for the uptake of nutrients into cells, and absorption into the bloodstream. These mechanisms can be classified as being either passive transport or active transport. The difference between the two types of transport is whether energy is required, and whether they move *with* or *against* a **concentration gradient**. **Passive transport** does not require energy and moves with a concentration gradient (high to low concentration). **Active transport** requires energy to move against the concentration gradient (low to high concentration).

A **concentration gradient** is a result of an unequal distribution of solutes within a solution. In a solution, a **solute** is dissolved in the **solvent**. For example, in salt water, the solute is salt and water is the solvent. The more solute a region has, the higher the its concentration, while the less solute a region has, the lower the its concentration. Moving **with the gradient** is moving from a region of higher concentration to an area of lower concentration. Moving **against the gradient** is moving from an area of lower concentration to an area of higher concentration.

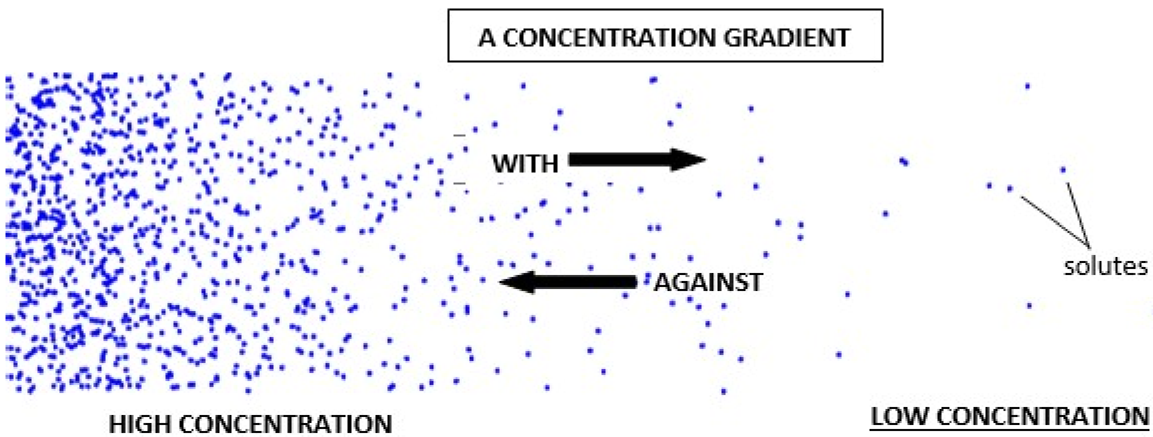

Figure 3.84 *Movement with and against a concentration gradient.*

The energy for active transport is provided by **adenosine triphosphate (ATP)**, which is the energy currency in the body. Tri- means three, thus ATP is adenosine (composed of an adenine and a ribose) with three phosphate groups bonded to it, as shown below.

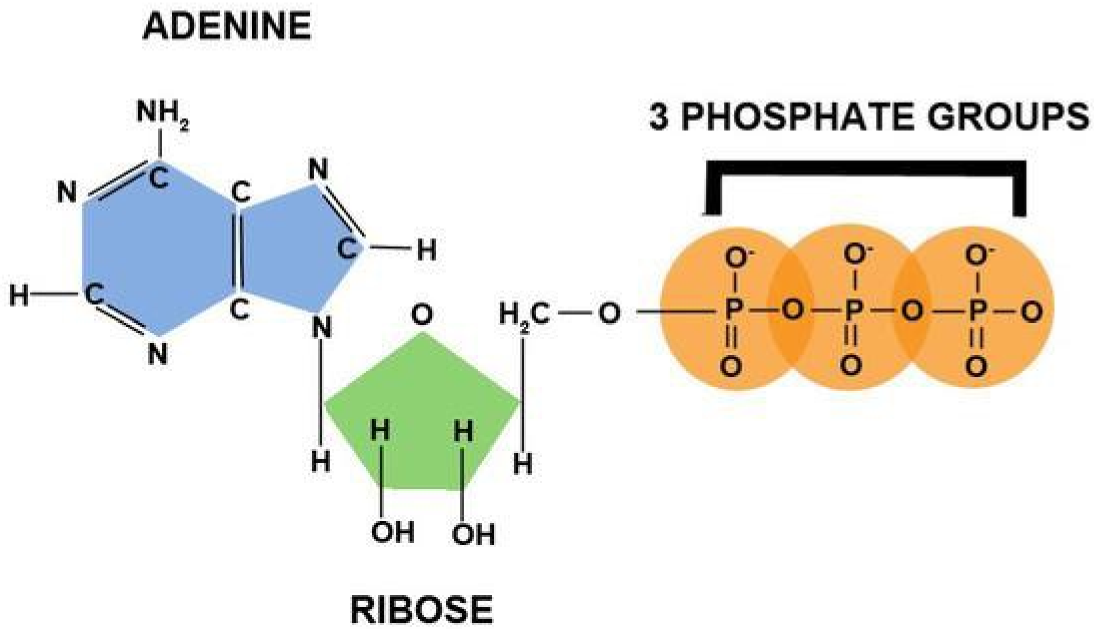

Figure 3.85 *Structure of adenosine triphosphate* (ATP). *Image source*

Phosphorylation is the formation of a phosphate bond. **Dephosphorylation** is the removal of a phosphate bond. Phosphorylation is an anabolic process that requires energy.

Dephosphorylation is a catabolic process that releases energy. Thus, energy is required to add phosphates to ATP, while energy is released through removing phosphates from ATP. Figure 3.86 depicts this process.

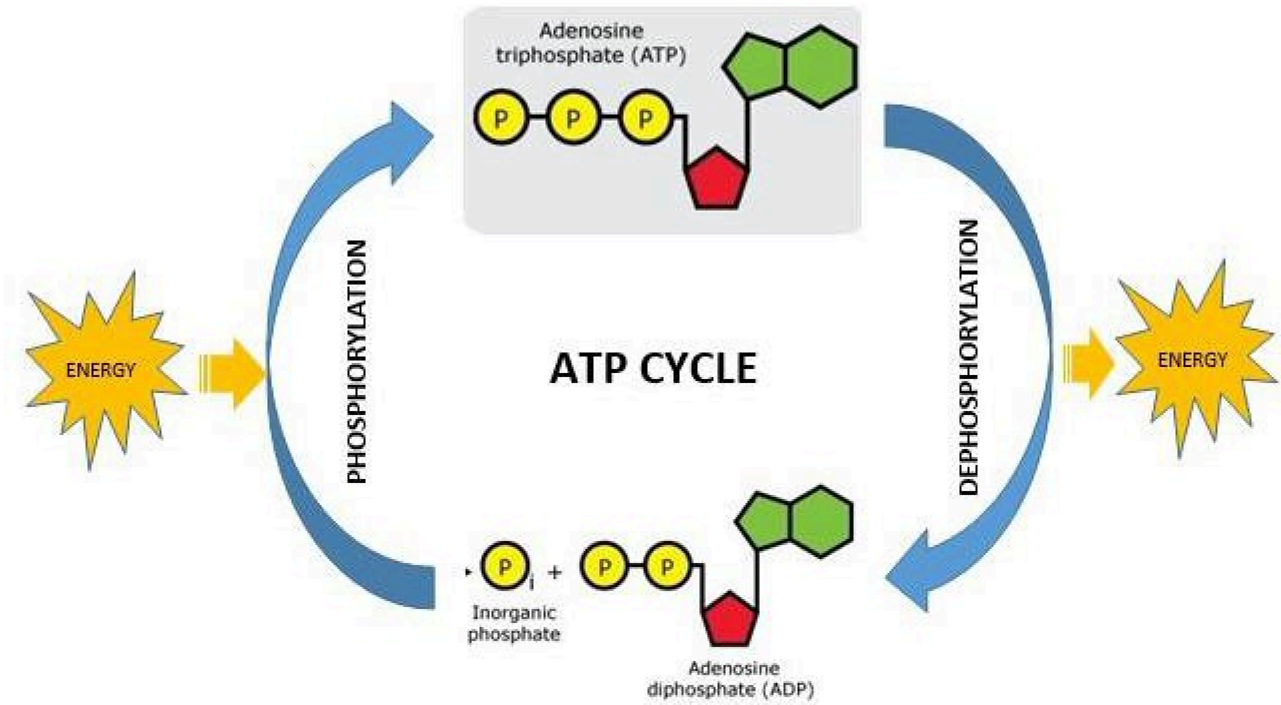

Figure 3.86 *The ATP Cycle demonstrating the processes of phosphorylation and dephosphorylation.*

Passive Transport Mechanisms

There are three forms of passive transport involved in uptake and absorption of nutrients in the body:

- Simple Diffusion
- Osmosis
- Facilitated Diffusion

Simple Diffusion

Simple diffusion is the movement of solutes from an area of higher concentration to an area of lower concentration (*with* the concentration gradient) without the help of a protein, as shown in Figure 3.87.

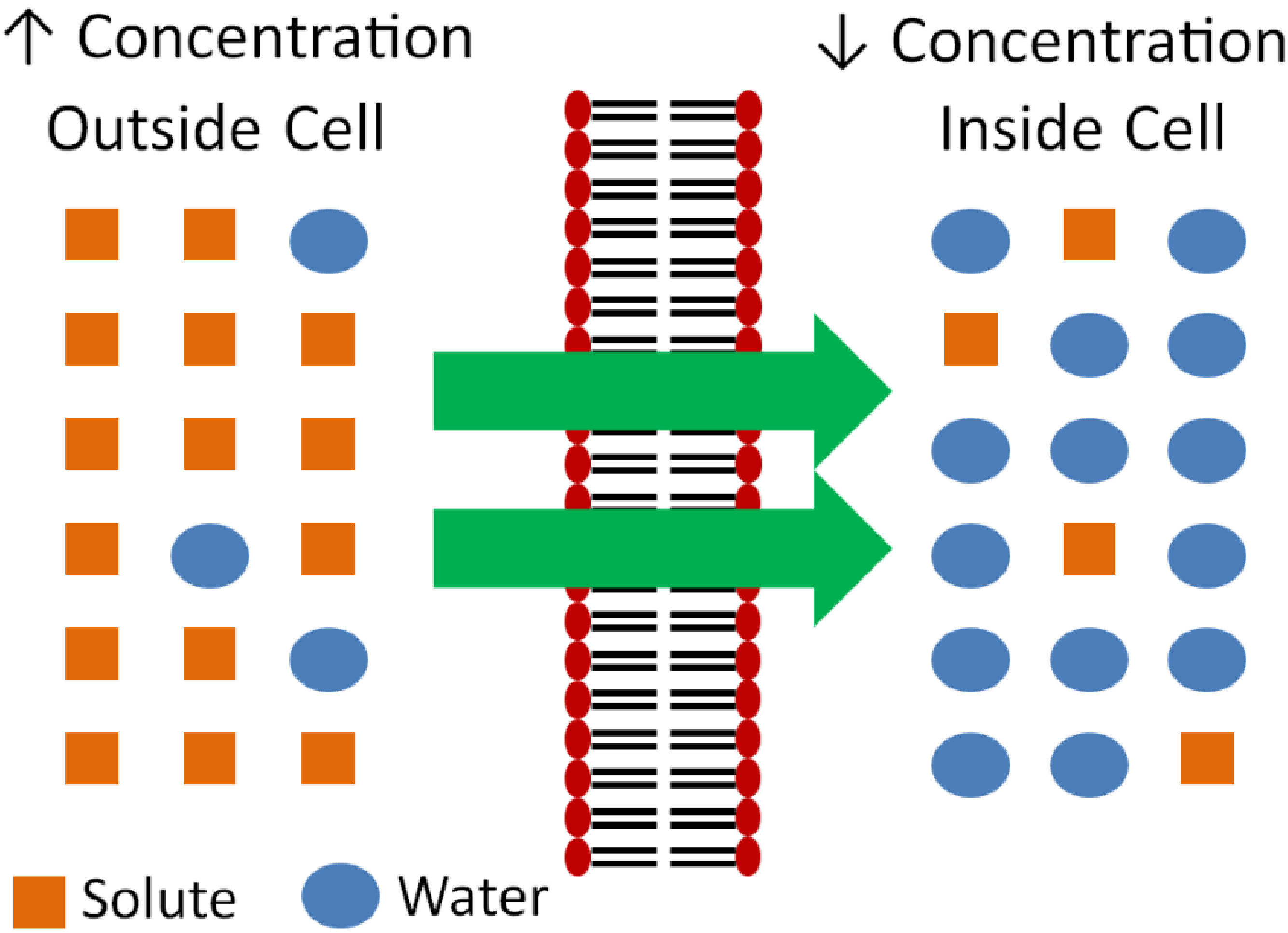

Figure 3.87 *Simple diffusion*

Osmosis

Osmosis is similar to simple diffusion, but water moves instead of solutes. In osmosis water molecules move from an area of lower solute concentration to an area of higher solute concentration as shown below. The effect of this movement is to dilute the area of higher concentration.

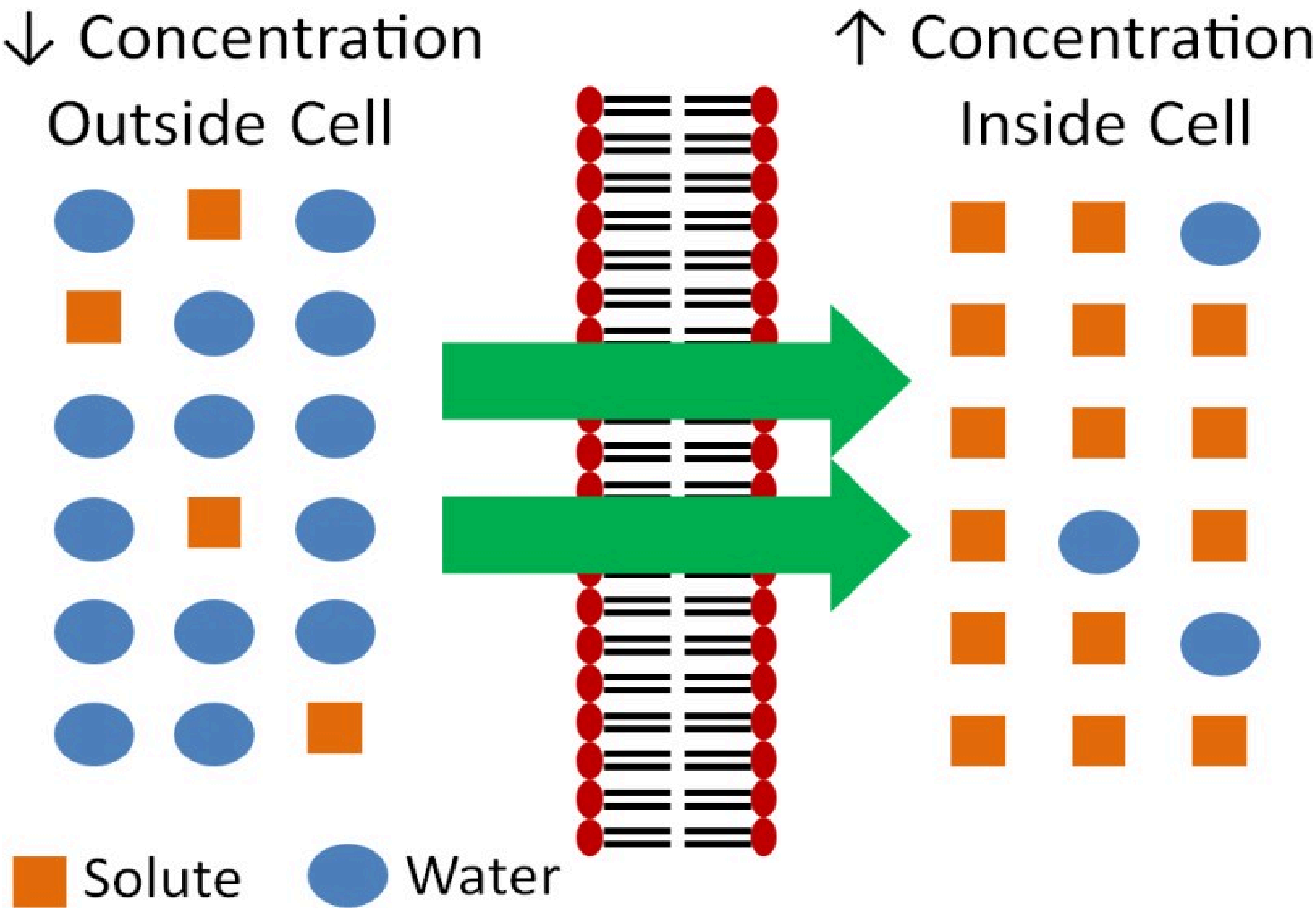

Figure 3.88 *Osmosis*

The following videos do a nice job of illustrating osmosis.

Video Links

Osmosis (0:47)

Osmosis in the Kitchen (0:58)

Another example illustrating osmosis is the red blood cells in different solutions shown below.

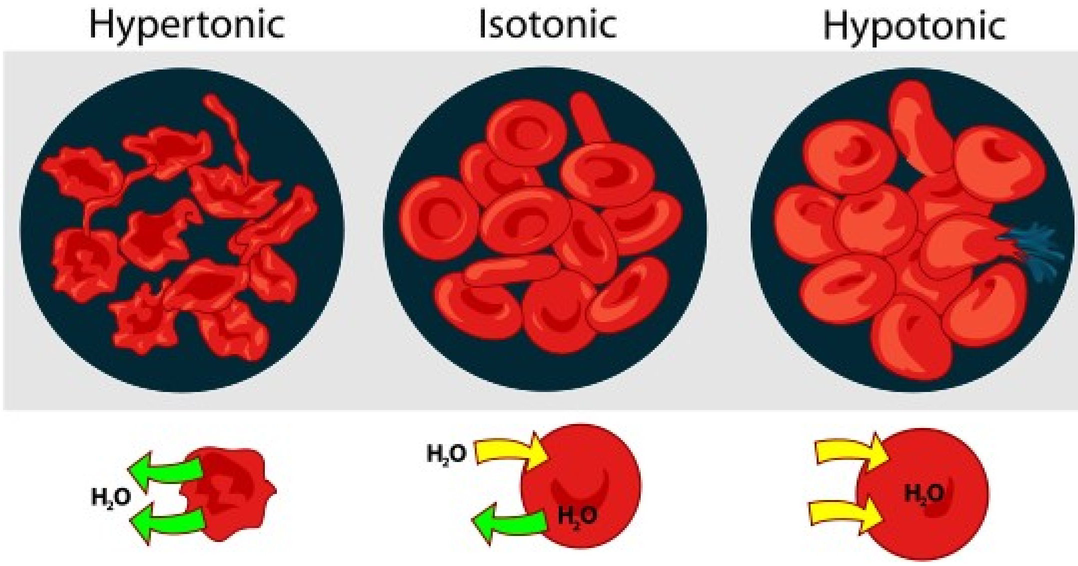

Figure 3.89 *Effect of salt solution concentration on red blood cells. Image source*

We will consider the simple example of salt as the solute. If the solution is hypertonic, that means that there is a greater concentration of salt outside (extracellular) the red blood cells than within them (intracellular). Water will then move out of the red blood cells to the area of higher salt concentration, resulting in the shriveled red blood cells depicted. Isotonic means that there is no difference between concentrations. There is an equal exchange of water between intracellular and extracellular fluids. Thus, the cells are normal, functioning red blood cells. A hypotonic solution contains a lower extracellular concentration of salt than the red blood cell intracellular fluid. As a result, water enters the red blood cells, possibly causing them to burst.

Facilitated Diffusion

The last form of passive transport is similar to diffusion in that it also moves *with* the concentration gradient (higher concentration to lower concentration). While it requires no energy, it does require a carrier protein to transport the solute across the membrane. Figure 3.810 and the video link below do a nice job of illustrating facilitated diffusion.

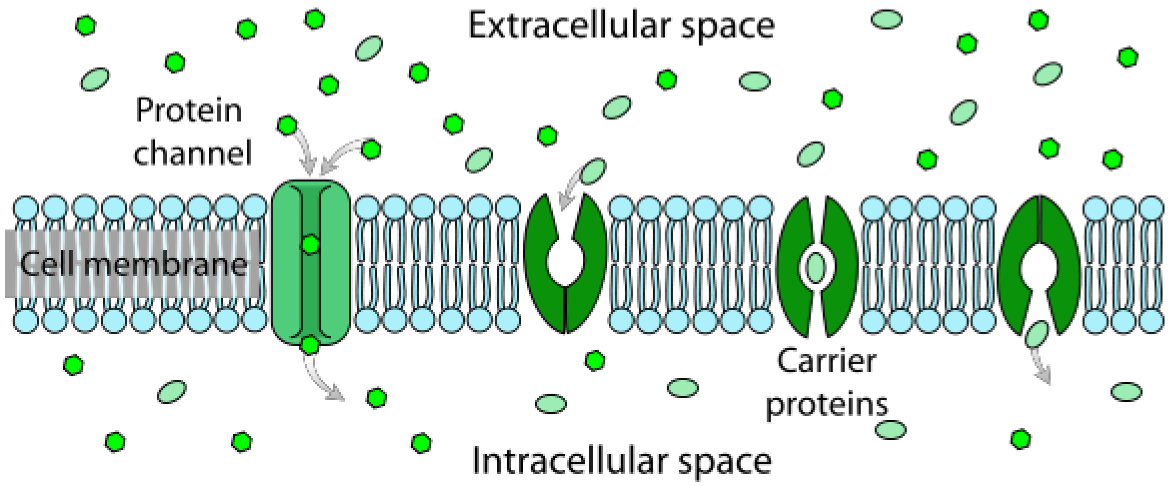

Figure 3.810 *Facilitated diffusion examples. Image source*

Video Link: Facilitated Diffusion (0:27)

Active Transport Mechanisms

There are two forms of active transport:

- Active Carrier Transport
- Endocytosis

Active Carrier Transport

Active carrier transport (sometimes referred to as secondary active transport) is similar to facilitated diffusion in that it utilizes a protein carrier. However, energy is also required to move compounds *against* their concentration gradient (lower to higher concentration). Figure 3.811 and the video below do a nice job of illustrating active carrier transport.

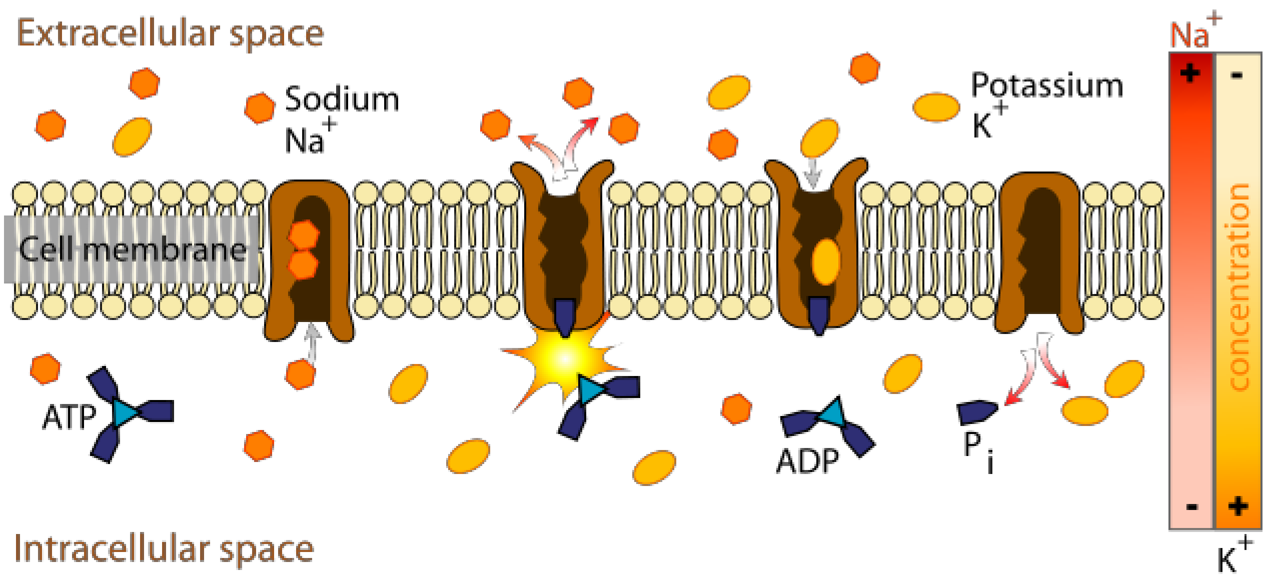

Figure 3.811 *Sodium-potassium ATPase (aka sodium-potassium pump) an example of active carrier transport. Image source*

Video Link: Active Transport (0:21)

Endocytosis

Endocytosis is the engulfing of particles, or fluids, to be taken up into the cell. If a particle is endocytosed, this process is referred to as **phagocytosis**. If a fluid is endocytosed, this process is referred to as **pinocytosis**. Whenever a receptor located on the membrane is used to assist in engulfing an extracellular component, it is known as **receptor mediated endocytosis**. These processes are shown in Figure 3.812.

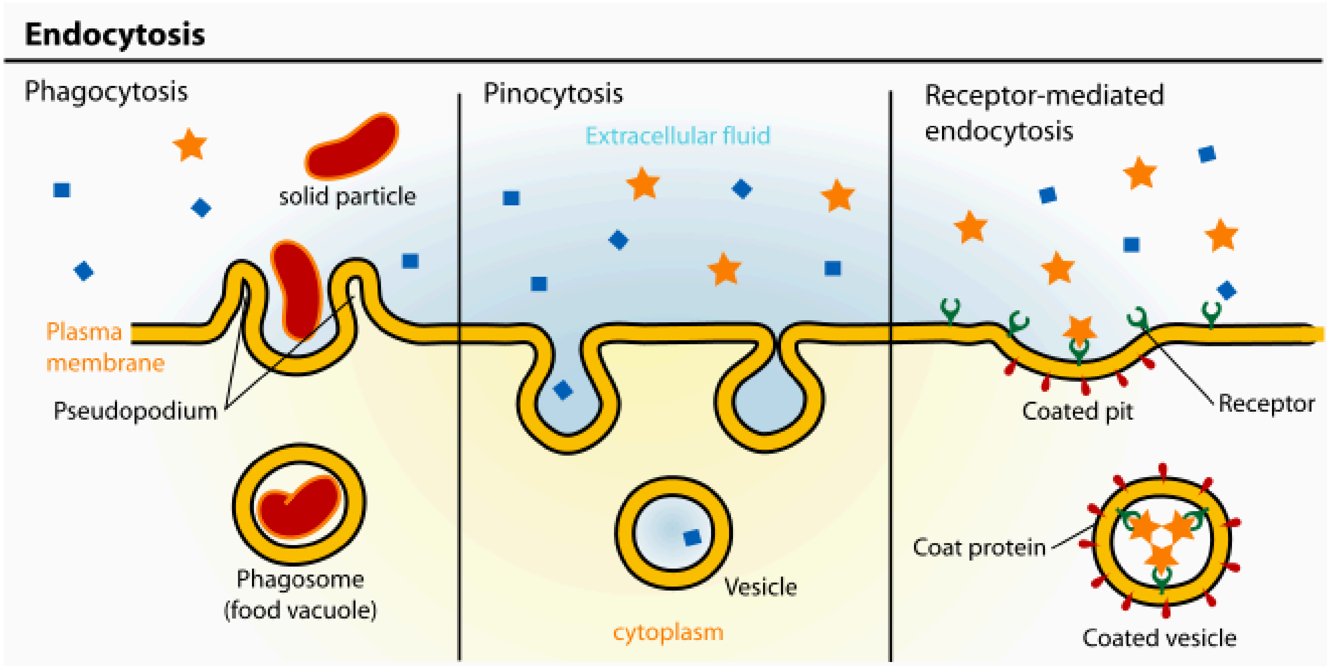

***Figure 3.812** Different types of endocytosis. Image source*

The following video does a really nice job of showing how endocytosis occurs.

Video Link: Endocytosis (0:35)

Circulation

There are two types of vessels that take up absorbed nutrients once they cross the intestinal wall: **capillaries** and **lacteals**. Capillaries are part of the circulatory system, the smallest blood vessels in your body. Lacteals are part of the lymphatic system, they are filled with tissue fluid called lymph. Most absorbed nutrients are taken up into the capillaries. The lacteals take up fat droplets that are too big to enter the capillaries. (This makes the lymph in the lacteals a milky white, which is why they're called lacteals!)

The diagram below shows two individual **villi**. The lacteals are in green and the capillaries in red and blue. Each villus in the small intestine has a lacteal and several capillaries running up the middle of it, perfectly positioned to pick up all of the nutrients absorbed through the intestinal cells (red arrows).

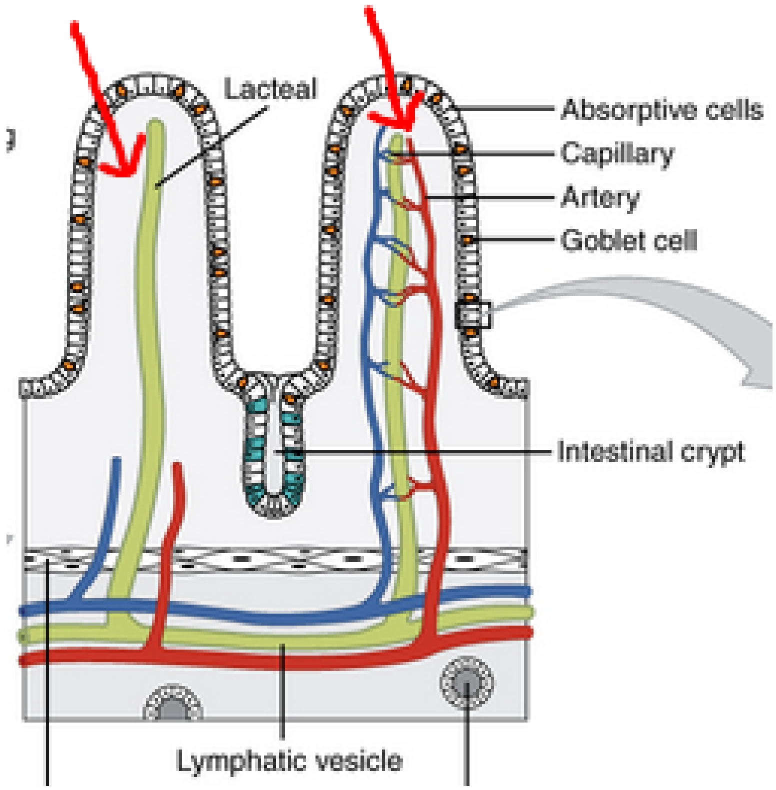

Figure 3.813 *Lacteals in the villi of the small intestine. Source: OpenStax College, Anatomy & Physiology. OpenStax CNX. Oct 3, 2013*

Nutrients that are absorbed into capillaries are swept directly to the liver for processing. Fats taken up by the lacteals bypass the liver initially and travel through the lymphatic system. This fluid is eventually returned to the bloodstream just before blood returns to the heart.

Summary of Nutrient Absorption

The figure below provides a summary of nutrient absorption. It shows the digestion of large molecules in the lumen of the small intestine and smaller molecules (products of digestion) being taken up across enterocytes. At the bottom of the figure, single sugars and amino acids enter capillaries (in red) for circulation to the liver, and lipids enter the lacteals (in yellow), for eventual entry into the bloodstream.

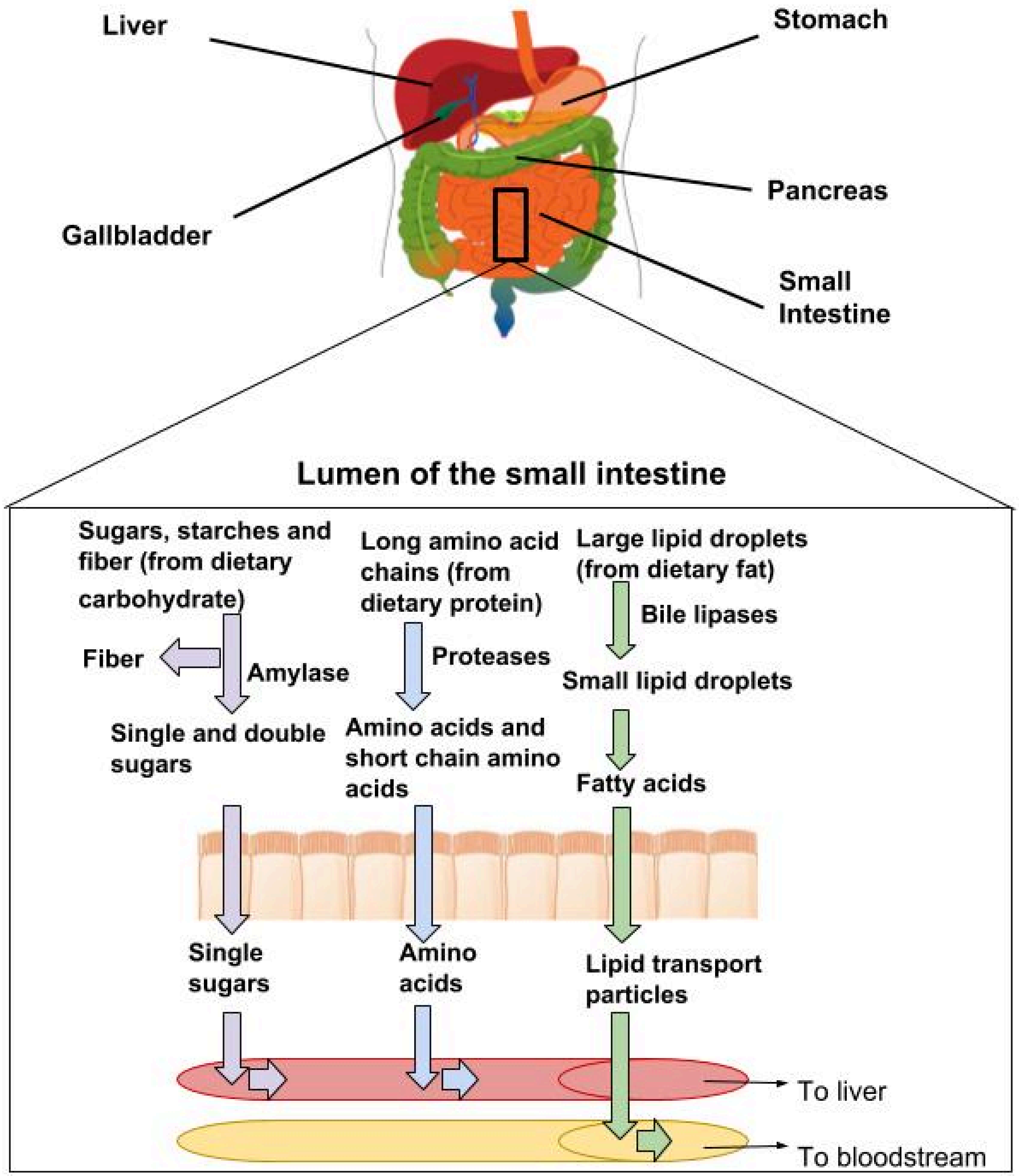

Figure 3.814 *Summary of nutrient absorption. Image by Allison Calabrese / CC BY 4.0*

We will go into greater detail on digestion and absorption of specific nutrients in later chapters.

CHAPTER IV

CHAPTER 4: COMMON DIGESTIVE PROBLEMS

When **nutrients** and energy are in short supply, cells, tissues, **organs**, and **organ systems** do not function properly. As a result, unbalanced diets can cause illness and disease. Conversely, certain illnesses and diseases can cause an inadequate uptake and absorption of nutrients, which in turn, simulates the health consequences of an unbalanced diet. Overeating high-fat foods and nutrient-poor foods can lead to **obesity** and exacerbate the symptoms of gastroesophageal reflux disease (GERD), gallstones, and irritable bowel syndrome (IBS). Many diseases and illnesses, such as celiac disease, interfere with the body getting its nutritional requirements. A host of other conditions and illnesses, such as peptic ulcers, Crohn's disease, and ulcerative colitis, can also impair the process of digestion and/or negatively affect nutrient balance and decrease overall health. In this chapter, we will explore a variety of these digestive disorders.

Sections:

Chapter from Jellum et al., *Principles of Nutrition.*

4.1 Gastroesophageal Reflux Disease

Gastroesophageal reflux disease (GERD) is a persistent form of acid reflux that occurs more than twice per week. Acid reflux occurs when the lower gastroesophageal **sphincter** (LES) fails to prevent the acidic contents of the stomach from leaking backward into the esophagus and causing irritation.

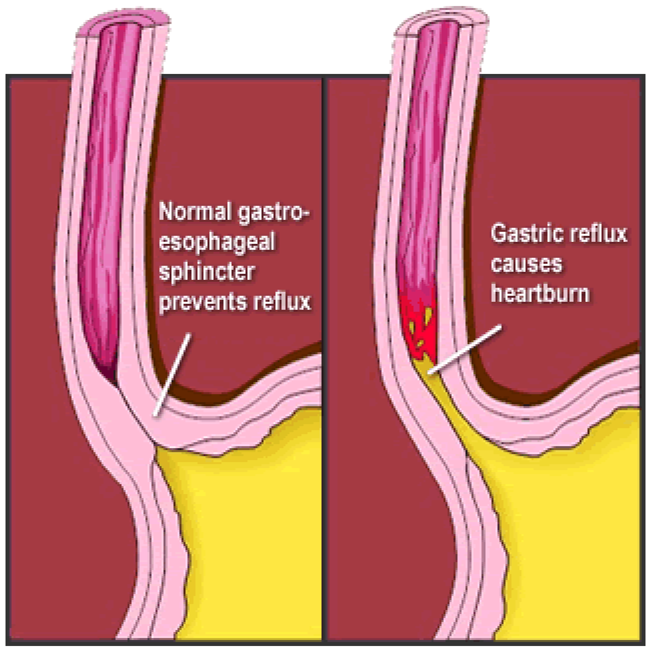

Figure 4.11 *The painful symptoms of GERD are caused by the leakage of acidic stomach contents into the esophagus. Image source*

It is estimated that GERD affects 25 to 35 percent of the US population. An analysis of several studies published in the August 2005 issue of *Annals of Internal Medicine* concludes that GERD is much more prevalent in people who are obese[1]. While the links between obesity and GERD are not completely understood, the links likely include: a) excess body fat putting pressure on the stomach, b) overeating leading to high pressure inside the stomach, and/or c) increased consumption of fatty foods triggering GERD symptoms.

There are other causative factors of GERD as well. Sometimes the peristaltic contractions of the esophagus are sluggish and can compromise the clearance of acidic contents. In addition, some people with GERD are sensitive to particular foods—chocolate, garlic, spicy foods, fried foods, and tomato-based foods—which worsen symptoms. Drinks containing alcohol or caffeine may also worsen GERD symptoms.

GERD is diagnosed most often by a history of recurring symptoms. The most common symptom of GERD is heartburn but people with GERD may also experience regurgitation (flow of the stomach's acidic contents into the mouth), frequent coughing, nausea, wheezing, and trouble swallowing. A more proper diagnosis can be made when a doctor inserts a small device into the lower esophagus that measures the acidity of the contents during one's daily activities.

Sometimes a doctor may use an endoscope, which is a long tube with a camera at the end, to view the tissue in the esophagus. About 50% of people with GERD have inflamed **tissues** in the esophagus. Recurrent tissue damage can cause **Barrett's esophagus**[2]. Barrett's esophagus occurs in 5 to 15 percent of patients diagnosed with GERD and in some of these individuals, the condition may develop into cancer of the esophagus, a highly lethal cancer.

Figure 4.12 *Normal esophagus (left) Barrett's esophagus (right). Barrett's esophagus occurs when the linings of the esophagus transform to tissue types that are more consistent with the linings of the stomach or intestine. Image source*

Approximately 35% of children born in the United States have GERD. In babies, the symptoms are more difficult to distinguish from what babies do normally. The symptoms are spitting up more than normal, incessant crying, refusal to eat, burping, and coughing. Most babies outgrow GERD before their first birthday but a small percentage do not.

The first approach to GERD treatment is dietary and lifestyle modifications. Suggestions are to reduce weight if you are overweight or obese, avoid foods that worsen GERD symptoms, eat smaller meals, stop smoking, and remain upright for at least three hours after a meal. There is some evidence that sleeping on a bed with the head raised at least six inches helps lessen the symptoms of GERD. People with GERD may not take in the nutrients they need because of the pain and discomfort associated with eating. As a result, GERD can cause an unbalanced diet and its symptoms can lead to a worsening of nutrient inadequacy, a vicious cycle that further compromises health. Many medications are available to treat GERD, including antacids (Maalox or Mylanta), histamine[3] (H2) blockers (Tagamet, Zantac, Axid, and Pepcid), and proton-pump inhibitors (Prilosec, Prevacid, Nexium, and Aciphex. Evidence from several scientific studies indicates that medications used to treat GERD may accentuate certain nutrient deficiencies, namely zinc and magnesium[4]. When these treatment approaches do not work surgery is an option. The most common surgical treatment involves reinforcing the lower esophageal sphincter, which serves as the barrier between the stomach and esophagus.

The following videos do a nice job of describing the causes, symptoms, and treatments of GERD.

Video Links:

Understanding GERD (3:04)

Gastric Reflux (GERD) (3:10)

Notes

1. Hampel, H. MD, PhD, N. S. Abraham, MD, MSc(Epi) and H. B. El-Serag, MD, MPH. "Meta- Analysis: Obesity and the Risk for Gastroesophageal Reflux Disease and Its Complications." *Ann Intern Med* 143, no. 3 (2005): 199–211. http://www.ncbi.nlm.nih.gov/pubmed/16061918
2. https://refluxcentar.com/en/diseases/barretts-esophagus/
3. Hampel, H. MD, PhD, N. S. Abraham, MD, MSc(Epi) and H. B. El-Serag, MD, MPH. "Meta- Analysis: Obesity and the Risk for Gastroesophageal Reflux Disease and Its Complications." *Ann Intern Med* 143, no. 3 (2005): 199–211. http://www.ncbi.nlm.nih.gov/pubmed/16061918

4. Heidelbaugh, J. J. (2013). Proton pump inhibitors and risk of vitamin and mineral deficiency: evidence and clinical implications. *Therapeutic Advances in Drug Safety*, 4(3), 125–133. http://doi.org/10.1177/2042098613482484

4.2 Peptic Ulcers

We introduced peptic ulcers briefly in chapter 1. A peptic ulcer (stomach or duodenal) is a break in the inner lining of the esophagus, stomach, or **duodenum**. A peptic ulcer of the stomach is called a gastric ulcer, or duodenal ulcer when located in the duodenum, and esophageal ulcer when in the esophagus. Peptic ulcers occur when the lining of these organs is corroded by the acidic digestive (peptic) juices of the stomach. A peptic ulcer differs from an erosion because it extends deeper into the lining of the esophagus, stomach, or duodenum and incites more of an inflammatory reaction from the tissues that are involved. Chronic cases of peptic ulcers are referred to as peptic ulcer disease.[1]

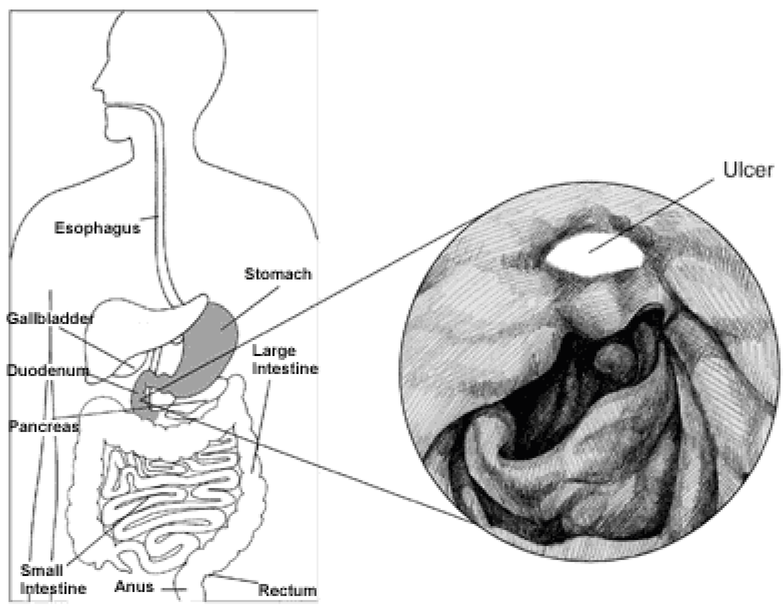

Figure 4.21 *A peptic ulcer in the duodenum. Image source*

Video Links:

Stomach Ulcer (5:44)

Endoscopy of Two Giant Gastric Ulcers (0:27)

Peptic ulcer disease is common, affecting millions of Americans yearly. Moreover, peptic ulcers are a recurrent problem; even healed ulcers can recur unless treatment is directed at preventing their recurrence. The medical cost of treating peptic ulcer and its complications runs into billions of dollars annually. Recent medical advances have increased our understanding of ulcer formation. Improved and expanded treatment options now are available.

Symptoms of duodenal or stomach ulcer disease vary. Many people with ulcers experience minimal indigestion, abdominal discomfort that occurs after meals, or no discomfort at all. Some complain of upper abdominal burning or hunger pain one to three hours after meals or in the middle of the night. These symptoms are often promptly relieved by food or antacids that neutralize stomach acid. The pain of ulcer disease correlates poorly with the presence or severity of active ulceration. Some individuals have persistent pain even after an ulcer is almost completely healed by medication. Others experience no pain at all. Ulcers often come and go spontaneously without the individual ever knowing that they are present unless a serious complication (like bleeding or perforation) occurs.[2]

For many years, excess acid was believed to be the only cause of ulcer disease. Accordingly, the emphasis of treatment was on neutralizing and inhibiting the secretion of stomach acid. While acid is still considered necessary for the formation of ulcers and its suppression is still the primary treatment, the two most important initiating causes of ulcers are infection of the stomach by a bacterium named ***Helicobacter pylori* (*H. pylori*)** and chronic use of **nonsteroidal anti-inflammatory medications** or NSAIDs, including aspirin. Cigarette smoking also is an important cause of ulcers as well as failure of ulcer treatment.[3]

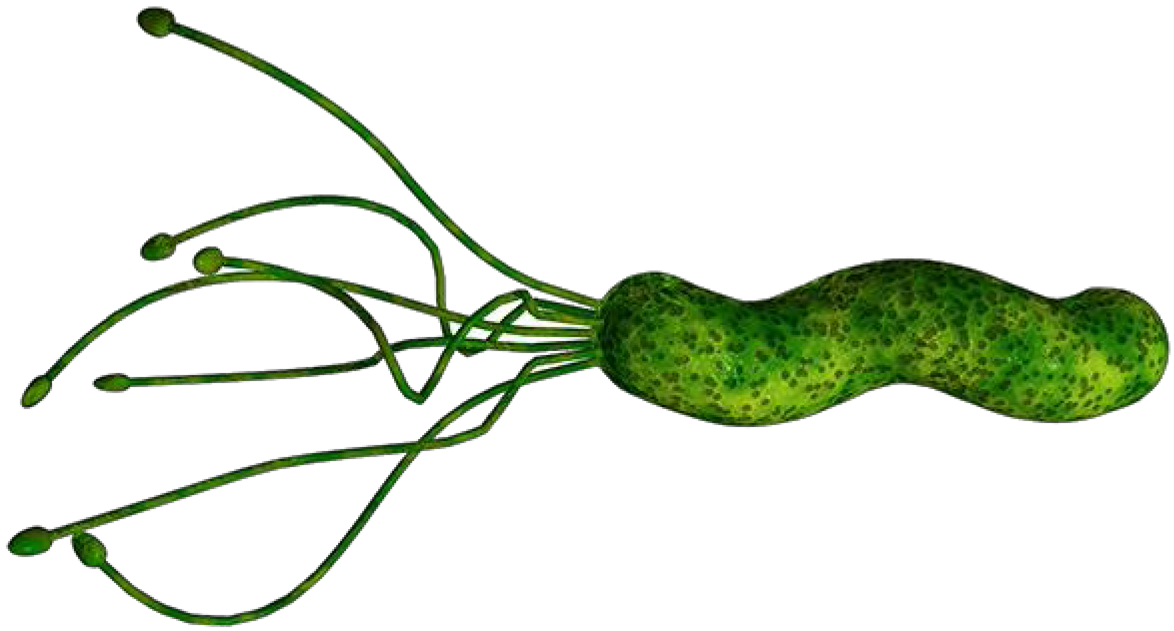

Figure 4.22 *Spiral-shaped H. pylori is the only bacteria known to colonize the human stomach. Image source*

Video Link: Tests for H. pylori (2:05)

Infection with *H. pylori* is very common, affecting more than a billion people worldwide. It is estimated that half of the United States population older than age 60 has been infected with *H. pylori*. Infection usually persists for many years, leading to ulcer disease in 10% to 15% of those infected. In the past, *H. pylori* was found in more than 80% of patients with gastric and duodenal ulcers. Diagnosis and treatment of this infection, the prevalence of infection with *H. pylori*, and the proportion of ulcers caused by the bacterium has decreased as the causes of peptic ulcers has been identified. It is estimated that currently only 20% of ulcers are associated with the bacterium. While the mechanism by which *H. pylori* causes ulcers is complex, elimination of the bacterium by antibiotics has clearly been shown to heal ulcers and prevent their recurrence.[4]

NSAIDs are medications used for the treatment of arthritis and other painful inflammatory conditions in the body. Aspirin, ibuprofen (Advil, Motrin), naproxen (Aleve, Naprosyn), and etodolac (Lodine) are a few examples of this class of medications. NSAIDs cause ulcers by interfering with the production of prostaglandins in the stomach.

Cigarette smoking has been shown to not only cause ulcers, but it also increases the risk of complications from ulcers such as ulcer bleeding, stomach obstruction, and perforation. Cigarette smoking is also a leading cause of failure of treatment for ulcers.

Contrary to popular belief, alcohol, coffee, colas, spicy foods, and caffeine have no proven role in ulcer formation. Similarly, there is no conclusive evidence to suggest that life stresses or personality types contribute to ulcer disease.

The goal of ulcer treatment is to relieve pain, heal the ulcer, and prevent complications. The first step in treatment involves the reduction of risk factors (NSAIDs and cigarettes). The next step is medications.

Antacids neutralize existing acid in the stomach. Histamine antagonists (H2 blockers) are drugs designed to block the action of histamine on gastric cells and reduce the production of acid.

While H2 blockers are effective in ulcer healing, they have a limited role in eradicating *H. pylori* without antibiotics. Therefore, ulcers frequently return when H2 blockers are stopped. Proton- pump inhibitors are more potent than H2 blockers in suppressing acid secretion. The different proton-pump inhibitors are very similar in action and there is no evidence that one is more effective than the other in healing ulcers. While proton-pump inhibitors are comparable to H2 blockers in effectiveness in treating gastric and duodenal ulcers, they are superior to H2 blockers in treating esophageal ulcers.[5]

Notes

1. https://www.niddk.nih.gov/health-information/digestive-diseases/peptic-ulcers-stomach-ulcers/definition-facts
2. https://www.mayoclinic.org/diseases-conditions/peptic-ulcer/symptoms-causes/syc-20354223
3. https://www.mayoclinic.org/diseases-conditions/peptic-ulcer/symptoms-causes/syc-20354223
4. http://www.helico.com/whatishelicobacterpylori.html
5. https://www.mayoclinic.org/diseases-conditions/peptic-ulcer/symptoms-causes/syc-20354223

4.3 Gallstones

It is estimated that up to 1 million Americans are hospitalized annually as a result of gallstones, making it the most common of all digestive diseases.[1] Gallstones are formed when **bile** hardens in the **gallbladder**. 80% of gallstones are a result of cholesterol precipitation, while 20% are the result of bile pigment precipitation.[2] The cause of gallstones is not fully understood. The way in which gallstones are formed is shown in the following video.

Video Link: Gallstones (0:27)

The following figure shows a severe case of gallstones.

Figure 4.31 *Gallstones within a dissected gallbladder. Image source*

Many people do not experience symptoms from gallstones. They are usually discovered during examination for another health condition. However, some people experience an "attack" or pain that results from blockage of the bile ducts.

Prevention of gallstones is accomplished by maintaining a healthy weight and eating a diet high in fiber and low in simple carbohydrates. If there are no symptoms, treatment is usually not needed. In those who are having gallbladder attacks, surgery to remove the gallbladder, called a cholecystectomy, is typically recommended since the gallbladder is not considered an essential organ. After surgery, bile then flows directly from the liver into the small intestine. In those who are unable to have surgery, medication to try to dissolve the stones or shock wave lithotripsy may be tried.

In the developed world, 10–15% of adults have gallstones. Rates in many parts of Africa, however, are as low as 3%. Gallbladder and biliary related diseases occurred in about 104 million people (1.6%) in 2013 and they resulted in 106,000 deaths. Women more commonly have stones than men and they occur more commonly after the age of 40. Certain ethnic groups have gallstones more often than others. For example, 48% of American Indians have gallstones. Once the gallbladder is removed, outcomes are generally good.

Notes

1. Bar-Meir S. (2001) Gallstones: Prevalence, diagnosis and treatment. The Israel Medical Association Journal 3(2): 111.
2. https://www.niddk.nih.gov/health-information/digestive-diseases/gallstones

4.4 Irritable Bowel Syndrome

Irritable bowel syndrome (IBS) is characterized by muscle spasms in the colon that result in abdominal pain, bloating, constipation, and/or diarrhea.[1] Interestingly, IBS produces no permanent structural damage to the large intestine as often happens to patients who have Crohn's disease or other inflammatory bowel diseases. It is estimated that one in five Americans displays symptoms of IBS. The disorder is more prevalent in women than in men. Two primary factors that contribute to IBS are an unbalanced diet and stress.

Symptoms of IBS significantly decrease a person's quality of life, as they are present for at least twelve consecutive or nonconsecutive weeks in a year. Large meals and foods high in fat and added sugars, or those that contain wheat, rye, barley, peppermint, and chocolate intensify or bring about symptoms of IBS. Additionally, beverages containing caffeine or alcohol may worsen IBS. Stress and depression compound the severity and frequency of IBS symptoms.

There is no specific test to diagnose IBS, but other conditions that have similar symptoms (such as celiac disease and **peptic ulcers**) must be ruled out. This involves stool tests, blood tests, and having a colonoscopy (which involves the insertion of a flexible tube with a tiny camera on the end through the anus so the doctor can see the colon tissues).

There is no cure for IBS. As with GERD, the first treatment approaches for IBS are diet and lifestyle modifications. People with IBS are often told to keep a daily food journal to help identify and eliminate foods that cause the most problems. Other recommendations are to eat slower, add more fiber to the diet, drink more water, and to exercise. There are some medications (many of which can be purchased over-the-counter) to treat IBS and the resulting diarrhea or constipation. Sometimes antidepressants and drugs to relax the colon are prescribed.

Video Link: Irritable Bowel Syndrome (IBS) (4:07)

Notes

1. https://www.niddk.nih.gov/health-information/digestive-diseases/irritable-bowel-syndrome

4.5 Inflammatory Bowel Disease

Inflammatory bowel disease (IBD) refers to a number of inflammatory conditions in the intestine. The two most common are Crohn's disease and **ulcerative colitis**. These two conditions differ mainly in the areas of the intestine that are affected. Crohn's disease can occur anywhere throughout the GI tract, but most commonly occurs in the last part of the ileum.

Crohn's disease may also involve all layers of the intestine.[1] Ulcerative colitis are ulcers, or sores, in the lining of the colon and/or rectum.[2] It is estimated that up to 1 million people have IBD in the United States. Half of these individuals have Crohn's disease, and the other half have ulcerative colitis.[3]

Table 4.51 Differences between Crohn's disease and ulcerative colitis[4]

	Crohn's Disease	**Ulcerative Colitis**
Location	Inflammation may occur anywhere along the digestive tract	Large intestine (colon) is typically the only affected site
Inflammation	Inflammation may occur in patches	Inflammation is continuous throughout affected areas
Pain	Pain is commonly experienced in the lower right abdomen	Pain is common in the lower left part of the abdomen
Appearance	• Colon wall may be thickened and may have a rocky appearance • Ulcers along the digestive tract are deep and may extend into all layers of the bowel wall	• Colon wall is thinner and shows continuous inflammation • Mucus lining of large intestine may have ulcers, but they do not extend beyond the inner lining
Bleeding	Bleeding from the rectum during bowel movements is not common	Bleeding from the rectum during bowel movements

The exact causes of these two diseases is not known. One hypothesized cause for Crohn's disease is an overactive immune system that results in the chronic inflammation and collateral damage to the **cells** of the intestine, resulting in formation of lesions.

Crohn's disease and ulcerative colitis present symptoms similar to other gastrointestinal diseases, such as irritable bowel syndrome and GERD. However, there are areas where the symptoms of the two do not overlap. Table 4.52 lists the typical symptoms of each.

Table 4.52 Comparison of the symptoms of Crohn's disease and ulcerative colitis.[5]

Symptoms of Crohn's Disease	• abdominal pain, cramping, or swelling • anemia • fever • gastrointestinal bleeding • joint pain • malabsorption • persistent or recurrent diarrhea • stomach ulcers • vomiting • weight loss
Symptoms of Ulcerative Colitis	• abdominal pain or discomfort • anemia caused by severe bleeding • bloody diarrhea • dehydration • fatigue • fever • joint pain • loss of appetite • malabsorption • rectal bleeding • urgent bowel movements • weight loss

Notes

1. http://www.niddk.nih.gov/health-information/health-topics/digestive-diseases/crohns-disease/Pages/facts.aspx
2. https://www.niddk.nih.gov/health-information/digestive-diseases/ulcerative-colitis
3. http://www.ccfa.org/info/about/crohns
4. http://www.columbia-stmarys.org/Crohn_vs_Ulcerative_Colitis [inactive]
5. http://www.columbia-stmarys.org/Crohn_vs_Ulcerative_Colitis [inactive]

4.6 Celiac Disease & Gluten

1 out of every 133 people in the United States has celiac disease.[1] People with celiac disease cannot consume the protein gluten because it causes their body to generate an autoimmune response (immune cells attack the body's own cells) that causes damage to the **villi** in the intestine, as shown in Figure 4.61.

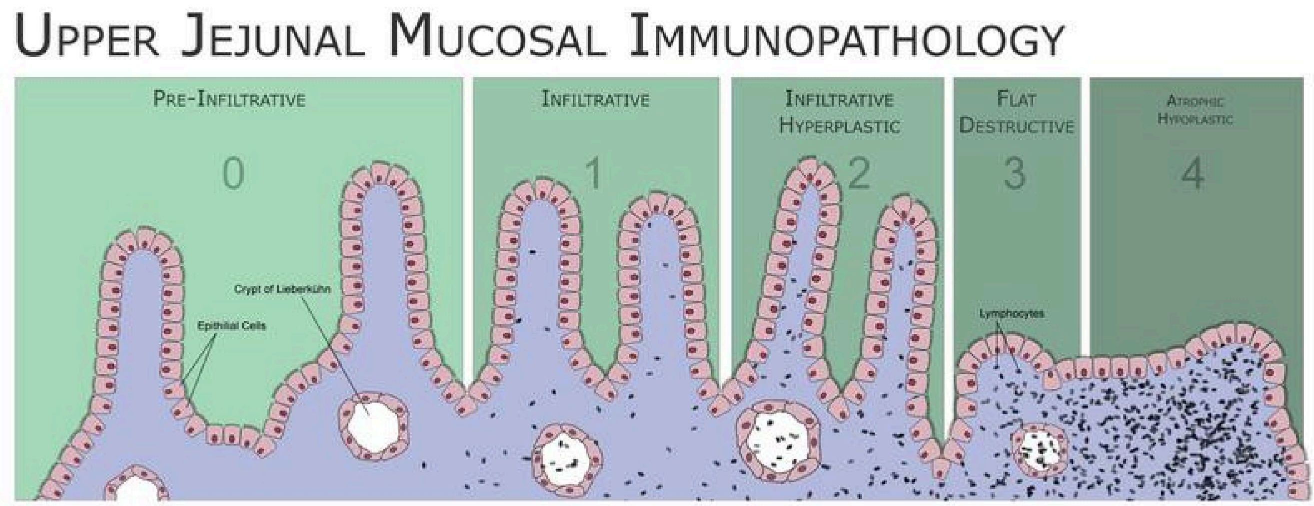

Figure 4.61 *Different stages of celiac disease. Image source*

This damage to the villi impairs the absorption of **macronutrients** and **micronutrients** from food.

There are a variety of symptoms for celiac disease that vary depending on age and from person to person. Digestive symptoms are more common in children and may include diarrhea or constipation, gas, nausea/vomiting. Adults are less likely to experience digestive symptoms. Symptoms in adults can include **anemia**, bone or joint pain, headaches, infertility, and seizures.[2] The web link below describes the difficulty in diagnosing this disease, which is reinforced by the video link.

Web Link: Celiac Disease, a Common, but Elusive, Diagnosis

Video Link: Celiac's Disease (2:00)

The symptoms can appear in **infancy** or much later in life, even by age seventy. Celiac disease is not always diagnosed because the symptoms may be mild. A large number of people have what is referred to as “silent” or “latent” celiac disease.

Villi destruction is what causes many of the symptoms of celiac disease. The destruction of the absorptive surface of the small intestine also results in the malabsorption of nutrients, so that while people with this disease may eat enough, nutrients do not make it to the bloodstream because absorption is reduced. The effects of nutrient malabsorption are most apparent in children and the elderly as they are especially susceptible to nutrient deficiencies. Over time, these nutrient deficiencies can cause health problems. Poor absorption of iron and folic acid can cause anemia, which is a decrease in red blood cells. Anemia impairs oxygen transport to all cells in the body. Calcium and vitamin D deficiencies can lead to **osteoporosis**, a disease in which bones become brittle.

What is gluten?

Gluten is a protein that is bound to starch in the endosperm of grains such as:

- Wheat
- Barley
- Rye
- Triticale

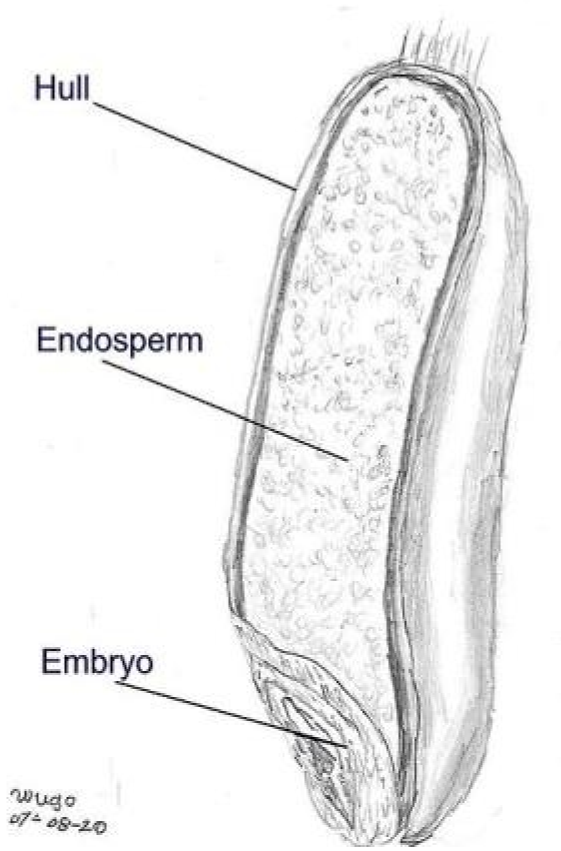

Figure 4.62 *Parts of a wheat granule. Image source*

Gluten-free diets have been increasing in popularity even for people who don't have celiac disease. The thinking among those consuming these diets is that they might be gluten-sensitive, meaning that they experience adverse effects from consuming it. However, as the following videos describes, there is not much evidence to support people being gluten-sensitive.

Video Link: Is Gluten-Sensitivity Real? (3:11)

Celiac disease is most common in people of European descent and is rare in people of African American, Japanese, and Chinese descent. It is much more prevalent in women and in people with Type 1 diabetes, autoimmune thyroid disease, and Down and Turner syndromes.

Symptoms can range from mild to severe and can include pale, fatty, loose stools, gastrointestinal upset, abdominal pain, weight loss and, in children, a failure to grow and thrive.

Notes

1. http://www.celiac.org/
2. https://www.niddk.nih.gov/health-information/digestive-diseases/celiac-disease/symptoms-causes

4.7 Diverticulosis and Diverticulitis

Approximately 10% of people under 40, and 50% of people over 60 years old have a condition known as diverticulosis.[1] In this condition, diverticula (plural, diverticulum singular), or out- pouches, are formed at weak points in the large intestine, primarily in the lowest section of the sigmoid colon, as nicely shown in the figure below and in the video in the web link below.

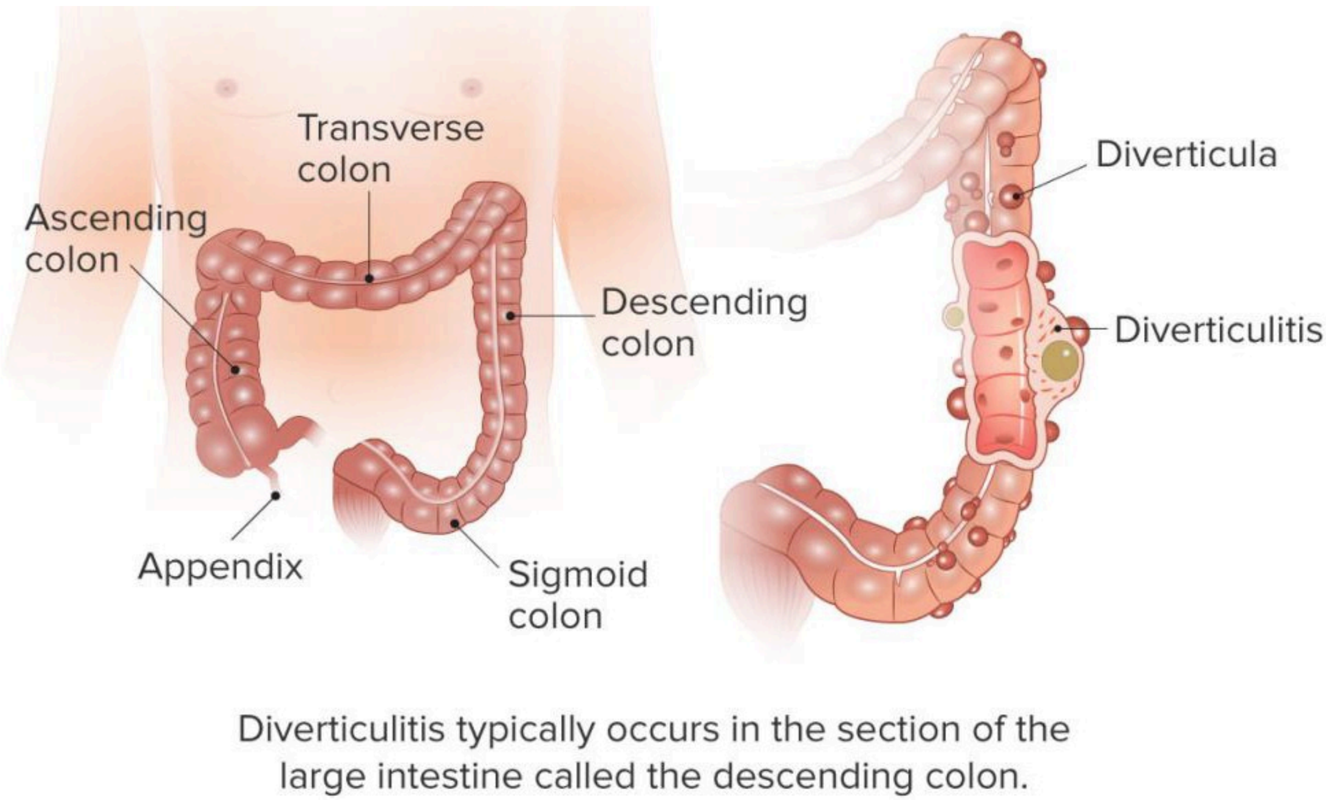

Figure 4.71 *Diverticula on the large intestine. Image source: National Institute of Diabetes and Digestive and Kidney Diseases, National Institutes of Health.*

Video Link: Diverticulosis (1:24)

It is believed that diverticula are formed as a result of a low-fiber diet because people may strain more during bowel movements. Most people with diverticulosis do not know that they have the condition. However, if the pouches become inflamed, then the condition is known as diverticulitis. Approximately 10 to 25 percent of people who have diverticulosis go on to develop diverticulitis.[2] Symptoms include lower abdominal pain, nausea, and alternating between constipation and diarrhea.

The chances of developing diverticulosis and hence diverticulitis can be reduced with fiber intake because of what the breakdown products of the fiber do for the colon. The bacterial breakdown of fiber in the large intestine releases short-chain fatty acids. These molecules have been found to nourish colonic cells, inhibit colonic inflammation, and stimulate the immune system (thereby providing protection of the colon from harmful substances). Additionally, the bacterial indigestible fiber, mostly insoluble, increases stool bulk and softness increasing transit time in the large intestine and facilitating feces elimination. One uncomfortable side effect of consuming foods high in fiber is increased gas production since the byproducts of bacterial digestion of fiber are gases.

Several studies have found a link between high dietary-fiber intake and a decreased risk for colon cancer. However, an analysis of several studies published in the *Journal of the American Medical Association* in 2005 did not find that dietary-fiber intake was associated with a reduction in colon cancer risk.[3] There is some evidence that specific fiber types (such as inulin) may protect against colon cancer, but more studies are needed to conclusively determine how certain fiber types (and at what dose) inhibit colon cancer development.

The treatment the doctor prescribes will depend on how severe the condition is. Most cases of diverticulitis — about 75 percent of them — are uncomplicated. This means they have no other problems besides the actual inflammation or possible infection from the diverticulitis itself.

With uncomplicated diverticulitis, the doctor will likely suggest lots of rest and fluids during recovery from symptoms. They will also want to conduct follow-up assessments within a few days. In the meantime, the doctor may prescribe or recommend treatments such as medication, a liquid diet, or a low-fiber diet.[4]

Notes

1. http://www.niddk.nih.gov/health-information/health-topics/digestive-diseases/diverticular-disease/Pages/facts.aspx#1

2. National Digestive Diseases Information Clearinghouse, a service of National Institute of Diabetes and Digestive and Kidney Diseases, National Institute of Health. "Diverticulosis and Diverticulitis." NIH Publication No. 08-1163 (July 2008).
3. Park, Y. et al. "Dietary Fiber Intake and Risk of Colorectal Cancer." JAMA 294, no. 22 (2005): 2849–57. doi:10.1001/jama.294.22.2849
4. https://www.healthline.com/health/diverticulitis#common-treatments

4.8 Hemorrhoids

Hemorrhoids are swollen or inflamed veins of the anus or lower rectum. An internal hemorrhoid occurs within the anus, while an external hemorrhoid occurs in the skin surrounding the anus. Symptoms of hemorrhoids include bleeding, pain during bowel movements, and/or itching.[1] It is estimated that "about 75% of people will have hemorrhoids at some point in their lives".[2]

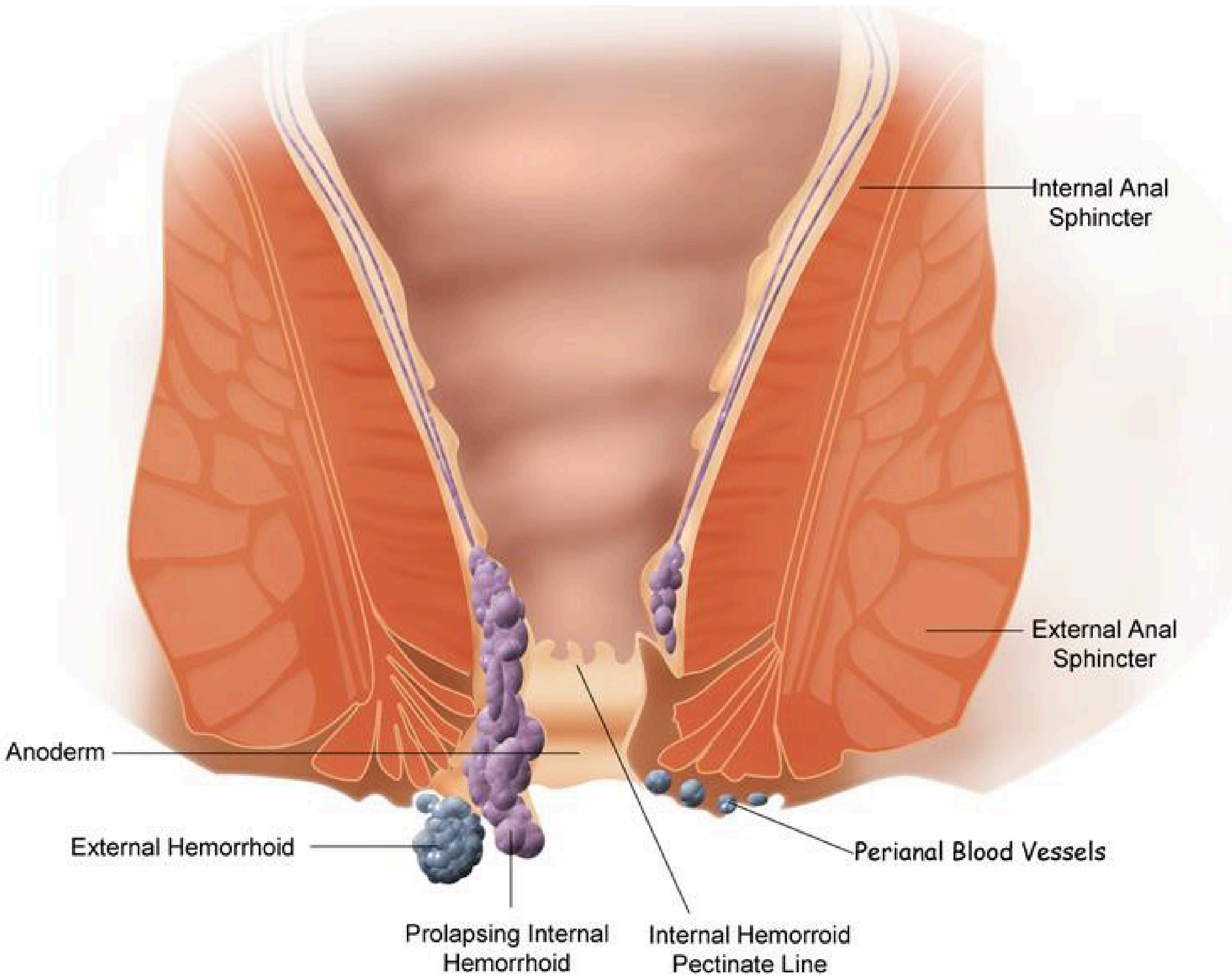

Figure 4.81 *Hemorrhoids. Image source*

The first 55 seconds of the following video does a nice job of illustrating what hemorrhoids are and how they develop.

Video Link: Hemorrhoids (2:05)

The anus and lower rectum experience high pressure during bowel movements. Thus, hemorrhoids are believed to be caused by straining during bowel movements. To prevent this condition from occurring, it is recommended that people consume a high-fiber diet, drink plenty of water, and exercise to produce regular, large, soft stools. In addition, people should "go" at first urge and not wait until it is more than an urge.[3]

Notes

1. http://www.webmd.com/a-to-z-guides/hemorrhoids-topic-overview
2. https://www.niddk.nih.gov/health-information/digestive-diseases/hemorrhoids/definition-facts
3. https://www.niddk.nih.gov/health-information/digestive-diseases/hemorrhoids/definition-facts

CHAPTER V
CHAPTER 5: CARBOHYDRATES

Chapters 5, 6, and 7 go into detail about the three energy-yielding macronutrients: carbohydrates (chapter 5), protein (chapter 6), and lipids (chapter 7). Each chapter will discuss the chemical nature of the macronutrient, how it is digested and absorbed, and how it functions in the body. Health-related topics will also be included.

Sections for chapter 5:

Sections 5.1-5.4 adapted from Fialkowski Revilla, et al. *Human Nutrition*

Section 5.5 contains content from both Fialkowski Revilla, et al. *Human Nutrition* and Jellum, et al. *Principle of Nutrition.*

5.0 Introduction to Carbohydrates

UNIVERSITY OF HAWAI'I AT MĀNOA FOOD SCIENCE AND HUMAN NUTRITION PROGRAM

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 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.

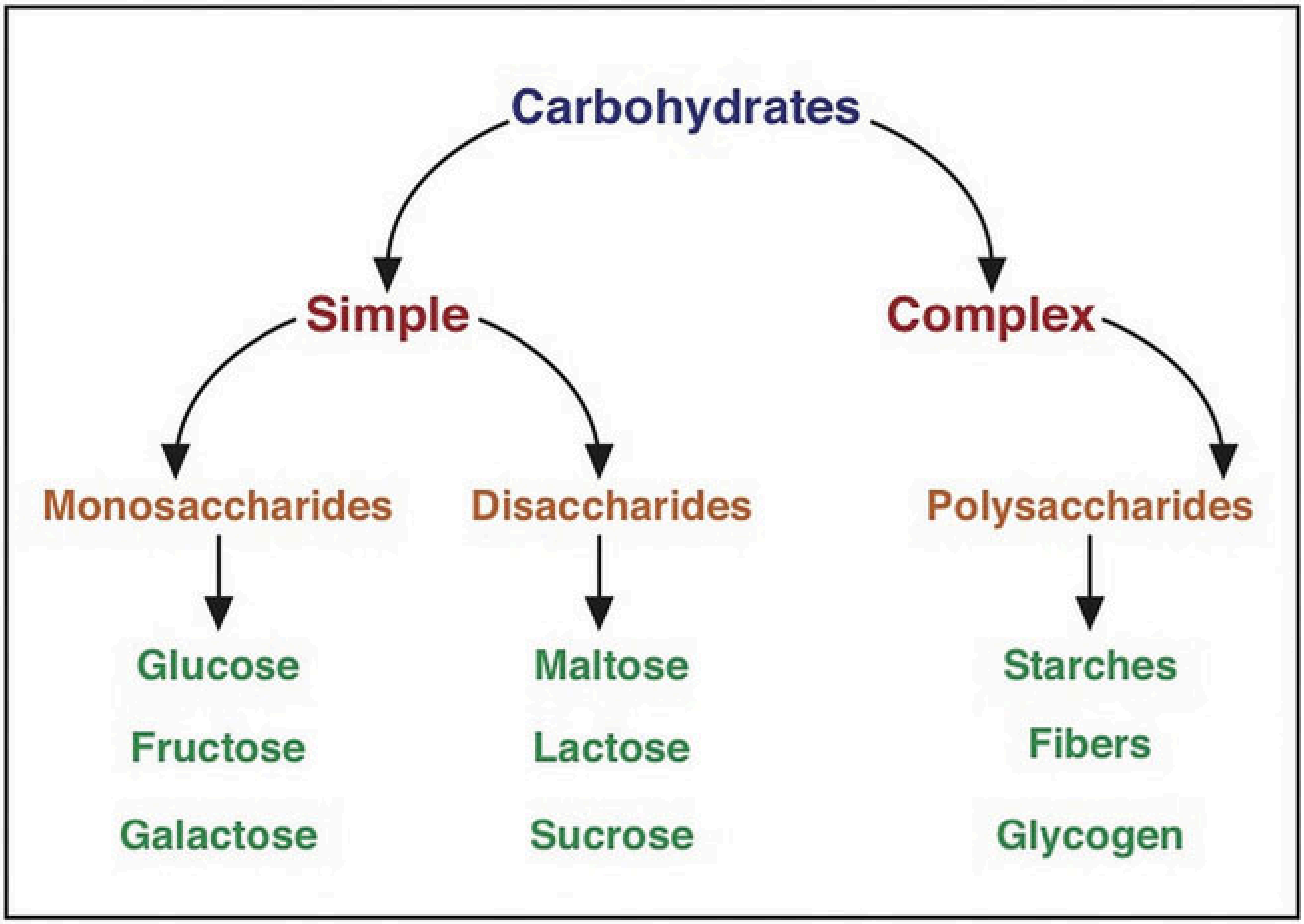

Figure 5.01 *Carbohydrate Classification Scheme. Carbohydrates are broken down into the subgroups simple and complex carbohydrates. These subgroups are further categorized into mono-, di-, and polysaccharides.*

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 C6H12O6. 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. The prefix "mono-" means "one" and "di-" means "two. So, *di*saccharides are made up of *two* monosaccharides joined together. Complex carbohydrates are long chains of monosaccharides, called

polysaccharides. The prefix "poly-" means "many", so you know that *poly*saccharides are made of *many* monosaccharides, joined together.

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 5.02 "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.

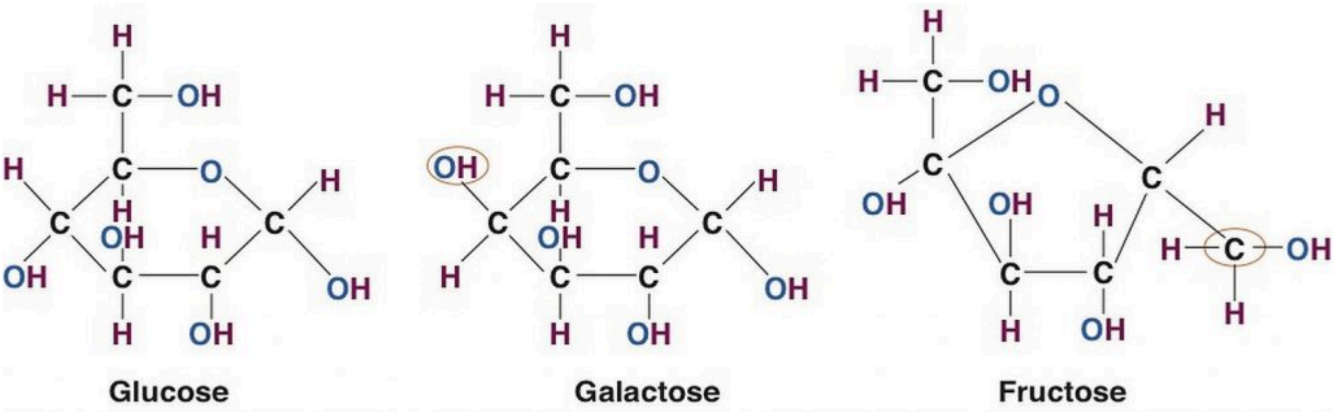

Figure 5.02 *Structures of the three most common monosaccharides: Glucose, Galactose, and Fructose. Circles indicate the structural differences between the three.*

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.

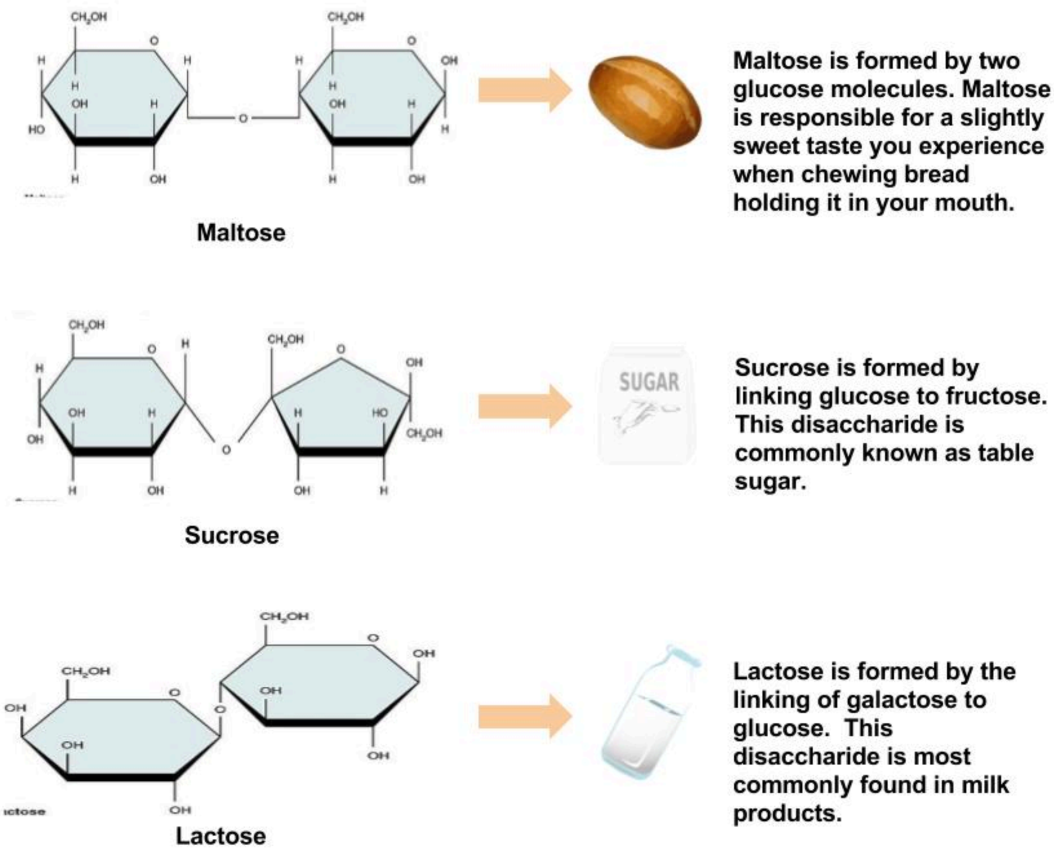

***Figure* 5.03** *The Most Common Disaccharides. Image by Allison Calabrese / CC BY 4.0*

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 are carbohydrate molecules found in plants that can be digested in the small intestine, giving glucose molecules to use for energy. Dietary fiber provides little or no energy, but is important for digestive health. Dietary fiber is not digested in the small intestine, but may be broken down by bacteria in the large intestine.

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.

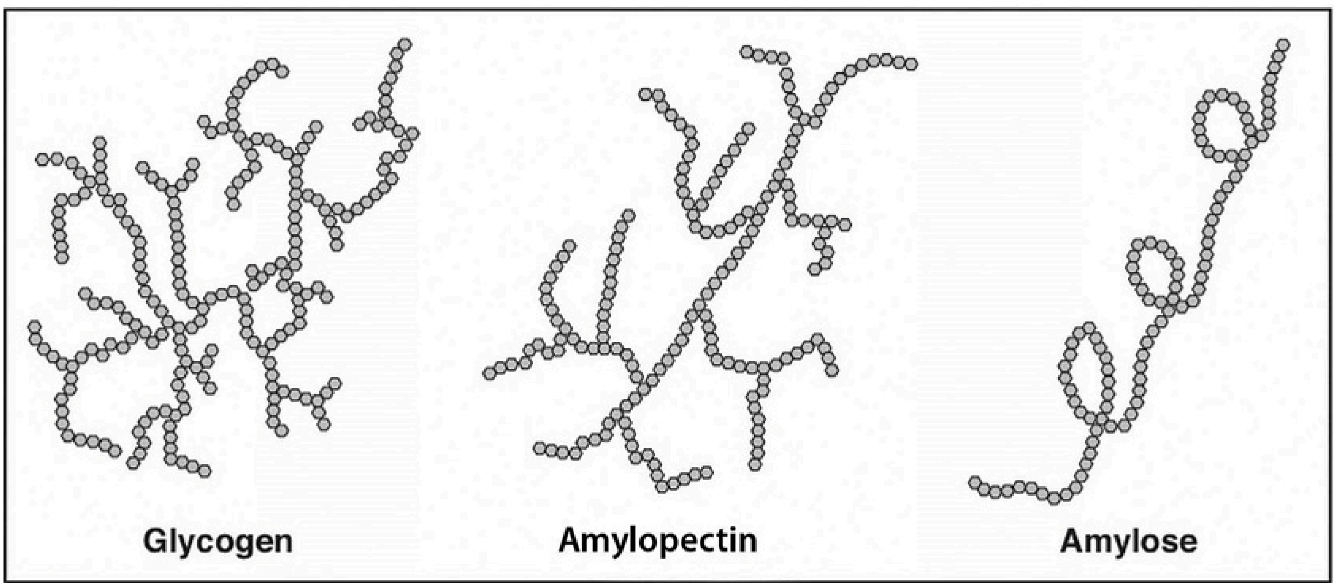

Figure 5.04 *Structures of the Plant Starches and Glycogen*

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. The Dietary Guidelines Advisory Committee states that 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.

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 and this **health claim** has been approved by the **FDA**. Total dietary fiber intake is the sum of dietary fiber and functional fiber consumed.

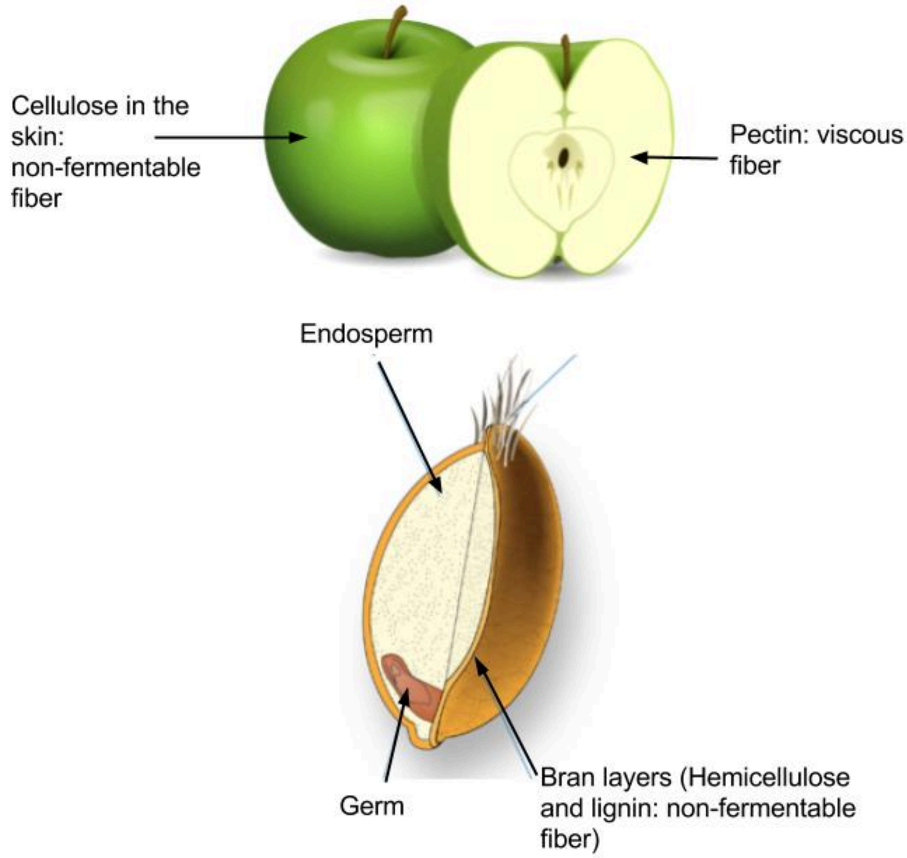

***Figure* 5.05** *Dietary Fiber. Image by Allison Calabrese / CC BY 4.0*

Oligosaccharides

The prefix *oligo*- means "few". Oligosaccharides are carbohydrate molecules of middling size, made of 3-10 monosaccharides joined together. Slightly larger than disaccharides, but much smaller than most polysaccharides.

Raffinose and **stachyose** are the most common oligosaccharides. They are found in legumes, onions, broccoli, cabbage, and whole wheat.[2]

Our digestive system lacks the enzymes necessary to digest the unique chemical bonds found in oligosaccharides. As a result, the oligosaccharides are not digested in the small intestine and reach the colon where they are fermented by the bacteria there. Gas (**methane**, **CH_4**) is produced as a byproduct of this bacteria **fermentation** that can lead to flatulence. To combat this problem, Beano® is a popular product that contains an enzyme (alpha-galactosidase) to break down oligosaccharides, thereby preventing them from being used to produce gas.

Notes

1. US Department of Agriculture. Part D. Section 5: Carbohydrates. In Report of the DGAC on the Dietary Guidelines for Americans, 2010. https://www.dietaryguidelines.gov/sites/default/files/2019-05/2010DGACReport-camera-ready-Jan11-11.pdf. Accessed September 30, 2011.
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5.1 Digestion and Absorption of Carbohydrates

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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.

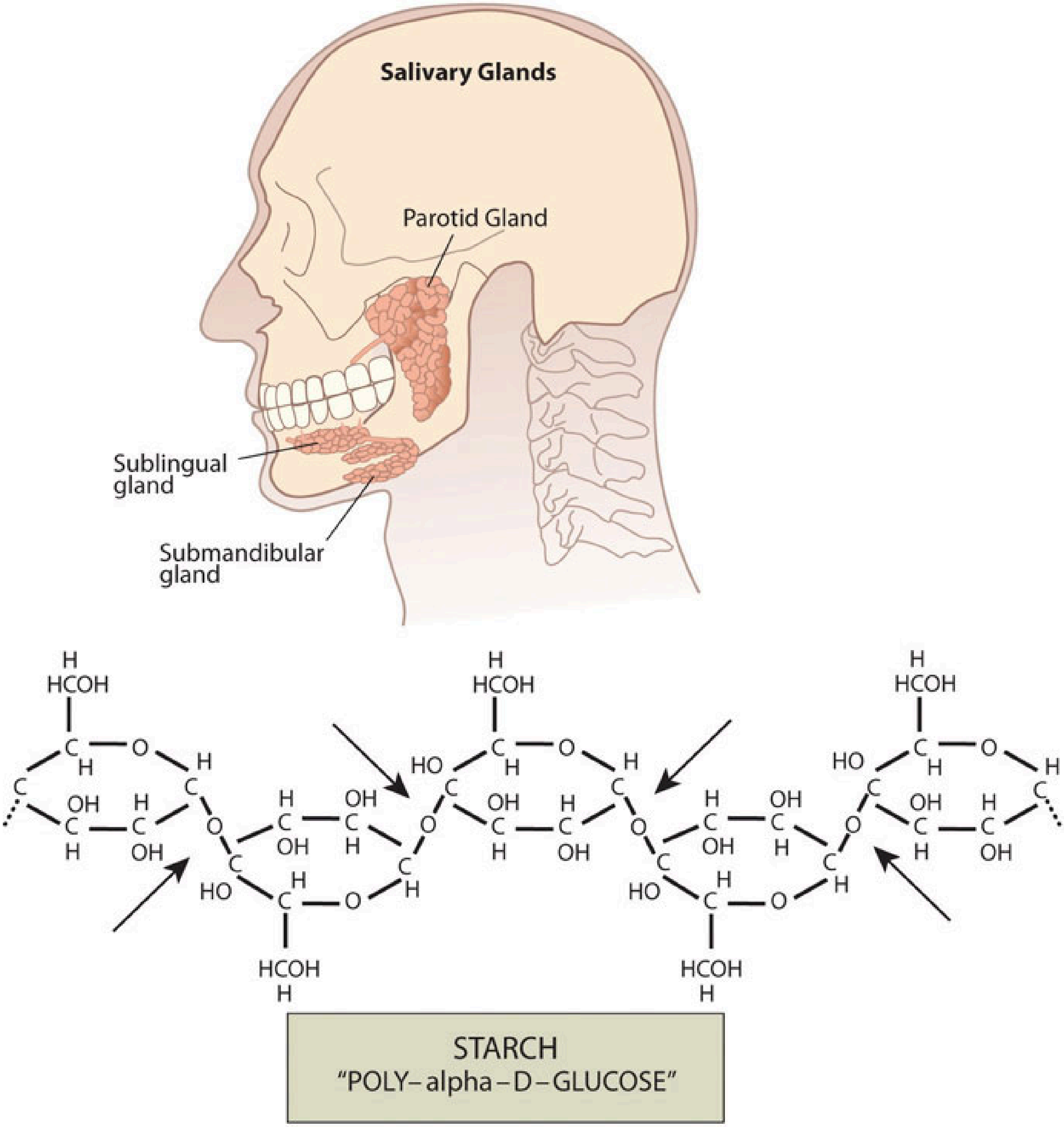

Figure 5.11 *Salivary Glands in the Mouth. Salivary glands secrete salivary amylase, which begins the chemical breakdown of carbohydrates by breaking the bonds between monomeric sugar units.*

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 and is associated with race. The National Digestive Diseases Information Clearing House states that African Americans, Hispanic Americans, American Indians, and Asian Americans have much higher incidences of lactose intolerance while those of northern European descent have the least.[1] 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.

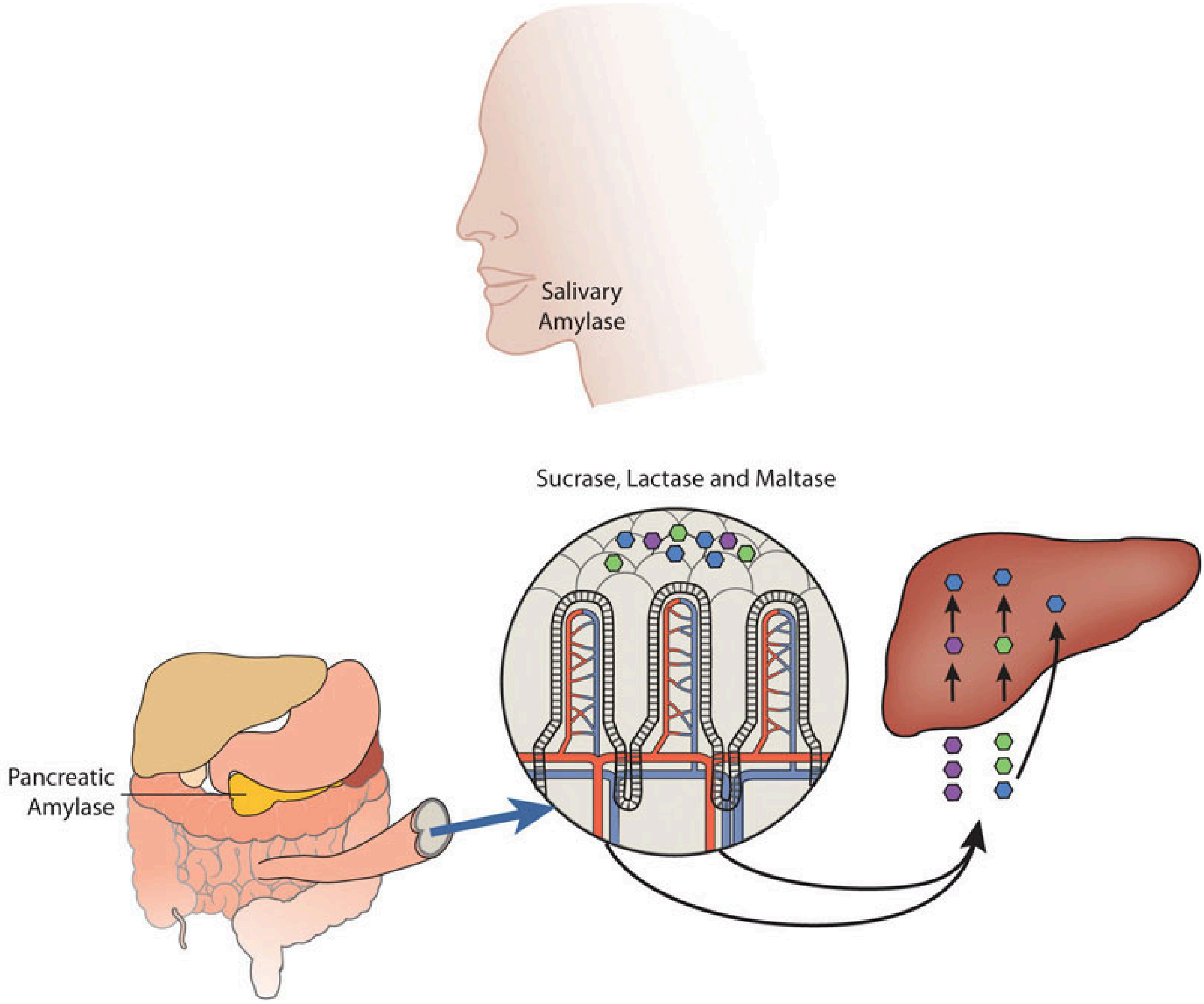

***Figure 5.12** Carbohydrate digestion begins in the mouth and is most extensive in the small intestine. The resultant monosaccharides are absorbed into the bloodstream and transported to the liver.*

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.

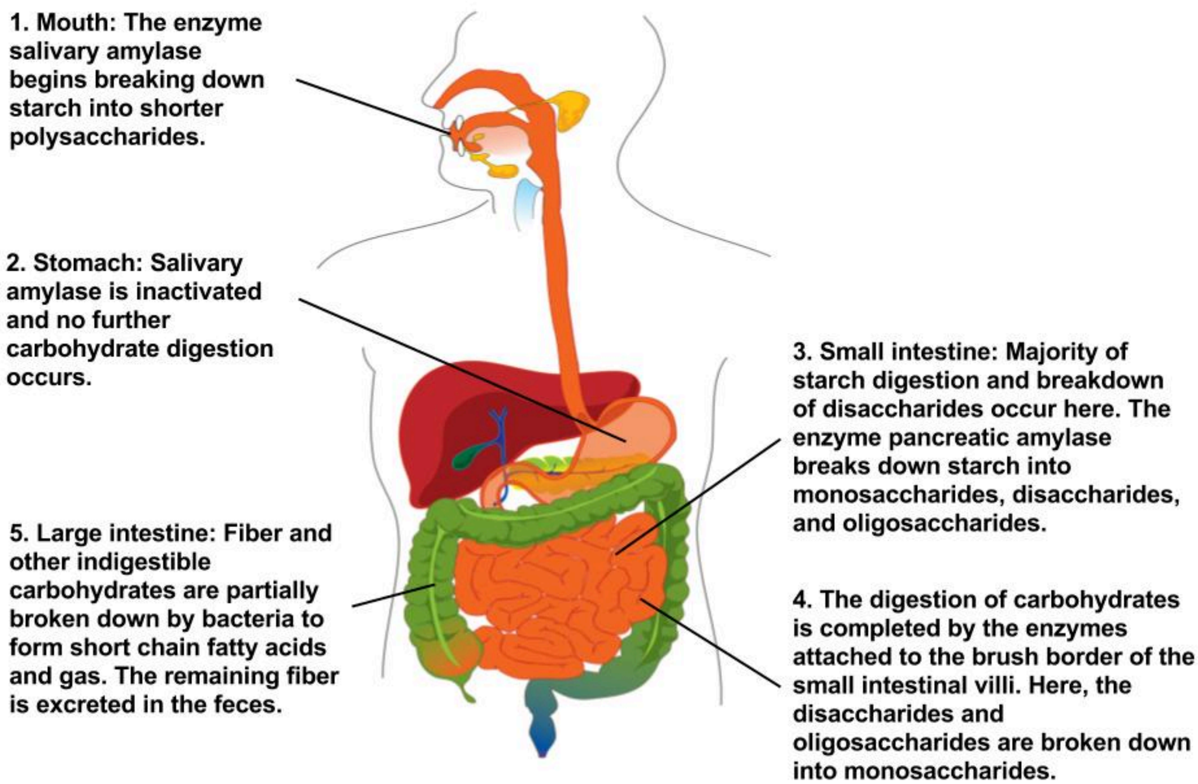

Figure 5.13 *Overview of Carbohydrate Digestion. Image by Allison Calabrese / CC BY 4.0*

Notes

1. Lactose Intolerance. National Digestive Diseases Information Clearing House. https://www.niddk.nih.gov/health-information/digestive-diseases/lactose-intolerance/definition-facts. Updated April 23, 2012. Accessed September 22, 2017.

5.2 The Functions of Carbohydrates in the Body

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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. We will talk about this process in more detail in chapter 8.

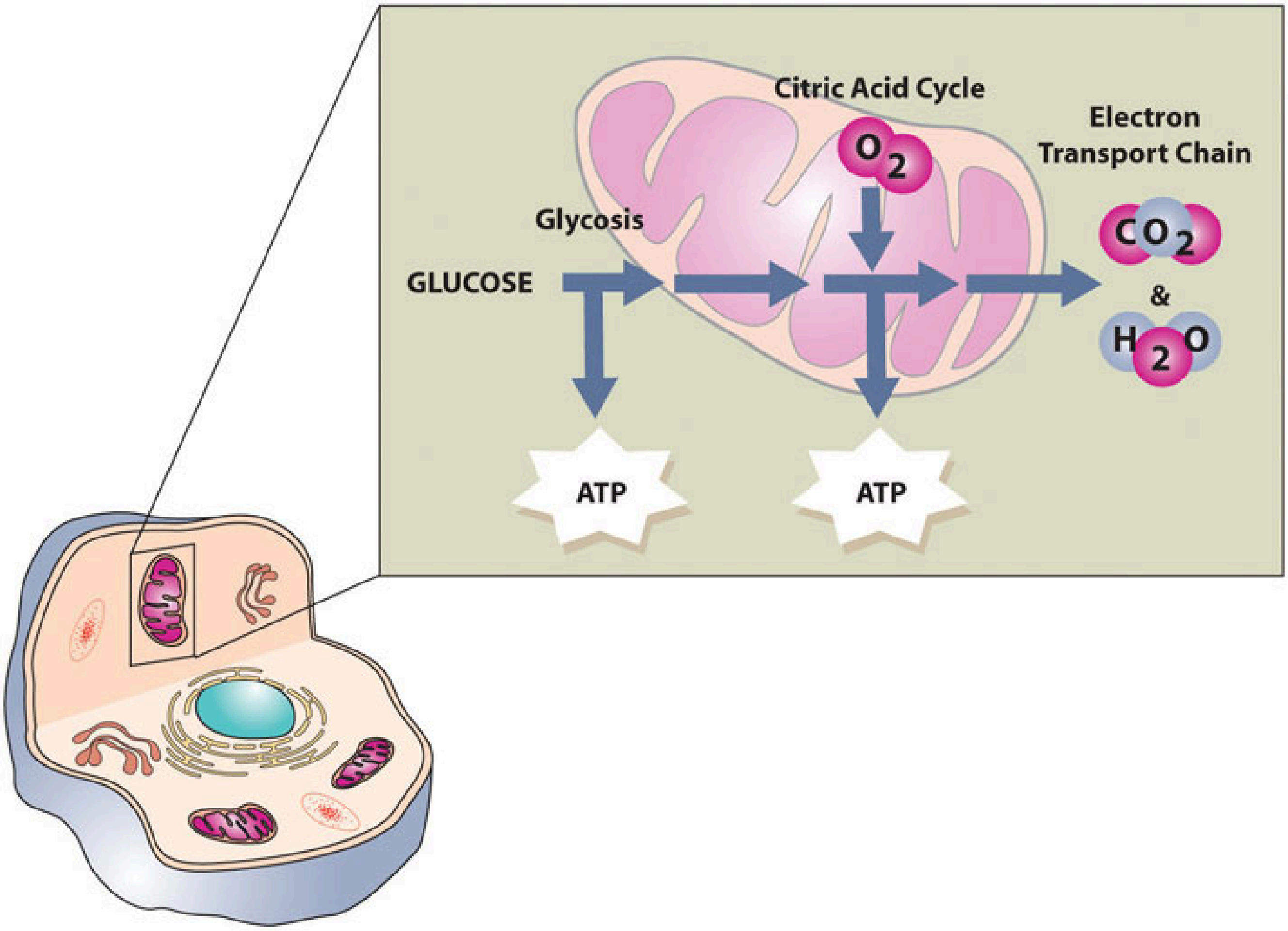

Figure 5.21 *Cellular respiration is the process by which energy is captured from glucose.*

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. 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.

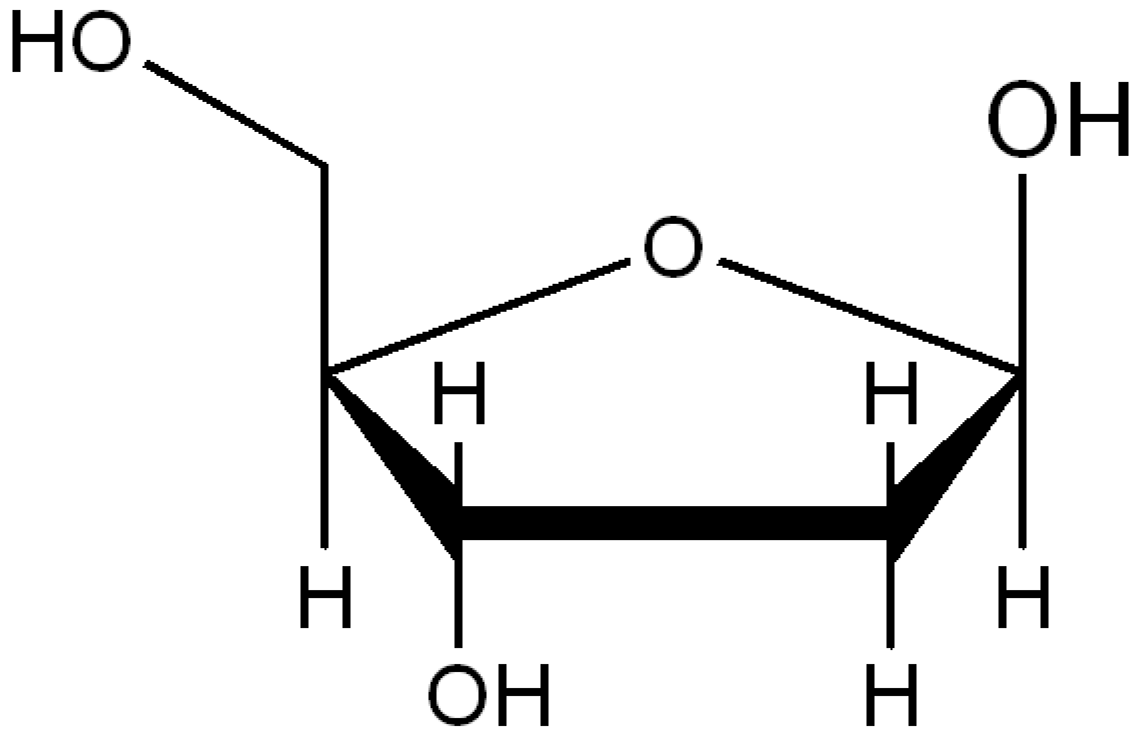

Figure 5.22 *Chemical Structure of Deoxyribose. The sugar molecule deoxyribose is used to build the backbone of DNA. Image by rozeta / CC BY-SA 3.0*

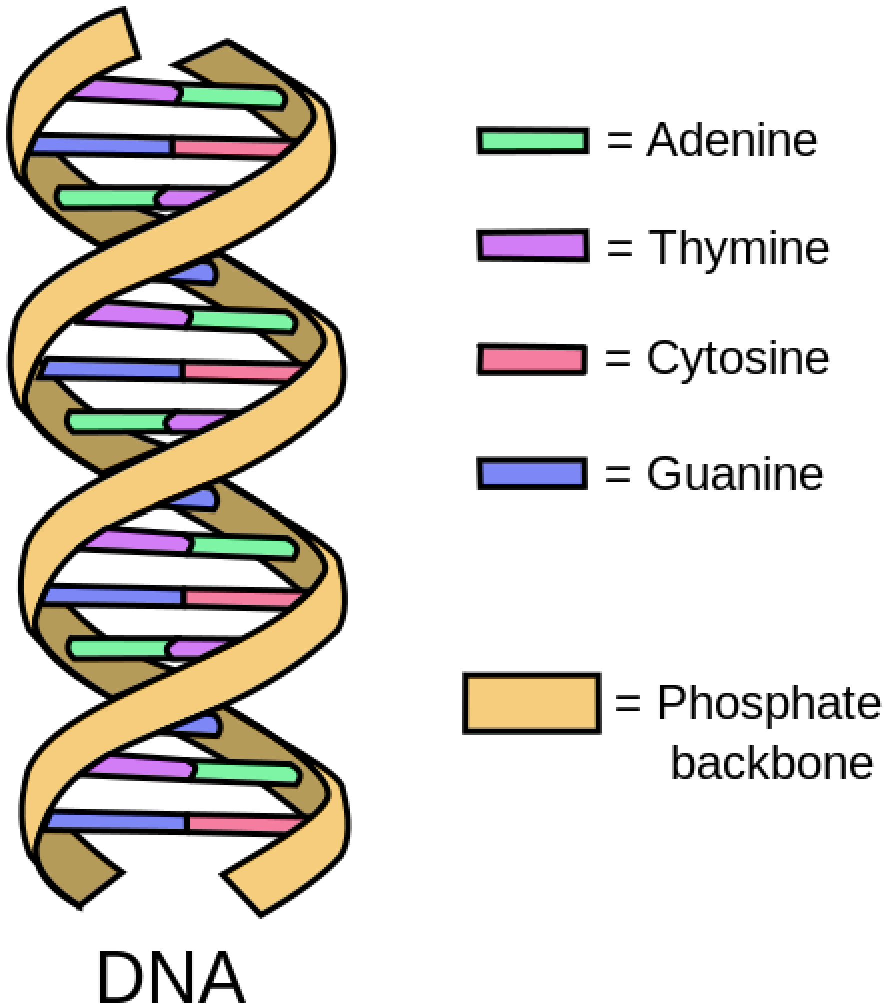

***Figure* 5.23** *Double-stranded DNA. Image by Forluvoft / Public Domain*

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.

5.3 Health Consequences and Benefits of High-Carbohydrate Diets

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Can America blame its 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

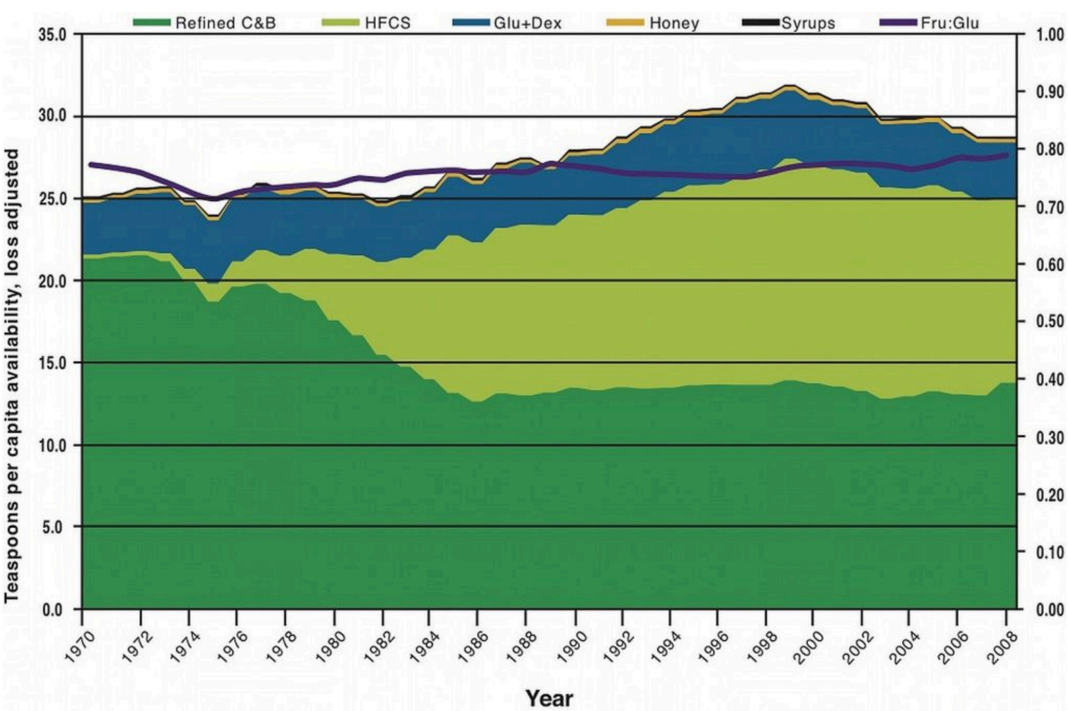

***Figure* 5.31** *Sugar Consumption (In Teaspoons) From Various Sources*

The Food and Nutrition Board of the Institute of Medicine (IOM) defines added sugars as "sugars and syrups that are added to foods during processing or preparation." The IOM goes on to state, "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]

This is still above the recommended intake of less than 10 percent of total calories. The **US Department of Agriculture (USDA)** reports that sugar consumption in the American diet in 2008 was, on average, 28 teaspoons per day (Figure 5.31 "Sugar Consumption (in Teaspoons) from Various Sources").

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

To understand the magnitude of the health problem in the United States consider this—in the United States approximately 130 million adults are overweight, and 30 percent of them are considered obese. 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 Americans. 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 American diet is soft 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 American Heart Association (AHA) 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. After its 2010 scientific conference on added sugars, the AHA made the following related dietary recommendations[4]:

- 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 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 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, and HFCS, a liquid, is easier to use; 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 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.[5]

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.

The video below, from the American Chemical Society, gives some background on how HFCS is produced and how it compares to sucrose (table sugar).

Video: What's the Difference Between Sugar and High Fructose Corn Syrup?

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-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.[6]

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 can significantly slow down the absorption process therefore affecting blood glucose levels (see Figure 5.32) . Americans typically do not consume the recommended amount of whole grains, which is 50 percent or more of grains from whole grains.

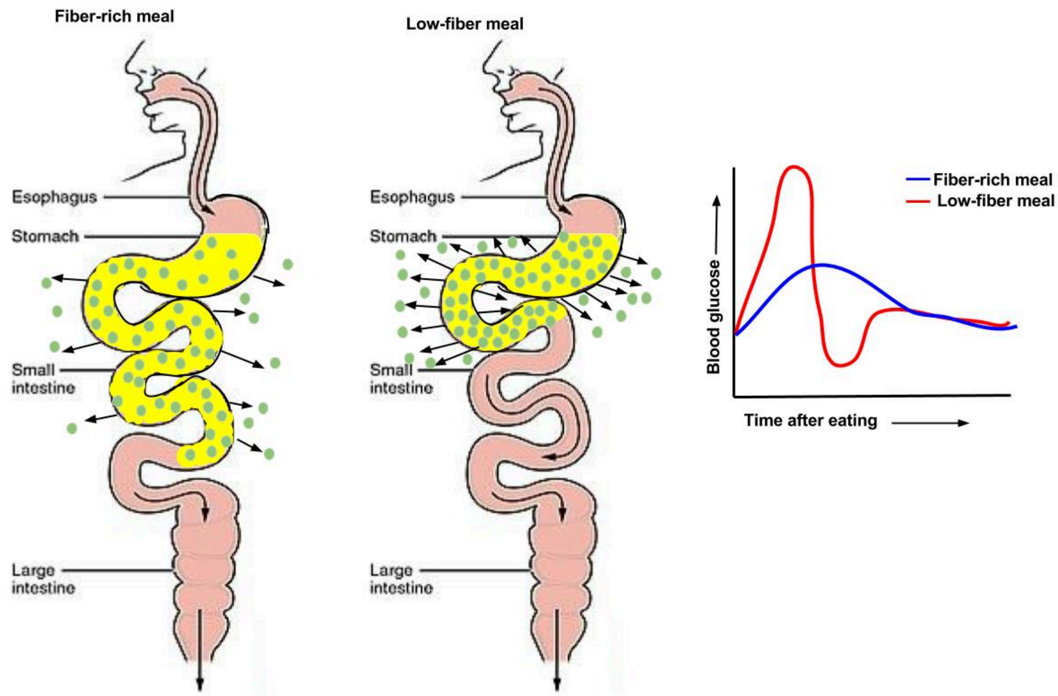

***Figure* 5.32** *Fiber slows carbohydrate absorption. Image by Allison Calabrese /* CC BY 4.0

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.[7] The Nurses' Health 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.[8]

The AHA makes the following statements on whole grains[9]:

- "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."

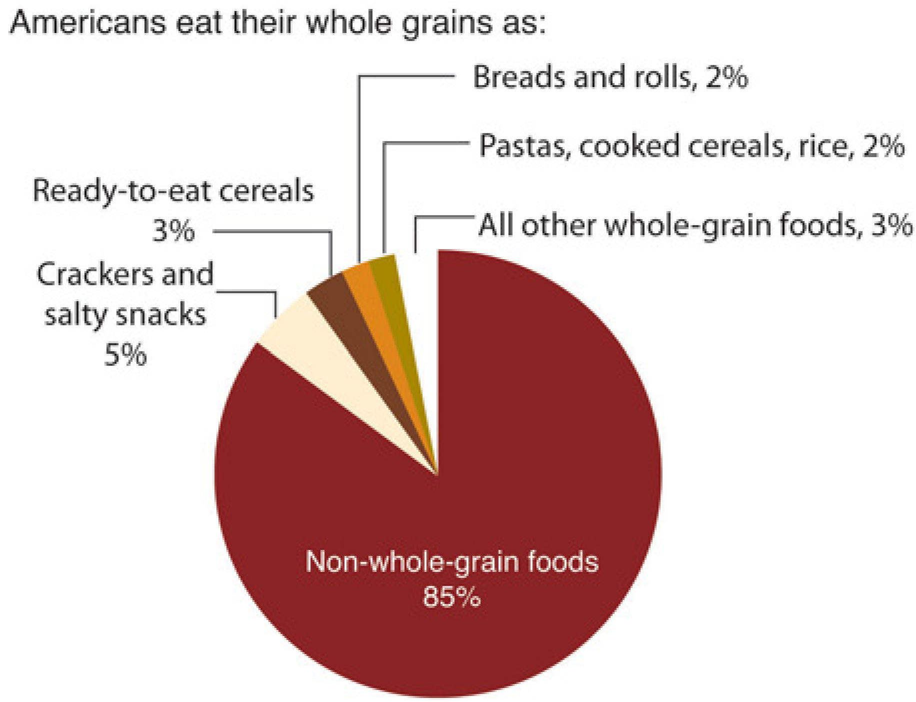

***Figure* 5.33** *Grain Consumption Statistics in America. Source: Economic Research Service.*

Notes

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5.4 Carbohydrates and Personal Diet Choices

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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 Food and Nutrition Board of the Institute of Medicine (IOM) has set 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. According to the IOM not more than 25 percent of total calories consumed should come from added sugars. The World Health Organization and the AHA recommend much lower intakes of added sugars—10 percent or less of total calories consumed. The IOM has also set **Adequate Intakes** for dietary fiber, which 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 5.41 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 5.42 "Carbohydrates in Foods (grams/serving)" gives the specific amounts of carbohydrates, fiber, and added sugar of various foods.

Table 5.42 Carbohydrates in Foods (grams/serving)[12]

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

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.. The Nutrition and Labeling Act of 1990 has defined for the food industry and consumers what these labels mean (Table 5.43 “Food Labels Pertaining to Carbohydrates”).

Table 5.43 Food Labels Pertaining to Carbohydrates[3]

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

In addition, the FDA permits foods that contain whole oats (which contain soluble fiber) to make the health claim on the package that the food reduces the risk of coronary heart disease. The FDA no longer permits Cheerios to make the claim that by eating their cereal "you can lower your cholesterol four percent in six weeks."

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. The 2010 **Dietary Guidelines** 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 5.44 “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 5.44 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 American Dental Association (ADA) allows manufacturers of chewing gum to label packages with an ADA 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.[4]

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: Contains Phenylalanine." For more details on sugar substitutes please refer to Table 5.45 "Sweeteners".

Table 5.45 Sweeteners

Sweeteners with Trade Name	Calories	Source/Origin	Consumer Recommendations	Controversial Issues	Product Uses
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 have potential to reach ADI if consuming many beverages, desserts, frozen desserts, and gums containing aspartame routinely.	Beverages, gelatin desserts, gums, fruit spreads.
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 doses of saccharin associated with bladder cancer in laboratory animals. In 1977, FDA proposed banning saccharin from use in food • protest launched by consumer & interest groups • warning label listed on products about saccharin and cancer risk in animals until 2001 when studies concluded that it did not cause cancer in humans	General purpose sweetener in all foods and beverages.Sold as Sweet 'n' Low in United States; also found in cosmetics and pharmaceutical products.

Sweeteners with Trade Name	Calories	Source/Origin	Consumer Recommendations	Controversial Issues	Product Uses
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.		Chewing gum, powdered beverage mixes, nondairy creamers, gelatins, puddings, instant teas and coffees.
Cyclamates • Sugar Twin	0 kcal/g	Thirty times sweeter than sucrose.Discovered in 1937.	No ADI available.	1949, cyclamate approved by FDA for use. Cyclamate was classified as GRAS (Generally Recognized As Safe) until 1970 when it was removed from GRAS status and banned from use in all food and beverage products within the United States on the basis of one study that indicated it caused bladder cancer in rats. Approval still pending for use in the United States since the ban.Canada and other countries use this type of sweetener.	Recommended as a substitute for table sugar for diabetics in 1950s, baked goods.

Sweeteners with Trade Name	Calories	Source/Origin	Consumer Recommendations	Controversial Issues	Product Uses
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.		General purpose sweetener, baked goods, beverages, gelatin desserts, frozen dairy desserts, canned fruits, salad dressings, dietary supplements; currently recommended as a replacement for table sugar and additive for diabetics.
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 sparingly, stevia may do little harm, but FDA could not approve extensive use of this sweetener due to concerns regarding its effect on reproduction, cancer development, and energy metabolism.	Sold in health food stores as a dietary supplement.

Sweeteners with Trade Name	Calories	Source/Origin	Consumer Recommendations	Controversial Issues	Product Uses
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-consumption has been linked to several health effects such as tooth decay or dental caries and contributes to increased risk for chronic diseases.	Biscuits, cookies, cakes, pies, candy canes, ice cream, sorbets, and as a food preservative.
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.		Sweeteners in various foods and beverages such as sodas, teas, alcoholic beverages, and baked goods.
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.		Controversial because it is found ubiquitously in processed food products, which could lead to overconsumption. Study results are varied regarding its role in chronic disease.	Soft drinks, desserts, candies, jellies.

Sweeteners with Trade Name	Calories	Source/Origin	Consumer Recommendations	Controversial Issues	Product Uses
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 gastrointestinal distress if consumed in large amounts.	Provide bulk and sweetness in the following sugar-free items: cookies, jams, jellies, chewing gum, candies, mints, pharmaceutical and oral health products.

Regulation

Prior to introducing any new artificial sweetener into foods it is rigorously tested and must be legally approved by the FDA. The FDA regulates artificial sweeteners along with other food additives, which number in the thousands. The FDA is responsible for determining whether a food additive presents "a reasonable certainty of no harm" to consumers when used as proposed. The FDA uses the best scientific evidence available to make the statement of no harm, but it does declare that science has its limits and that the "FDA can never be absolutely certain of the absence of any risk from the use of any substance."[5]

The FDA additionally has established Acceptable Daily Intakes (ADIs) for artificial sweeteners. The ADIs are the maximum amount in milligrams per kilogram of body weight considered safe to consume daily (mg/kg bw/day) and incorporates a large safety factor. The following list contains the artificial sweeteners approved for use in foods and beverages in the United States, and their ADIs:

- Acesulfame potassium (Sunett, Sweet One). ADI = 15 mg/kg bw/day
- Aspartame (Equal, NutraSweet). ADI = 50 mg/kg bw/day
- Neotame. ADI = 18 mg/kg bw/day
- Saccharin (SugarTwin, Sweet'N Low). ADI = 5 mg/kg bw/day
- Sucralose (Splenda). ADI = 5 mg/kg bw/day

Notes

1. 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.
2. 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.
3. Appendix A: Definitions of Nutrient Claims. Guidance for Industry: A Food Labeling Guide. US Food and Drug Administration. https://www.fda.gov/media/81606/download. Updated October 2009. Accessed September 22, 2017.
4. Artificial Sweeteners and Cancer. National Cancer Institute. http://www.cancer.gov/cancertopics/factsheet/Risk/artificial-sweeteners. Updated August 5, 2009. Accessed September 22, 2017.
5. Overview of Food Ingredients, Additives and Colors. US Food and Drug Administration. https://wayback.archive-it.org/7993/20170722025446/https://www.fda.gov/Food/IngredientsPackagingLabeling/FoodAdditivesIngredients/ucm094211.htm. Updated April 2010. Accessed September 22, 2017.

5.5 Carbohydrates and Blood Glucose Levels

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. **Hyperglycemia** is when blood glucose levels are higher than normal. Hyperglycemia is usually associated with diabetes, but it can occur in response to medications or other health conditions. If hyperglycemia is left untreated, high blood sugar levels can damage nerves, blood vessels, and other **organs**.[1] **Hypoglycemia** is when blood glucose levels are lower than normal. Hypoglycemia can lead to feelings of tiredness, anxiety, or irritability, and if not treated, can progress to seizures and lack of consciousness, as the brain is unable to function without glucose as an energy source.[2]

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.

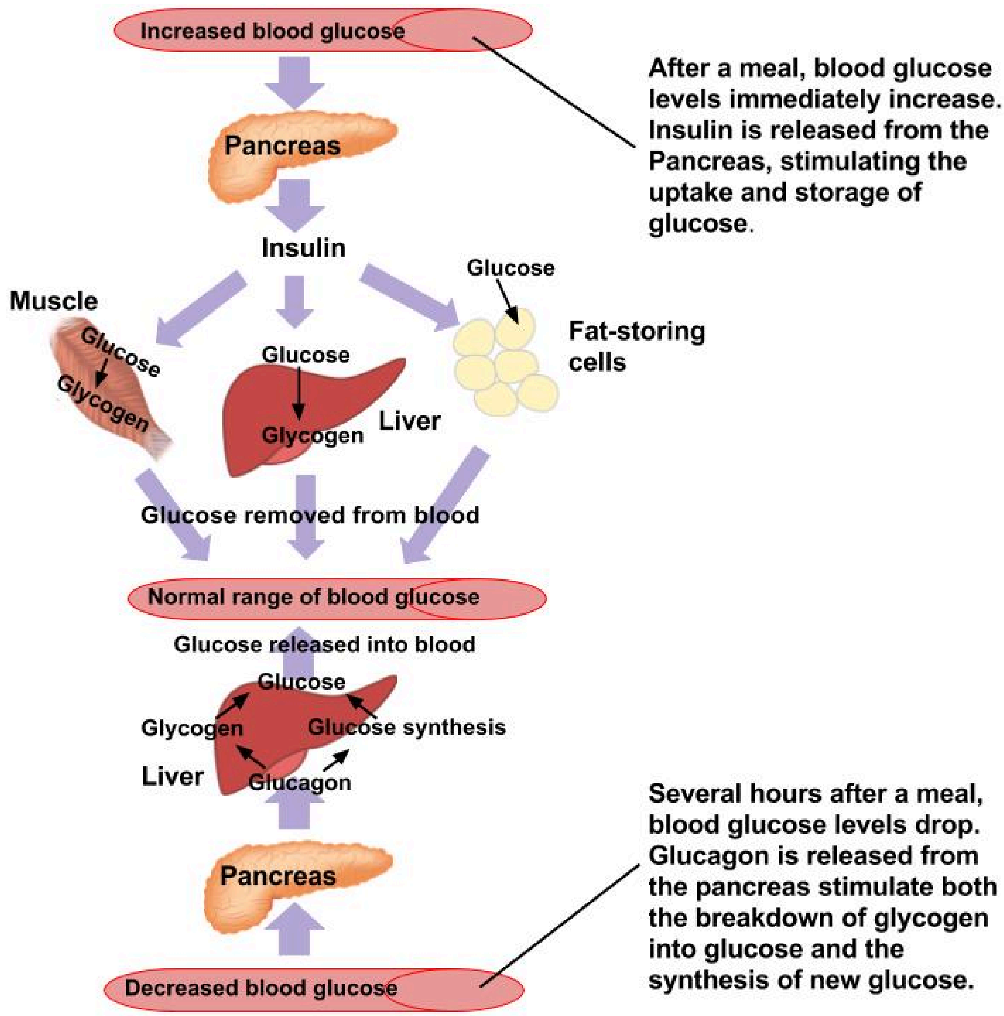

***Figure* 5.51** *The Regulation of Glucose. Image by Allison Calabrese / CC BY 4.0*

A Carbohydrate Feast

You are at a your grandma's house for family dinner and you just consumed turkey, mashed potatoes and gravy, cranberry sauce, and a hot sweet bread roll dripping with butter. Less than an hour later you top it off with a slice of pumpkin 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.

A typical American 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. The graph below shows the change in blood glucose levels over time after eating a high GI food (red) vs. a low GI food (blue).

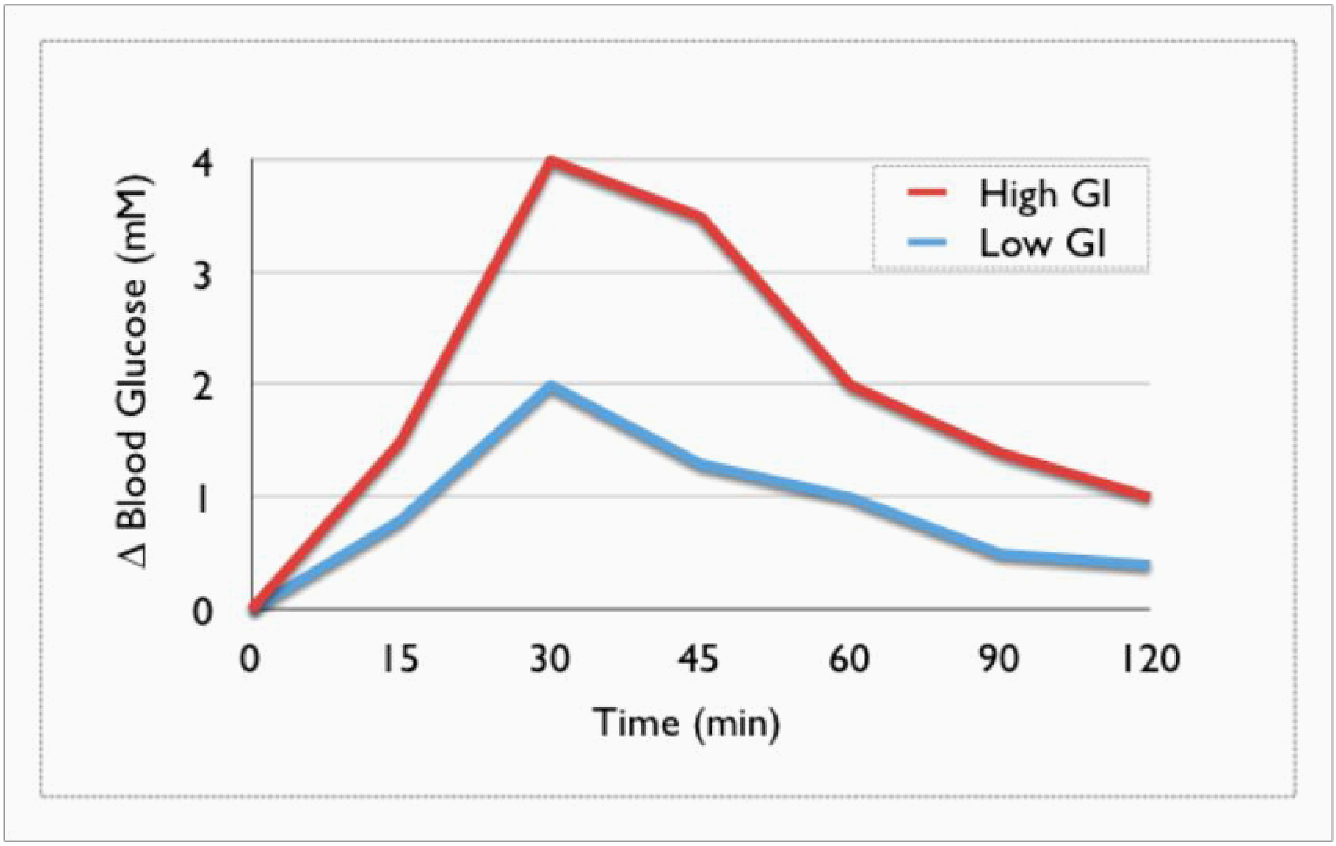

Figure 5.52 *Blood glucose response to a high glycemic index (GI) food compared to a low glycemic index food. Image source*

As a general guideline, a glycemic index that is 70 or greater is high, 56-69 is medium, and 55 and below is low. 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.[3]

Table 5.51 The Glycemic Index: Foods In Comparison To Glucose

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
Ice cream	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

Foods	GI Value
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 the United States 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.

The main problem with the glycemic index is that it does not take into account serving sizes. Let's take popcorn (glycemic index 89-127) as an example. A "serving size" of popcorn is 20 g, 11 g of which is carbohydrate. This is equal to approximately 2.5 cups of popcorn. Thus, a person would have to consume over 11 cups of popcorn to consume 50 g of carbohydrate needed for the glycemic index measurement. Another example is watermelon, which has a glycemic index of 103, with a 120 g serving containing only 6 g of carbohydrates. To consume the 50 g needed for glycemic index measurement, a person would need to consume over 1000 g (1 kg or 2.2 lbs.) of watermelon. Assuming this is all watermelon flesh (no rind), this would be over 6.5 cups of watermelon.[4]

The website glycemicindex.com contains a database you can search to see the glycemic index and glycemic load (covered in the next section) of various foods. The database also contains detail on how the measurement was done, and more information on the product itself. The top link below will take you to this website. The second link is to another database that lists foods by category and also by low, medium, or high glycemic index.

Web Links:

Glycemicindex.com

GIlisting.com

Glycemic Load

To incorporate serving size into the calculation, another measure known as the **glycemic load**

has been developed. It is calculated as shown below:

$$\text{Glycemic Load} = \frac{\text{Carbohydrate content (g)} \times \text{Glycemic index}}{100}$$

Thus, for most people, the glycemic load is a more meaningful measure of the glycemic impact of different foods. Considering the two previous examples from the glycemic index section, their glycemic loads would be:

Popcorn:

Glycemic load = (89-127 X 11 g)/100 = 9.79-13.97

Watermelon:

Glycemic load = (103 X 6 g)/100 = 6.18

As a general guideline for glycemic loads of foods: 20 or above is high, 11-19 is medium, and 10 or below is low.

Putting it all together, popcorn and watermelon have high glycemic indexes, but medium and low glycemic loads, respectively.

The glycemic index links above can also be used to find the glycemic loads of foods. The link below takes you to a NutritionData estimated glycemic load tool that is pretty good at estimating the glycemic loads of foods, even if actual glycemic indexes have not been measured.

Web Link: Estimated Glycemic Load

Notes

1. https://my.clevelandclinic.org/health/diseases/9815-hyperglycemia-high-blood-sugar
2. https://www.mayoclinic.org/diseases-conditions/hypoglycemia/symptoms-causes/syc-20373685
3. Brand-Miller J, et al. Dietary Glycemic Index: Health Implications. J Am Coll Nutr. 2009; 28(4), 446S–49S. https://doi.org/10.1080/07315724.2009.10718110. Accessed September 27, 2017.
4. Numbers taken from: Foster-Powell K, Holt SHA, Brand-Miller J. (2002) International table of glycemic index and glycemic load values: 2002. *Am J Clin Nutr* 76(1): 5. and the USDA National Nutrient Database

CHAPTER VI

CHAPTER 6: PROTEIN

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

Proteins are another major **macronutrient** that, like carbohydrates, are made up of small repeating units. But instead of sugars, proteins are made up of **amino acids**. 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.

Sections:

Chapter 6 is adapted primarily from Fialkowski Revilla, et al. *Human Nutrition.*

6.1 Defining Protein

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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.

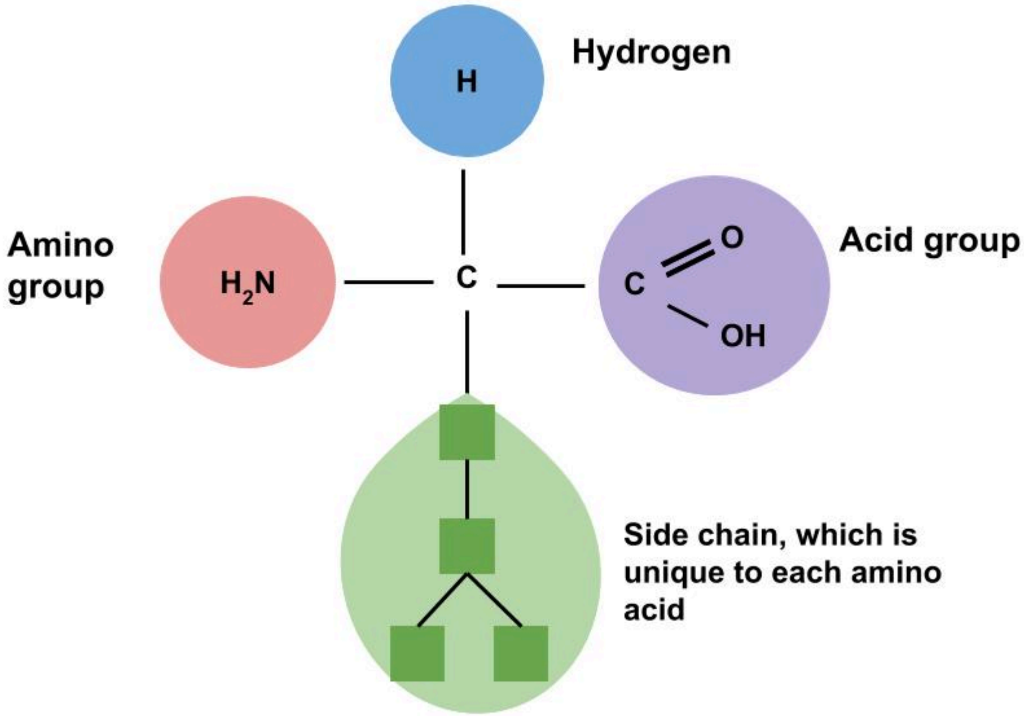
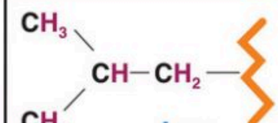
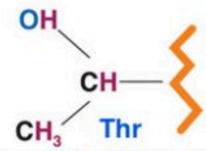
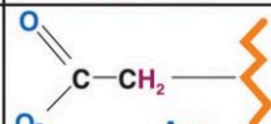
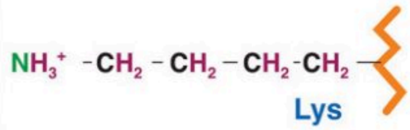


Figure 6.11 *Amino Acid Structure. Image by Allison Calabrese / CC BY 4.0*

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.

Group	Characteristics	Name	Example (-Rx)
non-polar	hydrophobic	Ala, Val, Leu, Ile, Pro, Phe Trp, Met	 Leu
polar	hydrophilic (non-charged)	Gly, Ser, Thr, Cys, Tyr, Asn Gln	 Thr
acidic	negatively charged	Asp, Glu	 Asp
basic	positively charged	Lys, Arg, His	 Lys

Total = 20

Figure 6.12 *Amino acids are classified into four groups. These are nonpolar, polar, acidic, and basic.*

You may hear someone talk about the branched-chain amino acids (BCAAs), which are a common nutritional supplement. While their effect on athletic performance is in question, BCAAs provide several metabolic and physiologic roles.[1] Of the 20 amino acids found in the human body, only isoleucine, leucine, and valine are classified as branched-chain amino acids.

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.

Table 6.11 Essential and Nonessential Amino Acids

Essential Amino Acids	Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Threonine, Tryptophan, Valine
Nonessential Amino Acids	Alanine, Arginine*, Asparagine, Aspartic acid, Cysteine*, Glutamic acid, Glutamine*, Glycine*, Proline*, Serine, Tyrosine*
* indicates the conditionally essential amino acids	

An example of a condition when an amino acid becomes essential is the disease **phenylketonuria (PKU)**. Individuals with PKU have a mutation in the **enzyme** that converts the amino acid phenylalanine to the amino acid tyrosine.

Since tyrosine cannot be synthesized by people with PKU, it becomes an essential amino acid for them. Thus, tyrosine is a conditionally essential amino acid. Individuals with PKU have to eat a very low protein diet and avoid the alternative sweetener aspartame, because aspartame can be broken down to phenylalanine. If individuals with PKU consume too much phenylalanine, phenylalanine and its metabolites can build up and cause brain damage and severe intellectual disability.

The nutritional value of a protein is dependent on what amino acids it contains and in what quantities.

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.

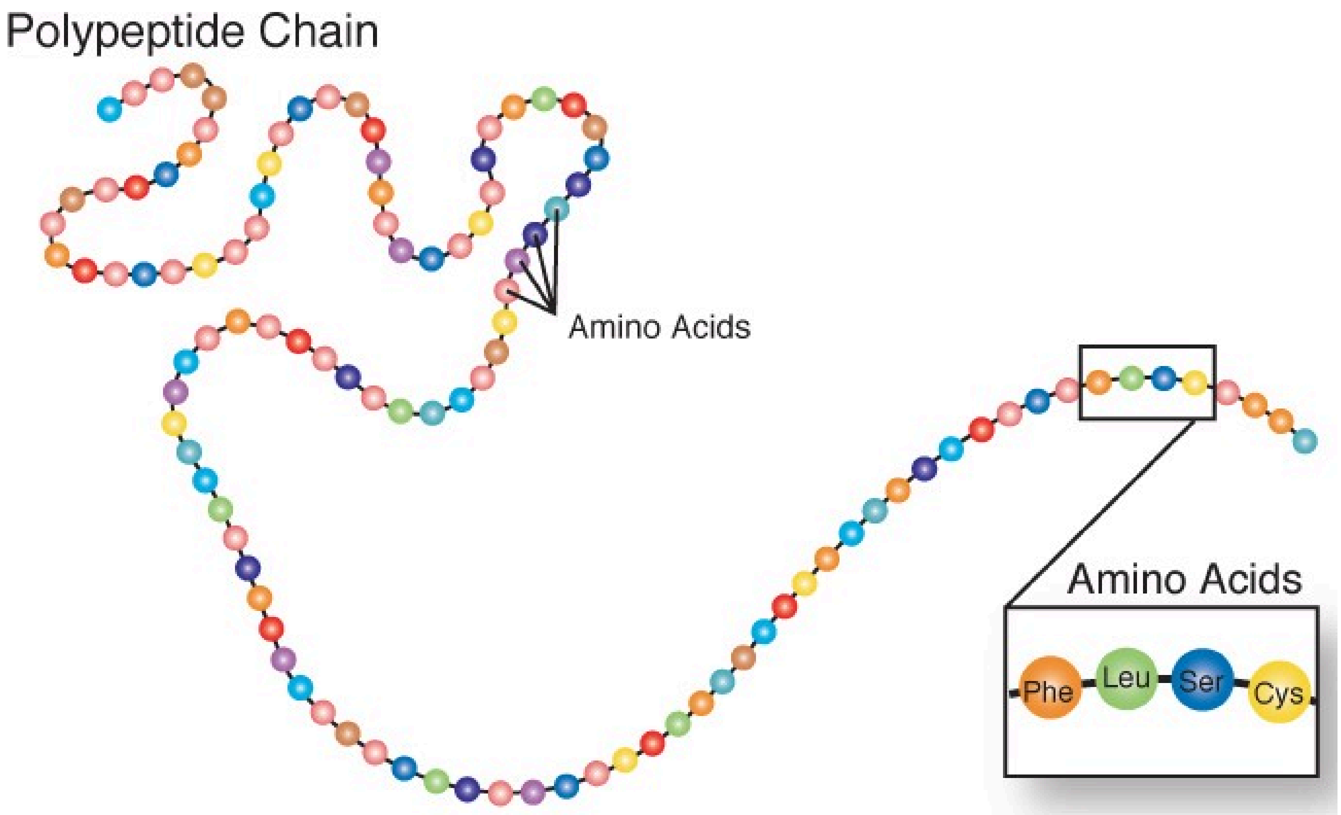


Figure 6.13 *A polypeptide chain. Image source*

These polypeptide chains then fold into a three-dimensional shape to form a protein (see Figure 6.13 "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 20^{104}, which is 2 followed by 135 zeros!

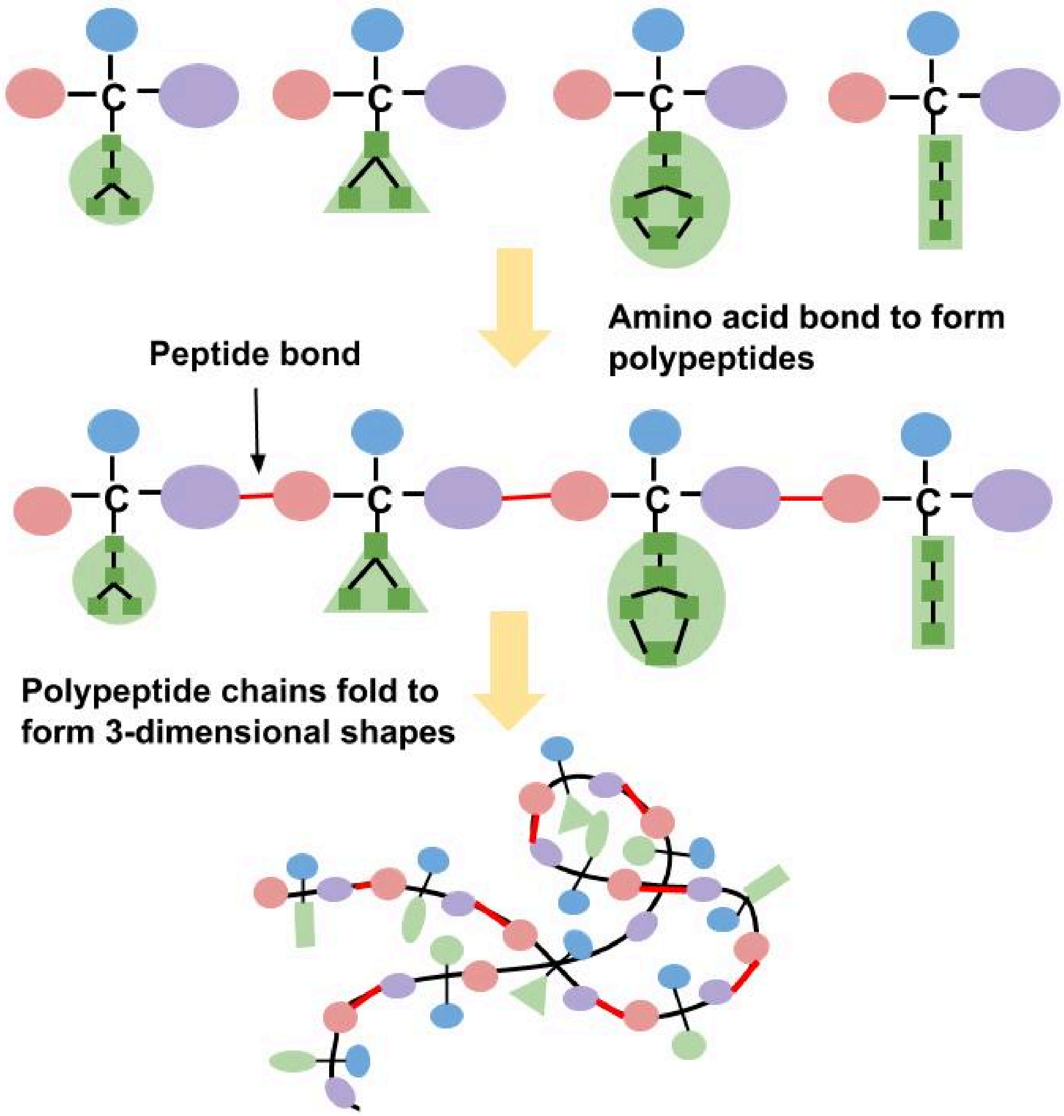


Figure 6.14 *The Formation of Polypeptides. Image by Allison Calabrese / CC BY 4.0*

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.

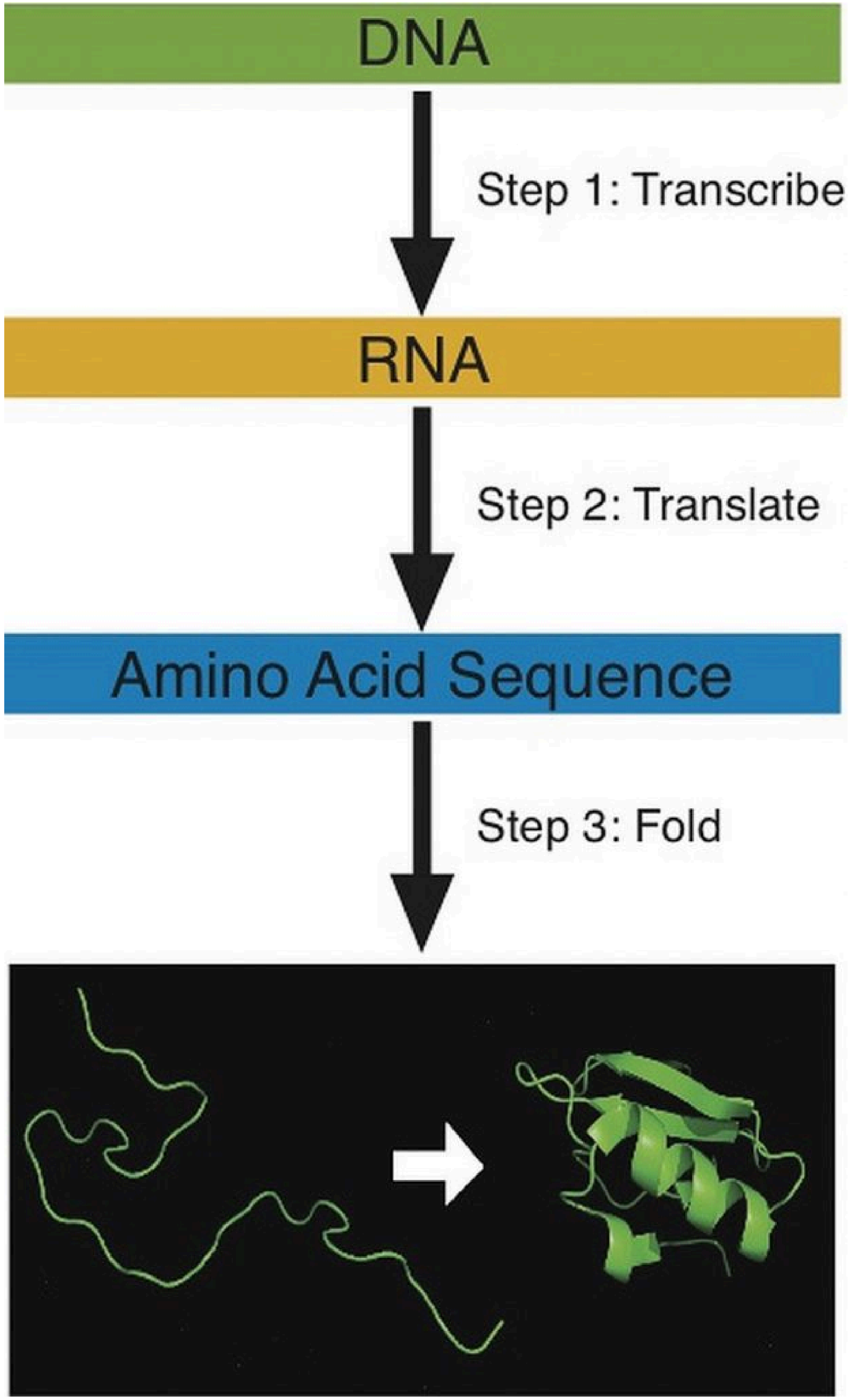


Figure 6.15 *Building a protein involves three steps: transcription, translation, and folding.*

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.

Video Links:

Transcription (1:49)

Translation (2:05)

Protein Structure

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 two or more amino acid chains (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.

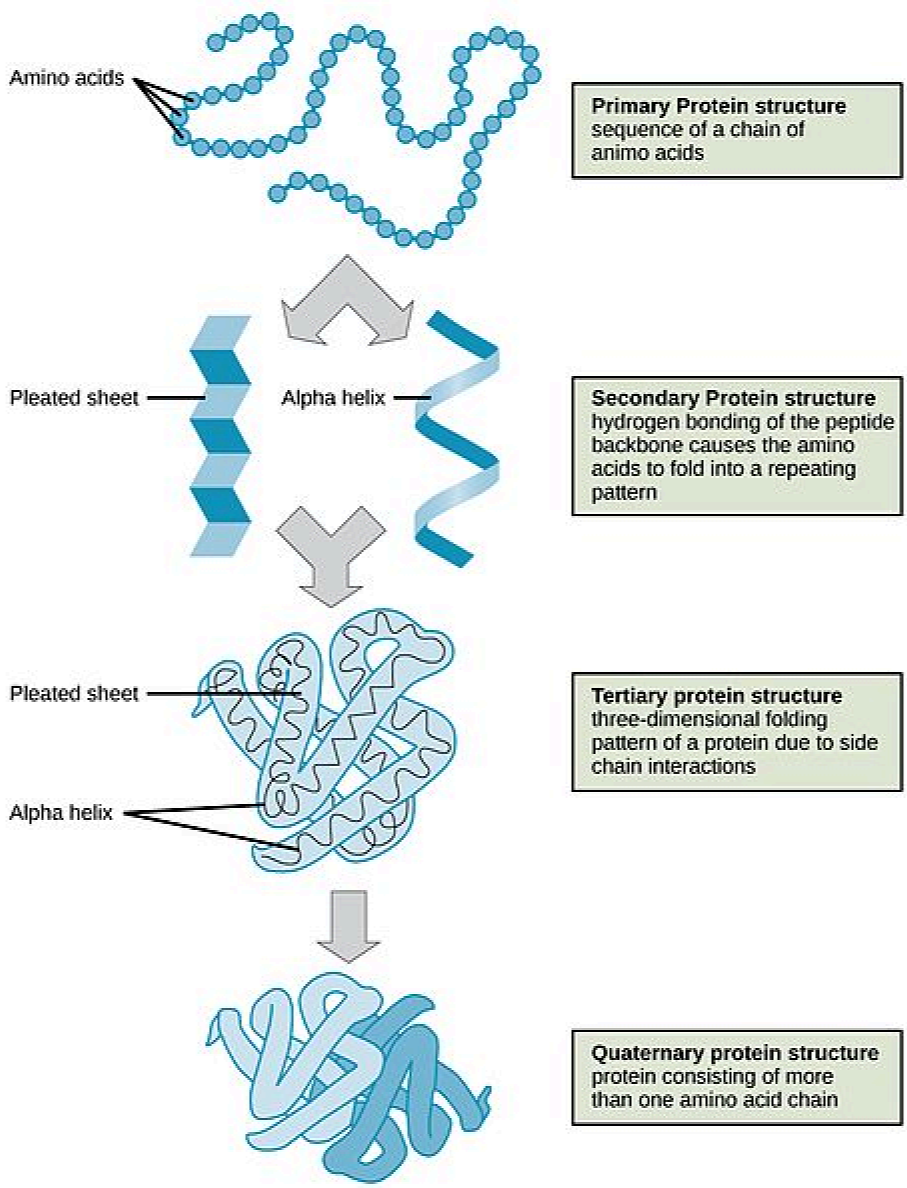


Figure 6.16 *The Four Structural Levels of Proteins. Image by OpenStax / CC BY 4.0*

Notes

1. Negro M, Giardina S, Marzani B, Marzatico F. 2008. Branched-chain amino acid supplementation does not enhance athletic performance but affects muscle recovery and the immune system. *J Sports Med Phys Fitness*. 48(3):347-51.

6.2 The Role of Proteins in Foods: Cooking and Denaturation

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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 unsplash.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).

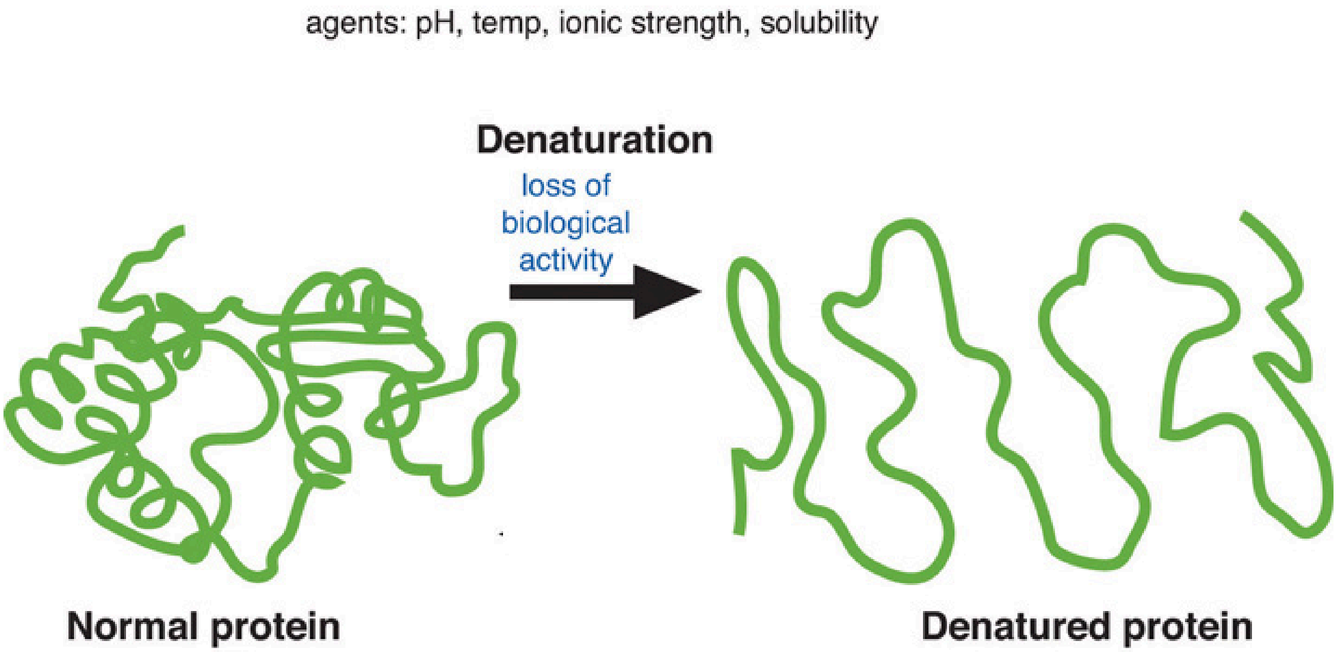

Figure 6.21 *Protein Denaturation. When a protein is exposed to a different environment, such as increased temperature, it unfolds into a single strand of amino acids.*

6.3 Protein Digestion and Absorption

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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 6.31 "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.

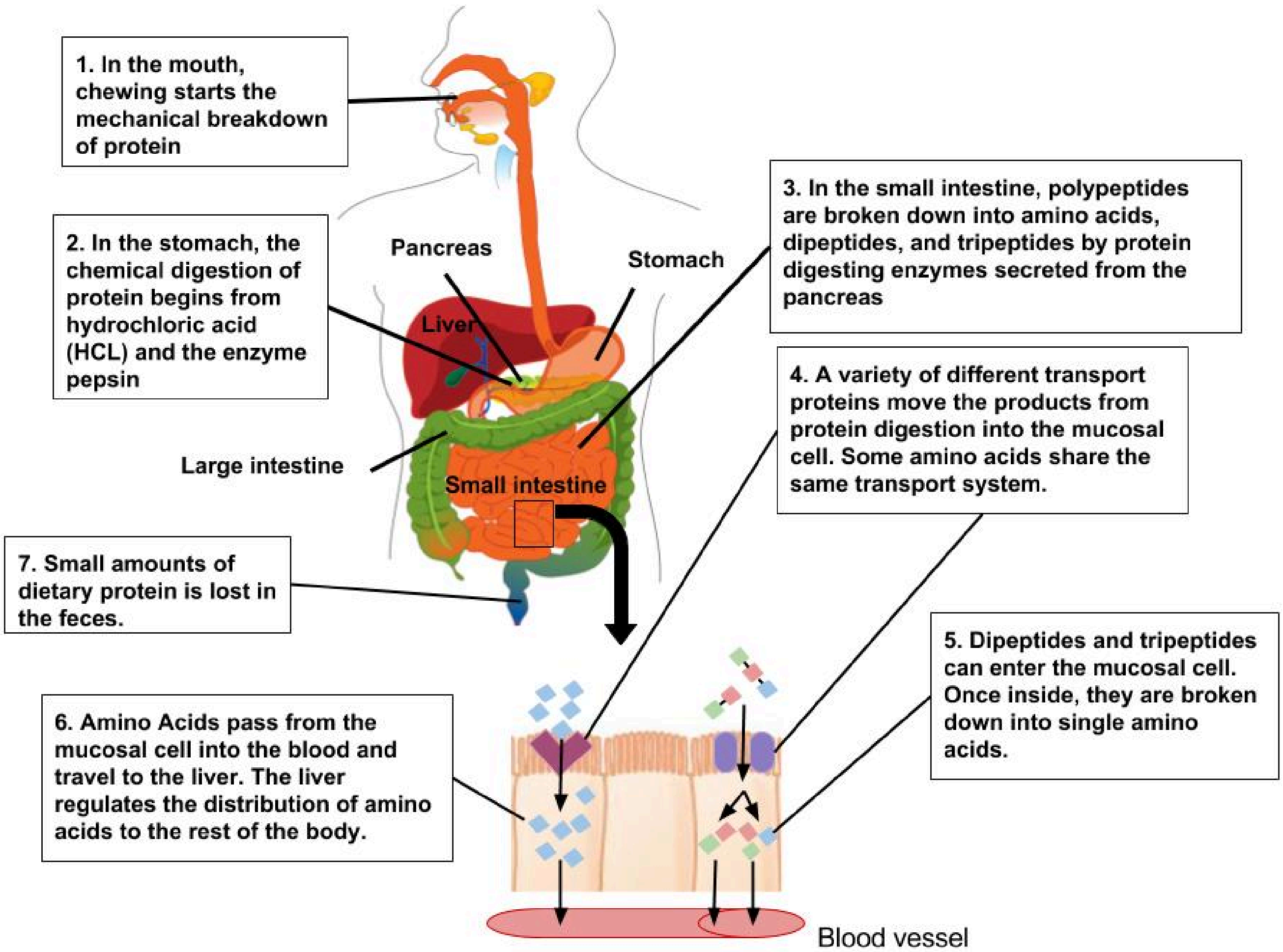

Figure 6.31 *Digestion and Absorption of Protein. Image by Allison Calabrese / CC BY 4.0*

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).

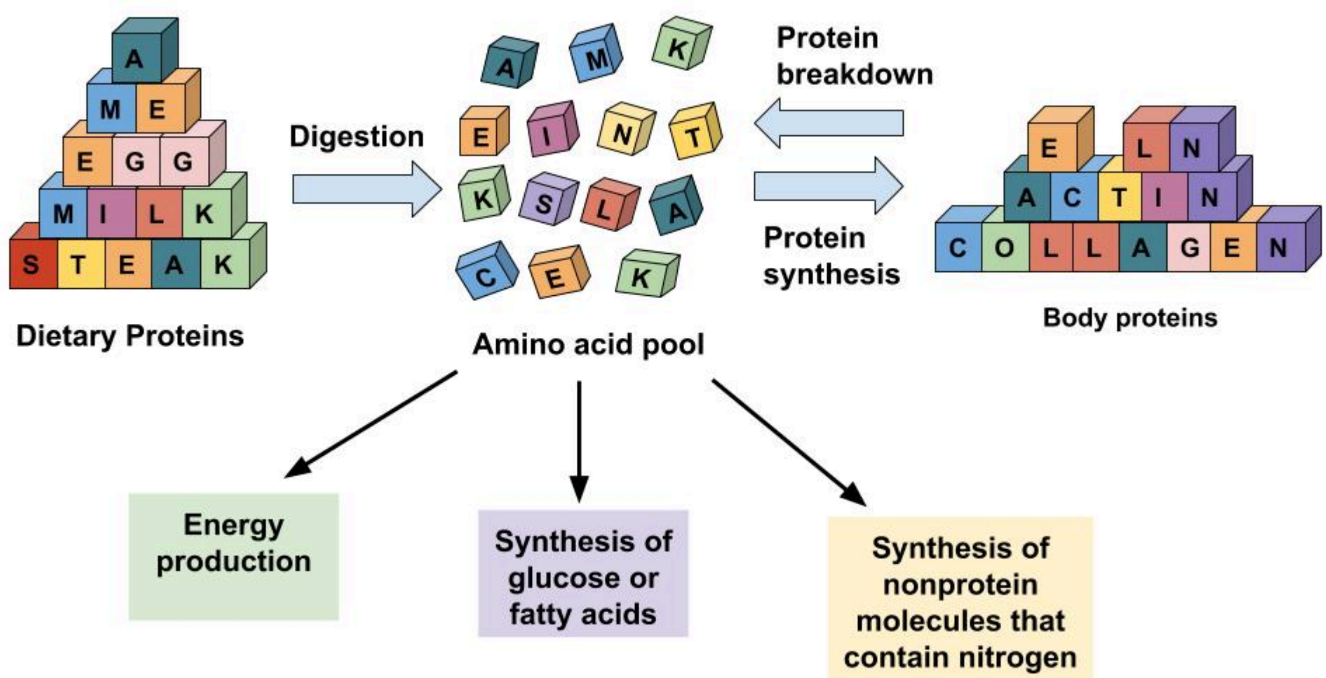

Figure 6.32 *Options For Amino Acid Use In The Human Body. Image by Allison Calabrese / CC BY 4.0*

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.

6.4 Protein's Functions in the Body

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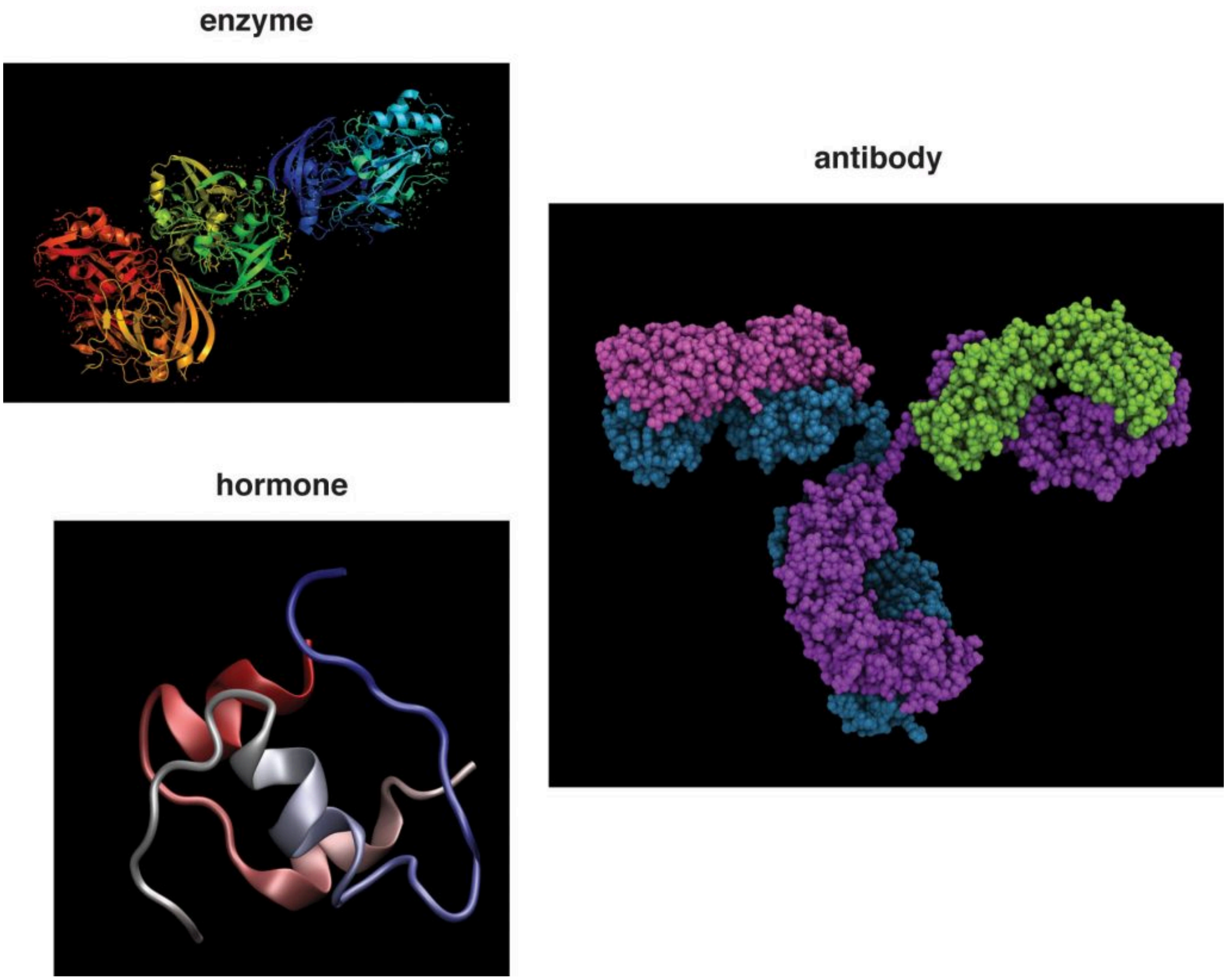

Figure 6.41 *Proteins are the "workhorses" of the body and participate in many bodily functions. Proteins come in all sizes and shapes and each is specifically structured for its particular function.*

Structure and Motion

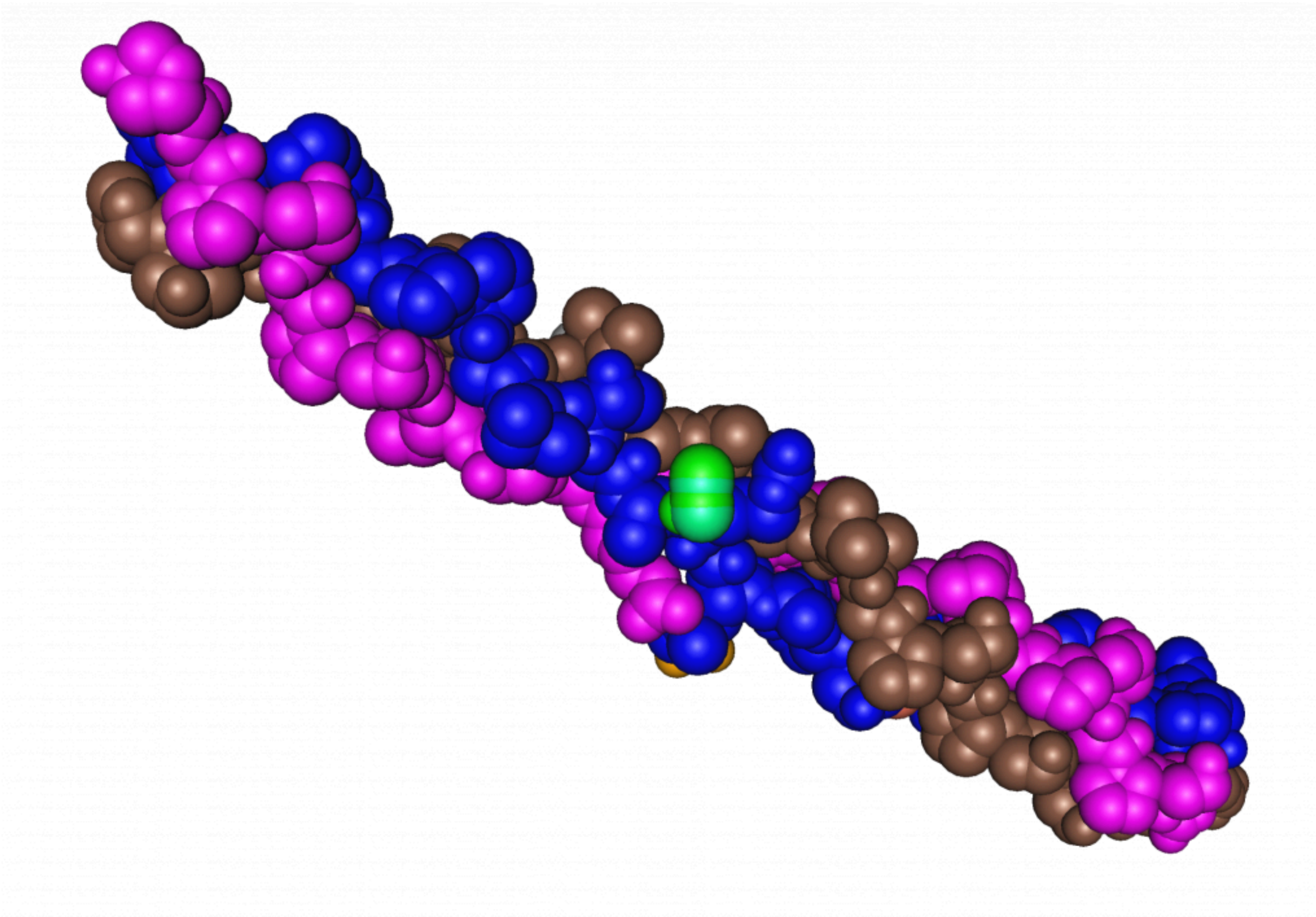

Figure 6.42 *Collagen Triple Helix by Nevit Dilmen / CC BY-SA 3.0*

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 6.43 "Enzymes Role in Carbohydrate Digestion").

Video Link: Enzymes (0:49)

In chapter 3, we talked about digestive enzymes, enzymes that catalyze reactions that break down large molecules from food to smaller molecules that can be absorbed into the body.

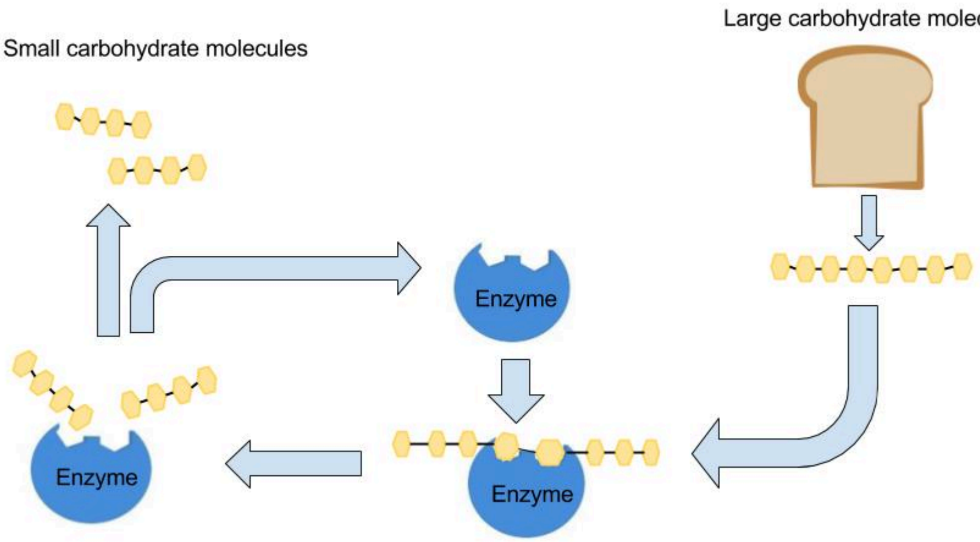

Figure 6.43 *Enzymes' Role in Carbohydrate Digestion. Image by Allison Calabrese* / CC BY 4.0

Enzymes' names commonly end in -ase, and many are named for their substrate. For example, the enzyme amylase cleaves bonds found in amylose and amylopectin.

Hormones

Many hormones are proteins. A **hormone** is a compound that is produced in one tissue, released into circulation, then has an effect on a different organ. Organs in the body that produce hormones are known as 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.

Video Link: Hormones (1:02)

Fluid 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** (Figure 6.45). 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.

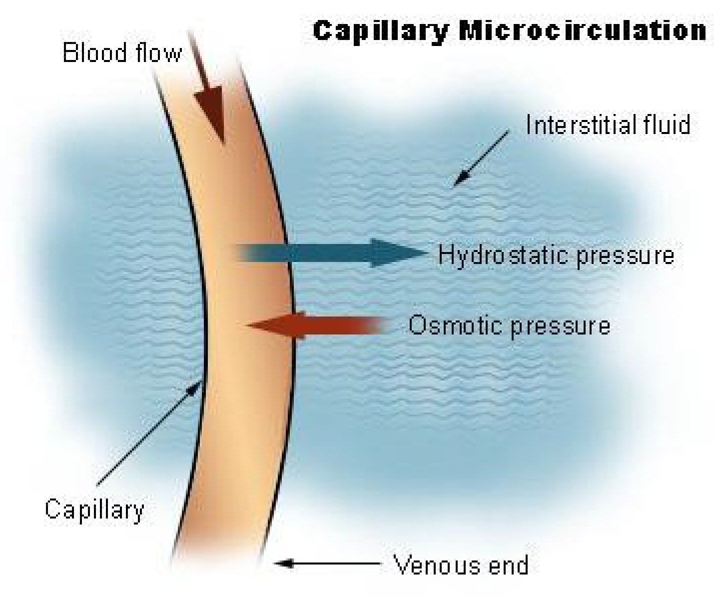

Figure 6.44 *There is a constant exchange of fluid between blood and interstitial fluid. Proteins make sure this fluid exchange remains balanced. Image source*

Figure 6.45 *The Protein Albumin. The butterfly-shaped protein, albumin, has many functions in the body including maintaining fluid and acid-base balance and transporting molecules. Source: PDB 1o9x EBI by Jawahar Swaminathan and MSD staff at the European Bioinformatics Institute / Public Domain*

Acid-Base Balance

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

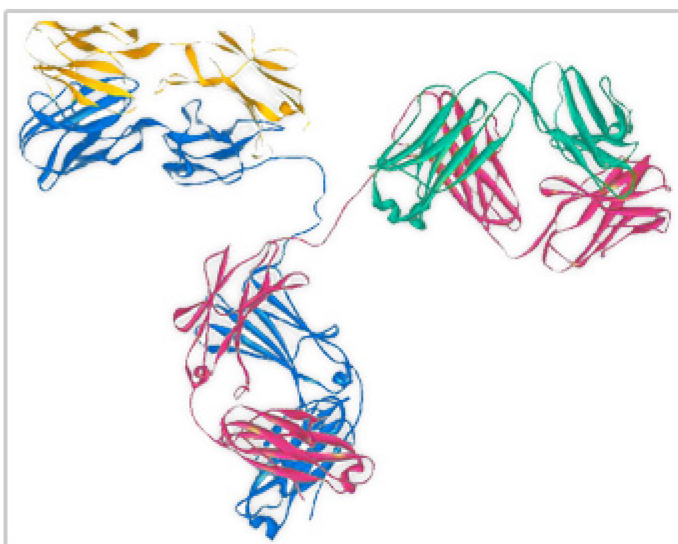

Figure 6.46 *Antibody Proteins. Souce: Abagovomab (monoclonal antibody) by Blake C / CC BY-SA 3.0*

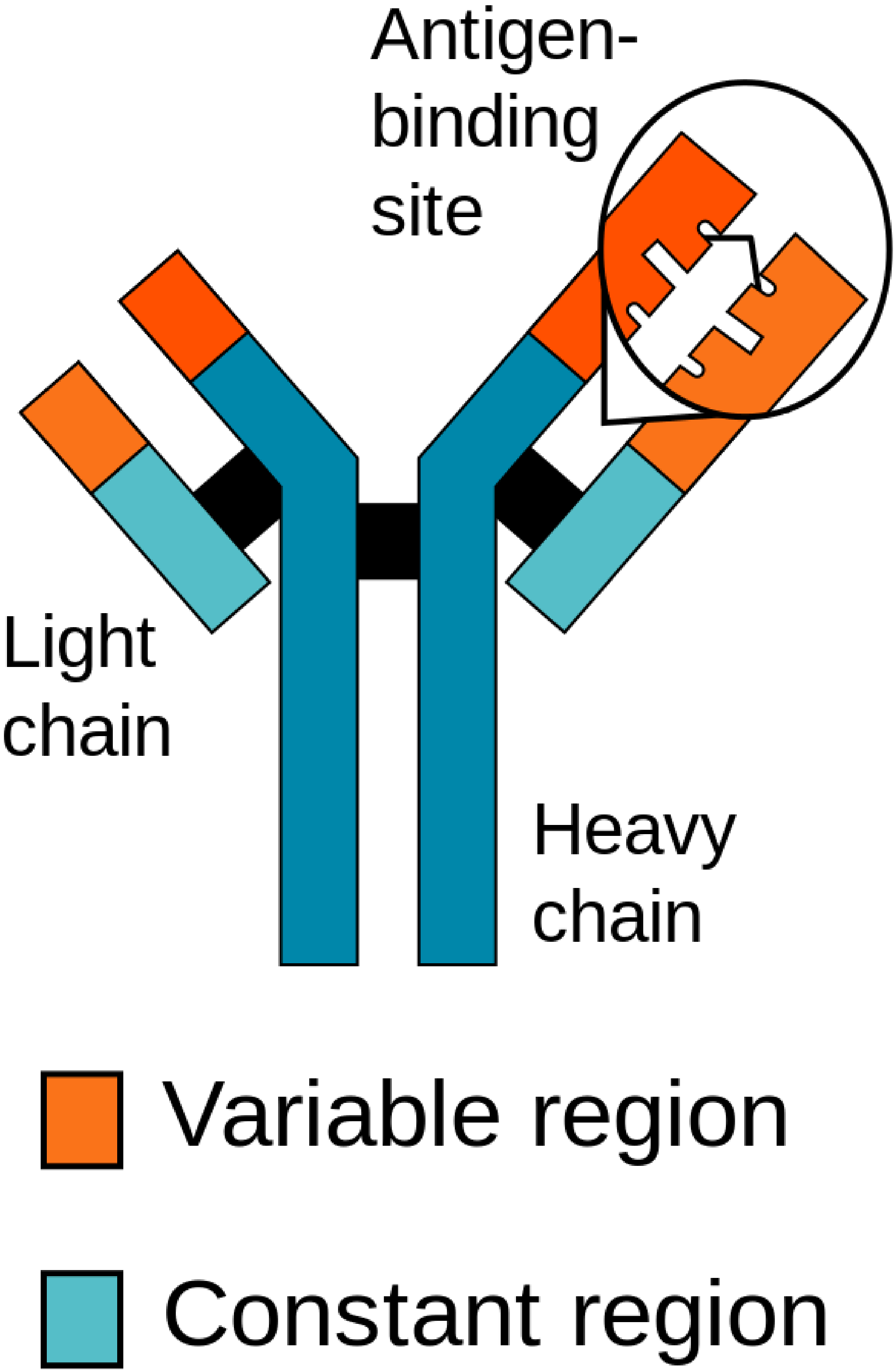
Antigen-
binding
site
Light
chain
Heavy
chain
Variable region
Constant region

Figure 6.47 *Antibody diagram by Fred the Oyster / Public Domain*

An **antibody** is a protein made by the immune system to protect against infection. Antibodies are made up of two longer (heavy) amino acid chains and two shorter (light) amino acid chains. These amino acid chains come together to form two antigen-binding sites. An **antigen** is a substance recognized by antibodies, and may be a bacteria, virus, fungus, parasite, or even some chemicals. When an antibody binds antigen, the immune system is activated to eliminate the infection. Sometimes antibodies are mistakenly produced against harmless substances, such as in allergies and in autoimmune disorders.

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 6.48 "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.

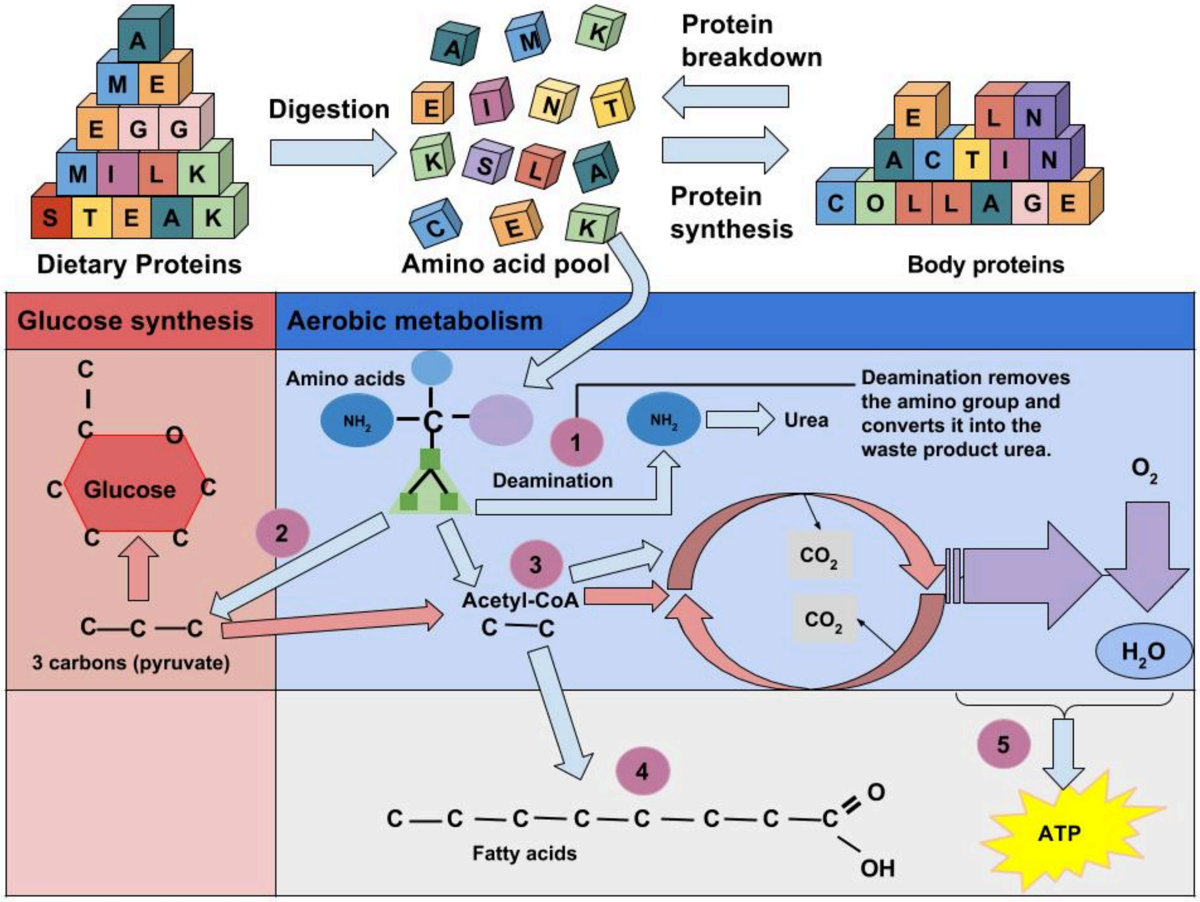

Figure 6.48 *Amino Acids Used for Energy. Image by Allison Calabrese / CC BY 4.0*

6.5 Diseases Involving Proteins

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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. Although severe protein deficiency is a rare occurrence in children and adults in the United States, it is estimated that more than half of the elderly in nursing homes are protein-deficient. 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 in **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 US, it is a leading cause of death in children in many poor countries. Protein deficiency rarely occurs alone. Instead it is often coupled with insufficient energy intake. As a result, the condition is called protein-energy malnutrition (PEM). **Kwashiorkor** and **marasmus** are the two forms of protein energy malnutrition. They differ in the severity of energy deficiency as shown in the figure below.

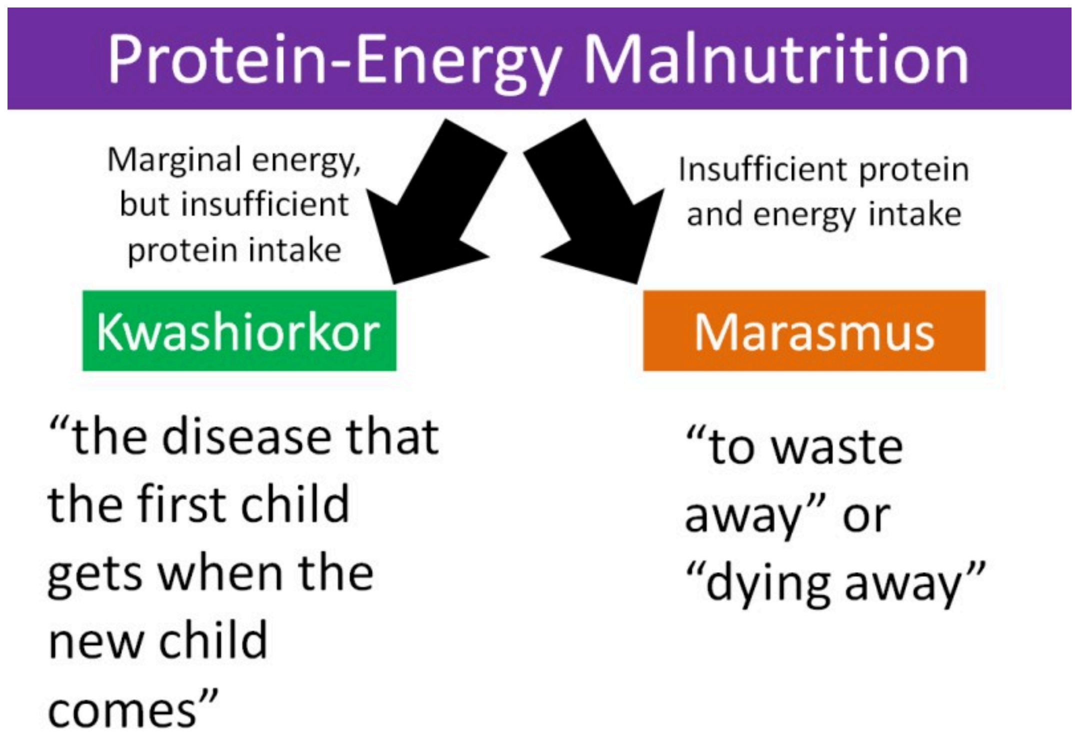

Figure 6.51 *The two types of protein-energy malnutrition. Source: Jellum, et al., Principles of Nutrition*

Kwashiorkor

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.

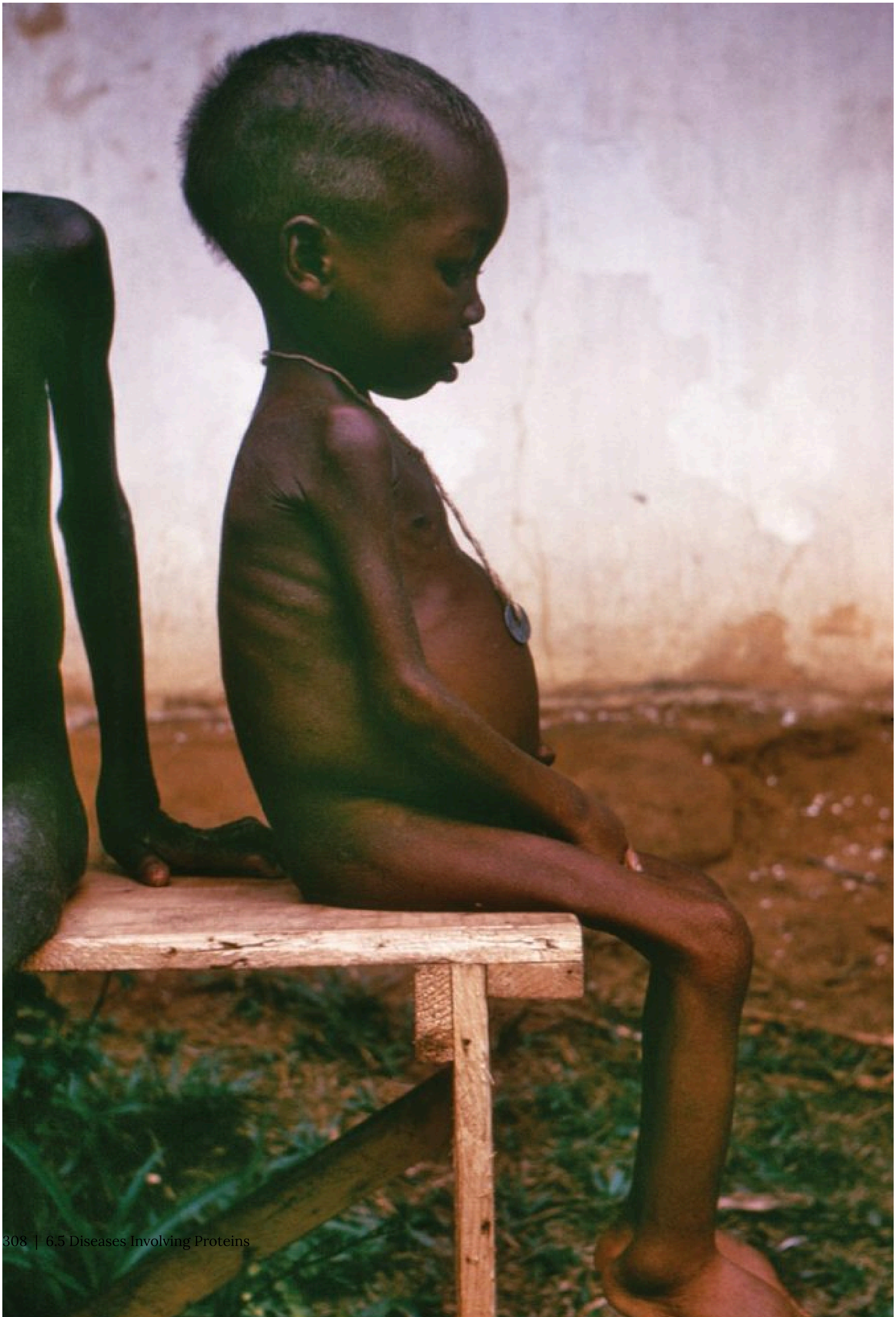

Figure 6.52 *A Young Boy With Kwashiorkor. Photo courtesy of the Centers for Disease Control and Prevention (CDC).*

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.

Video Link: Kwashiorkor (1:17)

Marasmus

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.

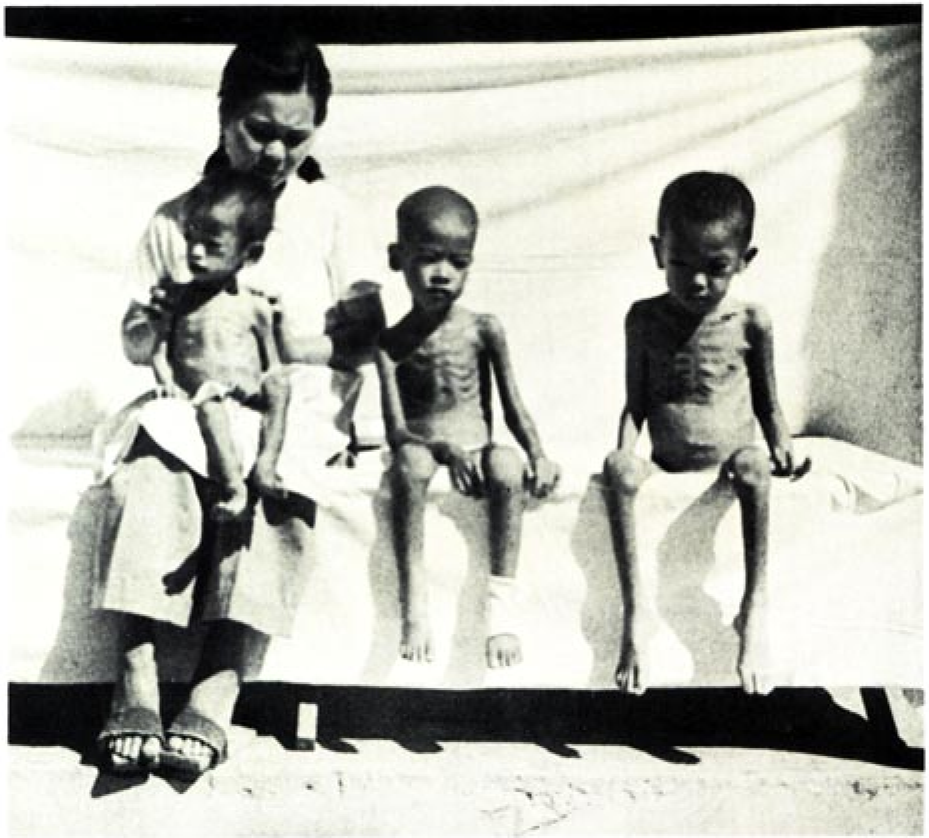

FIGURE 51.—Japanese nurse with dependent children having typical appearance of malnutrition. New Bilibid Prison, September–October 1945.

Figure 6.53 *Children With Marasmus. Source: Japanese nurse with dependent children having typical appearance of malnutrition, New Bilibid Prison, September-October 1945 by Unknown / Public Domain*

Video Link: Marasmus (1:25)

Kwashiorkor and marasmus combined

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.

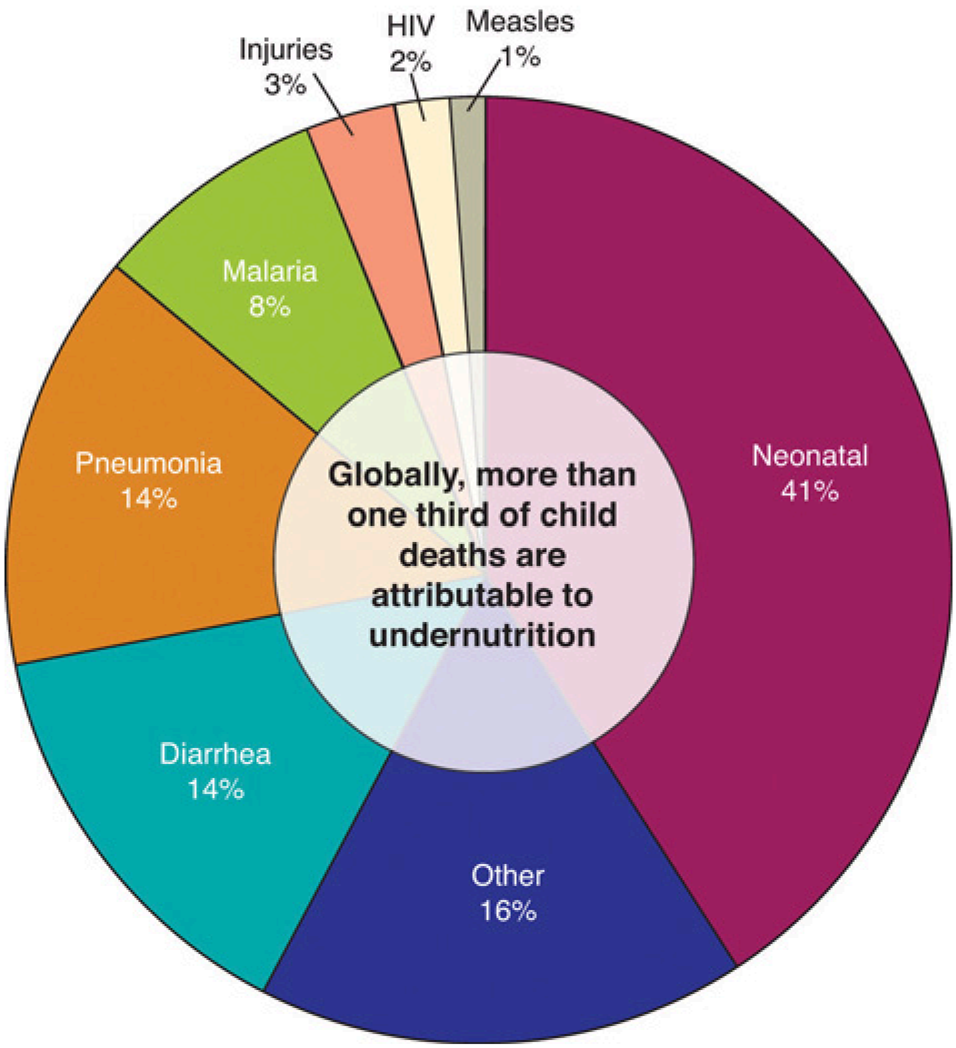

Figure 6.54 *Causes Of Death For Children Under The Age Of Five, Worldwide*

Health Consequences of Too Much Protein in the Diet

An explicit definition of a high-protein diet has not yet been developed by the Food and Nutrition Board of the Institute of Medicine (IOM), 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.[23]

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. The American Heart Association (AHA) states that "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.

Notes

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. https://doi.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. https://doi.org/10.1093/jn/128.6.1051. 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. https://doi.org/10.1161/hc4001.096152. Accessed September 28, 2017.
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. https://doi.org/10.1161/hc4001.096152. Accessed September 28, 2017.

6.6 Proteins in a Nutshell

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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. Moreover, the **FDA** says that 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 by the Dietary Guidelines Advisory Committee (DGAC) 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.

6.7 Proteins, Diet, and Personal Choices

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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 set by the IOM for the **Recommended Dietary Allowance (RDA)** and **AMDR** for protein for different age groups are listed in Table 6.71 "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 6.71 Dietary Reference Intakes for Protein[1]

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		

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.

The IOM used data from multiple studies that determined nitrogen balance in people of different age groups to calculate the RDA for protein. 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."[2]

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 6.72 "Sources of Dietary Protein". To find out the complete nutrient package of different foods, visit the **US Department of Agriculture (USDA)** Food Composition Databases.

Table 6.72 Sources of Dietary Protein

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

The USDA provides some tips for choosing your dietary protein sources. Their motto is, "Go Lean with Protein". The overall suggestion is to eat a variety of protein-rich foods to benefit health. The USDA recommends 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, the USDA has much more information on how to 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 6.71 *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 6.73 "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 6.73 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 adopted by the US Food and Drug Administration (FDA) 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 (amino acid score x digestibility). 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 6.74 "PDCAAS of Various Foods".

Table 6.74 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. The Dietary Guidelines Advisory Committee (DGAC) has analyzed how three different, plant-based dietary patterns can meet the recommended dietary guidelines for all nutrients.[3]

The diets are defined in the following manner:

- **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.

These diets are analyzed and compared to the more common dietary pattern of Americans, which is referred to as the USDA Base Diet. Table 6.75 "Percentage of "Meat and Beans Group" Components in the USDA Base Diet, and Three Vegetarian Variations" and Table 7.7 "Proportions of Milk Products and Calcium-Fortified Soy Products in the Base USDA Patterns and Three Vegetarian Variations" can be used to help determine what percentage of certain foods to eat when following a different dietary pattern. The percentages of foods in the different groups are the proportions consumed by the population, so that, on average, Americans obtain 44.6 percent of their foods in the meat and beans group from meats. If you choose to follow a lacto-ovo vegetarian diet, the meats, poultry, and fish can be replaced by consuming a higher percentage of soy products, nuts, seeds, dry beans, and peas. As an aside, the DGAC notes that these dietary patterns may not exactly align with the typical diet patterns of people in the United States. However, they do say that they can be adapted as a guide to develop a more plant-based diet that does not significantly affect nutrient adequacy.

Table 6.75 Percentage of "Meat and Beans Group" Components in the USDA Base Diet, and Three Vegetarian Variations[4]

Food Category	Base USDA (%)	Plant-Based (%)	Lacto-Ovo Vegetarian (%)	Vegan (%)
Meats	44.6	10.5	0	0
Poultry	27.9	8.0	0	0
Fish (high omega-3)	2.2	3.0	0	0
Fish (low omega-3)	7.1	10.0	0	0
Eggs	7.9	7.6	10.0	0
Soy products	0.9	15.0	30.0	25.0
Nuts and seeds	9.4	20.9	35.0	40.0
Dry beans and peas	n/a*	25.0	25.0	35.0
Total	**100.0**	**100.0**	**100.0**	**100.0**
*The dry beans and peas are in the vegetable food group of the base diet.				

Table 6.76 Proportions of Milk Products and Calcium-Fortified Soy Products in the Base USDA Patterns and Three Vegetarian Variations[5]

Food Category	Base USDA (%)	Plant-based (%)	Lacto-ovo vegetarian (%)	Vegan (%)
Fluid milk	54.6	54.6	54.6	0
Yogurt	1.6	1.6	1.6	0
Cheese	42.7	42.7	42.7	0
Soy milk (w/ calcium)	1.1	1.1	1.1	67.0
Rice milk (w/ calcium)	0	0	0	16.0
Tofu (w/ calcium)	0	0	0	15.0
Soy yogurt	0	0	0	2.0
Total	**100.0**	**100.0**	**100.0**	**100.0**

From these analyses the DGAC concluded that the plant-based, lacto-ovo vegetarian, and vegan diets do not significantly affect nutrient adequacy. Additionally, the DGAC states that people who choose to obtain proteins solely from plants should include foods fortified with vitamins B12, D, and calcium. Other nutrients of concern may be omega-3 fatty acids and choline.

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 US 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.[6]

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. The IOM does not set different RDAs for protein intakes for athletes, but the AND, the American College of Sports Medicine, and Dietitians of Canada have the following position statements[7]:

> 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 6.77 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 AND, 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 American already consumes more protein than is required. Despite these facts, many highly physically active individuals use protein or amino acid supplements. According to the AND, 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."[8]

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.[9]

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 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.

Notes

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CHAPTER VII

CHAPTER 7: LIPIDS

Lipids, commonly referred to as fats, have a poor reputation among some people, in that "fat free" is often synonymous with healthy. We do need to consume certain fats and we should try to incorporate some fats into our diets for their health benefits. However, consumption of certain fats is also associated with greater risk of developing chronic disease(s). In this section, we will dive deeper into fats and why they do not need to be feared altogether.

Sections:

Chapter 7 is primarily from Fialkowski Revilla, et al. *Human Nutrition*.

7.0 Introduction to Lipids

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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 is considered to be the 'Tree of Life' in the Pacific. The coconut provided wood for shelter and craftsmanship along with being a source of hydration, animal feed and income through copra. It also serves many ecological functions such as a source for shade, protection from the wind, and coastal erosion control.[1] A thriving coconut tree provided Pacific Island families with great prosperity.

For many Pacific communities 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.

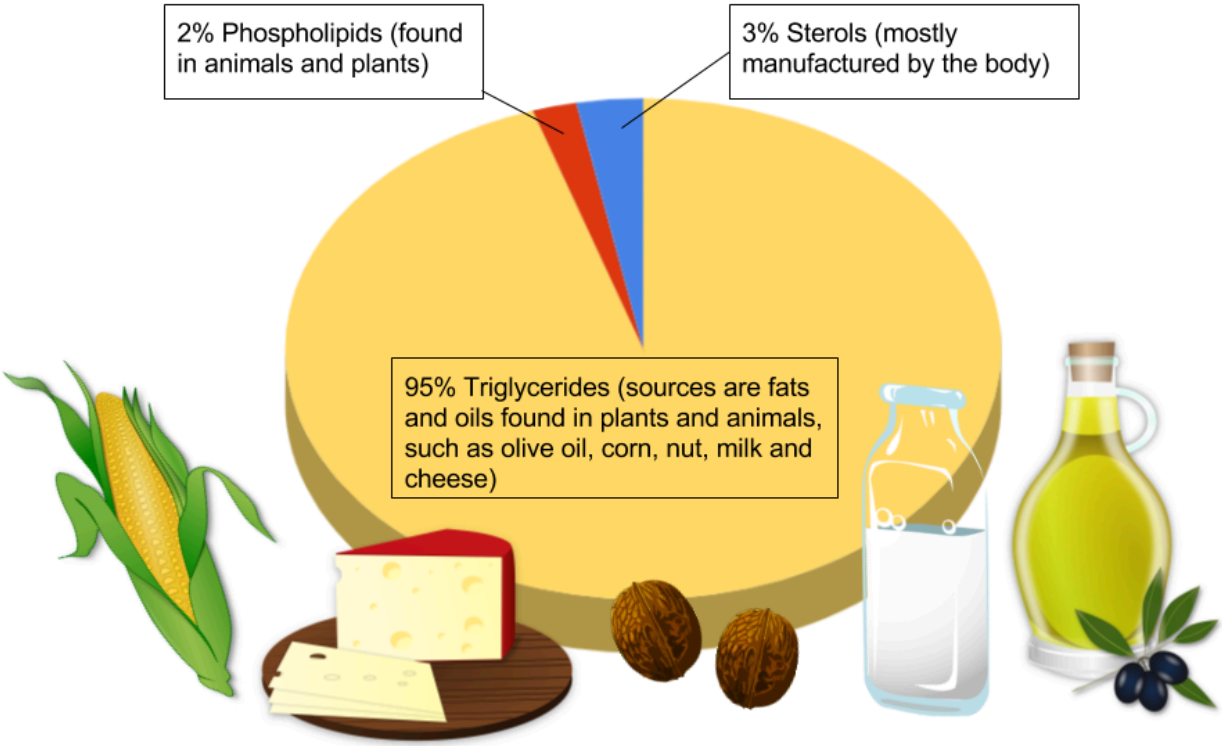

Figure 7.01 *Types of Lipids. Image by Allison Calabrese / CC BY 4.0*

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7.1 The Functions of Lipids in the Body

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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.

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

Figure 7.11 *Food Sources of Omega 3 fatty acids.*

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.

7.2 The Role of Lipids in Food

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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.

7.3 Triglycerides

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Lipids are unique organic compounds, each serving key roles and performing specific functions within the body. There are three main types of lipids in our bodies and in our food:

- Triglycerides
- Phospholipids
- Sterols

Triglycerides are the most common lipid in our bodies and in the foods we consume. We'll talk about triglycerides first and come back to phospholipids and sterols in a later section.

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. Breaking down the name triglyceride tells a lot about their structure. "Tri" refers to the three fatty acids, "glyceride" refers to the **glycerol** backbone that the three fatty acids are bonded to. You can also have **monoglycerides** with one fatty acid and **diglycerides** that contain two fatty acids.

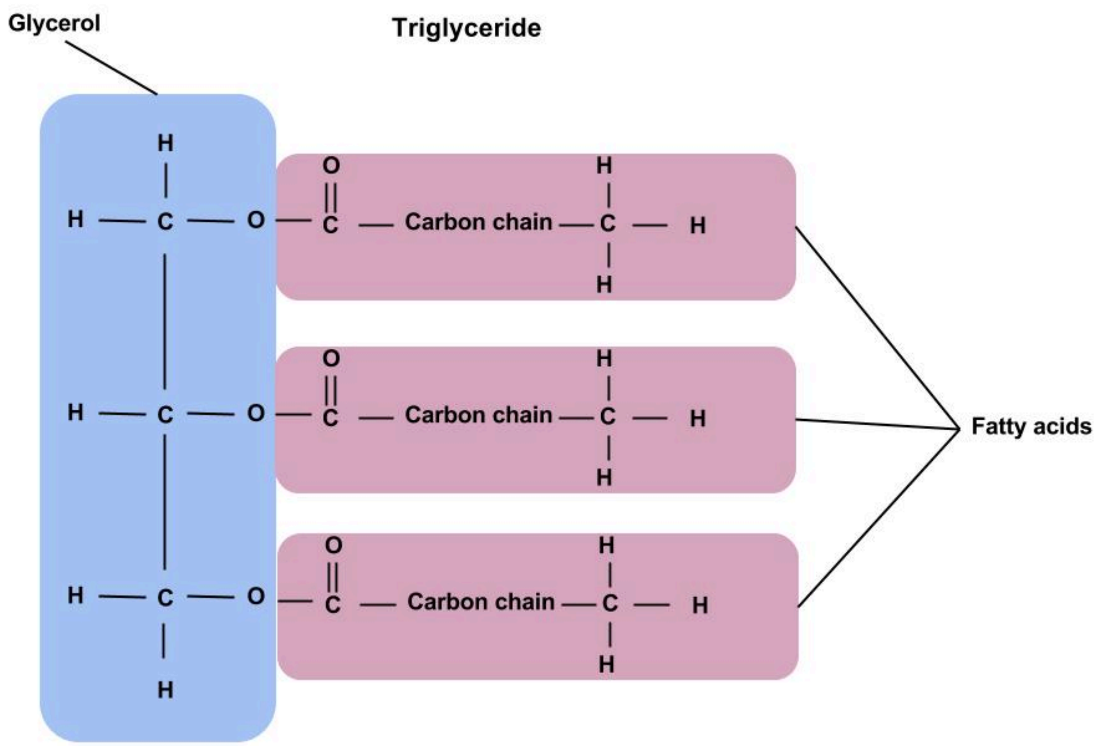


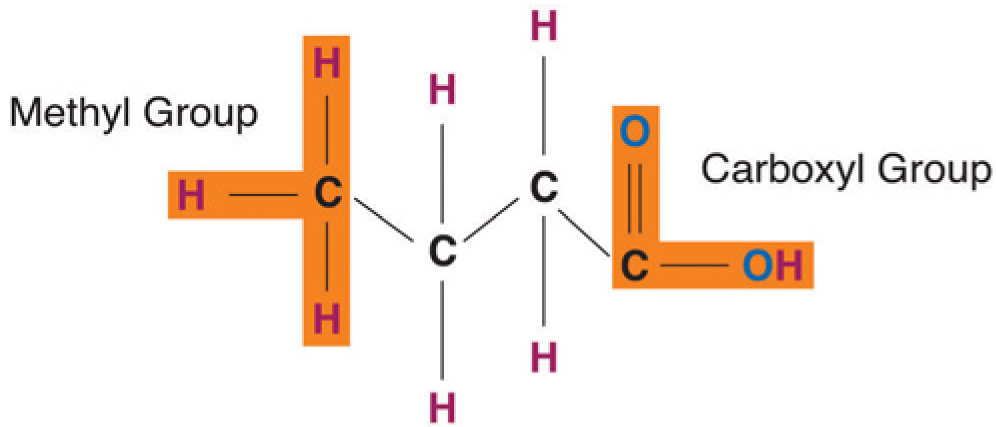
Figure 7.31 *The Structure of a Triglyceride. Image by Allison Calabrese/ CC BY 4.0*

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. The three fatty acids in a triglyceride can be the same or can each be a different fatty acid.

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.



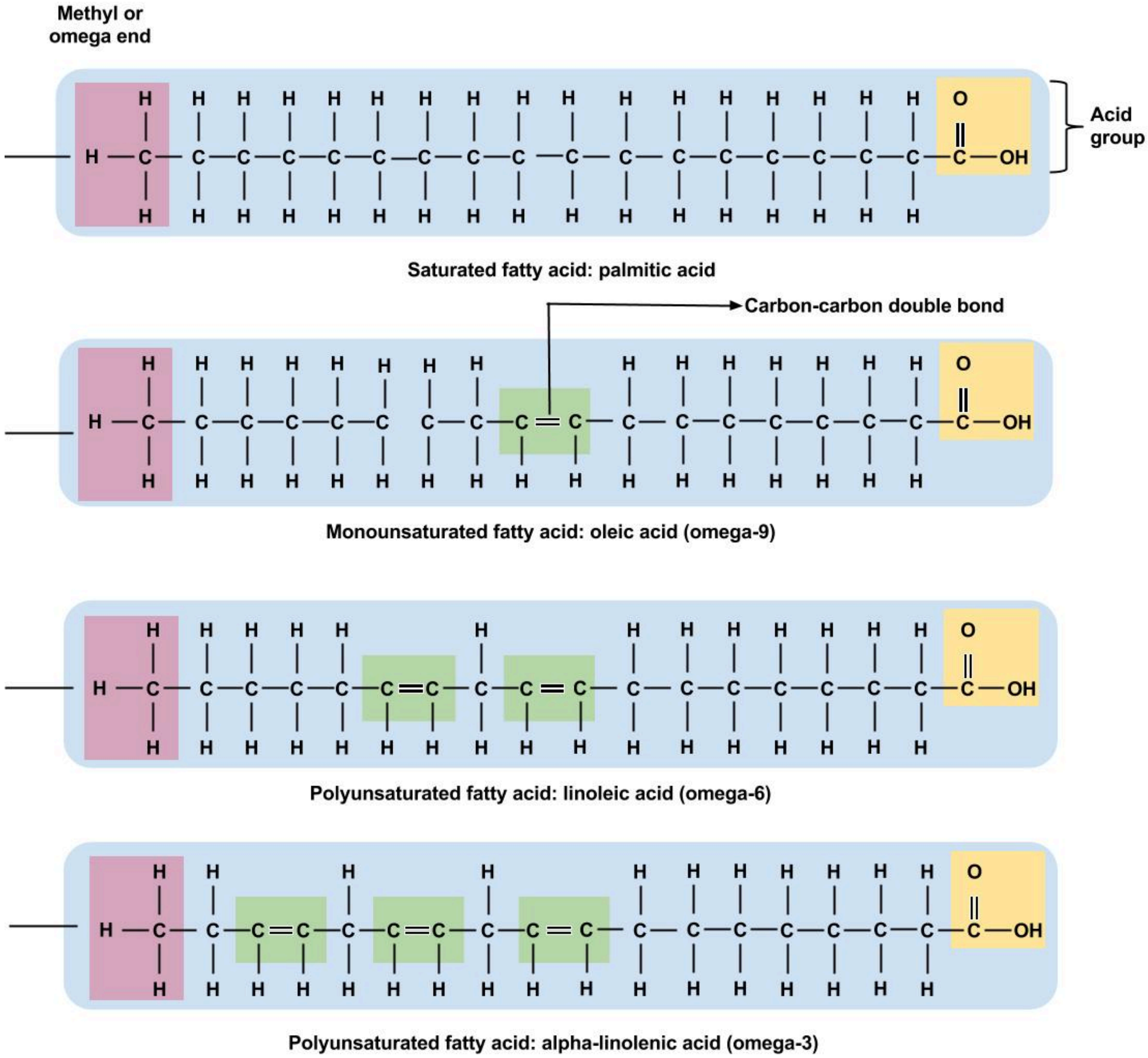


Figure 7.32 *Structures of a Saturated, Monounsaturated, and Polyunsaturated Fat. Image by Allison Calabrese / CC BY 4.0*

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

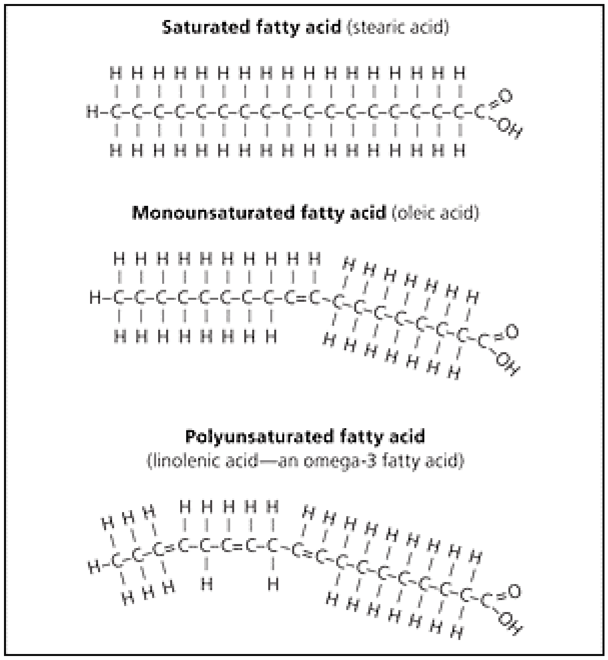


***Figure* 7.33** *Structure of saturated, monounsaturated, and polyunsaturated fatty acid. Image source*

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.

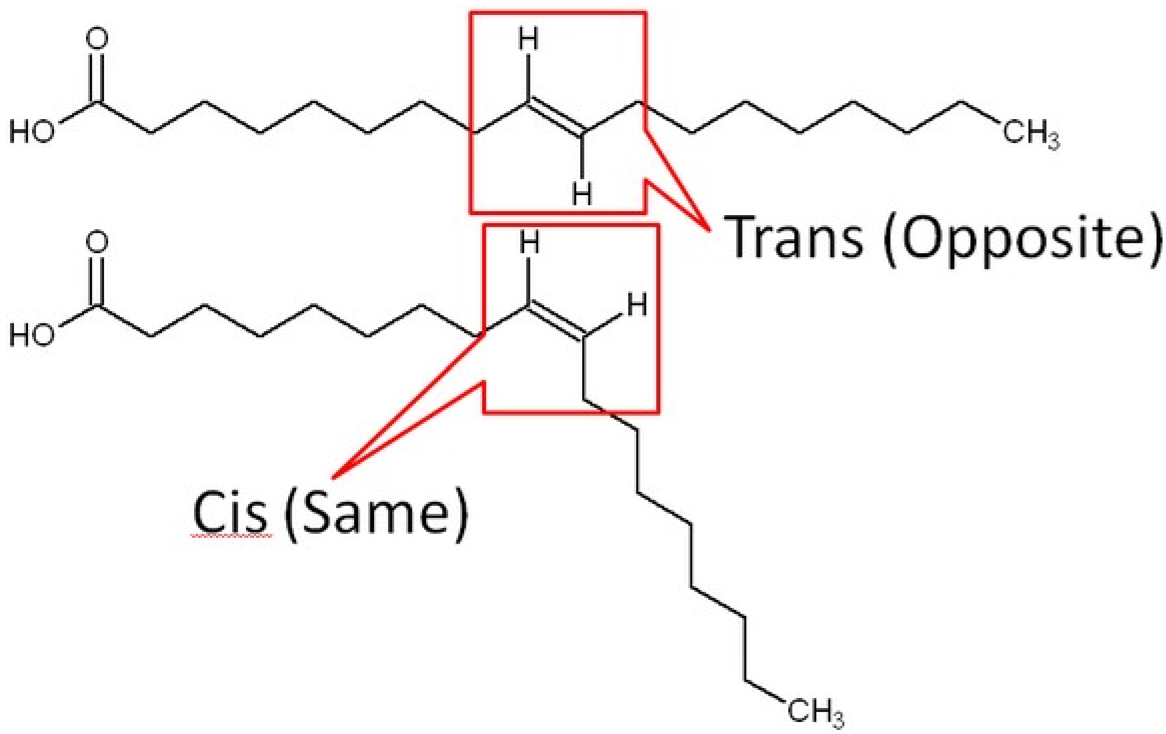


Figure 7.34 *Cis and trans structural conformations of a monounsaturated fatty acid*

In a trans fatty acid, the hydrogen atoms are attached on opposite sides of the carbon chain. There are some naturally occurring trans fatty acids, such as conjugated linoleic acid (CLA), in dairy products. However, for the most part, trans fatty acids in our diets are not natural; instead, they have been produced synthetically. The primary source of trans fatty acids in our food supply is **partially hydrogenated vegetable oil**. The 'hydrogenated' means that the oil has gone through the process of hydrogenation. Hydrogenation, like the name implies, is the addition of hydrogen. This is how vegetable oils are converted into semisolid fats for use in the manufacturing process.

If an unsaturated fatty acid is completely hydrogenated it would be converted to a saturated fatty acid as shown in Figure 7.35.

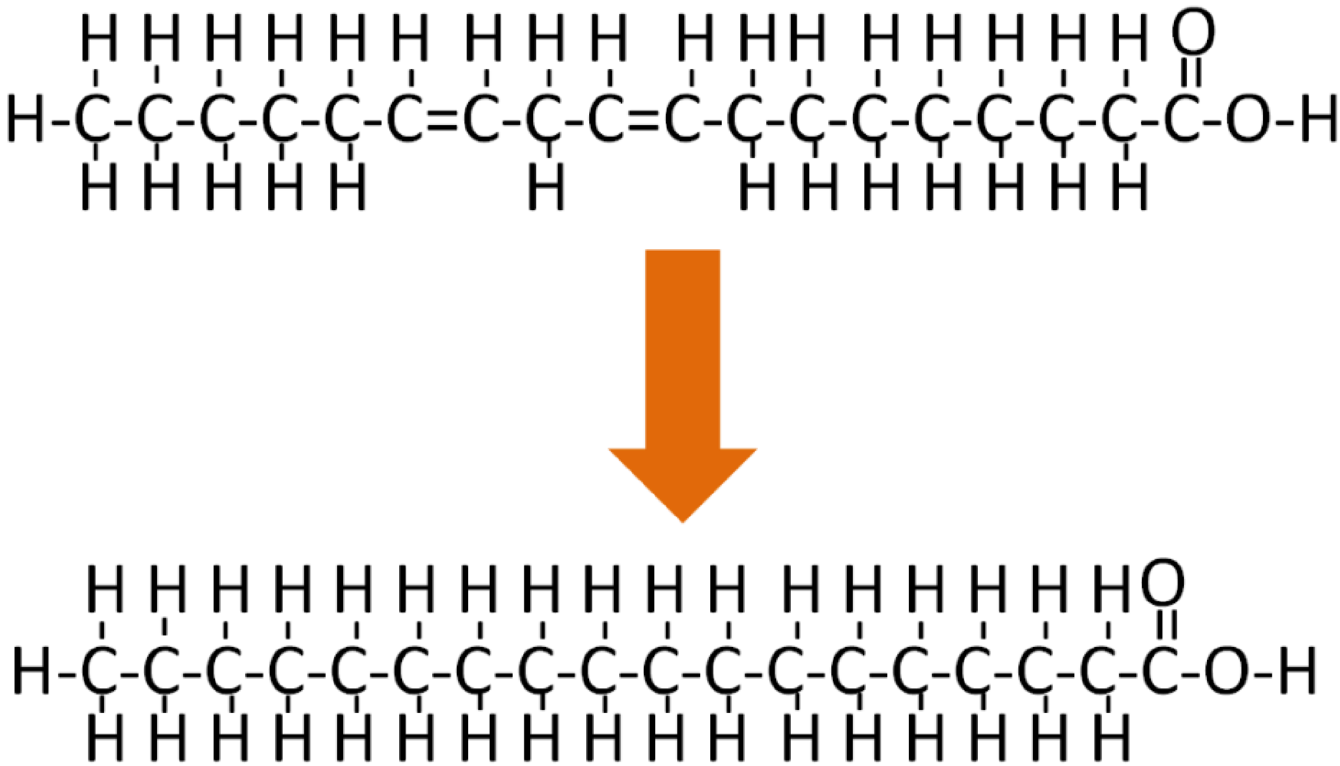


***Figure* 7.35** *Fatty acid hydrogenation*

However, complete hydrogenation isn't/wasn't always desirable, thus partially hydrogenated vegetable oil became widely used. To visualize the difference in the amount of hydrogenation consider the difference between tub margarine and stick margarine.

Stick margarine is more fully hydrogenated giving it a more solid texture. This is one of the two reasons to hydrogenate, to get a more solid texture. The second reason is that it makes it more shelf-stable, because the double bond(s) of unsaturated fatty acids are susceptible to oxidation, which causes them to become rancid.

Partial hydrogenation causes the conversion of cis to trans fatty acids along with the formation of some saturated fatty acids. Originally, it was thought that trans fatty acids would be a better alternative to saturated fat (think margarine vs. butter). However, it turns out that **trans fat** is actually worse than saturated fat in altering biomarkers associated with cardiovascular disease. Trans fat increases LDL and decreases HDL levels, while saturated fat increased LDL without altering HDL levels. But this does not mean that butter is a better choice than margarine as described in the first link. The **FDA** revoked Generally Recognized as Safe (GRAS) status of partially hydrogenated vegetable oil in 2015, requiring its use to be phased out by 2018.[2]

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. Reports from the **US Department of Agriculture (USDA)** indicate that 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.

Web Links:

Butter vs. Margarine: Which is better for my heart?

FDA to Limit Trans Fats in Foods

Notes

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.
2. https://www.hsph.harvard.edu/news/hsph-in-the-news/us-bans-artificial-trans-fats/

7.4 Essential Fatty Acids

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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. Both types of essential fatty acid are **polyunsaturated fatty acids**.

The structures of two of the most common essential fatty acids are shown below.

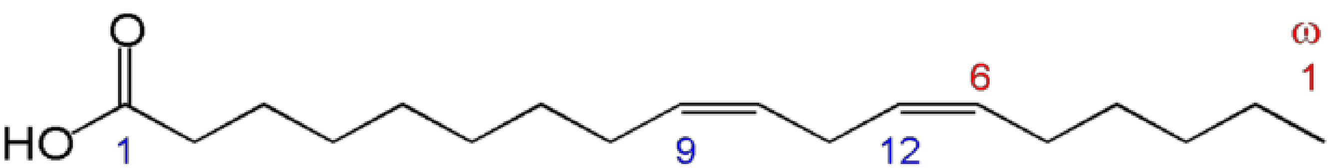

Figure 7.41 *Linoleic acid (an omega-6 fatty acid). Image source*

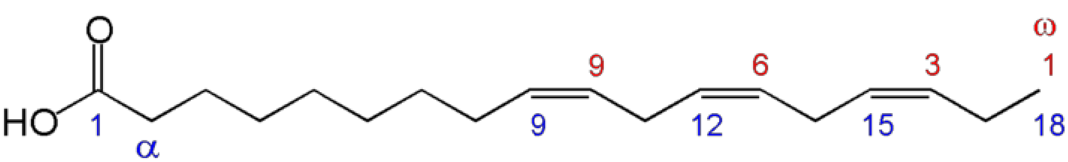

Figure 7.42 *Alpha-linolenic acid (an omega-3 fatty acid). Image source*

Our bodies can convert linoleic acid to other omega-6 fatty acids and alpha-linolenic acid to other omega-3 fatty acids, to some extent, but we cannot convert omega-3 fatty acids to omega-6 fatty acids, or omega-6 fatty acids to omega-3 fatty acids. Therefore, we need both to get both types of essential fatty acids in our diet.

Omega-3 and omega-6 fatty acids are precursors to important compounds called eicosanoids. **Eicosanoids** are powerful hormones that control many important body functions, such as the central nervous system and the immune system. Different eicosanoids are produced from different types of fatty acids, which leads to different health outcomes. 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. Omega-3 fatty acids are considered anti-inflammatory because replacing the more inflammatory omega-6 fatty acid derived eicosanoids with omega-3 fatty acid derived eicosanoids will decrease inflammation.

In general, polyunsaturated fatty acids are considered healthy. However, since omega-6 fatty acids are more inflammatory, consuming too many omega-6s is probably more detrimental than helpful. As a result, many people talk about the omega-3:6 fatty acid ratio in peoples' diets. For most Americans, the ratio is believed to be too high, at almost 10-20 times more omega-6 fatty acids than omega-3 fatty acids.[1] This is why you've probably heard that you should get more omega-3s in your diet.

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 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. When it does occur, symptoms include impaired growth, reproductive problems, skin lesions, and neurological and visual problems.

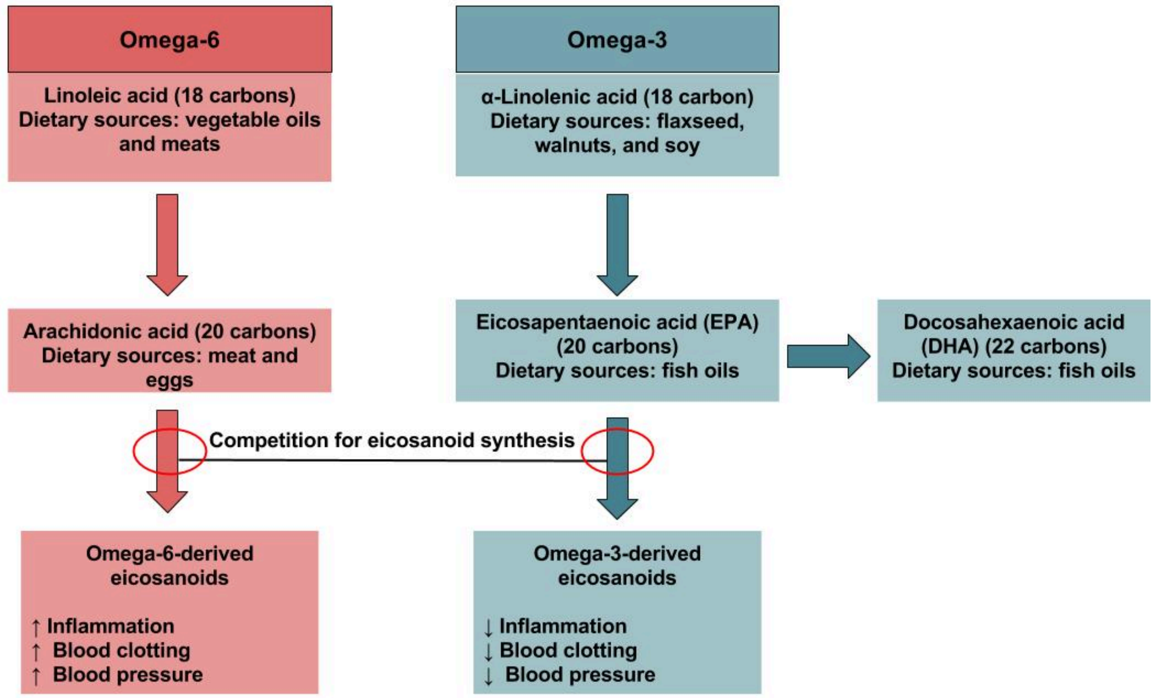

Figure 7.43 *Essential Fatty Acids. Image by Allison Calabrese / CC BY 4.0*

Food Sources of Fatty Acids

After going through this wide array of fatty acids, you may be wondering where they are found in nature. The figure below shows the fatty acid composition of certain oils and oil-based foods. As you can see, most foods contain a mixture of fatty acids. Stick margarine is the only product in the figure that contains an appreciable amount of **trans fatty acids**. Corn, walnut, and soybean oil are rich sources of n-6 polyunsaturated fatty acids (a.k.a. omega-6 fatty acids), while flax seed is fairly unique among plants in that it is a good source of n-3 polyunsaturated fatty acids (a.k.a. omega-3 fatty acids). Canola and olive oil are rich sources of monounsaturated fatty acids. Lard, palm oil, butter and coconut oil all contain a significant amount of **saturated fatty acids**.

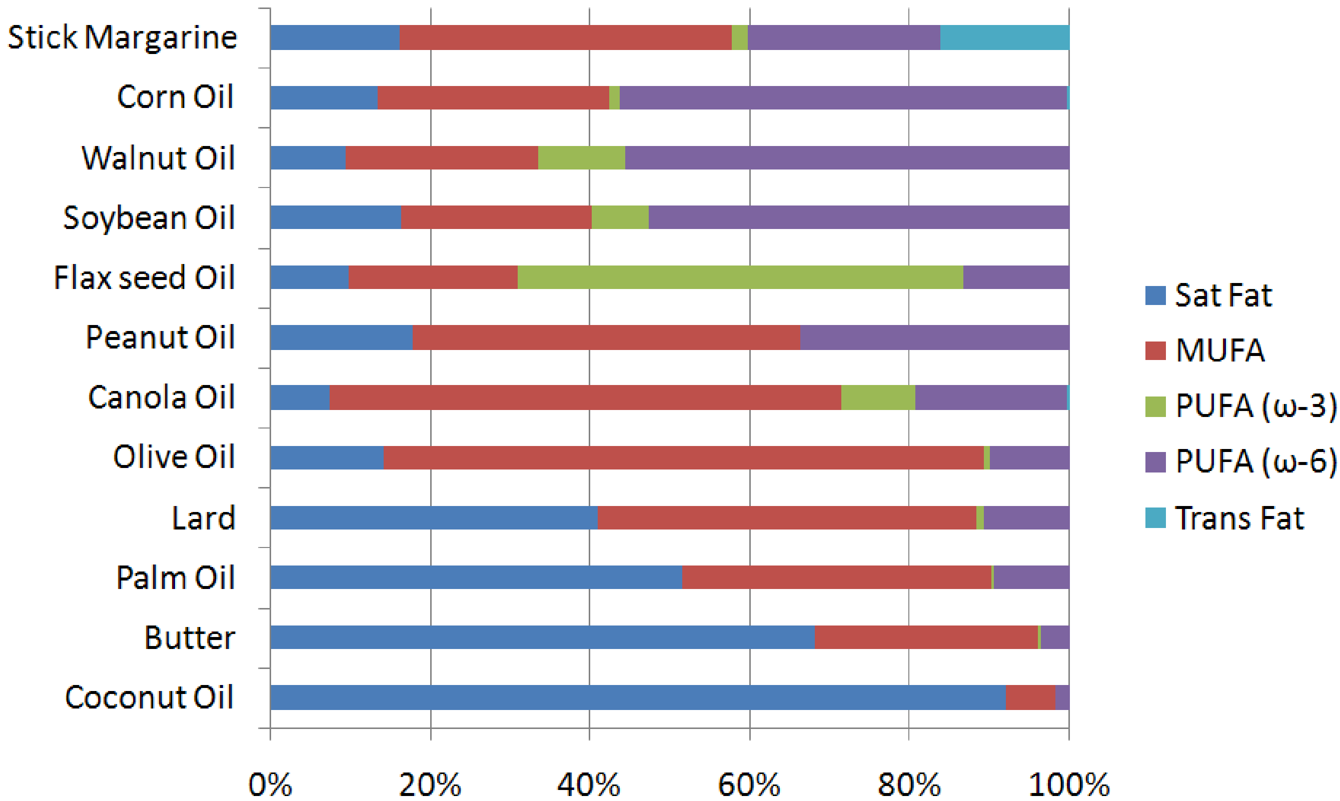

Figure 7.44 *Fatty acid composition of foods and oils. Source: www.nutritiondata.com*

Notes

1. 1. Simopoulos AP. (2008) The importance of the omega-6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases. Exp Biol Med 233(6): 674.

7.5 Phospholipids and Sterols

As mentioned in section 7.3, triglycerides are the most common type of lipid in our diets. But they are not the only type. Here, we'll talk about the other two categories of lipid found in food: phospholipids and sterols.

Phospholipids

Like triglycerides, phospholipids have a glycerol backbone. But unlike triglycerides, phospholipids are diglycerides (two fatty-acid molecules attached to the glycerol backbone). In place of the third fatty acid chain, phospholipids have 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.

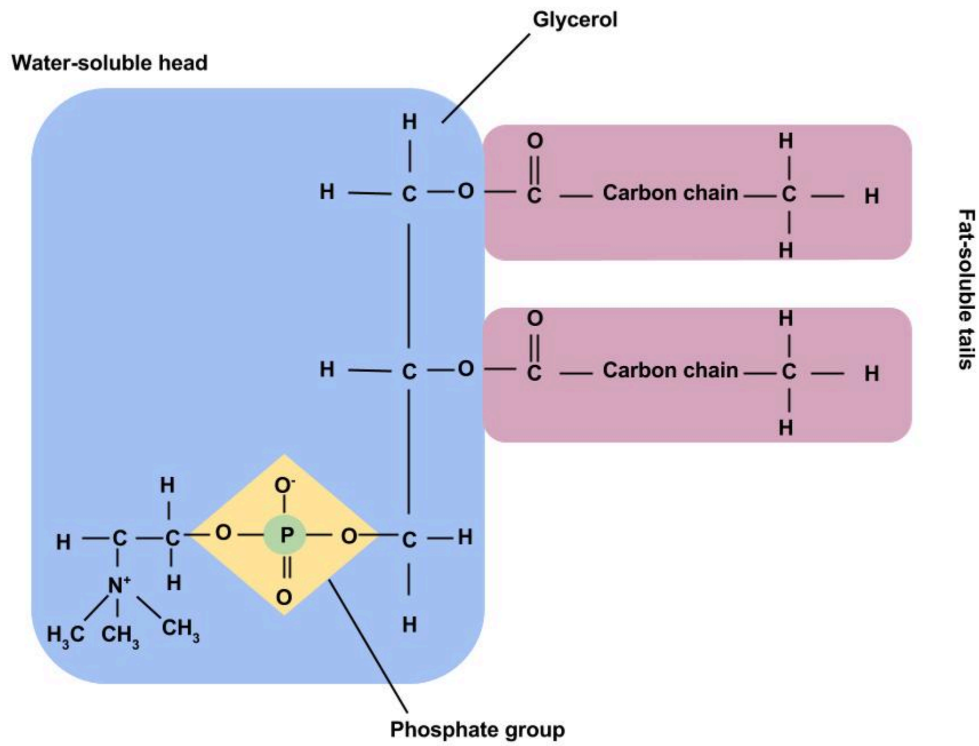

***Figure 7.51** The Structure of a Phospholipid. Image by Allison Calabrese / CC BY 4.0*

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. Emulsifiers can also be used to lift grease off of surfaces, like when you use soap to clean a dirty pan.

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.

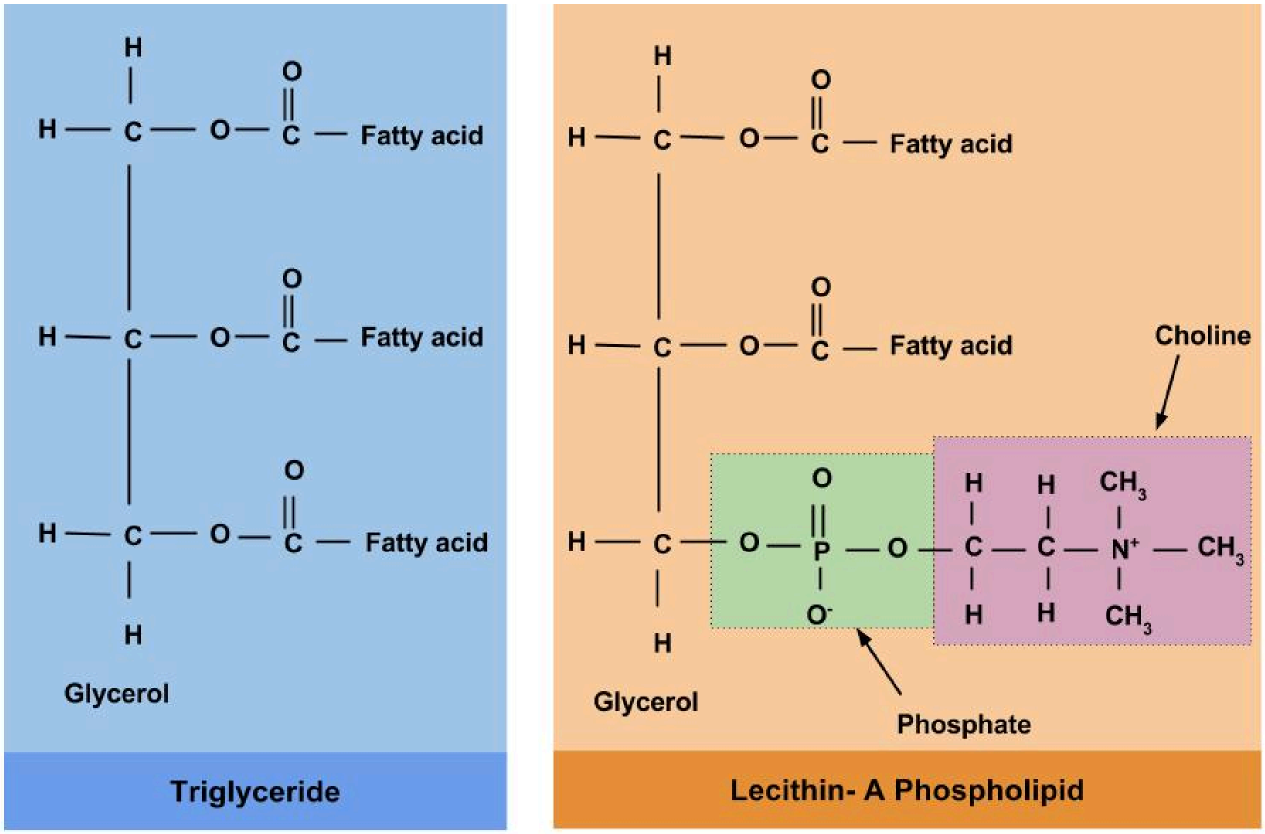

***Figure* 7.52** *The Difference Between Triglycerides and Phospholipids. Image by Allison Calabrese /* CC BY 4.0

Sterols

Sterols have a very different structure from triglycerides and phospholipids. Most sterols do not contain any fatty acids but rather have a multiring structure. 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.

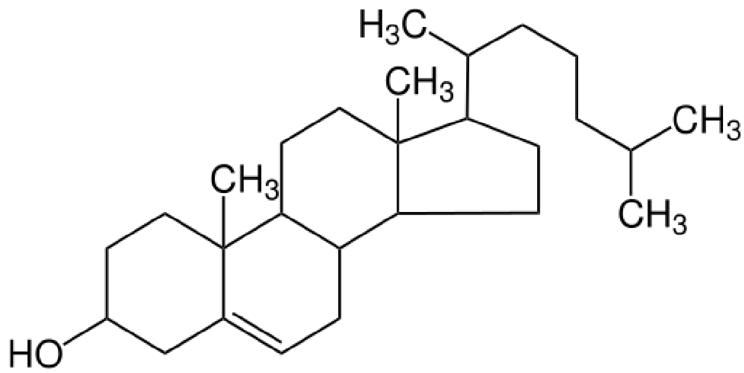

***Figure* 7.53** *The Structure of Cholesterol. Source: "Cholesterol Chemical Structure" by Wesalius / Public Domain*

7.6 Digestion and Absorption of Lipids

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Lipids are large molecules and generally are not water-soluble. Like carbohydrates and protein, lipids are broken into small components for **absorption**. Since our digestive enzymes are secreted in a watery solution, 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.

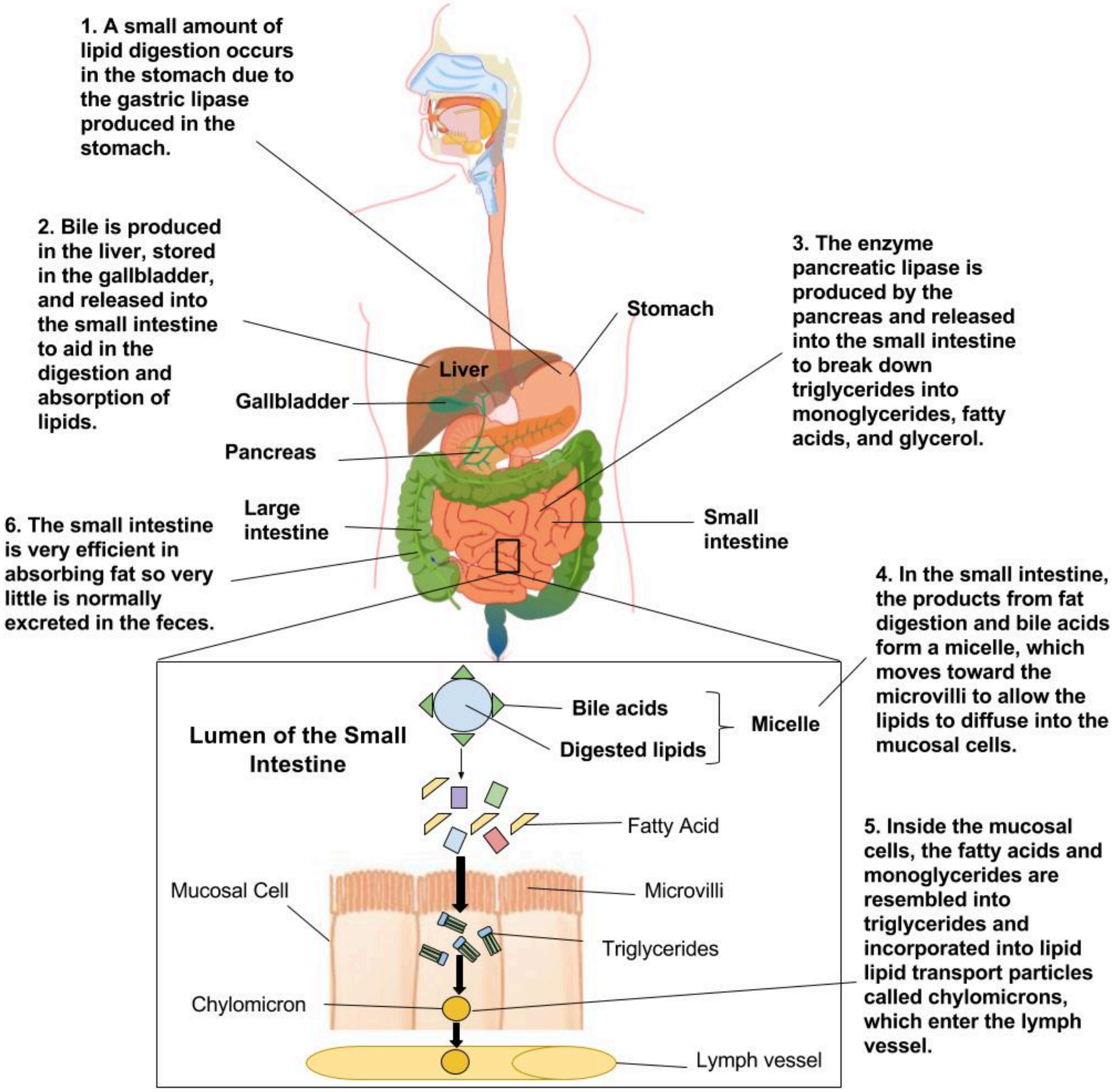

***Figure* 7.61** *Lipid Digestion and Absorption. Image by Allison Calabrese / CC BY 4.0*

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.

Bile in the Small Intestine

The majority of lipid digestion and absorption occurs in the small intestine. As stomach contents enter the small intestine, the digestive system must 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 much 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.

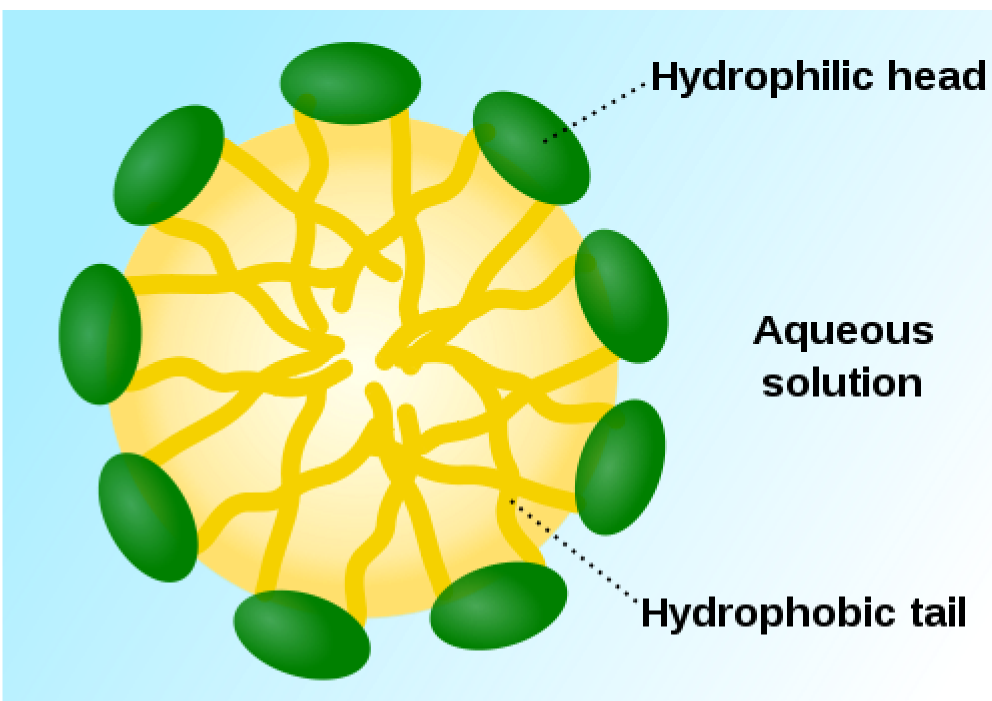

Figure 7.62 *Micelle formed by phospholipids in an aqueous solution. By Emmanuel Boutet / CC BY-SA 3.0*

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.**

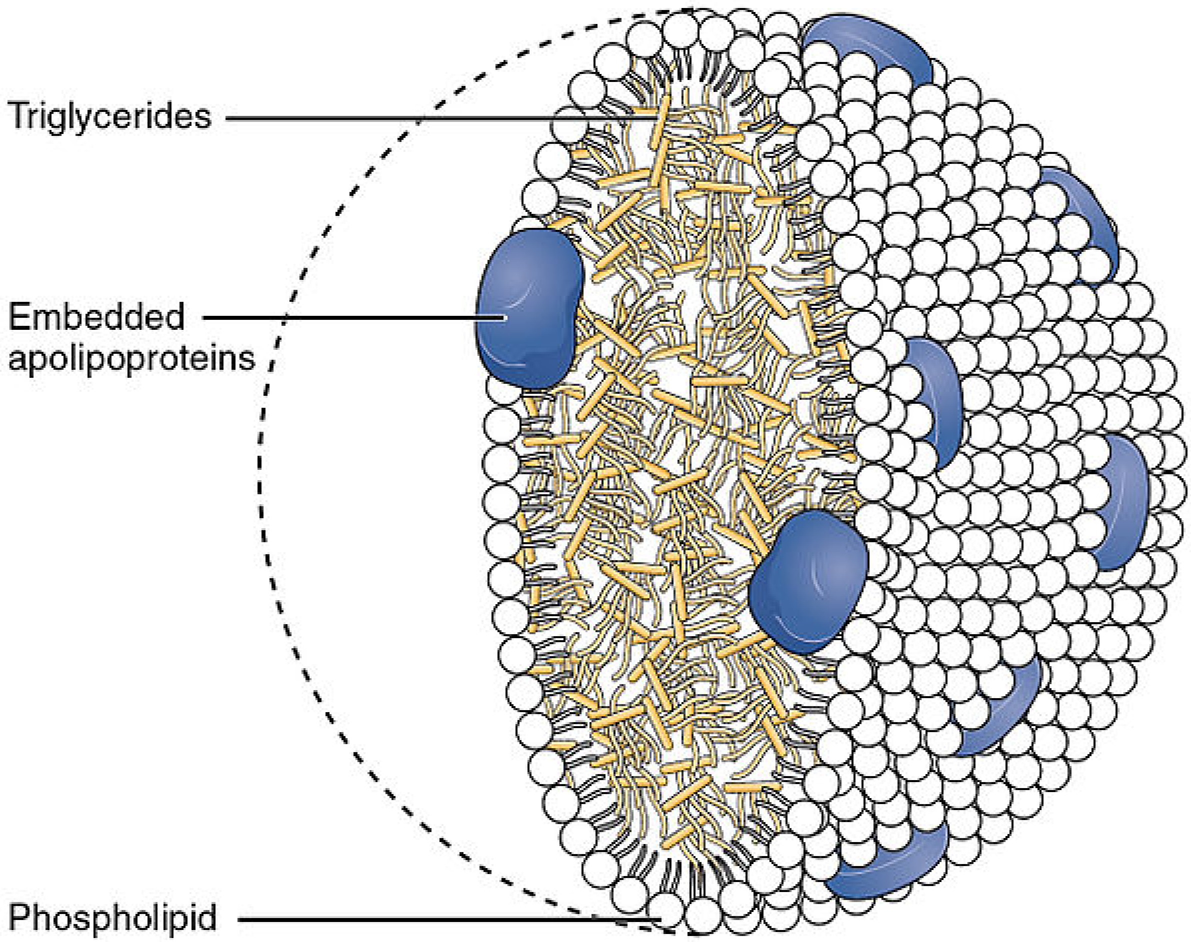

***Figure* 7.63** *Chylomicrons contain griglycerides, cholesterol molecules, and other lipids by OpenStax College / CC BY 3.0*

Chylomicrons are too large to fit through the pores in capillaries, but they can fit through the larger openings in lacteals. Therefore, most dietary fat is absorbed into lacteals and circulates through the lymphatic system before being returned to the blood.

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.

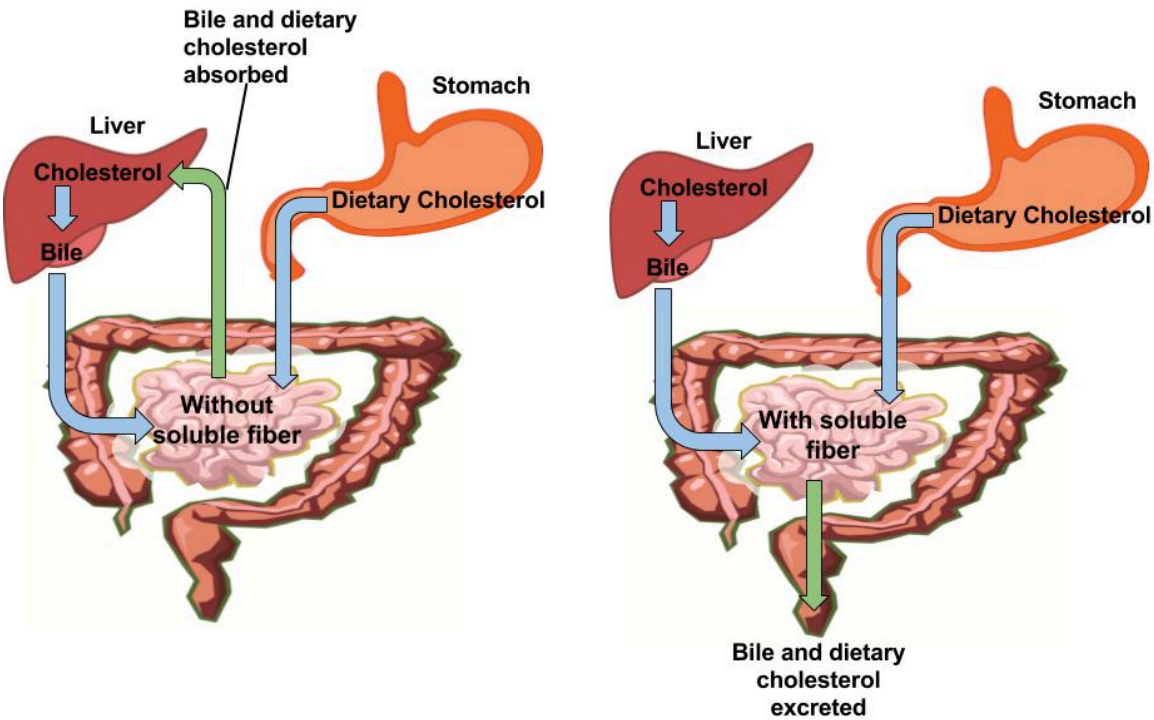

Figure 7.64 *Cholesterol and Soluble Fiber. Image by Allison Calabrese / CC BY 4.0*

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.

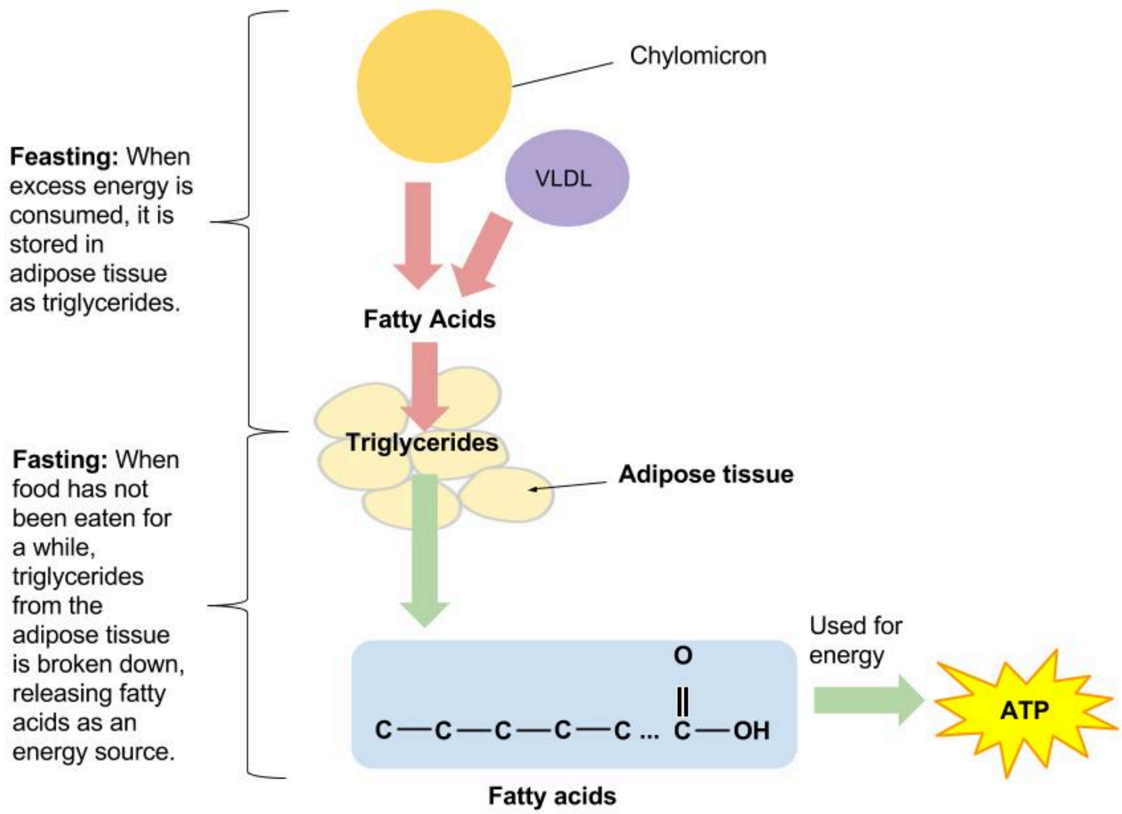

Figure 7.65 *Storing and Using Fat. Image by Allison Calabrese / CC BY 4.0*

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."

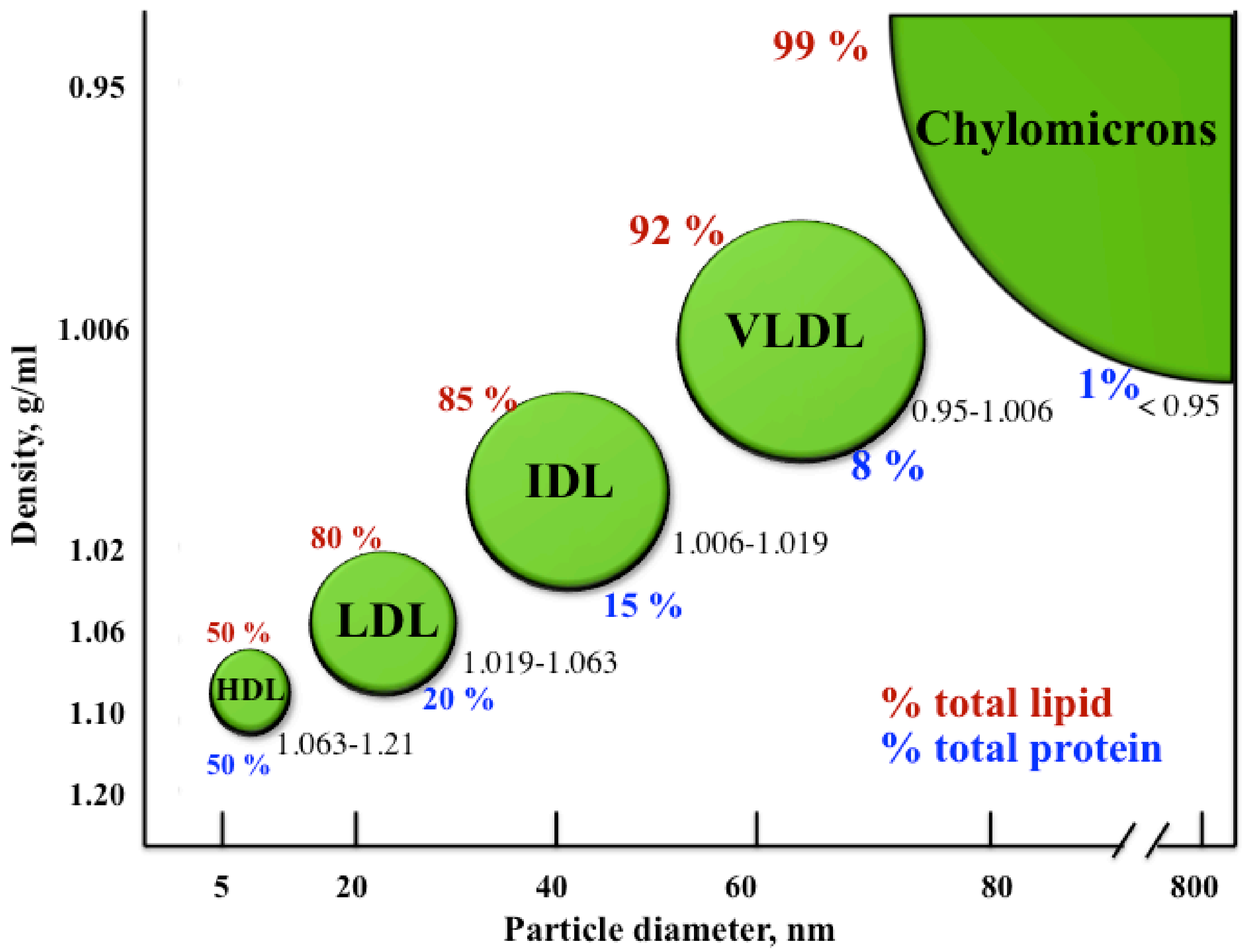

Figure 7.66 *The classification of the major types of lipoproteins are based on their densities. Density range is shown as well as lipid (red) and protein (blue) content. (Diagram not to scale.) Source / CC BY 3.0*

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

Notes

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.

7.7 Tools for Change

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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.)

According to the National Institutes of Health (NIH), 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

According to the NIH, 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

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.

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 American Heart Association (AHA) recommends choosing lean meats and vegetable alternatives, choosing dairy products with low fat content, and minimizing the intake of trans fats. The AHA 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. 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.

Notes

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.
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.
3. Fish and Omega-3 Fatty Acids. American Heart Association. https://healthyforgood.heart.org/Eat-smart/Articles/Fish-and-Omega-3-Fatty-Acids. Updated March 24, 2017. Accessed October 5, 2017.

7.8 Lipids and the Food Industry

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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. The AHA states that, like saturated fats, trans fats raise LDL "bad cholesterol," but unlike saturated fats, trans fats lower HDL "good cholesterol." The AHA advises limiting 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.

7.9 Lipids and Disease

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Because heart disease, cancer, and stroke are the three leading causes of death in the United States, it is critical to address dietary and lifestyle choices that will ultimately decrease risk factors for these diseases. According to the US Department of Health and Human Services (HHS), 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 the United States 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 American 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. The 2015-2020 **US Dietary Guidelines** suggest limiting saturated fats, thereby indirectly limiting 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 AHA, 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 the United States, 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. According to US Surgeon General Richard Carmona, obesity is the fastest growing cause of death in America. The HHS reports that the number of adolescents who are overweight has tripled since 1980 and the prevalence of the disease among younger children has doubled[2].
- 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.

Notes

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.
2. Childhood Obesity. US Department of Health and Human Services. http://aspe.hhs.gov/health/reports/child_obesity/. Published May 1, 2005. Accessed October 5, 2012.

7.10 A Personal Choice about Lipids

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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 VIII

CHAPTER 8: ENERGY FROM NUTRIENTS

Now that you've learned about the three energy-yielding **macronutrients**, it's time to focus on that "energy-yielding" function of these molecules. In this chapter, there will be a brief introduction to energy in living systems, followed by an overview of the chemical reactions that occur within cells that take the energy stored in carbohydrates, lipids, and proteins, and convert that energy to a form that your cells can use to do the work of life.

Sections:

Section 8.1: Bartee, Lisa and Anderson, Christine. *Mt. Hood Community College Biology 101.* https://openoregon.pressbooks.pub/mhccbiology101/chapter/energy-in-living-systems/

Section 8.2: Adapted from Bartee, Lisa, *MHCC Biology 112: Biology for Health Professions*, with content from Jellum, et al., *Principles of Nutrition*; Fialkowski Revilla, et al.,*Human Nutrition.*

Sections 8.3-8.8: Primarily from Bartee, Lisa. *MHCC Biology 112: Biology for Health Professions.* Mt. Hood Community College. https://mhccbiology112.pressbooks.com/

- Acknowledgements therein (8.1-8.8):
    - Unless otherwise noted, images are licensed under CC-BY 4.0 by OpenStax.

- Text adapted from: OpenStax, Concepts of Biology. OpenStax CNX. May 18, 2016 http://cnx.org/contents/b3c1e1d2-839c-42b0-a314-e119a8aafbdd@9.10

Section 8.9: From Jellum, et al. *Principles of Nutrition.*

8.1 Energy in Living Systems

LISA BARTEE AND CHRISTINE ANDERSON

All living **organisms** require energy to perform their life processes. Energy is the ability to do work or to create some kind of change. You are familiar with or have learned about many processes that can require energy:

- Movement
- Reproduction
- Maintaining homeostasis of many different conditions
- Acquiring and digesting food
- Producing proteins

Just as living things must continually consume food to replenish their energy supplies, **cells** must continually produce more energy to replenish that used by the many energy-requiring chemical reactions that constantly take place. Together, all of the chemical reactions that take place inside cells, including those that consume or generate energy, are referred to as the cell's **metabolism**.

A living cell cannot store significant amounts of free energy. Free energy is energy that is not stored in molecules. Excess free energy would result in an increase of heat in the cell, which would denature **enzymes** and other proteins, and destroy the cell. Instead, a cell must be able to store energy safely and release it for use only as needed. Living cells accomplish this using ATP, which can be used to fill any energy need of the cell. How? It functions as a rechargeable battery.

When ATP is broken down, energy is released. This energy is used by the cell to do work, usually by the binding of the released phosphate to another molecule, thus activating it. For example, in the mechanical work of muscle contraction, ATP supplies energy to move the contractile muscle proteins.

ATP Structure and Function

ATP is a complex-looking molecule, but for our purposes you can think of it as a rechargeable battery. ATP, the fully charged form of our battery, is made up of three phosphates (the "TP" part of ATP) attached to a sugar and an adenine (the "A" part of ATP) (**Figure 8.11**). When the last phosphate is broken off of the ATP, energy is released. The result is a single phosphate and a molecule called ADP ("D" stands for "di" which means two).

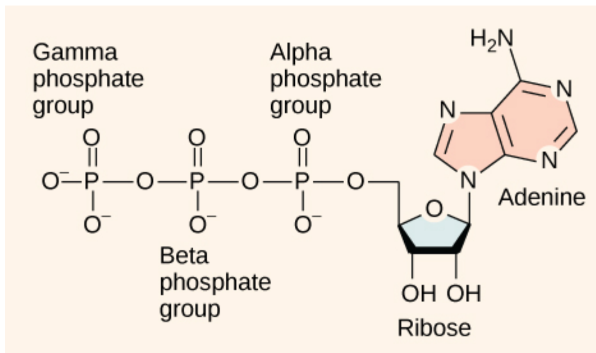

Figure 8.11 *The structure of ATP shows the basic components of a two-ring adenine, five-carbon ribose sugar, and three phosphate groups.*

A high amount of energy is required in order to recharge a molecule of ADP into ATP. This energy is stored in the bond between the second and third phosphates. When this bond is broken, the energy is released in a way that the cell can use it.

8.2 Metabolism Basics

In this section we'll introduce some basic concepts that will help you understand the following discussion of cellular **metabolism**. If you do not have much chemistry background, you may find it helpful to review Appendix C: Chemistry for Nutrition.

Metabolic Pathways

Consider the metabolism (both the creation and breakdown) of sugar. This is a classic example of one of the many cellular processes that use and produce energy. Living things consume sugars as a major energy source, because sugar molecules have a great deal of energy stored within their bonds. For the most part, photosynthesizing organisms like plants produce these sugars. During **photosynthesis**, plants use energy (originally from sunlight) to convert carbon dioxide gas (CO_2) into sugar molecules (like glucose: $C_6H_{12}O_6$). They consume carbon dioxide and produce oxygen as a waste product. This reaction is summarized as:

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

Because this process involves synthesizing an energy-storing molecule, it requires energy input to proceed. During photosynthesis, the energy from the sun is stored within molecules of **adenosine triphosphate (ATP)**, which is the primary energy currency of all cells. Just as the dollar is used as currency to buy goods, cells use molecules of ATP as energy currency to perform immediate work. Energy-storage molecules such as glucose and fat are consumed so that they can be broken down to use their energy. The reaction that harvests the energy of a sugar molecule in cells requiring oxygen to survive can be summarized by the reverse reaction to photosynthesis. In this reaction, oxygen is consumed and carbon dioxide is released as a waste product. The reaction is summarized as:

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

Both of these reactions involve many steps.

The processes of making and breaking down sugar molecules illustrate two examples of metabolic pathways. A **metabolic pathway** is a series of chemical reactions that takes a starting molecule and modifies it, step-by-step, through a series of metabolic intermediates, eventually yielding a final product. In the example of sugar metabolism, the first metabolic pathway synthesized sugar from smaller molecules, and the other pathway broke sugar down into smaller molecules. These two opposite processes—the first requiring energy and the second producing energy—are referred to as **anabolic** pathways (building polymers) and **catabolic** pathways (breaking down polymers into their monomers), respectively. Consequently, metabolism is composed of synthesis (**anabolism**) and degradation (**catabolism**) (Figure 8.21).

It is important to know that the chemical reactions of metabolic pathways do not take place on their own. Each reaction step is facilitated, or catalyzed, by a protein called an **enzyme**. Enzymes are important for catalyzing all types of biological reactions—those that require energy as well as those that release energy.

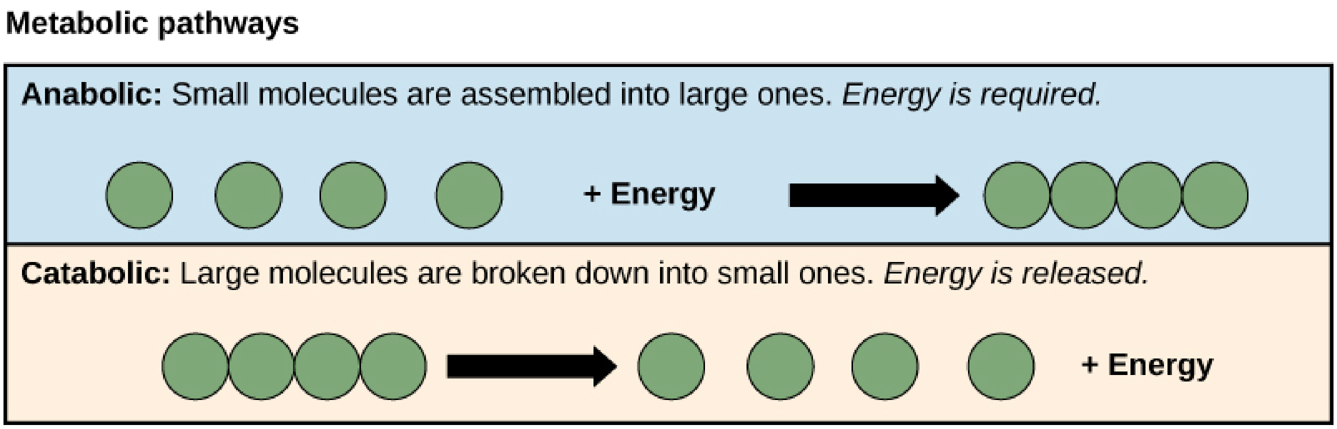

Figure 8.21 *Catabolic pathways are those that generate energy by breaking down larger molecules. Anabolic pathways are those that require energy to synthesize larger molecules. Both types of pathways are required for maintaining the cell's energy balance.*

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). The table below summarizes some of the catabolic and anabolic pathways and their functions in energy metabolism.

Table 8.21 Metabolic Pathways[1]

Catabolic Pathway	Function	Anabolic Pathway	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

Oxidation-Reduction Reactions[2]

A number of the metabolic reactions either **oxidize** or **reduce** compounds. A compound that is being **oxidized** loses at least one electron, while a compound that is **reduced** gains at least one electron. To remember the difference, a mnemonic device such as OIL (oxidation is lost), RIG (reduction is gained) is helpful. Oxidation reactions and reduction reactions are "coupled" reactions, one cannot exist without the other. For example, a reduction reaction requires an electron. Where does that electron come from? It comes from an oxidation reaction. Scientists commonly refer to oxidation reactions and reduction reactions as **oxidation-reduction reactions**, or as **redox reactions**. Oxidation-reduction reactions are illustrated in the figure below.

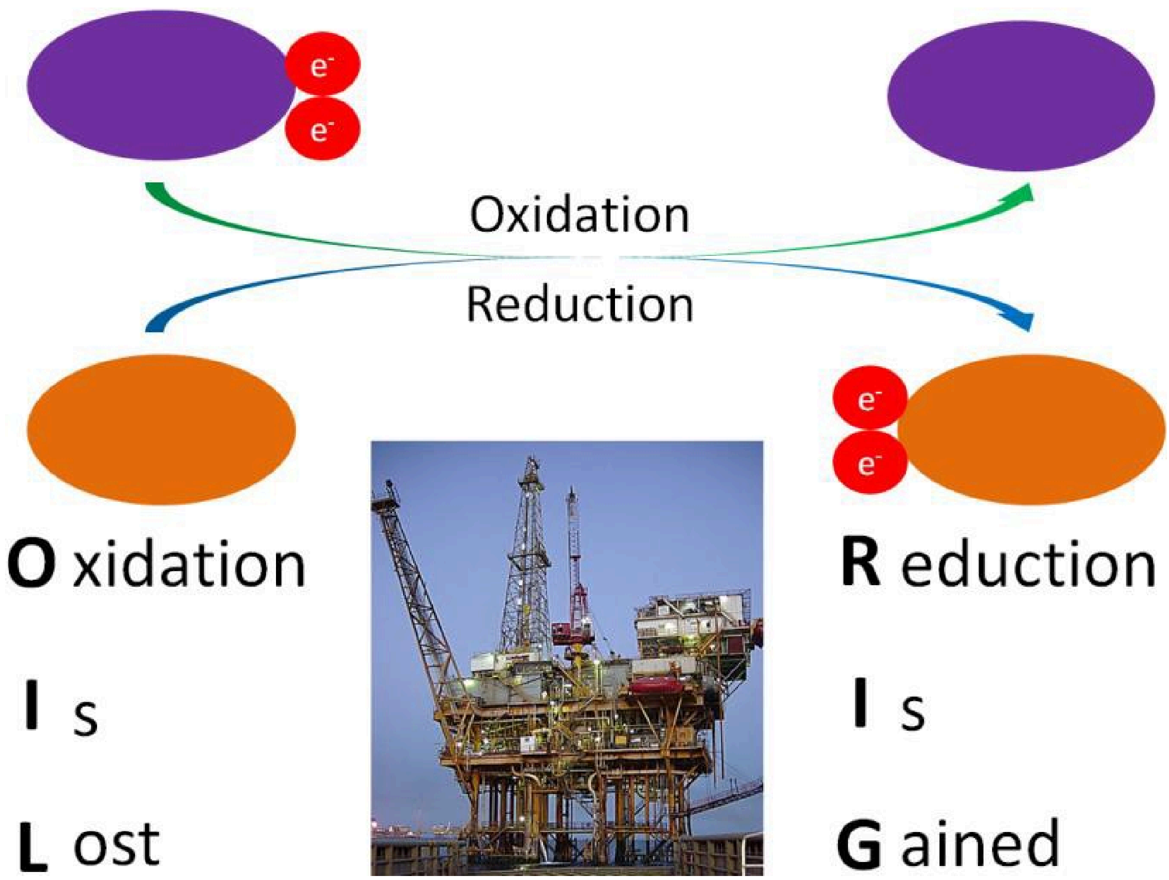

Figure 8.22 *The purple compound is being oxidized, the orange compound is being reduced. Image source*

Another way to remember oxidation versus reduction is **LEO goes GER** (like a lion)

Lose **E**lections = **O**xidation

Gain **E**lections = **R**eduction (YES, gaining electrons is considered reduction)

Iron is a good example we can use to illustrate oxidation-reduction reactions. Iron commonly exists in two states (Fe^{3+} or Fe^{2+}). It is constantly oxidized/reduced back and forth between the two states. The oxidation/reduction of iron is shown below.

Fe^{3+} loses an e- → Fe^{2+} (Oxidation) Fe^{2+} gains an e- → Fe^{3+} (Reduction)

Interestingly, the oxidation states of iron (mentioned above) are critical to our ability to use the iron present in our diet. Fe^{2+} (also known as ferrous iron) is easily absorbed in the small intestine. Fe^{3+} (also known as ferric iron) is not so easily absorbed. Gastric acid (produced by the stomach) and vitamin C promote the conversion of Fe^{3+} to Fe^{2+} so we can maximize iron absorption in the small intestine.

However, some oxidation reduction reactions are not as easy to recognize. There are some simple rules to help you recognize less-obvious oxidation/reduction reactions that are based upon the gain or loss of oxygen or hydrogen. These are as follows:

Oxidation: gains oxygen or loses hydrogen

Reduction: loses oxygen or gains hydrogen

Remembering how this applies to hydrogen will be very helpful later in this chapter.

Enzymes[3]

We briefly discussed enzymes earlier when learning about the functions of proteins in the body. We will review enzymes here and go into a bit more detail.

A substance that helps a chemical reaction to occur is called a *catalyst*, and the molecules that catalyze biochemical reactions are called **enzymes**. Most enzymes are proteins and perform the critical task of lowering the activation energies of chemical reactions inside the cell. Most of the reactions critical to a living cell happen too slowly at normal temperatures to be of any use to the cell. Without enzymes to speed up these reactions, life could not persist. Enzymes do this by binding to the reactant molecules and holding them in such a way as to make the chemical bond-breaking and -forming processes take place more easily. An enzyme itself is unchanged by the reaction it catalyzes. Once one reaction has been catalyzed, the enzyme is able to participate in other reactions.

The chemical reactants to which an enzyme binds are called the enzyme's **substrates**. There may be one or more substrates, depending on the particular chemical reaction. In some reactions, a single reactant substrate is broken down into multiple products. In others, two substrates may come together to create one larger molecule. Two reactants might also enter a reaction and both become modified, but they leave the reaction as two products. The location within the enzyme where the substrate binds is called the enzyme's **active site**. The active site is where the "action" happens. Since enzymes are proteins, there is a unique combination of amino acid side chains within the active site. Each side chain is characterized by different properties. They can be large or small, weakly acidic or basic, hydrophilic or hydrophobic, positively or negatively charged, or neutral. The unique combination of side chains creates a very specific chemical environment within the active site. This specific environment is suited to bind to one specific chemical substrate (or substrates).

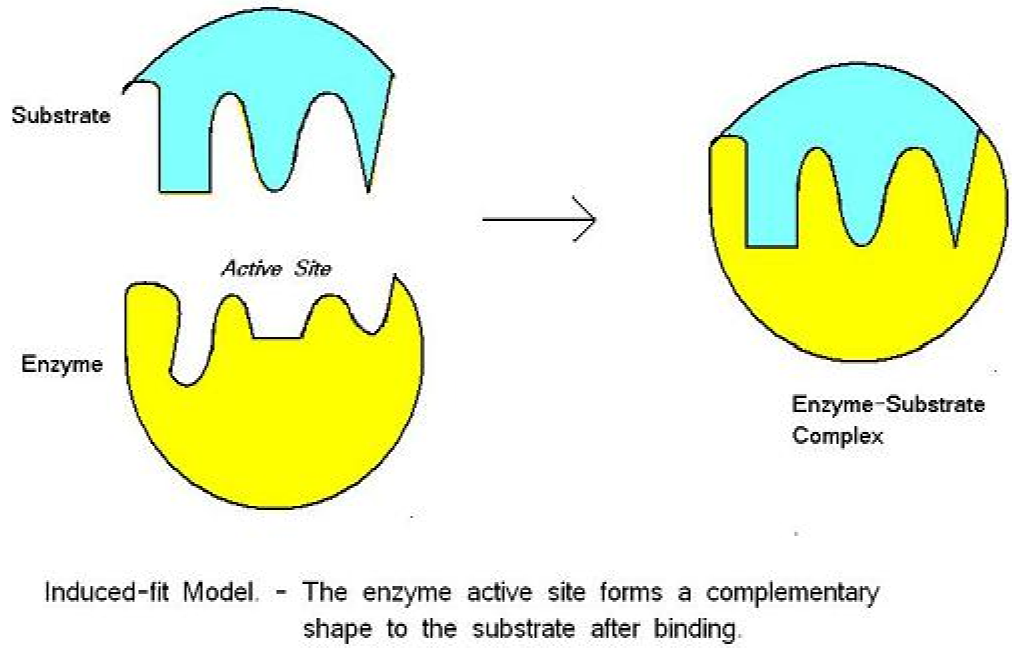

Figure 8.23 *The substrate binds to the enzyme at the active site. Credit: Induced Fit Model; Stephjc; wikimedia; public domain.*

For many years, scientists thought that enzyme-substrate binding took place in a simple "lock and key" fashion. This model asserted that the enzyme and substrate fit together perfectly in one instantaneous step. However, current research supports a model called **induced fit** (Figure 8.24). The induced-fit model expands on the lock-and-key model by describing a more dynamic binding between enzyme and substrate. As the enzyme and substrate come together, their interaction causes a slight shift in the enzyme's structure that forms an ideal binding arrangement between enzyme and substrate.

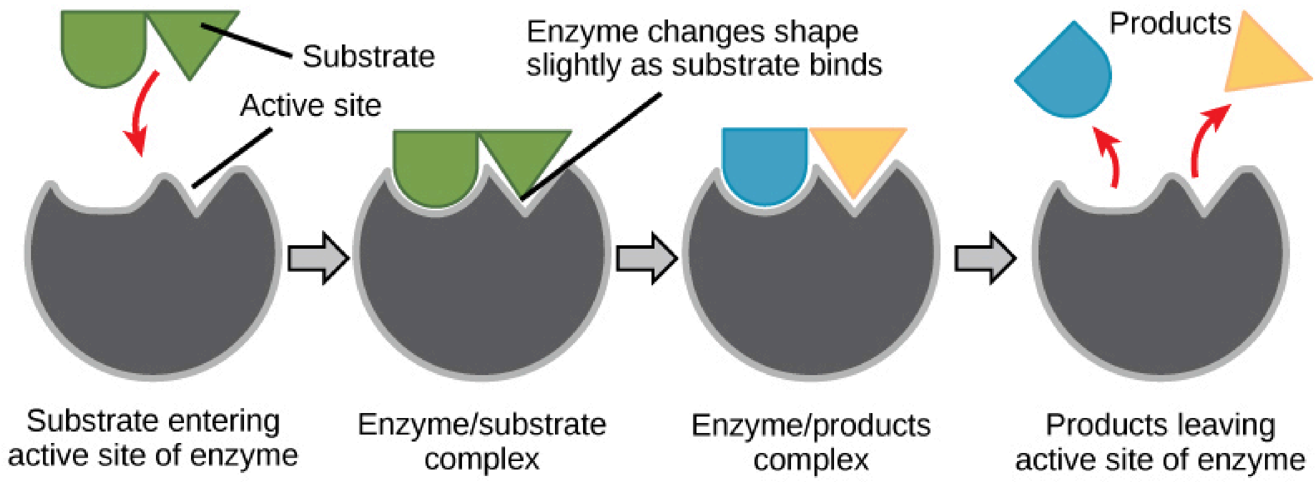

Figure 8.24 *The induced-fit model is an adjustment to the lock-and-key model and explains how enzymes and substrates undergo dynamic modifications during the transition state to increase the affinity of the substrate for the active site.*

When an enzyme binds its substrate, an enzyme-substrate complex is formed. This complex lowers the activation energy of the reaction and promotes its rapid progression in one of multiple possible ways.

- On a basic level, enzymes promote chemical reactions that involve more than one substrate by bringing the substrates together in an optimal orientation for reaction.
- Enzymes promote the reaction of their substrates is by creating an optimal environment within the active site for the reaction to occur. The chemical properties that emerge from the particular arrangement of amino acid R groups (side chains) within an active site create the perfect environment for an enzyme's specific substrates to react.
- The enzyme-substrate complex can also lower activation energy by compromising the bond structure so that it is easier to break.
- Finally, enzymes can also lower activation energies by taking part in the chemical reaction itself. In these cases, it is important to remember that the enzyme will always return to its original state by the completion of the reaction.

One of the hallmark properties of enzymes is that they remain ultimately unchanged by the reactions they catalyze. After an enzyme has catalyzed a reaction, it releases its product(s) and can catalyze a new reaction.

Cofactors[4]

A number of enzymes require cofactors to function. **Cofactors** can be either organic or inorganic molecules that are required by enzymes to function. Many organic cofactors are **vitamins** or molecules derived from vitamins. Most inorganic cofactors are **minerals**. Cofactors can be oxidized or reduced for the enzymes to catalyze the reactions. Organic cofactors are often referred to as **coenzymes**.

Two common cofactors that are derived from the B vitamins, niacin and riboflavin, are **NAD** (nicotinamide adenine dinucleotide) and **FAD** (flavin adenine dinucleotide), respectively.

Both of these cofactors can be reduced (remember that reduction is a process by which electrons, as part of H in this case, are gained); NAD is reduced to form **NADH**, while FAD is reduced to form **$FADH_2$** as shown in the two figures below.

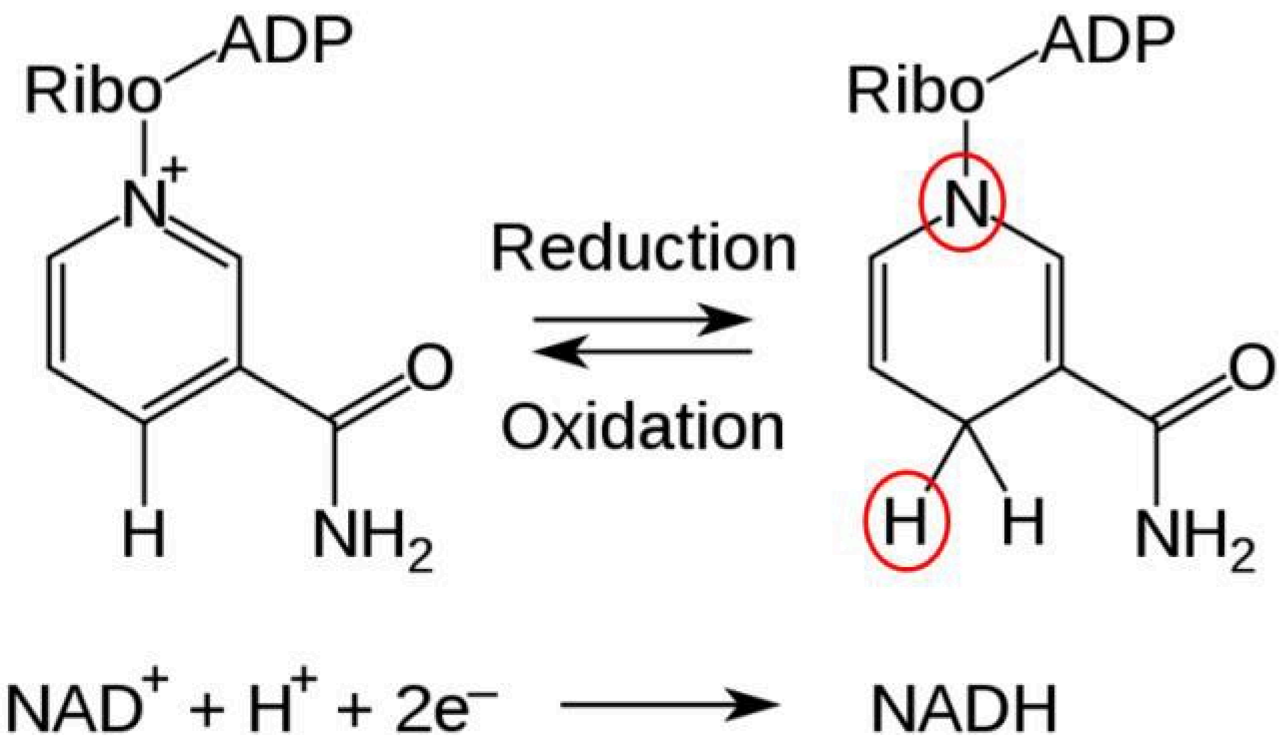

Figure 8.25 *The reduction of NAD (left) to form NADH (right). Image source*

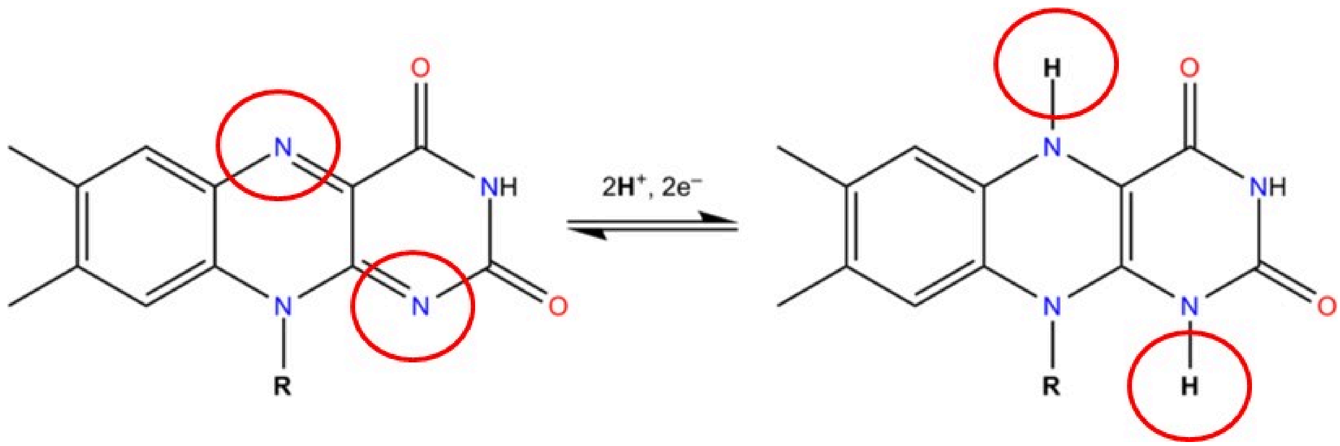

Figure 8.26 *The reduction of FAD (left) to FADH2 (right). Image source*

NADH and $FADH_2$ are molecules that are critical to our cells' ability to process the energized electrons obtained through the catabolism (digestion) of food molecules, like glucose. The energized electrons, which are highly reactive and potentially destructive, are temporarily managed by NADH and $FADH_2$ until they can be processed by the Electron Transport Chain step of Cellular Respiration.

Notes

1. Fialkowski Revilla, et al., *Human Nutrition*
2. Jellum et al. *Principles of Human Nutrition*
3. Bartee, Lisa, *MHCC Biology 112: Biology for Health Professions*
4. Jellum et al. *Principles of Nutrition*

8.3 An Overview of Cellular Respiration

LISA BARTEE AND JACK BROOK

Glucose and other molecules from food are broken down to release energy in a complex series of chemical reactions that together are called **cellular respiration**.

Cellular respiration is a set of metabolic reactions and processes that take place in the cells of organisms to convert biochemical energy from **nutrients** into ATP, and then release waste products. The reactions involved in respiration are catabolic reactions, which break large molecules into smaller ones, releasing energy in the process. These processes require a large number of enzymes which each perform one specific chemical reaction. Every time energy is converted from one form to another, some of the energy is lost as heat. That means that during each of these enzyme-catalyzed reactions, some of the original energy from the sugar molecule is lost as heat.

Aerobic Respiration

Aerobic respiration requires oxygen. This is the reason why we breathe oxygen in from the air. This type of respiration releases a large amount of energy from glucose that can be stored as ATP. Aerobic respiration happens all the time in animals and plants, where most of the reactions occur in the mitochondria. Even some prokaryotes can perform aerobic respiration (although since prokaryotes don't contain mitochondria, the reactions are slightly different). The overall chemical formula for aerobic respiration can be written as:

$$C_6H_{12}O_2 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{(approximately) } 38\ ATP$$

Translating that formula into English: One molecule of glucose can be broken down in the presence of oxygen gas to produce waste products of carbon dioxide (which we breathe out) and water. This process has an overall release of energy which is captured and stored in 38 molecules of ATP.

Aerobic respiration is a complex process that can be divided into three basic stages:

glycolysis, the citric acid cycle, and oxidative phosphorylation. The next several sections in the textbook address the details of these stages, but here is a basic summary:

- During **glycolysis,** 6-carbon glucose is broken in half and a small amount of energy is transferred to ATP and other energy carrier molecules.
- One carbon atom is broken off of each of the two halves of the glucose molecule (3-carbon molecules known as pyruvate) and released as carbon dioxide. This leaves two 2-carbon molecules called acetyls, which are attached to Coenzyme A to make acetyl-CoA.
- Acetyl-CoA enters the **citric acid cycle**, where it is completely broken down into carbon dioxide and all the energy from the molecule is transferred to ATP and other energy carrier molecules. The carbon atoms are released as carbon dioxide.
- The energy carrier molecules produced during glycolysis and the citric acid cycle are used to power the **electron transport chain and chemiosmosis** (together known as **oxidative phosphorylation**). The end result of this is the majority of ATP produced during aerobic respiration.

Video link: Cellular Respiration

Anaerobic Processes

Anaerobic Cellular Respiration

Some organisms (mostly bacteria) perform **anaerobic cellular respiration**. During anaerobic cellular respiration, cells use the same three basic stages: glycolysis, the citric acid cycle, and the electron transport chain / chemiosmosis, but another molecule is used in place of oxygen gas. This is not a common form of cellular respiration and isn't used by humans, so we will not be focusing on it.

Just as a side note here, typically when "anaerobic respiration" is mentioned in videos and animations, they are *not* talking about this process. They are talking about fermentation (below).

Fermentation

Fermentation is also a form of cellular respiration that occurs in the absence of oxygen. There are several different types of fermentation, which will be discussed in more detail later. Fermentation releases a much smaller amount of energy than aerobic respiration. In fact, it does not release enough energy to power human cells for long – think about how long a person can live if they are not able to breathe. Fermentation occurs in muscle cells during hard exercise (after the oxygen has been used up). It also occurs in yeast when brewing beer. Many prokaryotes perform anaerobic respiration.

All types of fermentation involve glycolysis, and none of them go through the citric acid cycle or oxidative phosphorylation. Instead, various other methods are used to regenerate the molecules needed for glycolysis, For now, we will summarize them all using this chemical formula:

$C_6H_{12}O_2$ NAD+ → various waste products + NADH + 2 ATP

NAD+ and NADH are two states of a molecule that will carry energy during this process. It will be addressed further in a later section. For right now, just know that NADH carries energy (similar to ATP) and NAD+ is the form that carries less energy (similar to ADP).

Aerobic vs Fermentation

Table 8.31 Comparison of aerobic respiration and fermentation.

	Aerobic Respiration	Fermentation
Requires oxygen?	Yes	No
Glucose breakdown	Complete	Incomplete
End products	CO_2 and H_2O	Animal cells: lactic acid Plant cells and yeast: carbon dioxide and ethanol
ATP produced	About 38	2

Aerobic respiration is much more efficient than fermentation. One molecule of glucose can generate up to 38 molecules of ATP if aerobic respiration is used. In contrast, only 2 molecules of ATP are generated in fermentation.

To put it another way, a cellular process which requires 100 molecules of ATP:

- Would require about 2.5 molecules of glucose to be broken down using aerobic respiration (100 / 38 = 2.63)
- Would require 50 molecules of glucose to be broken down using fermentation (100 / 2 = 50)

8.4 Glycolysis

LISA BARTEE AND JACK BROOK

You have read that nearly all of the energy used by living things comes to them in the bonds of the sugar, glucose. **Glycolysis** is the first step in the breakdown of glucose to extract energy for cell metabolism. Many living organisms carry out glycolysis as part of their metabolism. Glycolysis takes place in the cytoplasm of most prokaryotic and all eukaryotic cells.

Glycolysis begins with a molecule of glucose ($C_6H_{12}O_6$). Various enzymes are used to break glucose down into two molecules of pyruvate ($C_3H_4O_3$, basically a glucose molecule broken in half). This process releases a small amount of energy.

Glycolysis consists of two distinct phases. In the first part of the glycolysis pathway, energy is used to make adjustments so that the six-carbon sugar molecule can be split evenly into two three-carbon pyruvate molecules. In the second part of glycolysis, ATP and nicotinamide-adenine dinucleotide (NADH) are produced (Figure 8.41).

If the cell cannot catabolize (break down) the pyruvate molecules further, it will harvest only two ATP molecules from one molecule of glucose. For example, mature mammalian red blood cells are only capable of glycolysis, which is their sole source of ATP. If glycolysis is interrupted, these cells would eventually die.

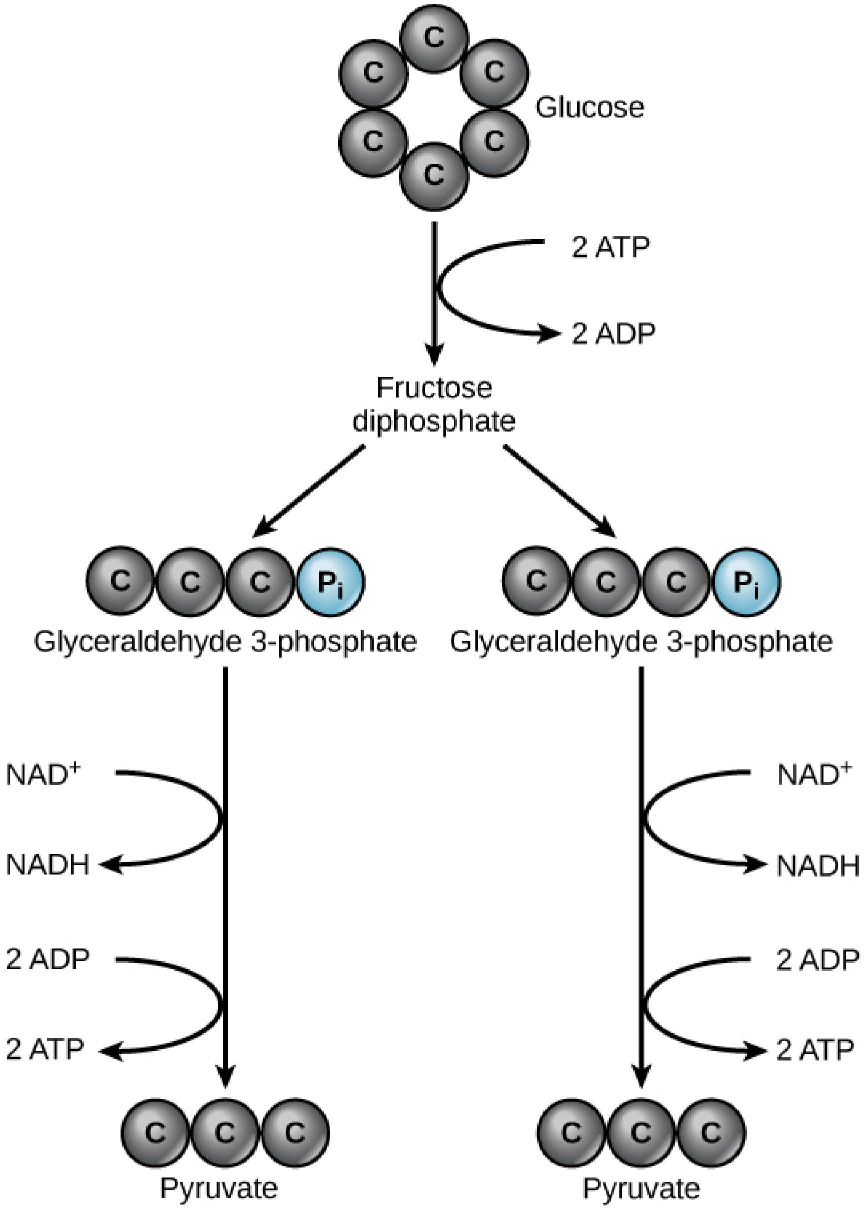

Figure 8.41 *In glycolysis, a 6-carbon glucose molecule is converted into two 3-carbon pyruvate molecules.*

8.5 The Citric Acid Cycle

LISA BARTEE AND JACK BROOK

In eukaryotic cells, the pyruvate molecules produced at the end of glycolysis are transported into mitochondria. Mitochondria are sites of cellular respiration; In the presence of oxygen, **aerobic respiration** will proceed. In the mitochondria, pyruvate is first transformed into a two-carbon acetyl group by removing a molecule of carbon dioxide. This acetyl group is attached to a carrier compound called coenzyme A (CoA), which is made from vitamin B5. The resulting 2-carbon compound is called **acetyl CoA**. (Figure 8.51). Acetyl CoA can be used in a variety of ways by the cell, but its major function is to deliver the acetyl group derived from pyruvate to the next pathway in glucose **catabolism**.

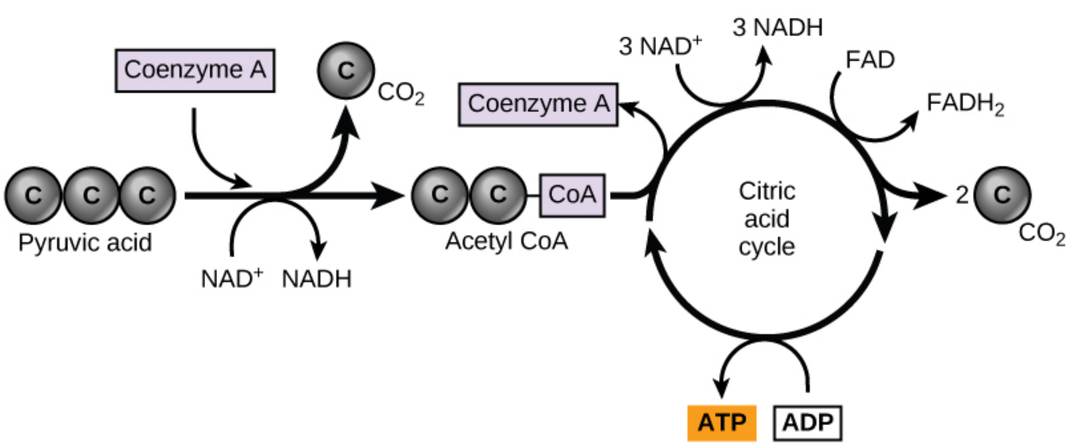

***Figure* 8.51** *The Citric Acid Cycle*

Like the conversion of pyruvate to acetyl CoA, the **citric acid cycle** in eukaryotic cells takes place in the matrix of the mitochondria. Unlike glycolysis, the citric acid cycle is a closed loop: The last part of the pathway regenerates the compound used in the first step. The eight steps of the cycle are a series of chemical reactions that produces the following from each molecule of pyruvate (remember that there are 2 molecules of pyruvate produced per molecule of glucose that originally went into glycolysis):

- 2 carbon dioxide molecules
- 1 ATP molecule (or an equivalent)

- 3 NADH and 2 $FADH_2$, which carry energy to the last part of the aerobic respiration pathway.

Part of this is considered an **aerobic** pathway (oxygen-requiring) because the NADH and $FADH_2$ produced must transfer their electrons to the next pathway in the system, which will use oxygen. If oxygen is not present, this transfer does not occur. The citric acid cycle does NOT occur in the absence of oxygen.

The citric acid cycle is also sometimes called the TCA cycle or the Krebs cycle. These names can be used interchangeably – they all refer to the same process.

More Details

Two carbon atoms come into the citric acid cycle from each acetyl group. Two carbon dioxide molecules are released on each turn of the cycle; however, these do not contain the same carbon atoms contributed by the acetyl group on that turn of the pathway. The two acetyl-carbon atoms will eventually be released on later turns of the cycle; in this way, all six carbon atoms from the original glucose molecule will be eventually released as carbon dioxide. It takes two turns of the cycle to process the equivalent of one glucose molecule. Each turn of the cycle forms three high-energy NADH molecules and one high-energy $FADH_2$ molecule. These high-energy carriers will connect with the last portion of aerobic respiration to produce ATP molecules. One ATP (or an equivalent) is also made in each cycle. Several of the intermediate compounds in the citric acid cycle can be used in synthesizing non-essential amino acids; therefore, the cycle is both anabolic and catabolic.

8.6 Oxidative Phosphorylation

LISA BARTEE AND JACK BROOK

You have just read about two pathways in glucose **catabolism**—glycolysis and the citric acid cycle—that generate ATP. Most of the ATP generated during the aerobic catabolism of glucose, however, is not generated directly from these pathways. Rather, it derives from a process that begins with passing electrons through a series of chemical reactions to a final electron acceptor, oxygen. This is the only place in **aerobic respiration** where O_2 is actually required. These reactions take place in specialized protein complexes located in the inner membrane of the mitochondria of eukaryotic organisms and on the inner part of the cell membrane of prokaryotic organisms. The energy of the electrons is used to generate ATP. The entirety of this process is called **oxidative phosphorylation**.

During oxidative phosphorylation:

- The energy from NADH and $FADH_2$is used up.
- Oxygen gas is converted into water.
- 30-36 ATP are recharged from ADP

Electron Transport Chain

The electron transport chain (Figure 8.61) is the last component of aerobic respiration and is the only part of metabolism that uses atmospheric oxygen. Oxygen continuously diffuses into plants for this purpose. In animals, oxygen enters the body through the respiratory system. Electron transport is a series of chemical reactions that resembles a bucket brigade in that electrons are passed rapidly from one component to the next, to the endpoint of the chain where oxygen is the final electron acceptor and water is produced. There are four complexes composed of proteins, labeled I through IV in Figure 8.61, and the aggregation of these four complexes, together with associated mobile, accessory electron carriers, is called the **electron transport chain**. The electron transport chain is present in multiple copies in the **inner mitochondrial membrane** of eukaryotes and in the plasma membrane of prokaryotes. In each transfer of an electron through the electron transport chain, the electron loses energy, but with some transfers, the energy is stored as **potential energy** by using it to pump hydrogen ions (H^+, protons) across the inner mitochondrial membrane into the **intermembrane space**, creating an **electrochemical gradient**. An electrochemical gradient consists of two parts: a difference in **solute** concentration across the membrane combined with a difference in charge across the membrane. Here, the electrochemical gradient is made up of a higher concentration of H+ in the inner membrane space compared to the mitochondrial matrix.

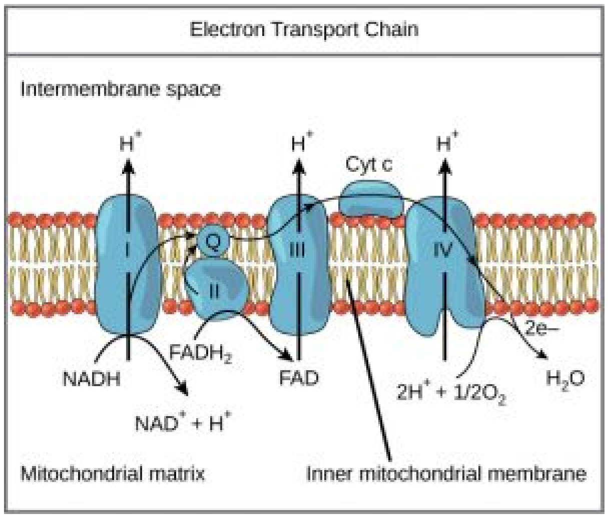

Figure 8.61 *The electron transport chain is a series of electron transporters embedded in the inner mitochondrial membrane that shuttles electrons from NADH and* $FADH_2$ *to molecular oxygen. In the process, protons are pumped from the mitochondrial matrix to the intermembrane space, and oxygen is reduced to form water.*

Electrons from NADH and $FADH_2$are passed to protein complexes in the electron transport chain. As they are passed from one complex to another (there are a total of four), the electrons lose energy, and some of that energy is used to pump hydrogen ions from the mitochondrial matrix into the intermembrane space. In the fourth protein complex, the electrons are accepted by oxygen, the terminal acceptor. The oxygen with its extra electrons then combines with two hydrogen ions, further enhancing the electrochemical gradient, to form water. If there were no oxygen present in the mitochondrion, the electrons could not be removed from the system, and the entire electron transport chain would back up and stop. The mitochondria would be unable to generate new ATP in this way, and the cell would ultimately die from lack of energy. This is the reason we must breathe to draw in new oxygen. This is the only place where oxygen is required during the processes of aerobic respiration.

In the electron transport chain, the free energy from the series of reactions just described is used to pump hydrogen ions across the membrane. The uneven distribution of H+ ions across the membrane establishes an electrochemical gradient, owing to the H+ ions' positive charge and their higher concentration on one side of the membrane.

Hydrogen ions diffuse from the intermembrane space through the inner membrane into the mitochondrial matrix through an integral membrane protein called **ATP synthase** (Figure 8.62). This complex protein acts as a tiny generator, turned by the force of the hydrogen ions diffusing through it, down their electrochemical gradient from the intermembrane space, where there are many mutually repelling hydrogen ions to the matrix, where there are few. The turning of the parts of this molecular machine regenerate ATP from ADP. This flow of hydrogen ions across the membrane through ATP synthase is called **chemiosmosis**.

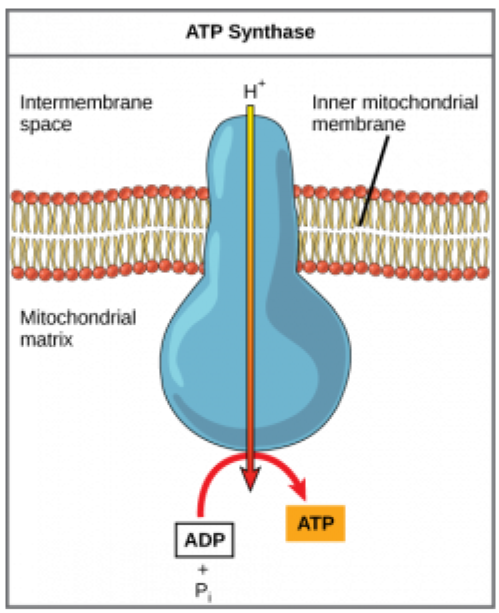

***Figure 8.62** ATP synthase is a complex, molecular machine that uses a proton (H+) gradient to form ATP from ADP and inorganic phosphate (Pi). (Credit: modification of work by Klaus Hoffmeier)*

Chemiosmosis (Figure 8.62) is used to generate 90 percent of the ATP made during aerobic glucose catabolism. The result of the reactions is the production of ATP from the energy of the electrons removed from hydrogen atoms. These atoms were originally part of a glucose molecule. At the end of the electron transport system, the electrons are used to reduce an oxygen molecule to oxygen ions. The extra electrons on the oxygen ions attract hydrogen ions (protons) from the surrounding medium, and water is formed. The electron transport chain and the production of ATP through chemiosmosis are collectively called **oxidative phosphorylation** (Figure 8.63).

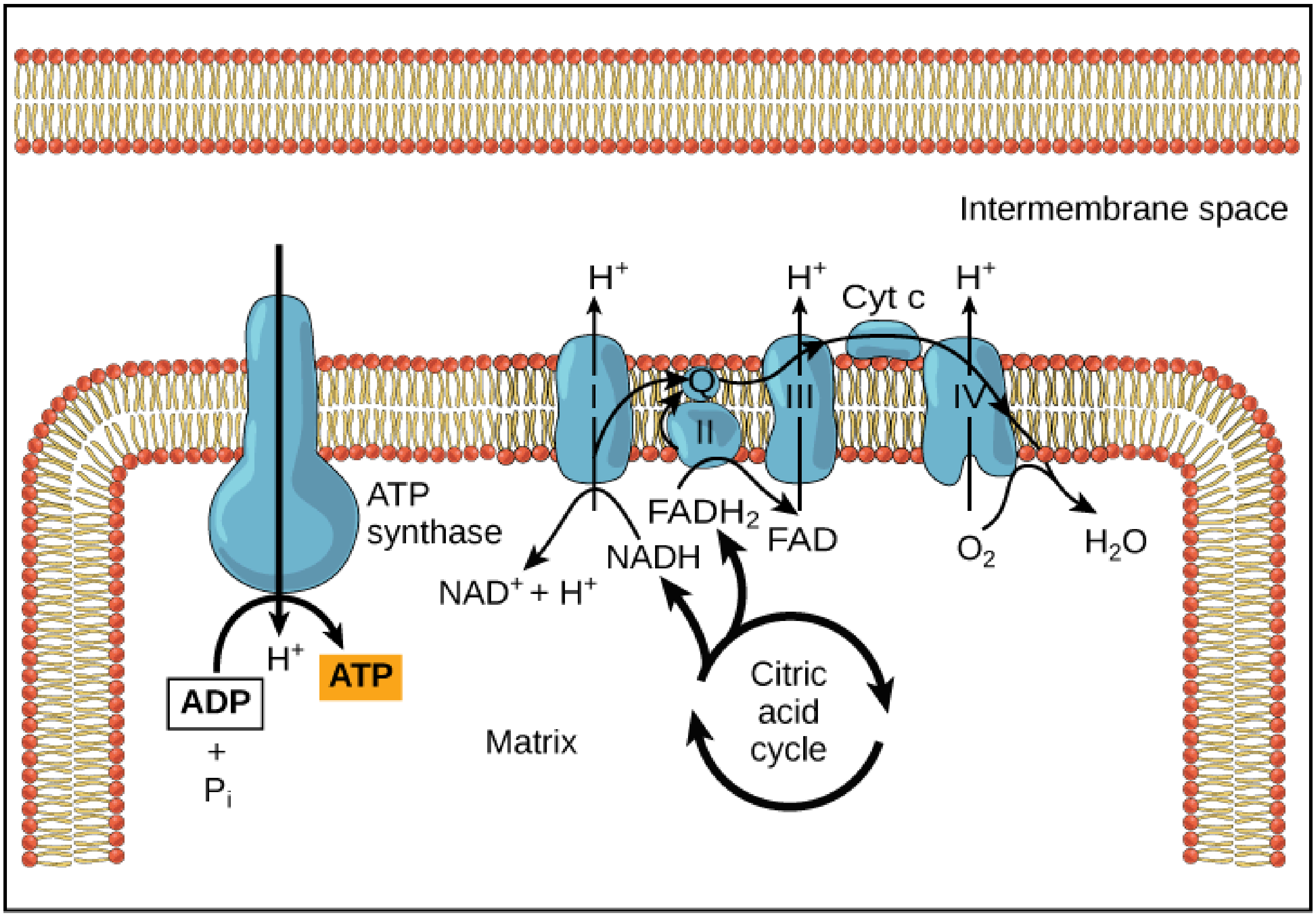

Figure 8.63 *In oxidative phosphorylation, the pH gradient formed by the electron transport chain is used by ATP synthase to form ATP.*

ATP Yield

The number of ATP molecules generated from the catabolism of glucose varies. For example, the number of hydrogen ions that the electron transport chain complexes can pump through the membrane varies between species. Another source of variance stems from the shuttle of electrons across the membranes of the mitochondria because the NADH generated from glycolysis cannot easily enter mitochondria. Thus, electrons are picked up on the inside of mitochondria by either NAD^+or FAD^+. As you have learned earlier, these FAD^+molecules can transport fewer ions; consequently, fewer ATP molecules are generated when FAD^+acts as a carrier. $NAD^+$is used as the electron transporter in the liver and FAD^+acts in the brain.

Another factor that affects the yield of ATP molecules generated from glucose is the fact that intermediate compounds in these pathways are used for other purposes. Glucose catabolism connects with the pathways that build or break down all other biochemical compounds in cells, and the result is somewhat messier than the ideal situations described thus far. For example, sugars other than glucose are fed into the glycolytic pathway for energy extraction. Moreover, the five-carbon sugars that form nucleic acids are made from intermediates in glycolysis. Certain **nonessential amino acids** can be made from intermediates of both glycolysis and the citric acid cycle. Lipids, such as cholesterol and triglycerides, are also made from intermediates in these pathways, and both amino acids and triglycerides are broken down for energy through these pathways. Overall, in living systems, these pathways of glucose catabolism extract about 34 percent of the energy contained in glucose.

Section Summary

The electron transport chain is the portion of aerobic respiration that uses free oxygen as the final electron acceptor of the electrons removed from the intermediate compounds in glucose catabolism. The electron transport chain is composed of four large, multiprotein complexes embedded in the inner mitochondrial membrane and two small diffusible electron carriers shuttling electrons between them. The electrons are passed through a series of reactions, with a small amount of free energy used at three points to transport hydrogen ions across a membrane. This process contributes to the gradient used in chemiosmosis. The electrons passing through the electron transport chain gradually lose energy until eventually they are donated to oxygen gas which accepts two protons (H+) and is converted into water. The end products of the electron transport chain are water and roughly 30-34 molecules of ATP. A number of intermediate compounds of the citric acid cycle can be diverted into the **anabolism** of other biochemical molecules, such as nonessential amino acids, sugars, and lipids. These same molecules can serve as energy sources for the glucose pathways.

8.7 Metabolism without Oxygen: Fermentation

LISA BARTEE AND JACK BROOK

In **aerobic respiration**, the final electron acceptor for the electron transport chain is an oxygen molecule, O_2. If aerobic respiration occurs, then approximately 30 molecules of ATP will be produced during the electron transport chain and **chemiosmosis** using the energy of the high-energy electrons carried by NADH or $FADH_2$ to the electron transport chain. When NADH or $FADH_2$ give their high energy electrons to the electron transport chain, NAD^+ and FAD are regenerated. These low energy molecules cycle back to glycolysis and/or the citric acid cycle, where they pick up more high energy electrons and allow the process to continue.

Glycolysis and the citric acid cycle can not occur if there is not NAD^+*present to pick up electrons as the reactions proceed.*When oxygen is present, this isn't a problem – all of the NADH and $FADH_2$ that were produced during glycolysis and the citric acid cycle are converted back into $NAD^+$and FAD after the electron transport chain. When no oxygen is present, the electron transport chain can't run because there is no oxygen to act as the final electron acceptor. This means that the ETC will not be accepting electrons from NADH as its source of power, so NAD^+will not be regenerated. Both glycolysis and the citric acid cycle require NAD^+ to accept electrons during their chemical reactions. In order for the cell to continue to generate *any*ATP, NADH must be converted back to $NAD^+$for use as an electron carrier. Anaerobic processes use different mechanisms, but all function to convert NAD^+back into NADH.

How is this done?

- Processes that use an organic molecule to regenerate $NAD^+$from NADH are collectively referred to as **fermentation**.
- In contrast, some living systems use an inorganic molecule (such as nitrate or sulfur) to regenerate $NAD^{+.}$

Both of these methods are called **anaerobic cellular respiration**. They do not require oxygen to achieve NAD^+regeneration and enable organisms to convert energy for their use in the absence of oxygen.

During anaerobic respiration, only glycolysis occurs. The 2 molecules of NADH that are generated during glycolysis are then converted back into NAD+ during anaerobic respiration so that glycolysis can continue. Since glycolysis only produces 2 ATP, anaerobic respiration is much less efficient than aerobic respiration (2 ATP molecules compared to 36-ish ATP molecules). However, 2 ATP molecules is much better for a cell than 0 ATP molecules. In anaerobic situations, the cell needs to continue performing glycolysis to generate 2 ATP per glucose because if a cell is not generating any ATP, it will die.

Note that the only part of aerobic respiration that physically uses oxygen is the electron transport chain. However, the citric acid cycle can not occur in the absence of oxygen because there is no way to regenerate the NAD+ used during this process.

Lactic Acid Fermentation

The fermentation method used by animals and some bacteria like those in yogurt is lactic acid fermentation (Figure 8.71). This occurs routinely in mammalian red blood cells and in skeletal muscle that does not have enough oxygen to allow aerobic respiration to continue (such as in muscles after hard exercise). The chemical reaction of lactic acid fermentation is the following:

Pyruvic acid + NADH ↔ lactic acid + NAD^+

The build-up of lactic acid causes muscle stiffness and fatigue. In muscles, lactic acid produced by fermentation must be removed by the blood circulation and brought to the liver for further metabolism. Once the lactic acid has been removed from the muscle and is circulated to the liver, it can be converted back to pyruvic acid and further catabolized (broken down) for energy.

Note that the purpose of this process is not to produce lactic acid (which is a waste product and is excreted from the body). The purpose is to convert NADH back into NAD^+so that glycolysis can continue so that the cell can produce 2 ATP per glucose.

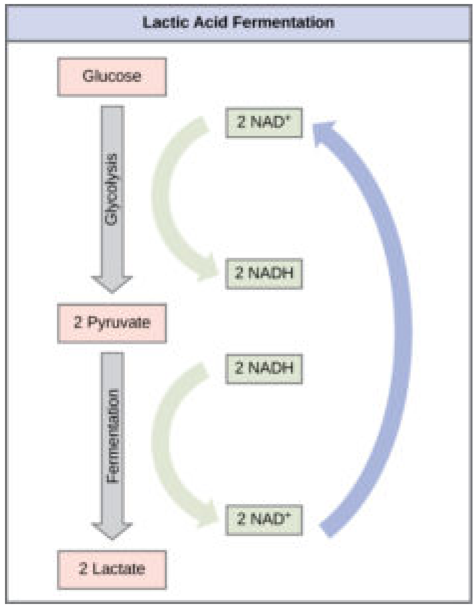

Figure 8.71 *Lactic acid fermentation is common in muscles that have become exhausted by use.*

Alcohol Fermentation

Another familiar fermentation process is alcohol fermentation (Figure 8.72), which produces ethanol, an alcohol. The alcohol fermentation reaction is the following:

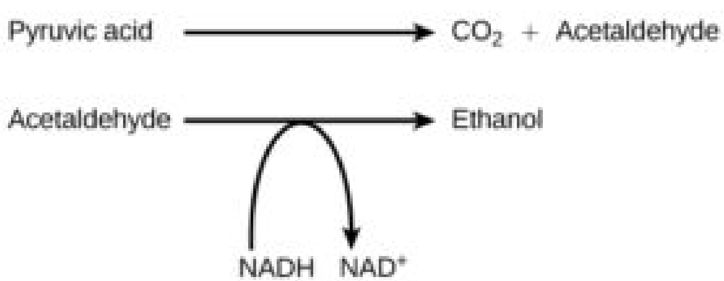

Figure 8.72 *The reaction resulting in alcohol fermentation is shown.*

The fermentation of pyruvic acid by yeast produces the ethanol found in alcoholic beverages (Figure 8.73). If the carbon dioxide produced by the reaction is not vented from the fermentation chamber, for example in beer and sparkling wines, it remains dissolved in the medium until the pressure is released. Ethanol above 12 percent is toxic to yeast, so natural levels of alcohol in wine occur at a maximum of 12 percent.

Figure 8.73 *Fermentation of grape juice to make wine produces* CO_2 *as a byproduct. Fermentation tanks have valves so that pressure inside the tanks can be released.*

Again, the purpose of this process is not to produce ethanol, but rather to convert NADH back into NAD^+ so that glycolysis can continue.

8.8 Metabolism of Molecules Other Than Glucose

LISA BARTEE AND JACK BROOK

You have learned about the **catabolism** of glucose, which provides energy to living cells. But living things consume more than just glucose for food. How does a turkey sandwich, which contains various carbohydrates, lipids, and protein, provide energy to your cells?

Basically, all of these molecules from food are converted into molecules that can enter the cellular respiration pathway somewhere. Some molecules enter at glycolysis, while others enter at the citric acid cycle. This means that all of the catabolic pathways for carbohydrates, proteins, and lipids eventually connect into glycolysis and the citric acid cycle pathways. Metabolic pathways should be thought of as porous—that is, substances enter from other pathways, and other substances leave for other pathways. These pathways are not closed systems. Many of the products in a particular pathway are reactants in other pathways.

Carbohydrates

So far, we have discussed the carbohydrate from which organisms derive the majority of their energy: glucose. Many carbohydrate molecules can be broken down into glucose or otherwise processed into glucose by the body. **Glycogen,** a polymer of glucose, is a short-term energy storage molecule in animals (Figure 8.81). When there is plenty of ATP present, the extra glucose is converted into glycogen for storage (a process called **glycogenesis**). Glycogen is made and stored in the liver and muscle. Glycogen will be taken out of storage and converted to glucose if blood sugar levels drop. The break down of glycogen to glucose is called **glycogenolysis**. The presence of glycogen in muscle cells as a source of glucose allows ATP to be produced for a longer time during exercise.

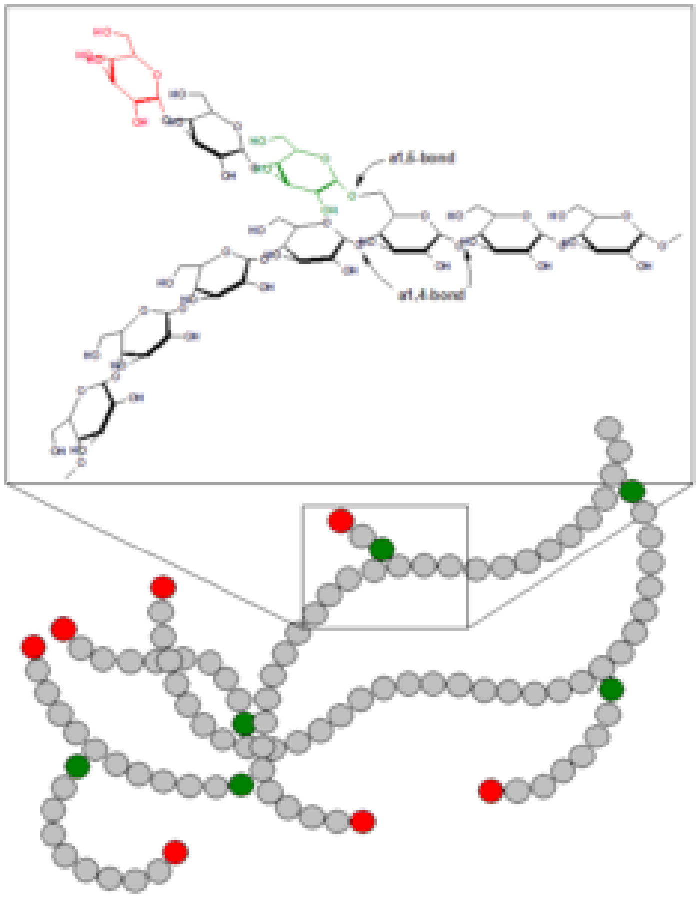

Figure 8.81 *Glycogen is made of many molecules of glucose attached together into branching chains. Each of the balls in the bottom diagram represents one molecule of glucose. (Credit: Glycogen by BorisTM. This work has been released into the public domain)*

The amount of glycogen we can store in the body is limited. After a high-carbohydrate meal, our glycogen stores will reach capacity fairly quickly. After glycogen stores are filled, glucose will have to be metabolized in different ways for it to be stored in a different form, often as fat.

Most other carbohydrates enter the cellular respiration pathway during glycolysis. For example, **sucrose** is a disaccharide made from glucose and fructose bonded together. Sucrose is broken down in the small intestine. The glucose enters the beginning of glycolysis as previously discussed, while fructose can be slightly modified and enter glycolysis at the third step. **Lactose,** the disaccharide sugar found in milk, can be broken down by the lactase enzyme into two smaller sugars: galactose and glucose. Like fructose, galactose can be slightly modified to enter glycolysis.

Because these carbohydrates enter near the beginning of glycolysis, their catabolism (breakdown) produces the same number of ATP molecules as glucose.

Proteins

Proteins are broken down by a variety of enzymes in cells. Most of the time, **amino acids** are recycled into new proteins and not used as a source of energy. This is because it is more energy efficient to reuse amino acids rather than making new ones from scratch. The body will use protein as a source of energy if:

- There are excess amino acids (you consume a lot of protein)
- The body is in a state of famine (you are starving and have no other source of energy available)

When proteins are used in the cellular respiration pathway, they are first broken down into individual amino acids. The amino group from each amino acid is removed (deaminated) and is converted into ammonia. In mammals, the liver synthesizes urea from two ammonia molecules and a carbon dioxide molecule. Thus, urea is the principal waste product in mammals from the nitrogen originating in amino acids, and it leaves the body in urine.

Once the amino acid has been deaminated, its chemical properties determine which intermediate of the cellular respiration pathway it will be converted into. These intermediates enter cellular respiration at various places in the Citric Acid Cycle (Figure 8.82).

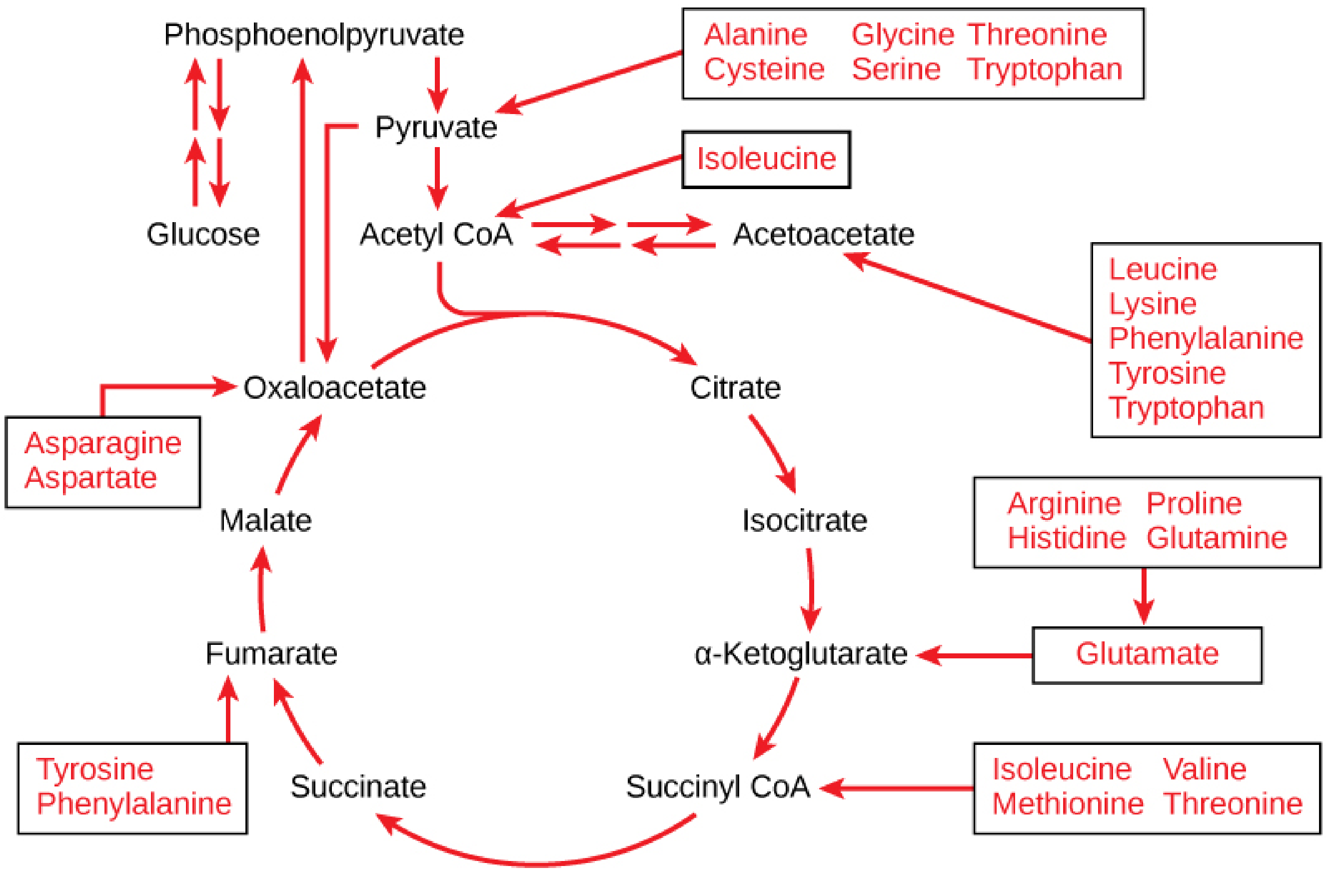

Figure 8.82 *The carbon skeletons of certain amino acids (indicated in boxes) derived from proteins can feed into the citric acid cycle. (credit: modification of work by Mikael Häggström)*

Gluconeogenesis

Gluconeogenesis is the synthesis of glucose from non-carbohydrate sources. Gluconeogenesis is basically glycolysis in reverse, with minor changes. The glycerol from triglycerides can also be used for gluconeogenesis, although fatty acids cannot. Certain amino acids can be used for this process.

Not all amino acids can be used for gluconeogenesis. The ones that can be used are termed **glucogenic**, and can be converted to either pyruvate or a citric acid cycle intermediate. Other amino acids can only be converted to acetyl-CoA or acetoacetyl-CoA, which cannot be used for gluconeogenesis. However, acetyl-CoA or acetoacetyl-CoA can be used for ketogenesis to synthesize the ketone bodies, acetone and acetoacetate. Thus, these amino acids are instead termed **ketogenic**. Ketone bodies can be used to form fatty acids for energy storage. Some amino acids can be either ketogenic or glucogenic, depending on the body's needs.

Lipids

Triglycerides (fats) are a form of long-term energy storage in animals. Triglycerides store about twice as much energy as carbohydrates. Triglycerides are made of glycerol and three fatty acids. Glycerol can enter glycolysis. Fatty acids are broken into two-carbon units that enter the citric acid cycle (Figure 8.83).

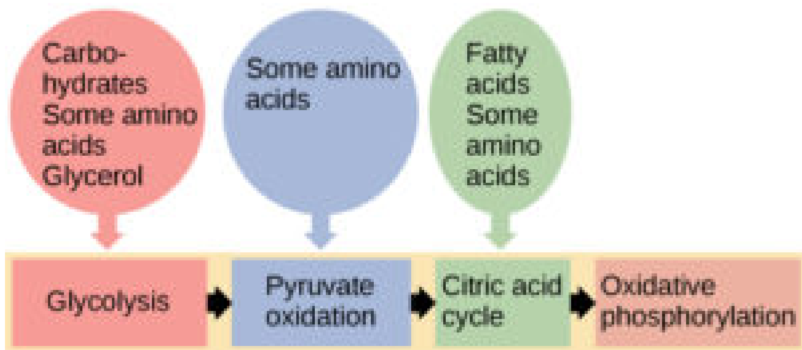

Figure 8.83 *Glycogen from the liver and muscles, together with fats, can feed into the catabolic pathways for carbohydrates.*

Remember that if oxygen is not available, glycolysis can occur but not the citric acid cycle or **oxidative phosphorylation**. Since fatty acids enter the pathway at the citric acid cycle, they can not be broken down in the absence of oxygen. This means that if cells are not performing **aerobic cellular respiration**, the body can not burn fat for energy. This is why posters about the "Fat Burning Zone" in a gym specify that you need to have a lower heart rate / breathing rate to burn more fat – cells that are not doing aerobic respiration can't burn fat for fuel!

Lipogenesis & Lipolysis[1]

Lipogenesis is the synthesis of fatty acids, beginning with acetyl-CoA. Remember that acetyl-CoA is the product of the transition reaction that is the starting point of the citric acid cycle. Acetyl-CoA moves out of the mitochondria and is subsequently combined with additional acetyl-CoA molecules to form palmitate, a 16-carbon fatty acid.[2] The palmitate produced can be used as a component in the production of triglycerides (fat) for storage.

Lipolysis is the cleavage of triglycerides to glycerol and fatty acids. There are two primary lipolysis enzymes: lipoprotein lipase (LPL) and hormone-sensitive lipase (HSL). Despite performing the same function, the enzymes are primarily active for seemingly opposite reasons.

In the anabolic state (after eating a meal), LPL on the lining of blood vessels cleaves lipoprotein triglycerides into fatty acids so that they can be taken up into adipocytes (fat cells) for storage as triglycerides, or muscle cells where they are primarily used for energy production.

HSL is an important enzyme in adipose tissue (fat), which is a major storage site of triglycerides in the body. HSL activity is increased by **glucagon** and epinephrine ("fight or flight" **hormone**), and decreased by **insulin**. Thus, during **hypoglycemia** (such as during a fast; a catabolic state), or a "fight or flight" response, triglycerides in the adipocytes (fat cells) are cleaved, releasing fatty acids into circulation. The free fatty acids bind with a transport protein that carries them to muscle cells for use as an energy source. Thus, HSL is important for mobilizing stored fatty acids so they can be used to produce energy.

Notes

1. Jellum et al., *Principles of Nutrition*
2. Gropper SS, Smith JL, Groff JL. (2008) *Advanced Nutrition and Human Metabolism*. Belmont, CA: Wadsworth Publishing.

8.9 Metabolic Conditions

You have learned about the metabolic pathways, so now we're going to apply that knowledge to three conditions: fasting, the Atkins diet, and the Ornish/Pritikin diet, as ways to illustrate how you can use this knowledge to understand what happens after you eat.

In fasting, we're going to be considering what is happening metabolically during a prolonged period without food. This is a catabolic condition. The Atkins diet is a carbohydrate-restricted diet, so we are going to consider what happens metabolically when someone is eating a diet that essentially only contains protein and fat over an extended period of time. This is an anabolic condition. Finally, the Ornish/Pritikin diet is a very low-fat diet, so we're going to consider what happens metabolically when someone is eating a diet that is essentially only carbohydrates and protein over an extended period of time. This is also an anabolic condition.

Tissue Specific Metabolism[1]

For each condition, we'll be discussing what happens in the liver, in muscle tissue, and in adipose tissue. All cells in the body can make ATP and proteins, but these three **tissues** have specialized metabolic functions.

The liver is the most metabolically flexible organ; it can store and breakdown glycogen and store and break down triglycerides. It can also use **amino acids** and other molecules to produce glucose that can then be released into the blood for other parts of the body to use. The liver also makes ketone bodies, an energy source that can be used by the brain when glucose is not available. The liver is the only tissue that makes ketone bodies and is the main site of **gluconeogenesis** (the kidneys also do small amounts).

Muscle tissue stores and breaks down both glycogen and triglycerides. Muscle tissue can also produce lactate under anaerobic conditions (see section 8.7). This lactate circulates back to the liver for gluconeogenesis. Muscle cells cannot secrete glucose into the blood the way that the liver does. They use the glucose they produce for themselves. You can think of muscle as being selfish with glucose and the liver as being generous.

The major function of adipose tissue is to store energy in the form of triglycerides.

Therefore the major metabolic activity of adipose tissue is the synthesis and breakdown of triglycerides.

Metabolic Hormones: Insulin and Glucagon

Now that you have an understanding of the glycemic response (Chapter 5) and macronutrient metabolism, you should be able to understand the broader effects of **insulin** and **glucagon** that are summarized in the following tables. Knowing what hormone is elevated in the different conditions helps you to understand the metabolism that occurs in different conditions.

Table 8.91 Insulin's effects on targets in tissues[2]

Effect	Tissue
↑ Glucose Uptake	Muscle, Adipose Tissue
↑ Glucose Uptake	Liver
↑ Glycogen Synthesis	Liver, Muscle
↓ Glycogen Breakdown	Liver, Muscle
↑ Glycolysis, ↑ Transition Reaction	Liver, Muscle
↑ Fatty Acid Synthesis	Liver
↑ Triglyceride Synthesis	Adipose Tissue

Table 8.92 Glucagon's effects on targets in tissues[3]

Effect	Tissue
↑ Glycogen Breakdown	Liver
↓ Glycogen Synthesis	Liver
↑ Gluconeogenesis	Liver
↓ Glycolysis	Liver
↑ Ketone Body Synthesis	Liver
↑ Triglyceride Breakdown	Adipose

Fasting

In this condition a person has been **fasting** for an extended period of time (18 hours or longer). As a result, the person is in a catabolic state with low blood glucose levels, which leads the pancreas to secrete glucagon.

The liver will break down glycogen to secrete glucose for other tissues to use until its stores are exhausted. Amino acids and lactate from muscle will be used for gluconeogenesis to synthesize glucose. Glycolysis will not be occurring to any great extent in an effort to spare glucose for use by other tissues. Fatty acids that are received from adipose tissue will be used to synthesize ketone bodies that can be used by tissues that cannot directly use fatty acids as a fuel, such as the brain..

Muscle tissue will break down glycogen to glucose until glycogen stores are exhausted. Glucose will be used to make ATP. Once there isn't enough glucose for the muscle to use, fatty acids taken up from adipose tissue, and from the breakdown of muscle stores, will be used for ATP. Amino acids from protein breakdown and lactate will be used by the liver for gluconeogenesis.

Adipose tissue will break down triglycerides to fatty acids and release these for use by the muscle and the liver. It will not be taking up anything.

Atkins Diet

In this condition, assume a person just started into Phase I of the Atkins Diet and he/she has just consumed a meal of all protein and fat with no carbohydrates of any kind. As a result, this person is in an anabolic state, but blood glucose levels are low, meaning the pancreas will secrete glucagon.

Liver glycogen stores will be broken down to secrete glucose for other tissues. The liver will also be using amino acids from digestion and lactate from muscle for gluconeogenesis.

Amino acids will also be used for protein synthesis. Some triglycerides absorbed from the meal will be broken down to fatty acids and used to synthesize ketone bodies. Other triglycerides will be packaged into VLDL and secreted from the liver.

Muscle tissue is going to break down glycogen to glucose, and receive glucose from the liver. This glucose will be used to make ATP until it runs out. Once there is not enough glucose for the muscle to use, fatty acids from multiple sources will be broken down for energy. Amino acids taken up will be used for protein synthesis, and lactate will be secreted for the liver to use for gluconeogenesis.

In adipose tissue, fatty acids are also going to be taken up. These fatty acids will be used to make triglycerides for storage.

Ornish/Pritikin Diet

In this condition, assume a person is on the Ornish/Pritikin Diet and just consumed a meal containing carbohydrates, with minimal but adequate amount of protein, and no fat. As a result, this person is in an anabolic state with high blood glucose levels, meaning the pancreas will secrete insulin.

The liver will take up glucose and synthesize glycogen until its stores are filled. After these stores are full, glucose can be used to make triglycerides for storage. These triglycerides will be packaged into VLDL and secreted from the liver. Amino acids will also be taken up and used for protein synthesis as needed. Because there is plenty of glucose, gluconeogenesis and ketone body synthesis will not be operating to any great extent.

Muscle tissue will take up glucose and synthesize glycogen until those stores are filled. Some glucose will be used to make ATP. Fatty acids that are cleaved from low-density lipoproteins are also going to be taken up. These fatty acids will be used to synthesize triglycerides for storage. Whatever amino acids are taken up will be used for protein synthesis. The muscle will not be secreting anything in this condition.

The adipose tissue is going to take up glucose to produce triglycerides for storage. The adipose tissue won't be secreting anything under this condition.

The brain will have plenty of glucose available for its use, so it is not going to have to use ketone bodies like it would during fasting and during prolonged Atkins diet consumption.

Notes

1. Jellum et al. *Principles of Nutrition*
2. Gropper SS, Smith JL, Groff JL. (2008) Advanced Nutrition and Human Metabolism. Belmont, CA: Wadsworth Publishing.
3. Gropper et al. (2008)

CHAPTER IX

CHAPTER 9: ENERGY BALANCE

Chapter 9 deals with energy balance: energy in – energy out. As part of this discussion, we will also talk about **obesity** and weight management.

Sections:

- 9.0 Introduction to Energy Balance
- 9.1 Weight Management
- 9.2 Factors Affecting Energy Intake
- 9.3 Factors Affecting Energy Expenditure
- 9.4 Dietary, Behavioral, and Physical Activity Recommendations for Weight Management
- 9.5 Body Mass Index, Body Fat Content, and Fat Distribution

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Chapter 9 is primarily adapted from Fialkowski Revilla, et al. *Human Nutrition.*

9.0 Introduction to Energy Balance

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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

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 the US, 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**. For more details on food composition data, go to the USDA Food Composition Databases page.

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.

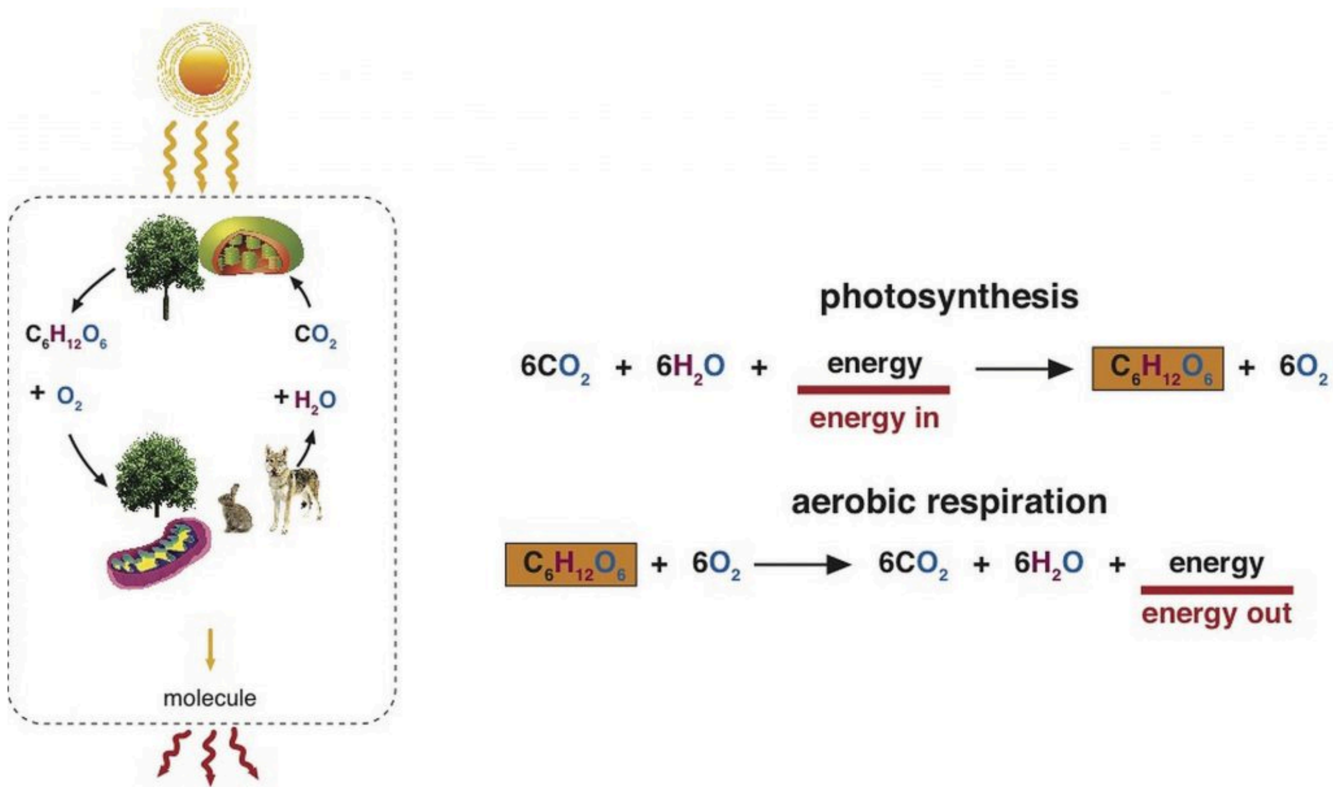

Figure 9.01 *Energy Flow From Sun to Plants to Animals. Plants harvest energy from the sun and capture it in the molecule glucose. Humans harvest the energy in glucose and capture it into the molecule ATP.*

9.1 Weight Management

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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. The **Centers for Disease Control and Prevention (CDC)** defines obesogenic as "an environment that promotes increased food intake, non-healthful foods, and physical inactivity."[1]

The health consequences of too much 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 one hundred billion dollars. On the individual level, people who are obese spend $1,429 more per year for medical care than people of healthy weight.

Numerous obesogenic agents that contribute to this immense public health problem have become a part of everyday life in American society. The fast food industry has been growing for decades and continues to grow despite the latest economic slump. In America today there are over twelve thousand McDonald's restaurants, while in 1960 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. Between 1960 and 2000 more than 123 million vehicles were added to the American society. Escalators, elevators, and horizontal walkways now dominate shopping malls and office buildings, factory work has become increasingly mechanized and robotized, the typical American 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 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 America 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, such as America on the Move.
- Support policies that support local farmers and the increased access and affordability of healthy food.

Some scientists predict that the childhood obesity rate will reach 100 percent by 2044. 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 fatness. You will also learn that it is not only society and environment that play a role in body weight and fatness, 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 in the United States.

Balancing Energy Input with Energy Output

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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. The Institute of Medicine has devised a formula 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) + 539.6 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. The table below shows you which value to use for PA in the equation above, based on your level of daily activity.

Table 9.11 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.			

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.

Estimating Caloric Intake

The 2015 **Dietary Guidelines** provides a table (Table 9.12 "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 9.13 "Acceptable Macronutrient Distribution Ranges").

Table 9.12 Estimated Daily Calorie Needs[3]

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

Table 9.13 Acceptable Macronutrient Distribution Ranges[4]

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

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 9.14 "Energy Expended by Individual 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 9.14 Energy Expended by Individual Organs[5]

Organ	Percent of Energy Expended
Liver	27
Brain	19
Heart	7
Kidneys	10
Skeletal muscle (at rest)	18
Other organs	19

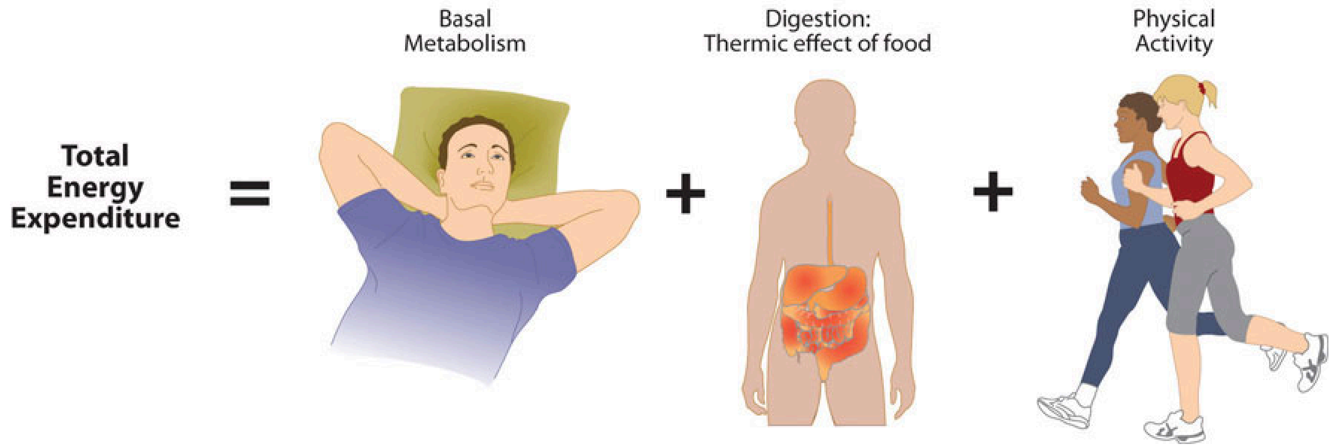

***Figure 9.11** Total Energy Expenditure. Total energy expenditure is the sum of energy expended at rest, during digestion, and during physical activity.*

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. You can access a web-based TEE calculator and a spreadsheet for recording daily activities at the links below:

Resources for Calculating Total Energy Expenditure:

- Health-calc.com Total Energy Expenditure calculator
- Daily Activity Record (complete before using TEE calculator)

Notes

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9.2 Factors Affecting Energy Intake

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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 9.21).

Figure 9.21 *Sagittal View of the Brain. Source: 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 body fatness 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 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]

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 the American 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, American 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. Even different cultures within the United States have different eating habits. For instance, Native Hawaiians and Pacific Islanders who have since adopted the western diet, post-colonization consume foods high in fat, which is a contributing factor to their higher incidences of overweight and obesity.

The fast food industry in America not only supplies Americans with a large proportion of their diet, but because of its massive presence in society dominates the workings of the entire food system. To generalize, 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, Americans 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 Americans should abruptly quit eating fast food to save their health (because they will not) 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 American 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.

Notes

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9.3 Factors Affecting Energy Expenditure

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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 fatness 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 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.[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]

NEAT stands for Non-Exercise Activity Thermogenesis. Even at rest we can burn calories, but we can increase the number of calories burnt by doing minor movements. Examples of NEAT movements include jiggling a leg, bouncing and catching a ball, gardening, squeezing an exercise ball, using a hand/ finger exerciser, sitting on an exercise ball etc. This is another way to burn more calories, even for people who aren't able to set aside time to exercise or go to the gym.

Americans 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.

Video Link: How to burn more calories during your day – NEAT
Watch this video to learn more about Non-Exercise Activity Thermogenesis.

Societal Influence

In the United States, many societal factors influence the number of calories burned in a day. Escalators, moving walkways, and elevators (not to 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 of Americans. Even the remote controls that many have for various electronic devices in their homes contribute to the US 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 the average body weight of Americans. The number of homeless in this country is rising with many children and adults living in hotels and cars. As you can imagine neither of these "home spaces" has a kitchen, making it impossible to cook nutritious meals and resulting in increased economically-forced access to cheap, unhealthy foods, such as that at a nearby gas station.

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.

Health Risks of Being Overweight and Being Obese

The health consequences of obesity are great and contribute to more than one hundred thousand deaths per year in the United States. According to the **CDC**, in the United States in 2013-2014[6]:

- 37.9% of adults age twenty years and over were obese
- 70.7% of adults age twenty years and over were overweight, including obese
- 20.6% of adolescents age twelve to nineteen years were obese
- 17.4% of children age six to eleven years were obese
- 9.4% of children age two to five years were obese

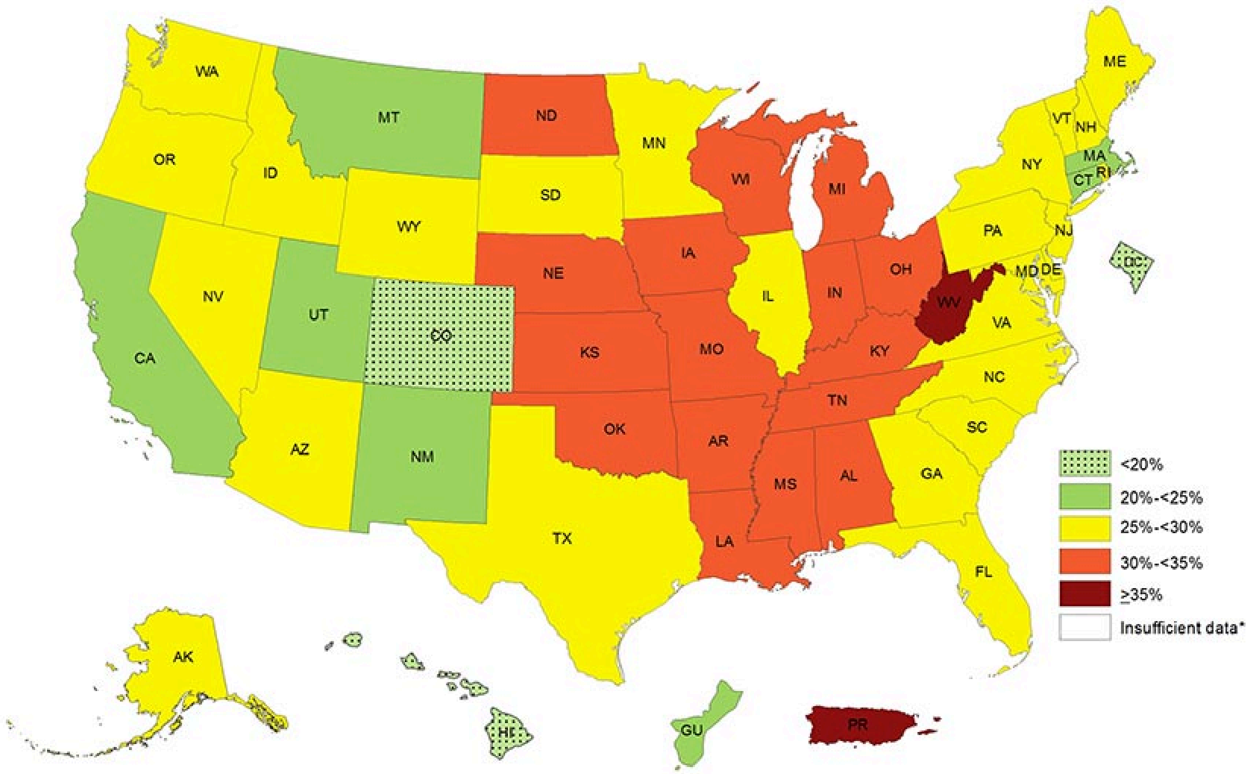

Figure 9.31 *State Map of the Prevalence of Obesity in America. Visit the CDC's Adult Obesity Prevalence Maps to see the prevalence of self-reported obesity among U.S. adults from 2014-2016.*

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.[7] 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.[8]

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.

Notes

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9.4 Dietary, Behavioral, and Physical Activity Recommendations for Weight Management

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We have just considered the gravity of the obesity problem in America and worldwide. How is America combating its weight problem on a national level, and have the approaches been successful? 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] 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.

The National Weight Control Registry (NWCR) tracks over ten thousand people who have been successful in losing at least 30 pounds and maintaining this weight loss for at least one year. Their research findings are 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 NWCR members 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 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, as over ten thousand Americans can attest. 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

The 2015 Dietary Guidelines for Americans 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, 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

Key quantitative recommendations are provided for several components of the diet that should be limited. These components are of particular public health concern in the United States, and the specified limits can help individuals achieve healthy eating patterns within calorie limits[5]:

- Consume less than 10 percent of calories per day from added sugars
- Consume less than 10 percent of calories per day from saturated fats
- Consume less than 2,300 milligrams (mg) per day of sodium

If alcohol is consumed, it should be consumed in moderation—up to one drink per day for women and up to two drinks per day for men—and only by adults of legal drinking age.

Evidence-Based Physical Activity Recommendations

The other part of the energy balance equation is physical activity. The Dietary Guidelines are complemented by the 2008 Physical Activity Guidelines for Americans issued by the Department of Health and Human Services (HHS) in an effort to provide evidence-based guidelines for appropriate physical activity levels. The 2008 Physical Activity Guidelines provide guidance to Americans aged six and older about how to improve health and reduce chronic disease risk through physical activity. 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 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.

The 2008 Physical Activity Guidelines broadly classify moderate physical activities as those when "you can talk while you do them, but can't sing" and vigorous activities as those when "you can only say a few words without stopping to catch your breath."[7]

Table 9.41 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

Campaigns for a Healthy-Weight America

On a national level, strategies addressing overweight and obesity in the past have not been all that successful, as obesity levels continue to climb. However, in the recent past (2007–2011) several newly created initiatives and organizations are actively reinforcing strategies aimed to meet the challenge of improving the health of all Americans.

In 2010 the national campaign to reduce obesity was reinforced when First Lady Michelle Obama launched the "Let's Move" initiative, which has the goal of "solving the challenge of childhood obesity within a generation so that children born today will reach adulthood at a healthy weight."[9] Another campaign, "Campaign to End Obesity," was recently established to try to enable more Americans to eat healthy and be active by bringing together leaders from academia and industry, as well as public-health policy-makers in order to create policies that will reverse the obesity trend and its associated diseases.

The "Small-Change" Approach

Currently, most people are not obese in this country. The gradual rise in overweight is happening because, on average, people consume slightly more calories daily than they expend, resulting in a gradual weight gain of one to two pounds a year. In 2003 the idea was first published that promoting small lifestyle changes to reduce weight gain occurring over time in all age groups may better reduce obesity rates in the American population.[10]

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 overweight children.[11] 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.[12] Several more studies funded by the National Institutes of Health and USDA are ongoing and are evaluating the effectiveness of the "small-changes" approach in reducing weight gain.

In 2009, a report of the Joint Task Force of the American Society for Nutrition, Institute of Food Technologists, and International Food Information Council proposed that the "small-changes" approach when supported at the community, industry, and governmental levels will be more effective than current strategies in gradually reducing the obesity rate in America.[13]

Notes

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9.5 Body Mass Index, Body Fat Content, and Fat Distribution

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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.

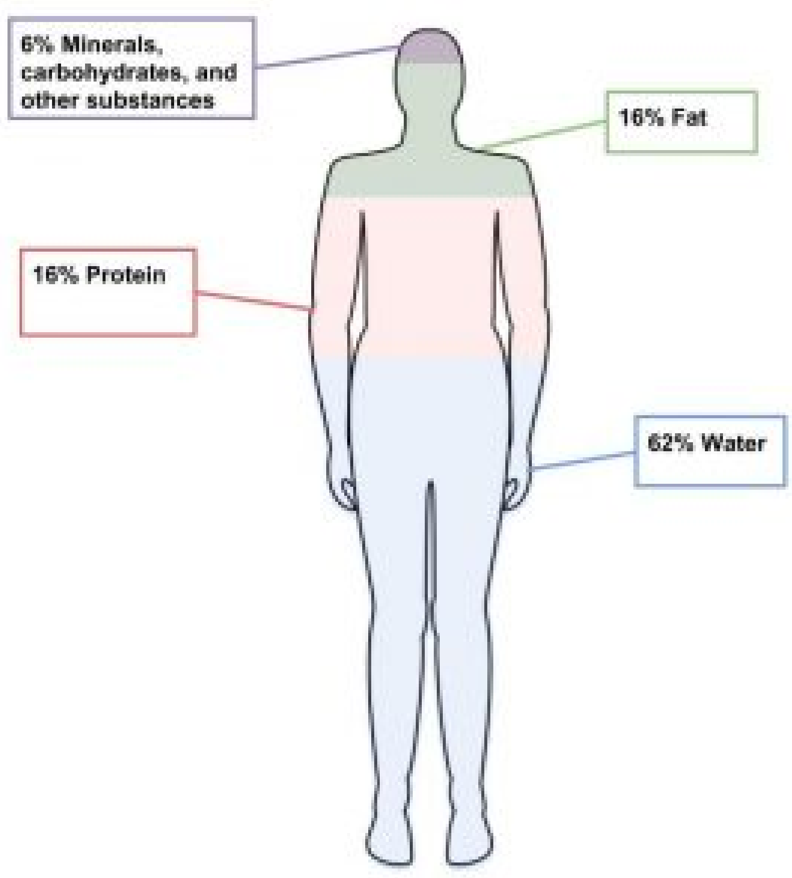

Figure 9.51 *Body Composition. Image by Allison Calabrese / CC BY 4.0*

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 health hazards ahead, 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 pounds by 703 (conversion factor for converting to metric units) and then divide the product by your height in inches, squared.

$$BMI = [weight\ (lb) \times 703] \div height\ (in)^2$$

or

$$BMI = [weight\ (kg)] \div height\ (m)^2$$

More Ways to Calculate

The National Heart, Lung, and Blood Institute and the **CDC** have automatic BMI calculators on their websites:

- https://www.nhlbisupport.com/bmi/
- https://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/english_bmi_calculator/bmi_calculator.html

To see how your BMI indicates the weight category you are in, see Table 9.51 "BMI Categories" or use a chart of weight and height to figure out your BMI.

Table 9.51 BMI Categories[1]

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 9.52** 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 9.53 *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 9.54 *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.

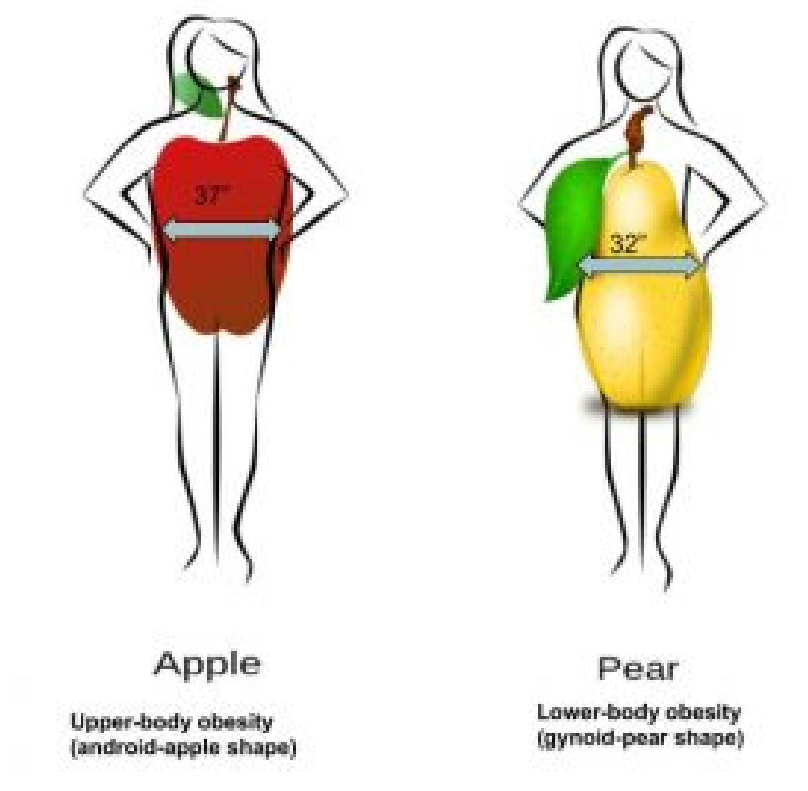

***Figure* 9.55** *Two different patterns of fat distribution. Image by Allison Calabrese /* CC BY 4.0

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.[2]. 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.

Notes

1. National Heart, Lung, and Blood Institute. Accessed November 4, 2012. https://www.nhlbi.nih.gov.
2. 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 X

CHAPTER 10: MICRONUTRIENTS OVERVIEW AND ROLE AS ANTIOXIDANTS

Recall from chapter 1 that **micronutrients** are nutrients that are essential for body functioning, but are only needed in small amounts. The micronutrients include both **vitamins** and **minerals**. We introduced the vitamins and minerals in chapter 1. The table below summarizes some important differences between the two.

Table 10.01 Differences between vitamins and minerals

Vitamins	Minerals
Vitamins are organic	Minerals are inorganic
All vitamins are essential	Only some minerals are essential
Vitamins are classified by solubility: **fat-soluble** vs. **water-soluble**	Minerals are classified by the amount needed: major minerals vs. trace minerals
Can be destroyed by heat and sunlight	Cannot be destroyed

There are two common ways to teach about vitamins and minerals in nutrition classes. The traditional way is to start with fat-soluble vitamins and go down through the vitamins alphabetically (i.e. vitamin A, vitamin D, vitamin E, vitamin K). However, this method leads students to learn about vitamins and minerals more individually instead of how they work together. For instance, it makes sense to cover calcium with vitamin D, and iron with copper and zinc. We are going to cover vitamins and minerals based on their function rather than covering them by whether they are a water-soluble vitamin or trace mineral. The hope is that you will gain a more integrative understanding of vitamins and minerals from this approach.

We'll first give an overview of each type of micronutrient, and then we'll discuss the specific functions of each micronutrient in the body. The micronutrients will be grouped into the functional categories indicated in the table below. Notice that some micronutrients fit into more than one functional category. Each vitamin and mineral will be covered only in one section, with some mention of its overlap in other section(s) in certain cases.

Table 10.02 Functional categories of micronutrients

Functional Category	Micronutrients
Antioxidants	Vitamin E, Vitamin C, Selenium, Iron, Copper, Zinc, Manganese, Riboflavin
Metabolism	All B vitamins, Vitamin C, Iodine, Manganese, Magnesium
Bones and Teeth	Vitamin D, Calcium, Phosphorus, Fluoride, Vitamin K, Magnesium, Vitamin A, Iron, Copper, Zinc
Blood	Vitamin K, Iron, Copper, Vitamin B_6, Vitamin B_{12}, Folate, Calcium
Electrolytes	Sodium, Potassium, Chloride, Phosphorus, Magnesium

In chapter 10, we'll first talk more about what vitamins and minerals are. Then, this chapter will describe what antioxidants are and discuss the three major antioxidant micronutrients: vitamin E, vitamin C and selenium.

10.1 Vitamins
10.2 Minerals
10.3 Antioxidants
10.4 Vitamin E
10.5 Vitamin C
10.6 Selenium

Sections 10.1-10.2: Adapted from Jellum, et al. *Principles of Nutrition* and Fialkowski Revilla, et al. *Human Nutrition.*

Section 10.3: Adapted from Jellum, et al. *Principles of Nutrition.*

Sections 10.4-10.6: Adapted from Fialkowski Revilla, et al. *Human Nutrition.*

10.1 Vitamins

The name vitamin comes from Casimir Funk, who in 1912 thought vital amines (NH_3) were responsible for preventing what we know now are vitamin deficiencies. He coined the term 'vitamines' to describe these compounds. Eventually it was discovered that these compounds were not amines and the 'e' was dropped to form vitamins.[1]

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. The table below shows the two categories of vitamins, and also shows both the common names and numbers of the B vitamins. Most B vitamins are known by their common names, except for vitamin B_6 and vitamin B_{12}.

Table 10.11 Fat-soluble and water-soluble vitamins

Fat-Soluble Vitamins	Water-Soluble Vitamins
• Vitamin A • Vitamin D • Vitamin E • Vitamin K	• Vitamin C • All B Vitamins: ◦ Thiamin (B_1) ◦ Riboflavin (B_2) ◦ Niacin (B_3) ◦ Pantothenic acid (B_5) ◦ Pyridoxine (B_6)* ◦ Biotin (B_7) ◦ Folate (B_9) ◦ Cobalamin (B_{12})*
* Vitamins B_6 and B_{12} are known by their numbers	

Before they even knew that vitamins existed, a scientist named E.V. McCollum recognized that a deficiency in what he called 'fat-soluble factor A' resulted in severe ophthalmia (inflammation of the eye). In addition, a deficiency in 'water-soluble factor B' resulted in beriberi (a deficiency discussed more later).

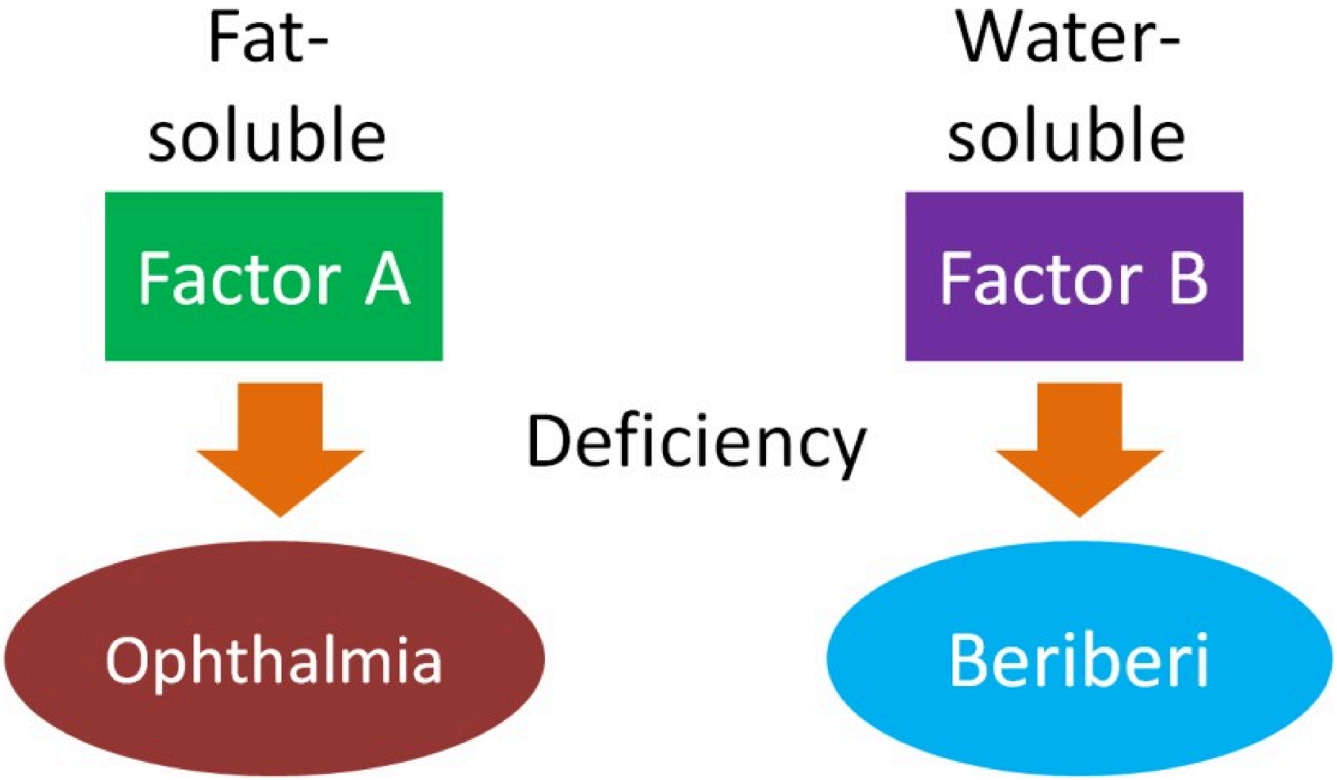

Figure 10.11 *Factor A deficiency led to ophthalmia, factor B deficiency led to beriberi*

Factor A is what we now know as vitamin A. However, researchers soon realized that factor B actually consisted of two factors that they termed B_1 and B_2. Then they realized that there are multiple components in B_2, and they began identifying the wide array of B vitamins that we know today.[2]

You might be thinking "but the numbers on the B vitamins still do not add up." You are right, vitamins B_4, B_8, B_{10}, and B_{11} were discovered and then removed leaving us with the B vitamins shown in Table 10.11.

Relative to other scientific milestones, the discovery of vitamins is a fairly recent occurrence, as shown in Table 10.12.

Table 10.12 Vitamin, year proposed, isolated, structure determined, and synthesis achieved up to 1944[3]

Vitamin	Year Proposed	Isolated	Structure Determined	Synthesis Achieved
Thiamin	1901	1926	1936	1936
Vitamin C	1907	1926	1932	1933
Vitamin A	1915	1939	1942	–
Vitamin D	1919	1931	1932	1932
Vitamin E	1922	1936	1938	1938
Niacin	1926	1937	1937	1867*
Biotin	1926	1939	1942	1943
Vitamin K	1929	1939	1942	1943
Pantothenic Acid	1931	1939	1939	1940
Folate	1931	1939	–	–
Riboflavin	1933	1933	1934	1935
Vitamin B_6	1934	1936	1938	1939
* Was established long before it was known to be a vitamin				

Vitamin Absorption[4]

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 10.12 "Absorption of Fat-Soluble and Water-Soluble Vitamins").

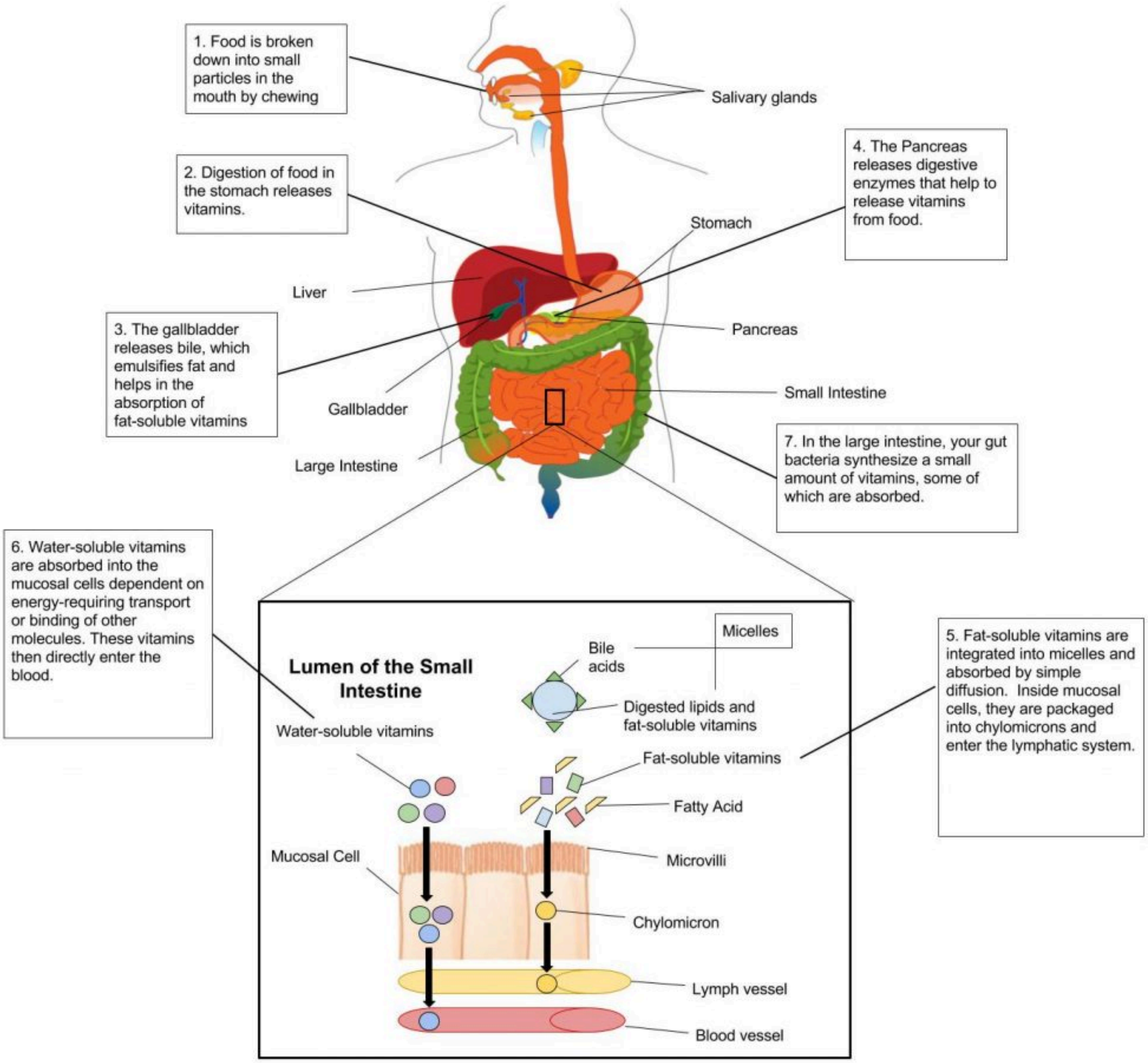

Figure 10.12 *Absorption of Fat-Soluble and Water-Soluble Vitamins*

The following two tables give an overall summary of the vitamins. You'll be learning more about each in detail over the next few chapters.

Table 10.13 Fat-Soluble Vitamins

Vitamin	Sources	Recommended Intake for adults	Major functions	Deficiency diseases and symptoms	Groups at risk of deficiency	Toxicity	UL
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	Xerophthalmia, night blindness, eye infections; poor growth, dry skin, impaired immune function	People living in poverty (especially infants and children), premature infants, pregnant and lactating women people who consume low-fat or low-protein diets	Hypervitaminosis A: Dry, itchy skin, hair loss, liver damage, joint pain, fractures, birth defects, swelling of the brain	3000 mcg/ day
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 in children: abnormal growth, misshapen bones, bowed legs, soft bones; osteomalacia in adults	Breastfed infants, older adults people with limited sun exposure, people with dark skin	Calcium deposits in soft tissues, damage to the heart, blood vessels, and kidneys	4000 IU/day (100 mcg/ day)
Vitamin E	Sunflower seeds, almonds, hazelnuts,peanuts	15 mg/day	Antioxidant, protects cell membranes	Broken red blood cells, nerve damage	People with poor fat absorption, premature infants	Inhibition of vitamin K clotting factors	1000 mcg/ day from supplemental sources

Vitamin	Sources	Recommended Intake for adults	Major functions	Deficiency diseases and symptoms	Groups at risk of deficiency	Toxicity	UL
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	Hemorrhage	Newborns, people on long term antibiotics	Anemia, brain damage	ND

Table 10.14 Water-Soluble Vitamins

Vitamin	Sources	Recommended Intake for adults	Major Functions	Deficiency diseases and symptoms	Groups at risk of deficiency	Toxicity	UL
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,	Smokers, alcoholics, elderly	Kidney stones, GI distress, diarrhea	2000 mg/day
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, heart failure	Alcoholics, older adults, eating disorders	None reported	ND
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	Ariboflavinosis: dry scaly skin, mouth inflammation and sores, sore throat, itchy eyes, light sensitivity	None	None reported	ND
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	Alcoholics	Nausea, rash, tingling extremities	35 mg/day from fortified foods and supplements
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	Alcoholics	Fatigue, rash	ND

Vitamin	Sources	Recommended Intake for adults	Major Functions	Deficiency diseases and symptoms	Groups at risk of deficiency	Toxicity	UL
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	Alcoholics	Nerve damage	100 mg/day
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	Those consuming raw egg whites	None reported	ND
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	Pregnant women, alcoholics	Masks B12 deficiency	1000 mcg/ day from fortified foods and supplements
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	Vegans, elderly	None reported	ND
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	None	Liver damage, excessive sweating, hypotension	3500 mg/ day

Notes

1. Carpenter K. (2003) A short history of nutritional science: Part 3 (1912-1944). J Nutr 133(10):3023-3032. https://academic.oup.com/jn/article/133/10/3023/4687555
2. Carpenter K. (2003) A short history of nutritional science: Part 3 (1912-1944). J Nutr 133(10):3023-3032
3. Carpenter (2003)
4. Fialkowski-Revilla, et al. *Human Nutrition*

10.2 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. 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.

Minerals can be categorized according to the amount needed by the body. Major minerals (sometimes called macrominerals) 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. 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.

Minerals are inorganic elements that can be found on the periodic table. As elements, each mineral also has a chemical symbol. As you study **nutrition**, you may see the chemical symbol for a mineral being used as well as the name. Both are listed in the table below.

Table 10.21 Alphabetical listing of the minerals and their chemical symbols

Major Minerals	Calcium (Ca), Chloride (Cl)[a], Magnesium (Mg), Phosphorus (P)[b], Potassium (K), Sodium (Na), Sulfur (S)
Trace Minerals	Chromium (Cr), Copper (Cu), Fluoride (F), Iodine (I), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Selenium (Se), Zinc (Zn)
[a]Chlorine is found in the body as chloride ion (Cl^-) [b]Phosphorus is found in the body as phosphate (PO_4)	

Table 10.22 shows the estimated amount of the major minerals and trace minerals found in the body. Note that minerals that are required in large amounts in the diet are also present in the body in relatively large amounts.

Table 10.22 Amount of different minerals found in the body[1]

Mineral	Amount found in body
Major Minerals	
Calcium	1200 g
Phosphorus	780 g
Potassium	110-140 g
Sodium	100 g
Chloride	95 g
Magnesium	25 g
Trace Minerals	
Iron	4 g
Fluoride	3-6 g
Zinc	2.3 g
Copper	70 mg
Selenium	14 mg
Manganese	12 mg
Iodine	10-20 mg
Molybdenum	5 mg
Chromium	1-2 mg

The following tables provide an overall summary of the two groups of minerals. You'll be learning more about most of these in the chapters to follow.

Table 10.23 A Summary of the Major Minerals

Micronutrient	Sources	Recommended Intakes for adults	Major functions	Deficiency diseases and symptoms	Groups at risk for deficiency	Toxicity	UL
Calcium	Yogurt, cheese, sardines, milk, orange juice, turnip	1,000 mg/day	Component of mineralized bone, provides structure and microarchitecture	Increased risk of osteoporosis	Postmenopausal women, those who are lactose intolerant, or vegan	Kidney stones	2,500 mg
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	Older adults, alcoholics	None	3,000 mg
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	Alcoholics, individuals with kidney and gastrointestinal disease	Nausea, vomiting, low blood pressure	350 mg/day
Sulfur	Protein foods	None specified	Structure of some vitamins and amino acids, acid-base balance	None when protein needs are met	None	None	ND
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	People consuming too much water, excessive sweating, those with vomiting or diarrhea	High blood pressure	2,300 mg/day
Potassium	Fruits, vegetables, legumes, whole grains, milk	4700 mg/day	Major positive intracellular ion, nerve transmission, muscle contraction, fluid balance	Irregular heartbeat, muscle cramps	People consuming diets high in processed meats, those with vomiting or diarrhea	Abnormal heartbeat	ND

Micronutrient	Sources	Recommended Intakes for adults	Major functions	Deficiency diseases and symptoms	Groups at risk for deficiency	Toxicity	UL
Chloride	Table salt, processed foods	<3600 mg/day; ideally 2300 mg/day	Major negative extracellular ion, fluid balance	Unlikely	none	None	3,600 mg/day

Table 10.24 Summary of the Trace Minerals

Micronutrient	Sources	Recommended Intakes for adults	Major Functions	Deficiency diseases and symptoms	Groups at risk for deficiency	Toxicity	UL
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	Infants and preschool children, adolescents, women, pregnant women, athletes, vegetarians	Liver damage, increased risk of diabetes and cancer	45 mg/day
Copper	Nuts, seeds, whole grains, seafood	900 mcg/day	Assists in energy production, iron metabolism	Anemia: fatigue, paleness, faster heart rate	Those who consume excessive zinc supplements	Vomiting, abdominal pain, diarrhea, liver damage	10 mg/day
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	Vegetarians, older adults	Depressed immune function	40 mg/day
Selenium	Meat, seafood, eggs, nuts	55 mcg/day	Essential for thyroid hormone activity	Fatigue, muscle pain, weakness, Keshan disease	Populations where the soil is low in selenium	Nausea, diarrhea, vomiting, fatigue	400 mcg/day

Micronutrient	Sources	Recommended Intakes for adults	Major Functions	Deficiency diseases and symptoms	Groups at risk for deficiency	Toxicity	UL
Iodine	Iodized salt, seaweed, dairy products	150 mcg/day	Making thyroid hormone, metabolism, growth and development	Goiter, congenital hypothyroidism, other signs and symptoms include fatigue, depression, weight gain, itchy skin, low heart-rate	Populations where the soil is low in iodine, and iodized salt is not used	Enlarged thyroid	1110 mcg/ day
Chromium		25-35 mcg/ day	Assists insulin in carbohydrate, lipid and protein metabolism	abnormal glucose metabolism	Malnourished children	None	ND
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	Populations with non fluoridated water	Fluorosis mottled teeth, kidney damage	10 mg/ day
Manganese	Legumes, nuts, leafy green vegetables	1.8-2.3 mg/day	Glucose synthesis, amino-acid catabolism	Impaired growth, skeletal abnormalities, abnormal glucose metabolism	None	Nerve damage	11 mg/ day
Molybdenum	Milk, grains, legumes	45 mcg/day	Cofactor for a number of enzymes	Unknown	None	Arthritis, joint inflammation	2 mg/ day

Notes

1. Emsley, John. *Nature's building blocks: An A-Z guide to the elements*. 2001. Oxford, Oxford University Press.

10.3 Antioxidants

The antioxidant vitamins and minerals include the following:

- Vitamin E
- Vitamin C
- Selenium
- Iron
- Copper
- Zinc
- Manganese
- Riboflavin

In this section, we are going to cover vitamin E, vitamin C, and selenium in detail because being an antioxidant is their primary function. Iron, copper, and zinc will be discussed in chapter 12, with other blood micronutrients. Manganese and riboflavin will be discussed in chapter 11, with other micronutrients involved in **metabolism**.

Free Radicals & Oxidative Stress

Before you can understand what an antioxidant is, it is important to have an understanding of oxidants. As you learned in chapter 8, oxidation is the loss of an electron. (See Figure 10.31 below for a reminder.) An oxidant is a molecule that causes oxidation of other molecules. When this happens, the other molecule is said to become **oxidized**. In other words, an oxidant is a molecule that takes electrons away from other molecules. Oxidation is a normal part of many important **metabolic pathways** in the cell, including those pathways that produce ATP. However, if too much oxidation occurs, essential molecules can become irreparably damaged.

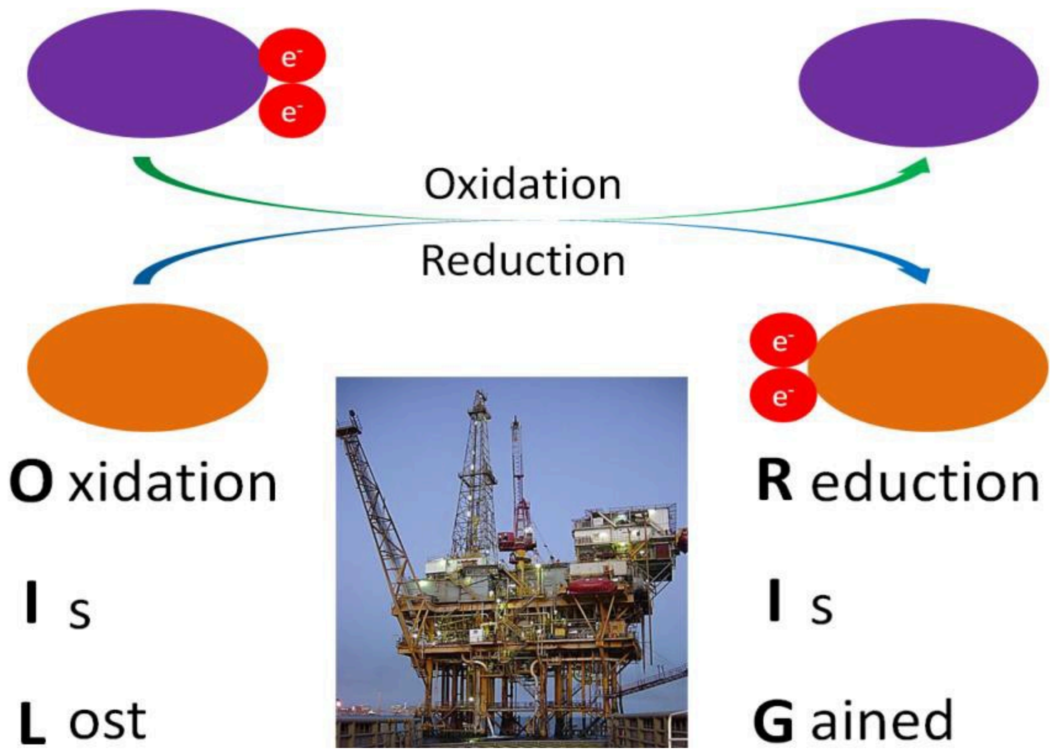

Figure 10.31 *The purple compound is oxidized; the orange compound is [pb_glossary id="4234"]reduced[/pb_glossary]. Image source*

Some important terms to understand:

Free Radical – a molecule with an unpaired electron in its outer orbital.

The following example shows normal oxygen losing an electron from its outer orbital and thus, becoming an oxygen free radical.

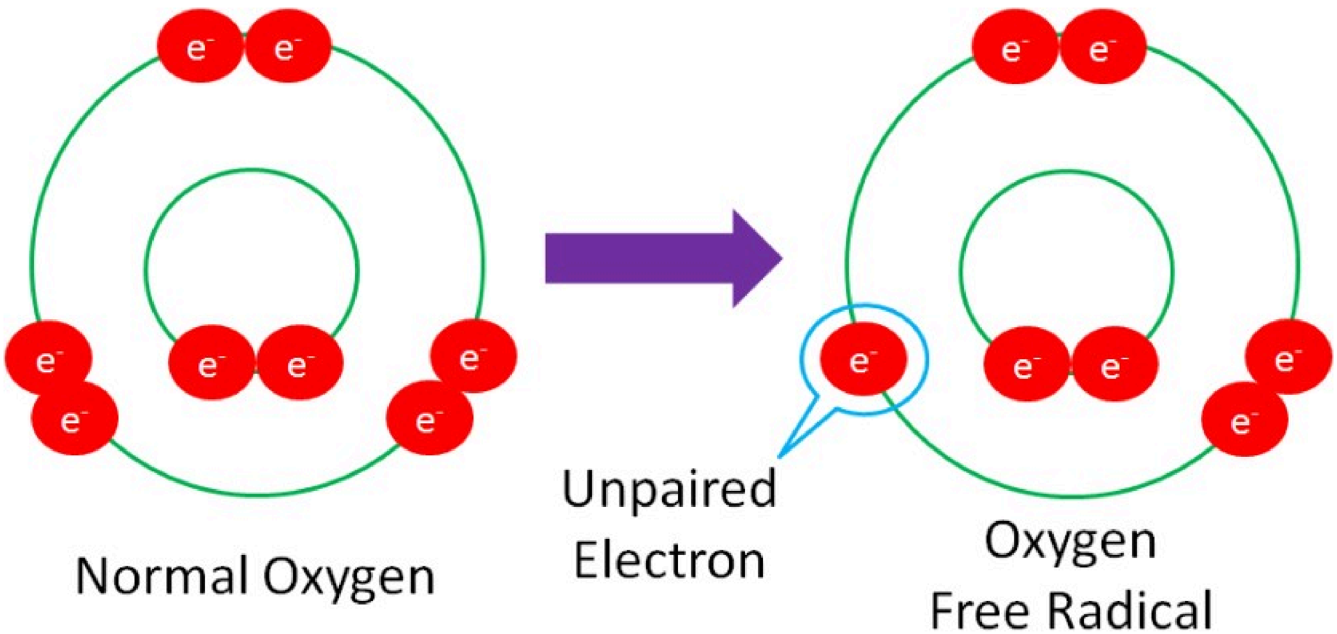

Figure 10.32 *Normal oxygen is converted to an oxygen free radical by losing one electron in its outer orbital, leaving one unpaired electron.*

Free radicals are highly reactive because they actively seek an electron to stabilize (pair with) the unpaired electron within the molecule. This makes free radicals very strong oxidants.

Reactive Oxygen Species (ROS) – an oxygen-containing free radical species. Some of the most common ROS are (● symbolizes radical):

- Superoxide (O ●)
- Hydroxyl Radical (●OH)
- Hydrogen Peroxide Radical (HO ●)
- Peroxyl Radical (ROO ●)
- Alkoxyl Radical (RO●)
- Ozone (O_3)
- Singlet Oxygen ($^1O_2$)
- Hydrogen Peroxide (H_2O_2)

Oxidative Stress – the imbalance between the production of ROS/free radicals and the body's ability to quench them. In other words, oxidative stress is what your cells experience when you're making more free radicals than your cells can handle.

Free radicals can be generated by a variety of sources both within the body and outside the body. The figure below shows some of the sources of free radicals.

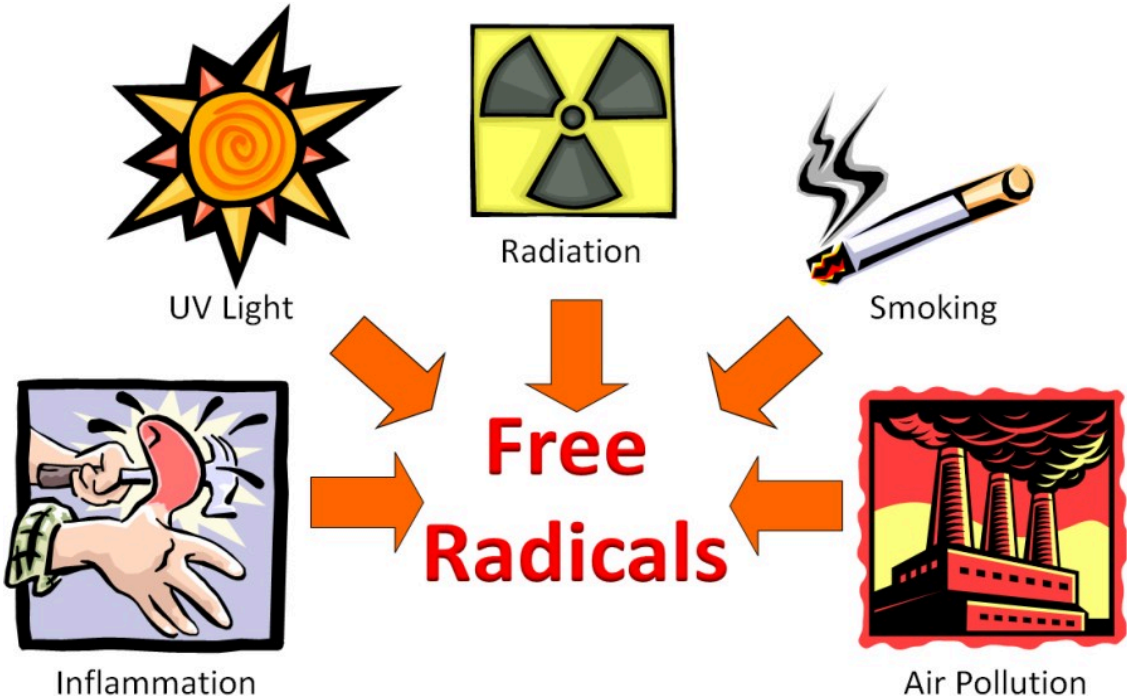

Figure 10.33 *Some sources of free radicals*

The Web Link below does a good job explaining what oxidative stress is, how free radicals can be formed, how they are neutralized by antioxidants, where we get antioxidants.

Video Link: Oxidative Stress, Free Radicals, & Antioxidants

So, we have these free radicals searching for an electron, what's the big deal? The problem arises if the free radicals oxidize low-density lipoproteins (LDLs), proteins, or DNA.

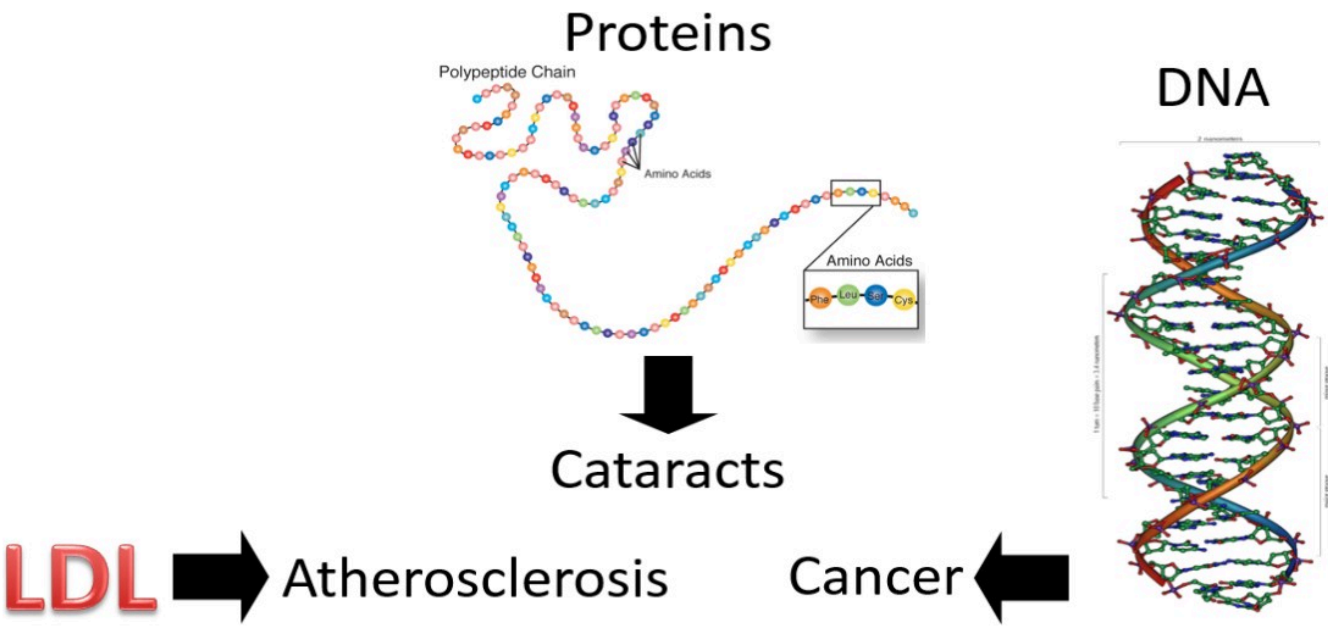

Figure 10.34 *Free radicals can attack low-density lipoproteins (LDLs), proteins, and DNA.*

Oxidized LDL is more likely to contribute to **atherosclerosis** (hardening of the arteries) than normal LDL. Protein oxidation is believed to be involved in the development of cataracts. Cataracts are the clouding of the lens of the eye, which can lead to blindness if not corrected. If DNA becomes oxidized, it can result in a mutation. A mutation is a change in the nucleotide or base pair sequence of DNA. If enough mutations occur, or if they occur in the wrong place, they can lead to cancer. You may have noticed that at least a few of the sources of free radicals in figure 10.33 are known to cause cancer.

What is an Antioxidant?

We are now ready to move on to antioxidants, which as their name indicates, combat free radicals, ROS, and oxidative stress. As a humorous introduction, the link below is to a cartoon that shows Auntie Oxidant kicking free radicals out of the bloodstream.

Web Link: Auntie Oxidant

Unfortunately, it's not quite that simple. You have probably heard the saying "take one for the team." Instead of taking one for the team, antioxidants "give one for the team." The 'giving' in this example is the donation of an electron from itself to a free radical, in order to regenerate a stable compound, as shown in Figure 10.35.

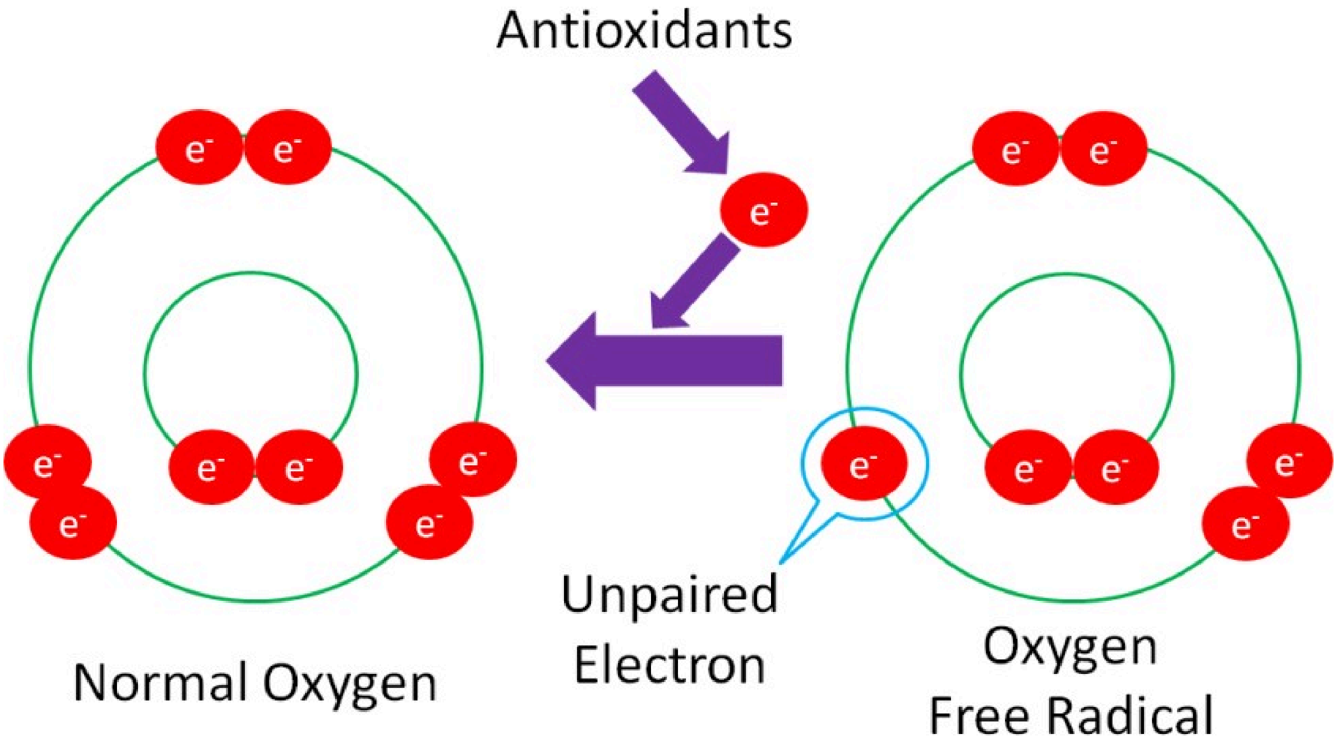

Figure 10.35 *Regeneration of normal oxygen from oxygen free radical by the donation of an electron from an antioxidant*

Donating an electron is how vitamins (A, C & E) act as antioxidants. Minerals, on the other hand, are not antioxidants themselves. Instead, they are cofactors for antioxidant enzymes.

These antioxidant enzymes include:

- **Superoxide dismutase (SOD):** uses copper, zinc, and manganese as cofactors (there is more than one SOD enzyme); converts superoxide to hydrogen peroxide and oxygen.[1]
- **Catalase**: uses iron as a cofactor; converts hydrogen peroxide to water.[2]
- **Glutathione peroxidase (GPX):** is a selenoenzyme that converts hydrogen peroxide to water. It can also convert other reactive oxygen species (ROSs) to water.[3]
- **alpha-Lipoic acid**: reacts with reactive oxygen species such as superoxide radicals,

- hydroxyl radicals, hypochlorous acid, peroxyl radicals, and singlet oxygen. It also protects membranes by interacting with vitamin C, which may in turn recycle vitamin E.[4]
- **Peroxiredoxin:** participates directly in eliminating hydrogen peroxide (H_2O_2) and neutralizing other reactive oxygen species (ROS).[5]

Antioxidants are thought to work in concert with one another, forming what is known as the antioxidant network. For example, vitamin E, vitamin C, and selenium often work together to process a single reactive oxygen species.

Meaningful Antioxidant(s)

There is a lot of confusion among the public on antioxidants. For the most part, this is for a good reason. Many food companies put antioxidant numbers on the packages that sound good to consumers, who often have no idea how to interpret them. Thus, it is increasingly important to have an understanding of what a meaningful antioxidant actually is.

A **meaningful antioxidant** has two characteristics (these are based on the assumption that the compound is an antioxidant):

- Found in appreciable amounts in a location where there are free radicals/ROS that need to be quenched
- It is not redundant with another antioxidant that is already providing that function

What do these mean? Let's consider the example of lycopene and vitamin E, which are both fat-soluble antioxidants. In a lab setting (*in vitro*), lycopene has been shown to be 10x more effective than vitamin E. However, when you look at the concentrations found in the body, there is far more vitamin E (alpha-tocopherol) than lycopene:[6]

- LDL – 13x more alpha-tocopherol than lycopene.
- Prostate – 162x higher alpha-tocopherol than lycopene concentrations
- Skin – 17 to 269x higher alpha-tocopherol than lycopene concentrations
- Plasma – 53x higher alpha-tocopherol than lycopene concentrations

Thus, despite the fact that lycopene is a better antioxidant in the laboratory, vitamin

E is likely the more meaningful antioxidant in the body, as evidenced by the fact that its concentration so much higher in the various **tissues** (locations of need.) In addition, if lycopene and alpha-tocopherol had similar antioxidant functions, lycopene's potential antioxidant action is redundant to alpha-tocopherol's antioxidant function and thus, lycopene is less likely to be a meaningful antioxidant.

Too Much of a Good Thing? Antioxidants as Pro-oxidants

A clinical trial once found that high-dose beta-carotene supplementation increased lung cancer risk in smokers.[7] This is an example of findings that support that high doses of antioxidants may be "too much of a good thing", causing more harm than benefit. The parabolic, or U-shaped figure, below displays how the level of nutrient concentration or intake (horizontal axis) relates to an antioxidant measure (vertical axis). The lowest level of antioxidant intake or tissue concentration results in nutrient deficiency if the antioxidant is essential (vitamins and minerals). Intake levels above deficient, but less than optimal, are referred to as low suboptimal. Suboptimal means the levels are not optimal. Thus, low suboptimal and high suboptimal sandwich optimal. The high suboptimal level is between optimal and where the nutrient becomes toxic.

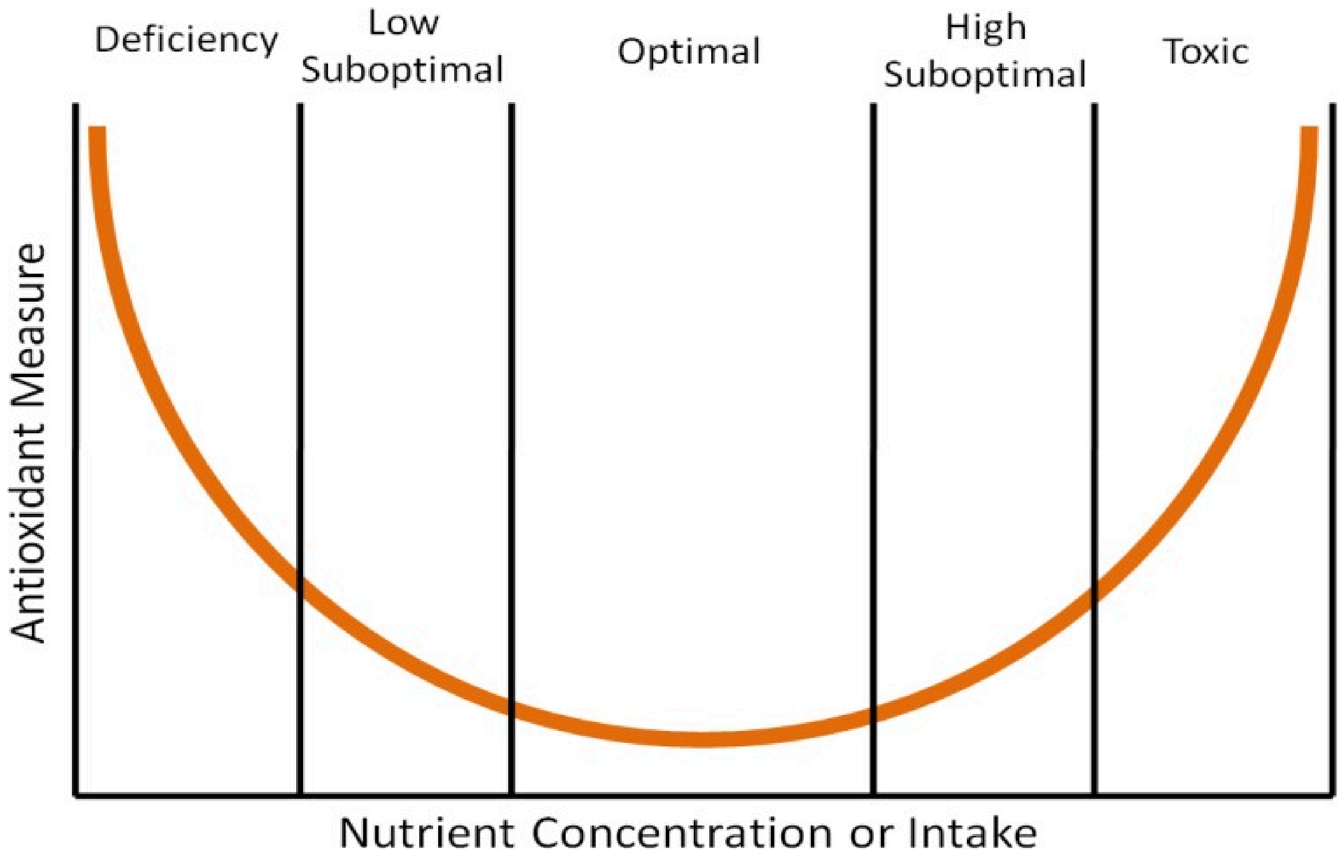

Figure 10.36 *How the levels of nutrient concentration or intake alters antioxidant measures in the body. Adapted from Waters (2005)*

Another example of this phenomenon can be seen when we look at DNA damage in the prostate gland of dogs as it relates to toenail selenium concentration measurements, which are a good indicator of long-term selenium status.[8] Researchers found that when they plotted prostate DNA damage (a measure of oxidative stress) against toenail selenium status (nutrient concentration or intake) that it resulted in a U-shaped curve like the one shown above. Thus, it is good to have antioxidants in your diet, but too much can be counterproductive.

Notes

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10.4 Vitamin E

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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.[12]

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.[3]

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 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.[45]

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 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.[6]

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, 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.[7]

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 10.41 "Dietary Reference Intakes for Vitamin E".

Table 10.41 Dietary Reference Intakes for Vitamin E[8]

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		

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 10.42 "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 10.42 Vitamin E Content of Various Foods[9]

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

Notes

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Supplements. http://ods.od.nih.gov/factsheets/VitaminE-QuickFacts/. Updated October 11, 2011. Accessed October 5, 2017.

8. 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.
9. 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.

10.5 Vitamin C

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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 10.51 "The Role of Vitamin C in Collagen Synthesis")

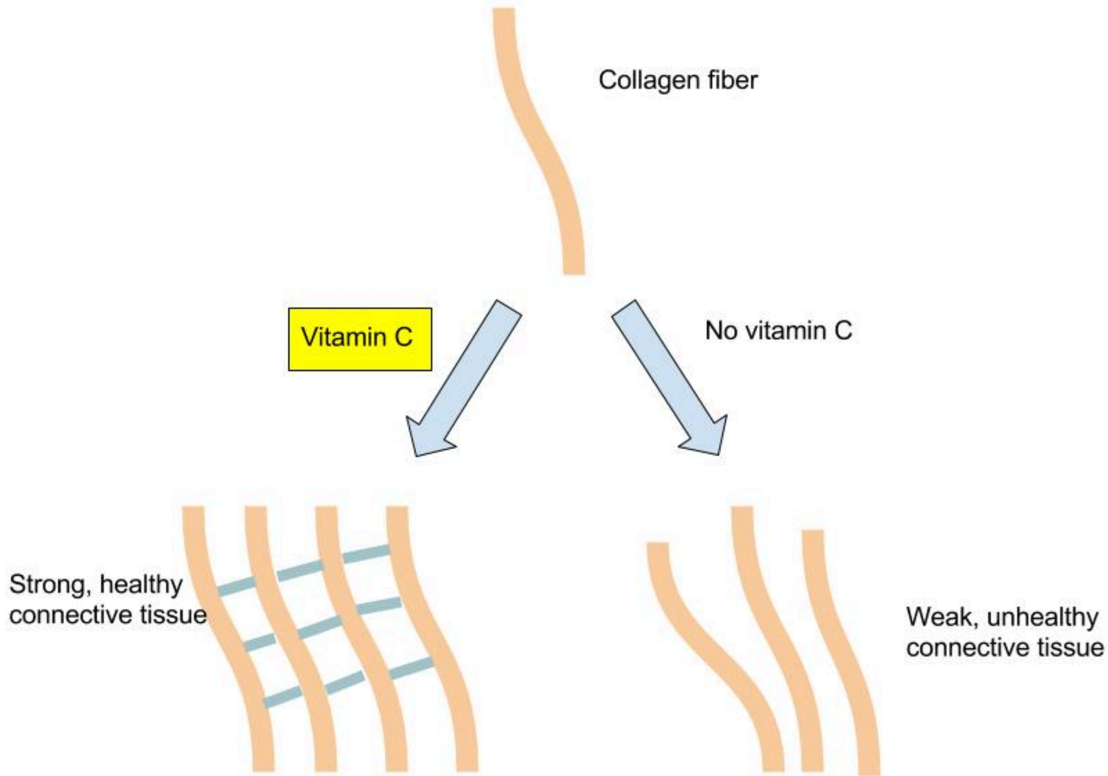

Figure 10.51 *The Role of Vitamin C in Collagen Synthesis. Image by Allison Calabrese / CC BY 4.0*

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 10.52 *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 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 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 IOM has set a UL for adults at 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.

Dietary Reference Intakes for Vitamin C

The RDAs and ULs for different age groups for vitamin C are listed in Table 10.51 "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 10.51 Dietary Reference Intakes for Vitamin C[4]

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		

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 10.52 "Vitamin C Content of Various Foods".

Table 10.52 Vitamin C Content of Various Foods[5]

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

Notes

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10.6 Selenium

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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.

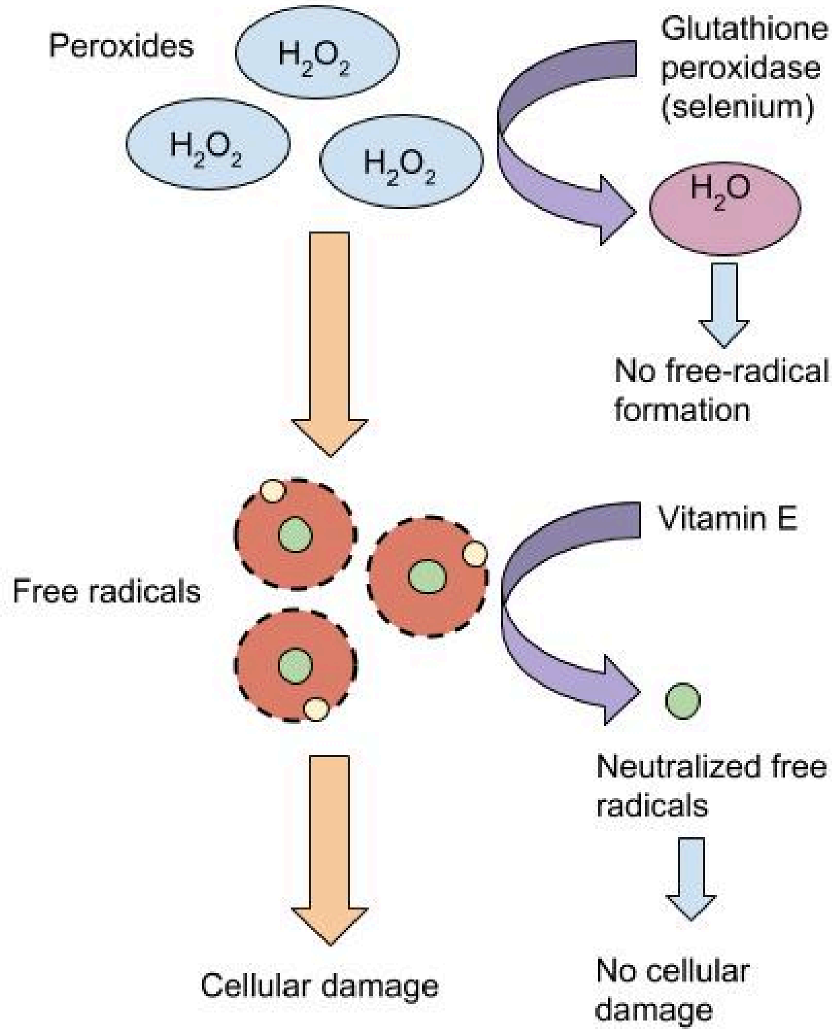

Figure 10.61 *Selenium's Role in Detoxifying Free Radicals. Image by Allison Calabrese / CC BY 4.0*

Dietary Reference Intakes for Selenium

The Institute of Medicine has set the RDAs for selenium 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 10.61 "Dietary Reference Intakes for Selenium".

Table 10.61 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 IOM has set the UL for selenium for adults at 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.

The selenium content of plants is dependent on the soil where they are grown. The figure below shows that soil selenium levels vary greatly throughout the United States, meaning that the selenium content of plant foods is also very variable.

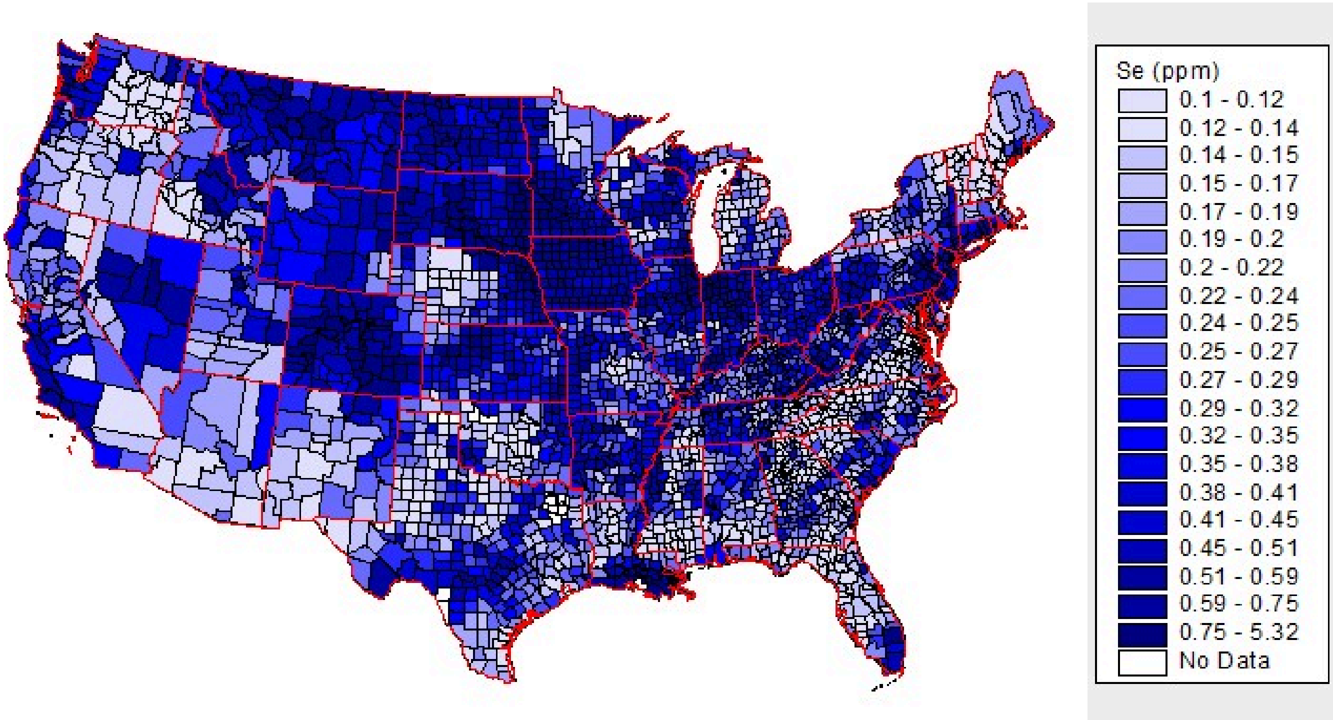

Figure 10.62 *United States soil selenium levels. Image source*

Nevertheless, we can make an average estimate of the amount of selenium in different foods.

Table 10.62 Selenium Contents of Various Foods[2]

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

Notes

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.
2. 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.

CHAPTER XI

CHAPTER 11: MICRONUTRIENTS IN METABOLISM

Essentially all of the B vitamins are involved in metabolism, as well as vitamin C and the **minerals** iodine, manganese, and magnesium. Vitamin C was covered in the antioxidant chapter. Magnesium will be covered with the electrolytes. The rest will be discussed here.

Do B-Vitamin Supplements Provide an Energy Boost?[1]

As you read about **micronutrients** and energy metabolism, you may find yourself thinking of advertisements for vitamin supplements that claim to "boost your energy". 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.

Sections:

11.5 Vitamin B6
11.6 Biotin (Vitamin B7)
11.7 Folate (Vitamin B9)
11.8 Vitamin B12
11.9 Iodine
11.10 Manganese

Chapter 11 is primarily adapted from Fialkowski Revilla, et al. *Human Nutrition*

Notes

1. Fialkowski Revilla, et al. *Human Nutrition*

11.1 Thiamin (Vitamin B1)

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Thiamin (B_1)

Thiamin is especially important in glucose **metabolism**. It acts as a coenzyme for enzymes that break down glucose for energy production. 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.[1]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 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.[2]

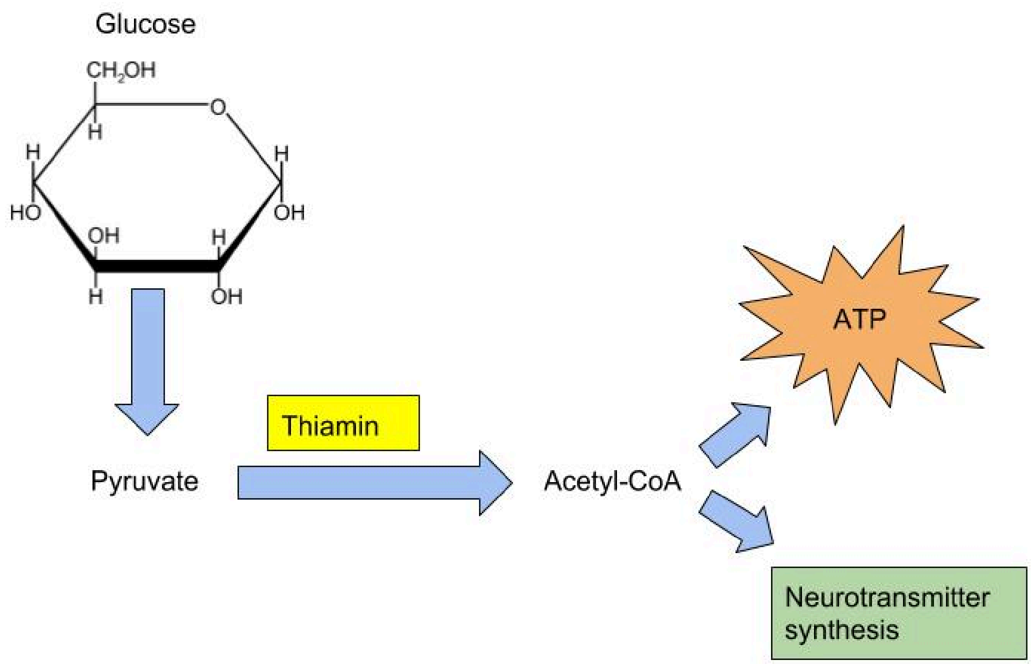

Figure 11.11 *The Role of Thiamin. Image by Allison Calabrese / CC BY 4.0*

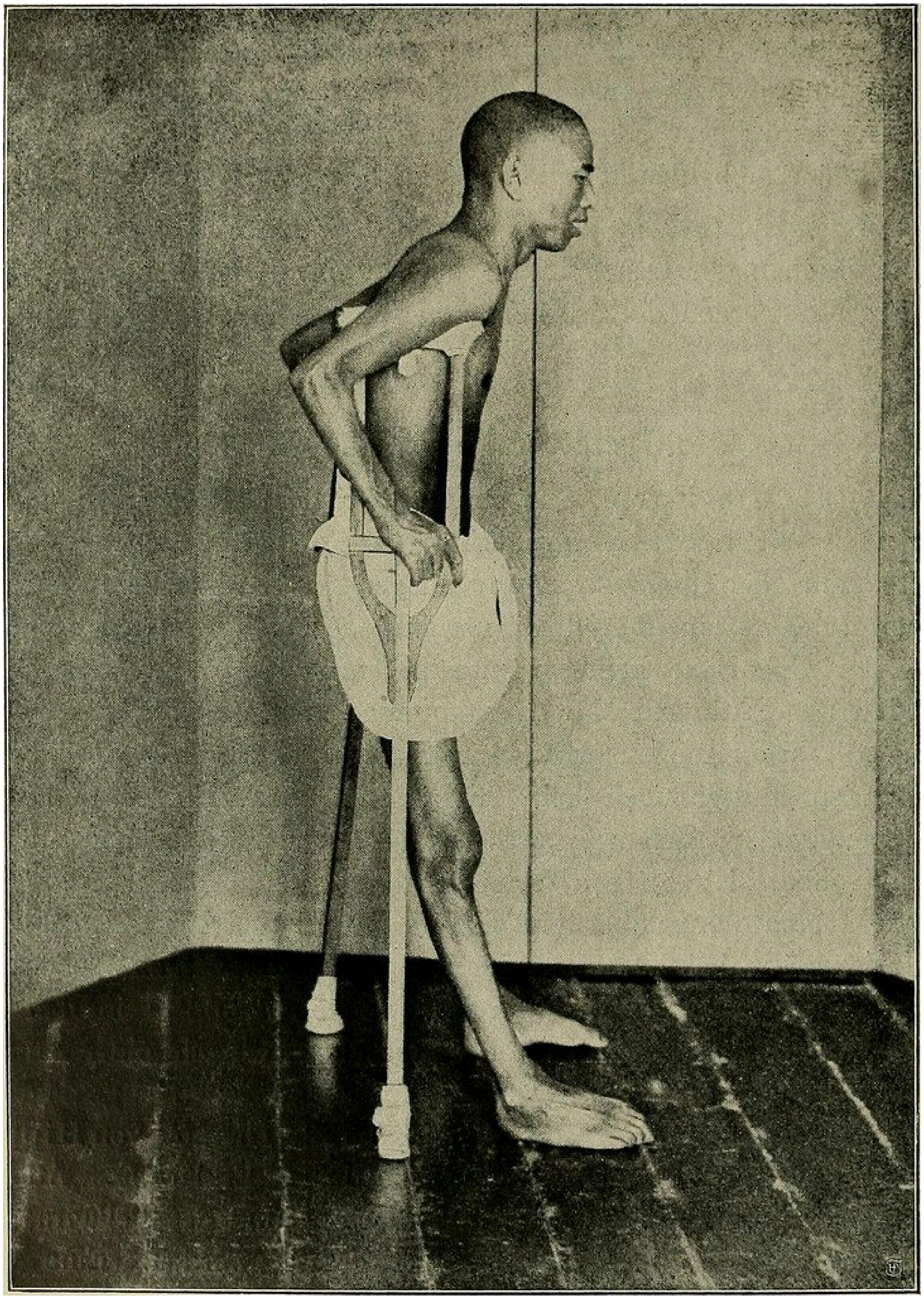

Figure 11.12 *Beriberi, Thiamin Deficiency. Image by Casimir Funk (1914) / No known copyright restrictions*

Dietary Reference Intakes

The RDAs and ULs for different age groups for thiamin are listed in Table 11.11 "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 11.11 Dietary Reference Intakes for Thiamin[3]

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	

Dietary Sources

Whole grains, meat and fish are great sources of thiamin. The United States as well as many other countries, fortify their refined breads and cereals. For the thiamin content of various foods, see Table 11.12 "Thiamin Content of Various Foods".

Table 11.12 Thiamin Content of Various Foods[4]

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

Notes

1. 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.
2. 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.
3. 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.
4. 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.

11.2 Riboflavin (Vitamin B2)

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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 11.21 "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 11.21 Dietary Reference Intakes for Riboflavin[1]

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	

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 11.22 Riboflavin Content of Various Foods".

Table 11.22 Riboflavin Content of Various Foods[2]

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

Notes

1. 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.
2. 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.

11.3 Niacin (Vitamin B3)

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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.

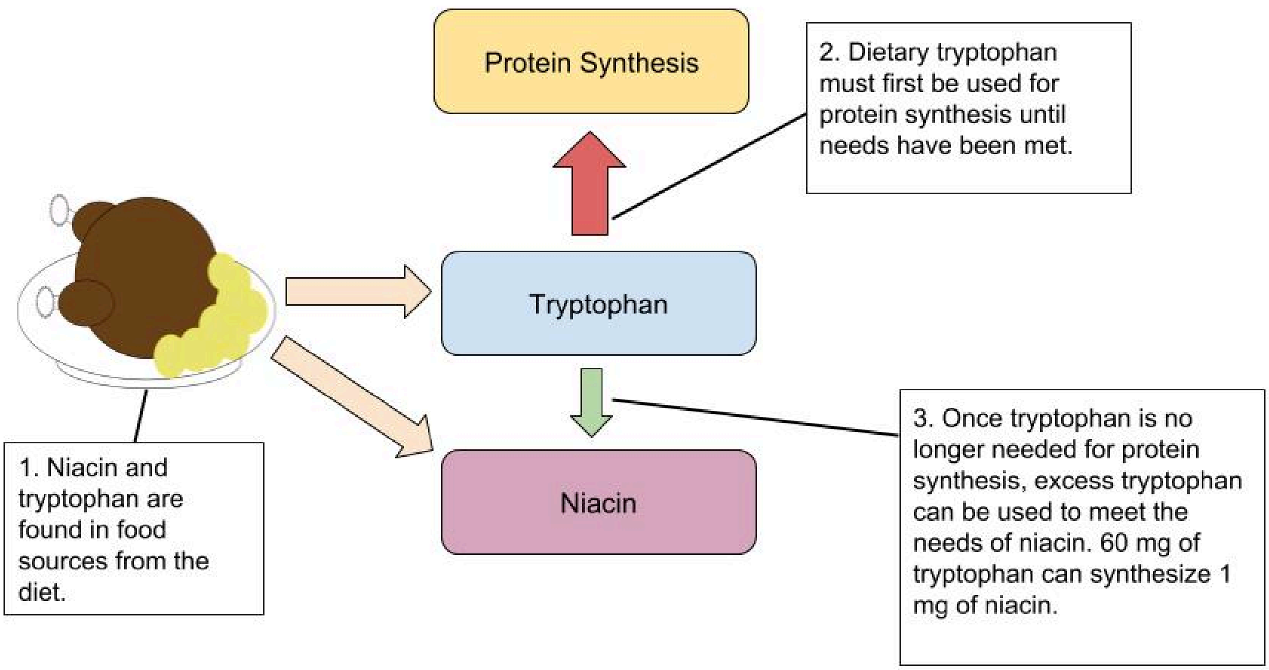

Figure 11.31 *Conversion of Tryptophan to Niacin. Image by Allison Calabrese / CC BY 4.0*

Figure 11.32 *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 11.31 “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 11.31 Dietary Reference Intakes for Niacin[1]

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		

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 11.32 "Niacin Content of Various Foods".

Table 11.32 Niacin Content of Various Foods[2]

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

Notes

1. 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.
2. 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.

11.4 Pantothenic Acid (Vitamin B5)

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Pantothenic Acid (B5)

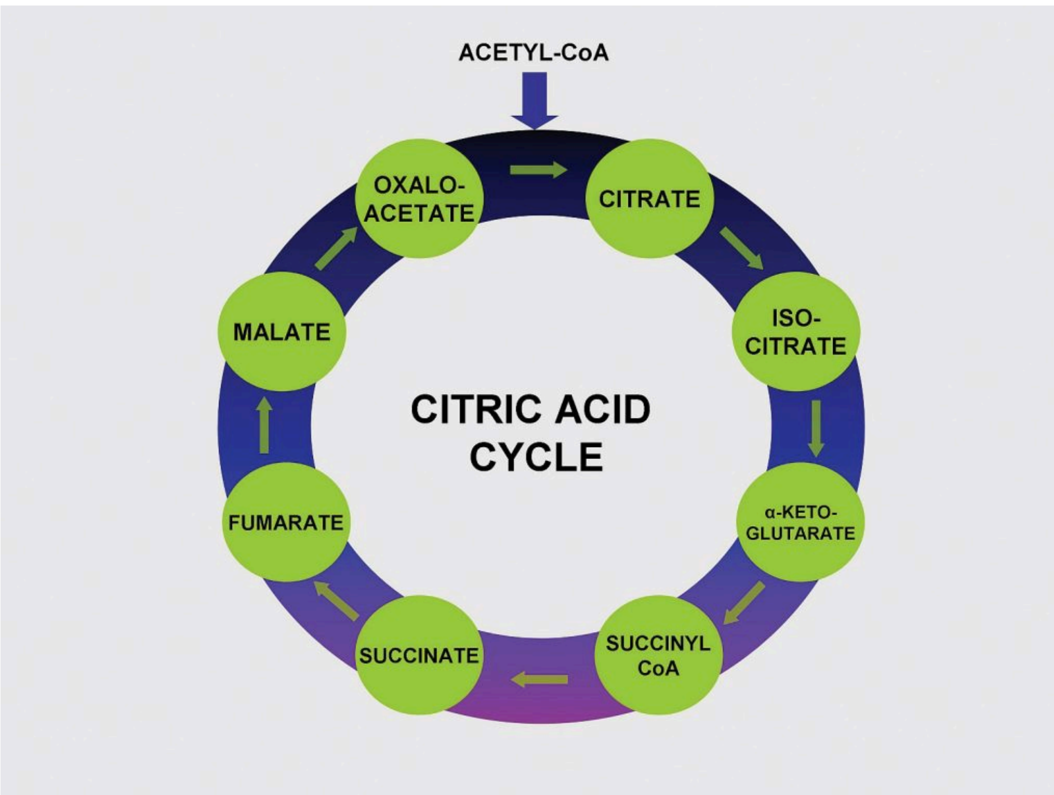

Figure 11.41 *Pantothenic Acid (Vitamin B5) makes up coenzyme A, which carries the carbons of glucose, fatty acids, and amino acids into the citric acid cycle as Acetyl-CoA.*

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 11.41). 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 acid, the Food and Nutrition Board (FNB) has developed **Adequate Intakes** (AI) based on the observed dietary intakes in healthy population groups. The AI for different age groups for pantothenic acid are listed in Table 11.41 "Dietary Reference Intakes for Pantothenic Acid ".

Table 11.41 Dietary Reference Intakes for Pantothenic Acid[1]

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

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 11.42 Pantothenic Acid Content of Various Foods".

Table 11.42 Pantothenic Acid Content of Various Foods[2]

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

Notes

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.
2. Micronutrient Information Center: Pantothenic Acid. Oregon State University, Linus Pauling Institute. http://lpi.oregonstate.edu/mic/vitamins/pantothenic-acid . Updated in July 2013. Accessed October 22, 2017.1

11.5 Vitamin B6

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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 11.51 "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.

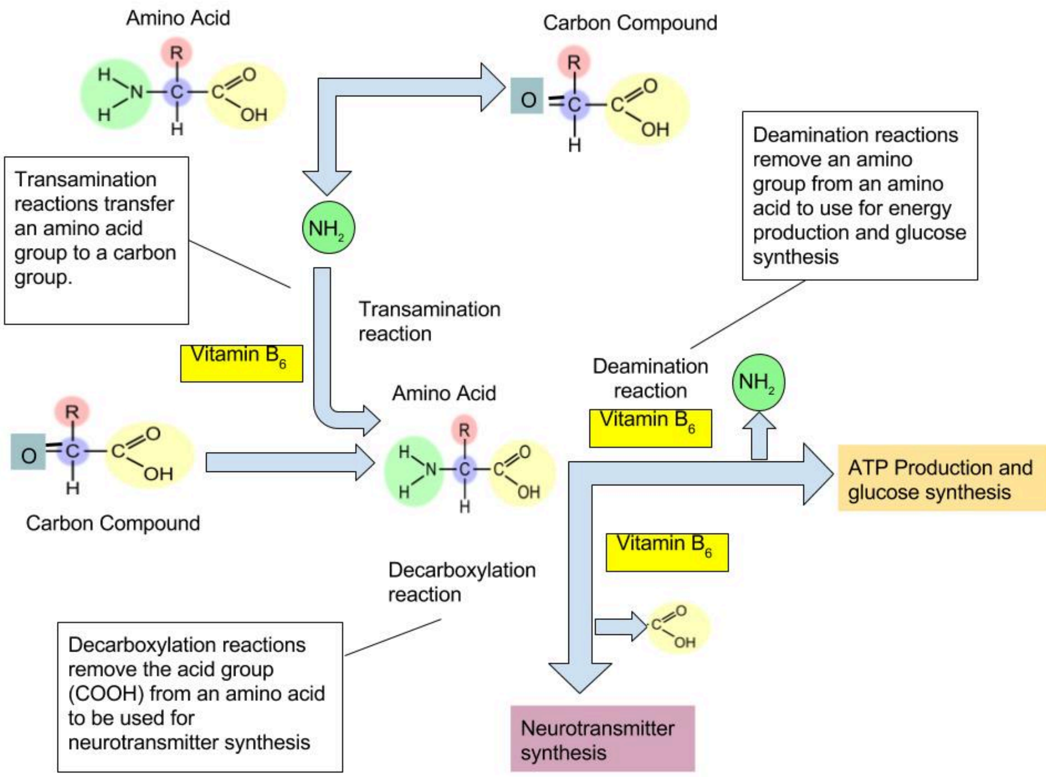

Figure 11.51 *The Function of Vitamin B6 in Amino Acid Metabolism. Image by Allison Calabrese / CC BY 4.0*

The vitamin B_6 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.

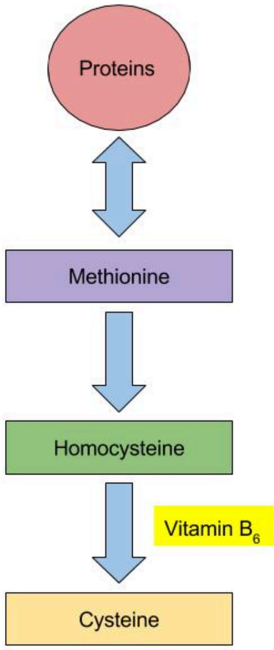

Figure 11.52 *Vitamin B6 Functional Coenzyme Role. Image by Allison Calabrese / CC BY 4.0*

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 B6 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 11.51 "Dietary Reference Intakes for Vitamin B_6".

Table 11.51 Dietary Reference Intakes for Vitamin B_6[1]

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 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 11.52 Vitamin B_6 Content of Various Foods".

Table 11.52 Vitamin B_6 Content of Various Foods[2]

Food	Serving	Vitamin B_6 (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

Notes

1. 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.
2. 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.

11.6 Biotin (Vitamin B7)

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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 FNB has developed **Adequate Intakes** (AI) based on the observed dietary intakes in healthy population groups. The AI for different age groups for biotin are listed in Table 11.61 "Dietary Reference Intakes for Biotin".

Table 11.61 Dietary Reference Intakes for Biotin[1]

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

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 11.62 Biotin Content of Various Foods".

Table 11.62 Biotin Content of Various Foods[2]

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			

Notes

1. 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.
2. 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.

11.7 Folate (Vitamin B9)

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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 11.71 "Folate and the Formation of Macrocytic Anemia")

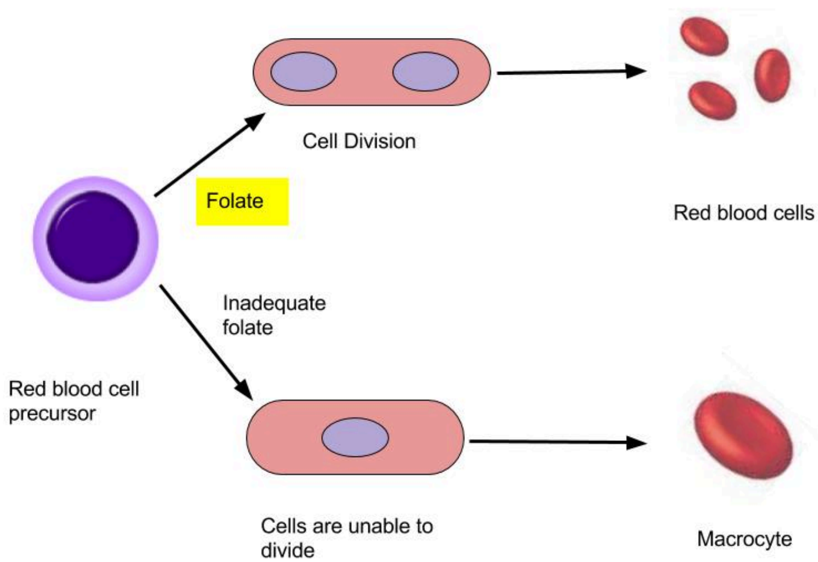

***Figure 11.71** Folate and the Formation of Macrocytic Anemia. Image by Allison Calabrese / CC BY 4.0*

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 11.72 "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 1996 in the United States (and 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. In response to the scientific evidence, the Food and Nutrition Board of the Institute of Medicine (IOM) raised the RDA 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.

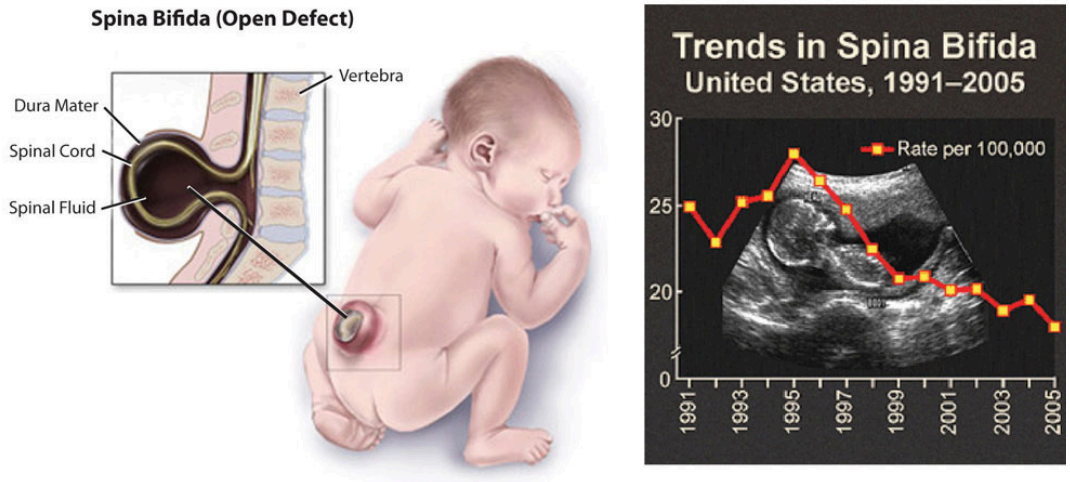

Figure 11.72 *Spina Bifida in Infants. Spina bifida is a neural-tube defect that can have severe health consequences.*

Dietary Reference Intakes

The RDAs and ULs for different age groups for folate are listed in Table 11.71 "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 FNB has developed dietary folate equivalents (DFE) 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 11.71 Dietary Reference Intakes for Folate[1]

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 Sources

Folate is found naturally in a wide variety of food especially in dark leafy vegetables, fruits, and animal products. The U.S. **Food and Drug Administration (FDA)** began requiring manufacturers to fortify enriched breads, cereals, flours, and cornmeal to increase the consumption of folate in the American diet. For the folate content of various foods, see Table 11.72 "Folate Content of Various Foods".

Table 11.72 Folate Content of Various Foods[2]

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

Notes

1. 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.
2. 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.

11.8 Vitamin B12

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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

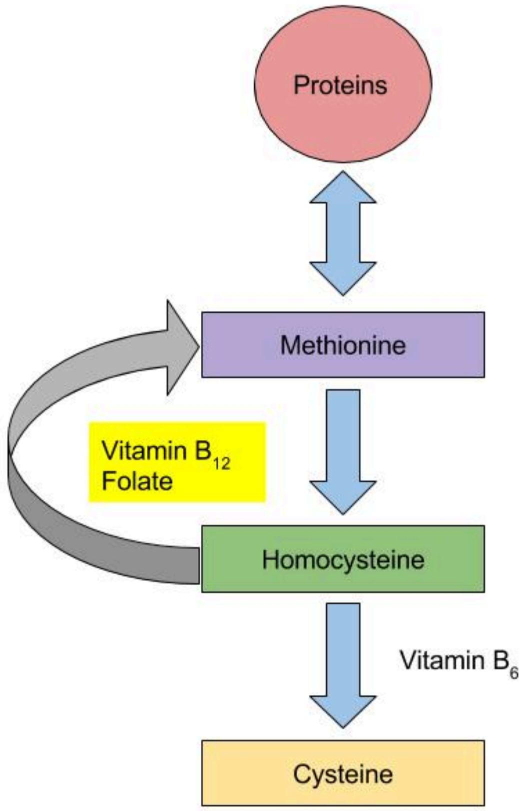

Figure 11.81 *B Vitamins Coenzyme Roles. Image by Allison Calabrese / CC BY 4.0*

Vitamin B_{12} and folate play key roles in converting homocysteine to amino acid methionine. As mentioned in Section 11.5, high levels of homocysteine in the blood increases the risk for heart disease. Low levels of vitamin B_{12}, folate or vitamin B_6 will increase homocysteine levels, therefore increasing the risk of heart disease.

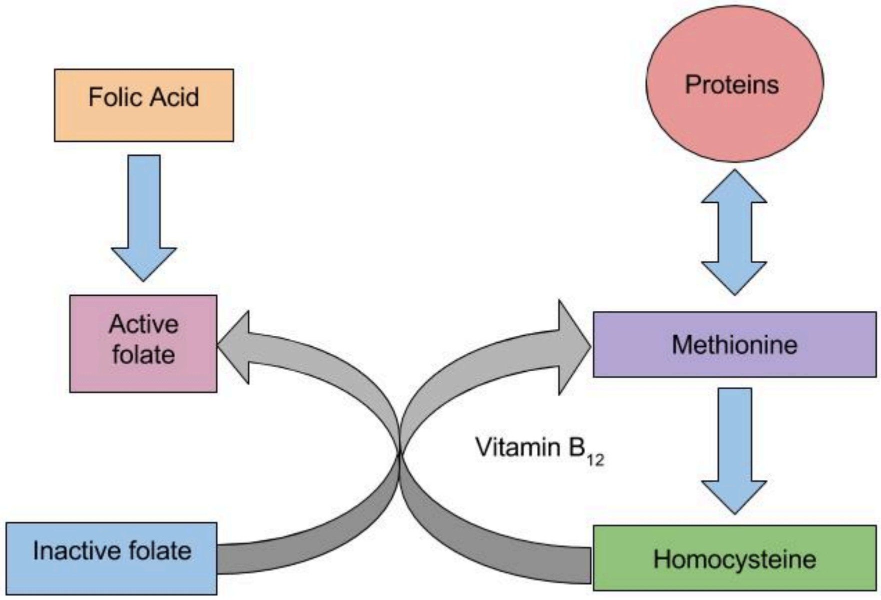

Figure 11.82 *The Relationship Between Folate and Vitamin* B_{12}*. Image by Allison Calabrese / CC BY 4.0*

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 11.81 "Dietary Reference Intakes for Vitamin B_{12}".

Table 11.81 Dietary Reference Intakes for Vitamin B_{12}[1]

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 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 11.82 "Vitamin B_{12} Content of Various Foods".

Table 11.82 Vitamin B_{12} Content of Various Foods[2]

Food	Serving	Vitamin B_{12} (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

Notes

1. 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.
2. 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.

11.9 Iodine

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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]

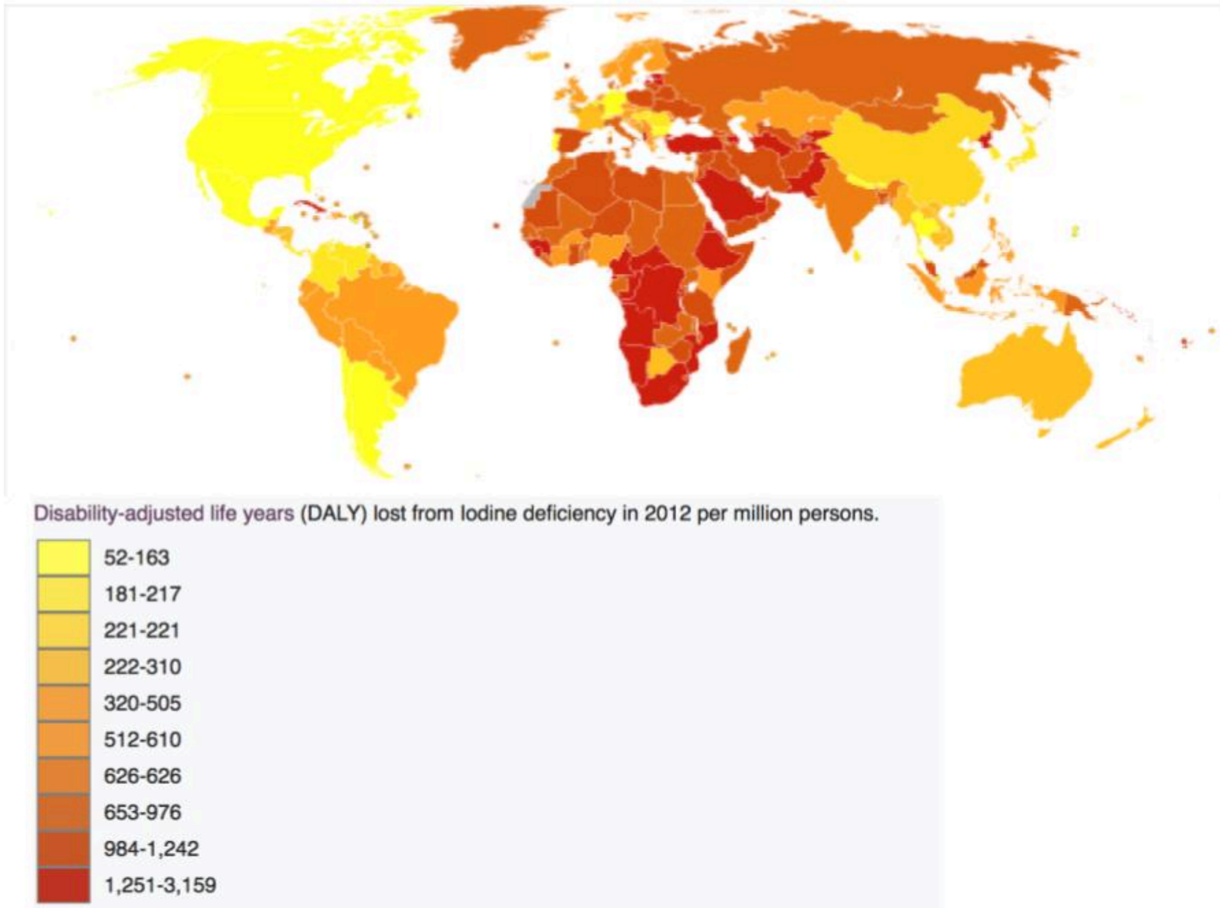

Figure 11.91 *Deaths Due to Iodine Deficiency Worldwide in 2012. Image by Chris55 / CC BY 4.0*

Figure 11.92 *Iodine Deficiency: Goiter. Credit: A large goiter by Dr. J.S.Bhandari, India / CC BY-SA 3.0*

Dietary Reference Intakes for Iodine

Table 11.91 Dietary Reference Intakes for Iodine[2]

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		

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. Because of this high variability in iodine content and the importance of iodine in brain development, many countries add iodine to table salt. Consumption of 1/2 teaspoon of iodized salt meets the RDA for iodine.

Table 11.92 Iodine Content of Various Foods[3]

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

Notes

1. World Health Organization. "Iodine Status Worldwide." Accessed October 2, 2011. http://whqlibdoc.who.int/publications/2004/9241592001.pdf.
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.
3. 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.

11.10 Manganese

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Manganese is a cofactor for enzymes that are required for carbohydrate and cholesterol metabolism, bone formation, and the synthesis of urea. The antioxidant enzyme **superoxide dismutase** also uses manganese as a cofactor.

Manganese deficiency is uncommon, and there is not a clear syndrome that has been characterized. When it has been observed, symptoms have included impaired growth, bone demineralization, and changes to blood cholesterol and/or glucose tolerance. Toxicity is more of a concern with manganese. Occupational exposure has been seen in welders and miners who inhale manganese dust. Toxicity has also occurred as a result of contaminated drinking water. Long-term overexposure to manganese can cause neurological symptoms similar to Parkinson's disease.[1]

Dietary Reference Intakes for Manganese

Table 11.101 Dietary Reference Intakes for Manganese[2]

Age Group	AI, Males (mg/day)	AI, Females (mg/day)	UL (mg/day)
Infants (0–6 mon.)	0.003	0.003	–
Infants (7–12 mon.)	0.6	0.6	–
Children (1–3 years)	1.2	1.2	2
Children (4–8 years)	1.5	1.5	3
Children (9–13 yrs)	1.9	1.6	6
Adolescents (14–18 yrs)	2.2	1.6	7
Adults (> 19 years)	2.3	1.8	11

Dietary Sources of Manganese

Table 11.102 Some Food Sources of Manganese[3]

Food	Serving	Manganese (mg)
Pineapple, raw	1/2 cup, chunks	0.77
Pineapple juice	1/2 cup (4 fl. oz.)	0.63
Pecans	1 ounce (19 halves)	1.28
Almonds	1 ounce (23 whole kernels)	0.65
Peanuts	1 ounce	0.55
Instant oatmeal (prepared with water)	1 packet	0.99
Raisin bran cereal	1 cup	0.78-3.02
Brown rice, cooked	1/2 cup	1.07
Whole wheat bread	1 slice	0.60
Pinto beans, cooked	1/2 cup	0.39
Lima beans, cooked	1/2 cup	0.49
Spinach, cooked	1/2 cup	0.44
Sweet potato, cooked	1/2 cup, mashed	0.44
Tea (green)	1 cup (8 ounces)	0.41-1.58

Notes

1. Micronutrient Information Center: Manganese. Oregon State University, Linus Pauling Institute. https://lpi.oregonstate.edu/mic/minerals/manganese. Updated in March 2010. Accessed September 02, 2020.
2. Source: Micronutrient Information Center: Manganese. Oregon State University, Linus Pauling Institute. https://lpi.oregonstate.edu/mic/minerals/manganese. Updated in March 2010. Accessed September 02, 2020.
3. Source: Micronutrient Information Center: Manganese. Oregon State University, Linus Pauling

Institute. https://lpi.oregonstate.edu/mic/minerals/manganese. Updated in March 2010. Accessed September 02, 2020.

CHAPTER XII

CHAPTER 12: MICRONUTRIENTS IN BONES, BLOOD, AND EYES

This chapter is a collection of vitamins and **minerals** that are involved in the structure or function of bones and teeth, blood, and eyes. The individual sections are:

Sections:

- Bones & Teeth:
  - 12.1 Vitamin D
  - 12.2 Calcium
  - 12.3 Phosphorus
  - 12.4 Fluoride
- Blood:
  - 12.5 Vitamin K
  - 12.6 Iron
  - 12.7 Zinc
  - 12.8 Copper
- Eyes:
  - 12.9 Vitamin A

Chapter 12 is adapted from Fialkowski Revilla et al., *Human Nutrition*.

12.1 Vitamin D

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Vitamin D Functions and Health Benefits

Vitamin D refers to a group of fat-soluble vitamins derived from cholesterol. Vitamins D_2 (**ergocalciferol**) and D_3 (**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 D_3 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 D_3 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 D_3 more than orally taking 10,000 IU (250 micrograms) of vitamin D_3.

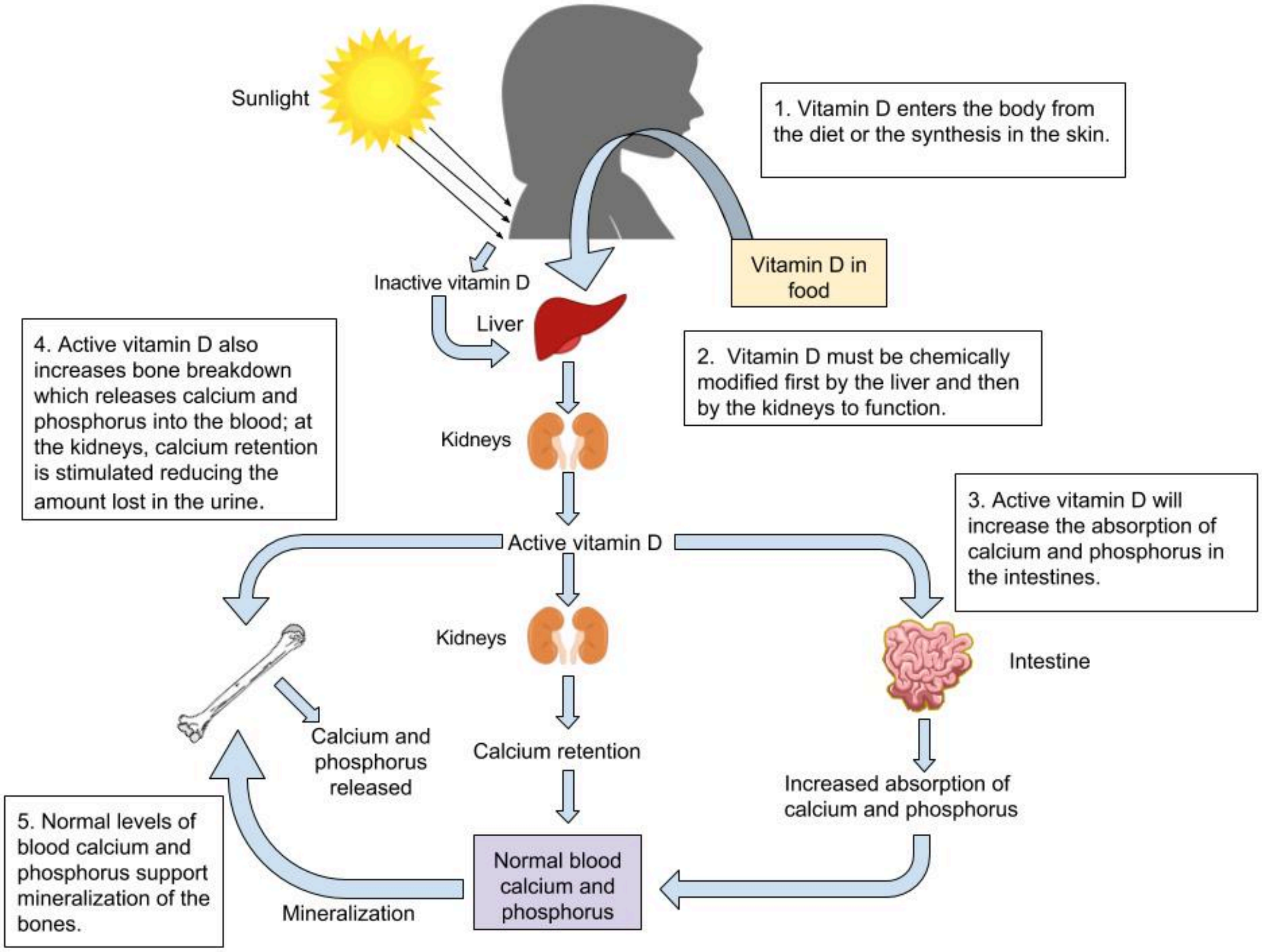

Figure 12.11 *The Functions of Vitamin D. Image by Allison Calabrese / CC BY 4.0*

Vitamin D's Functional Role

Activated vitamin D_3 (**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 **bone mineral density (BMD)**. Osteomalacia has the same symptoms and consequences as osteoporosis and often coexists with osteoporosis. Osteoporosis is a condition where the bones become fragile due to loss of bone density. 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 12.12 *Rickets in Children. Credit: 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.[1] 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 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 D_3 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 12.11 "Dietary Reference Intakes for Vitamin D". For adults, the RDA is 600 international units (IUs), which is equivalent to 15 micrograms of vitamin D. The National Osteoporosis Foundation recommends slightly higher levels and that adults under age fifty get between 400 and 800 international units of vitamin D every day, and adults fifty and older get between 800 and 1,000 international units of vitamin D every day. According to the National Academy of Medicine, 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 12.11 Dietary Reference Intakes for Vitamin D[2]

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		

Dietary Sources of Vitamin D

Table 12.12 Vitamin D Content of Various Foods[3]

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

Notes

1. 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.
2. 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.
3. 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.

12.2 Calcium

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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. 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 phosphate salts (hydroxyapatite) 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, and **osteoporosis** develops (see below). Thus, increased calcium intake helps to increase the mineralized content of bone tissue. Greater mineralized bone tissue corresponds to a greater **bone mineral density (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.

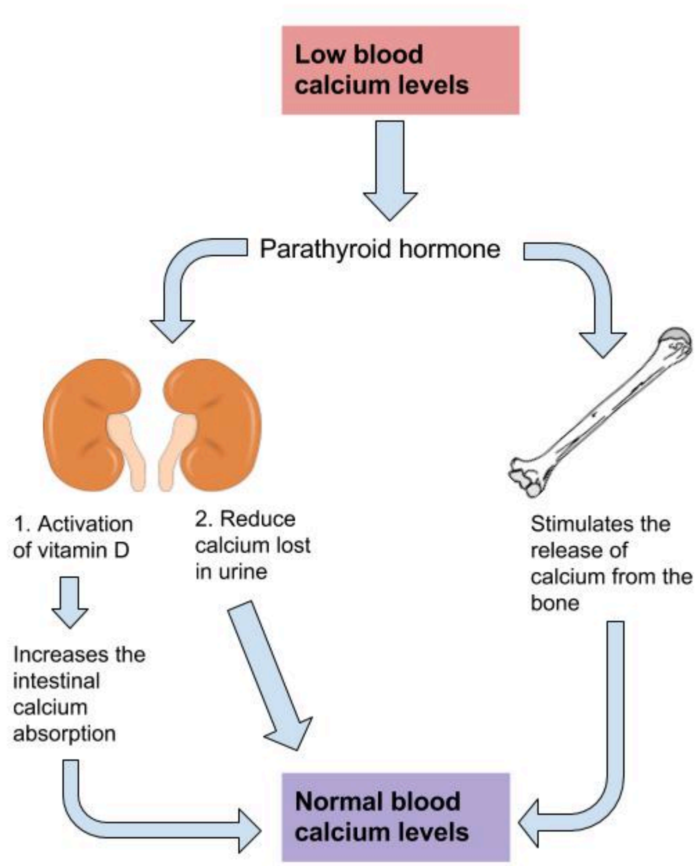

Figure 12.21 *Maintaining Blood Calcium Levels. Image by Allison Calabrese / CC BY 4.0*

Osteoporosis

As mentioned above, one of the most important reasons to get an adequate amount of calcium in your diet is to keep your bones strong. A diet deficient in calcium can lead to the development of osteoporosis. Osteoporosis occurs when bone mineral density and bone mass decrease. Healthy bone is porous, like a sponge, but in osteoporotic bone, the holes become larger and the network of bone tissue becomes very thin and fragile (Figure 12.22). This fragility means that bones are easily broken and can even collapse under the weight of the body, as seen in Figure 12.23. Osteoporosis can occur in anyone, but there are many risk factors that can make a person more likely to develop the disease. Some risk factors we cannot control (nonmodifiable) and some we can control (modifiable).

Nonmodifiable risk factors for osteoporosis include:

- **Age.** The older you are, the more likely you are to develop osteoporosis.
- **Sex.** Women are at higher risk of developing osteoporosis, particularly after **menopause**. The hormone estrogen promotes bone density. At menopause, the ovaries stop producing estrogen and bone breaks down more quickly than it can be rebuilt.
- **Body size.** Bone becomes stronger and more dense as pressure is put on it. Therefore, shorter, slender individuals will have less dense bone than taller, heavier individuals. With less bone to start with, smaller-framed individuals are at greater risk of developing osteoporosis.
- **Family history.** If you have a close relative with osteoporosis, you may be at increased risk of developing osteoporosis yourself.
- **Medical conditions or medications.** Different types of medical conditions can increase the risk of developing osteoporosis, including rheumatoid arthritis, gastrointestinal disease, types of cancer, HIV/AIDS, and **anorexia nervosa**. There are also certain medications that increase the risk if used over the long term.

Modifiable risk factors include:

- **Exercise.** Weight-bearing exercise makes your bones stronger as well as your muscles. Regularly walking, jogging, or lifting weights can strengthen your bones and keep them strong as you age.
- **Diet.** Adequate amounts of calcium and vitamin D are essential for building strong bones when you're young and for maintaining bone density as you age.
- **Exposure to sunlight**. Sunlight causes the formation of vitamin D in your skin, which allows you to better absorb calcium from your diet.
- **Smoking and alcohol use.** Both smoking and heavy drinking of alcohol increase your risk of developing osteoporosis. Avoid secondhand smoke as well.[12]

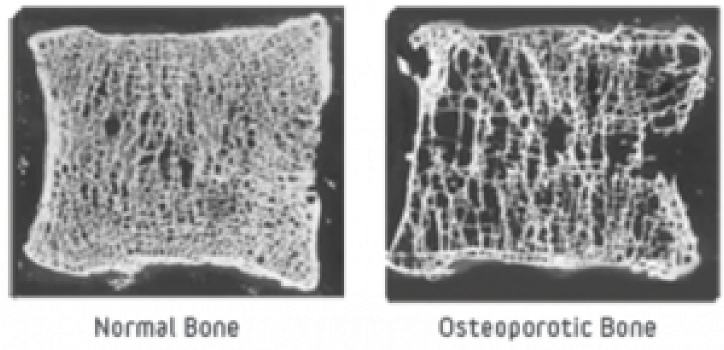

Figure 12.22 *Comparison of vertebrae from a healthy 37 year old male (left) and a 75 year old female suffering from osteoporosis (right). Image from Turner Biomechanics Laboratory / CC0*

Figure 12.23 *An elderly woman showing the "dowager's hump" characteristic of osteoporosis. The hunched posture comes from compression of vertebrae. Image by James Heilman, MD / CC BY-SA 3.0*

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**. The National Cancer Institute reports that 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.[3]
- **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.

Calcium inadequacy is most prevalent in adolescent girls and the elderly. Proper dietary intake of calcium is critical for proper bone health.

Despite the wealth of evidence supporting the many health benefits of calcium (particularly bone health), the average American diet falls short of achieving the recommended dietary intakes of calcium. In fact, in females older than nine years of age, the average daily intake of calcium is only about 70 percent of the recommended intake. 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.[45] 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.[67]

- **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 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.[8]
- **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.[9]
- **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.[10]

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, 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.[11]

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 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.[12]

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.
2. People with risk factors for osteoporosis are advised to take calcium supplements if they are unable to get enough calcium in their diet. The National Osteoporosis Foundation advises that adults age fifty and above consume 1,200 milligrams of

calcium per day. 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 12.21 "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. The Institute of Medicine (IOM) recommends that people do not consume over 2,500 milligrams per day of calcium as it may cause adverse effects in some people.

Table 12.21 Dietary Reference Intakes for Calcium[13]

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		

Dietary Sources of Calcium

In the typical American 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. Although the typical American diet relies mostly on dairy products for obtaining calcium, there are other good non-dairy sources of calcium.

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 12.22 Calcium Content of Various Foods[14]

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

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.

Notes

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12.3 Phosphorus

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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 parathyroid hormone stimulates renal excretion of phosphate so that it does not accumulate to toxic levels.

Dietary Reference Intakes for Phosphorus

In comparison to calcium, most Americans are not at risk for having a phosphate deficiency. Phosphate is present in many foods popular in the 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 average intake of phosphorus in US adults ranges between 1,000 and 1,500 milligrams per day, well above the RDA of 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 12.31 Dietary Reference Intakes for Phosphorus[1]

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		

Dietary Sources of Phosphorus

Table 12.32 Phosphorus Content of Various Foods[2]

Foods	Serving	Phosphorus (mg)	Percent Daily Value (1000mg)
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

Notes

1. 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.
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12.4 Fluoride

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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 was first added to drinking water in 1945 in Grand Rapids, Michigan; now over 60 percent of the US population consumes fluoridated drinking water. The **Centers for Disease Control and Prevention (CDC)** has reported that fluoridation of water prevents, on average, 27 percent of cavities in children and between 20 and 40 percent of cavities in adults. The CDC considers water fluoridation one of the ten great public health achievements in the twentieth century[1].

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 12.41** A Severe Case of Fluorosis. Credit: 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 **bone mineral density (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. The Food and Drug Administration has not approved fluoride for the treatment of osteoporosis mainly because its benefits are not sufficiently known and it has several side effects including frequent stomach upset and joint pain. The doses of fluoride used to treat osteoporosis are much greater than that in fluoridated water.

Dietary Reference Intake

The IOM has given **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 12.41 Dietary Reference Intakes for Fluoride[2]

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

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 12.42 Fluoride Content of Various Foods[3]

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			

Notes

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12.5 Vitamin K

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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. The Food and Nutrition Board (FNB) has not established an UL for vitamin K because it has a low potential for toxicity. According to the FNB, "no adverse effects associated with vitamin K consumption from food or supplements have been reported in humans or animals."[1]

Table 12.51 Dietary Reference Intakes for Vitamin K[2]

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	

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 12.52 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

Notes

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12.6 Iron

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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 12.61). 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.

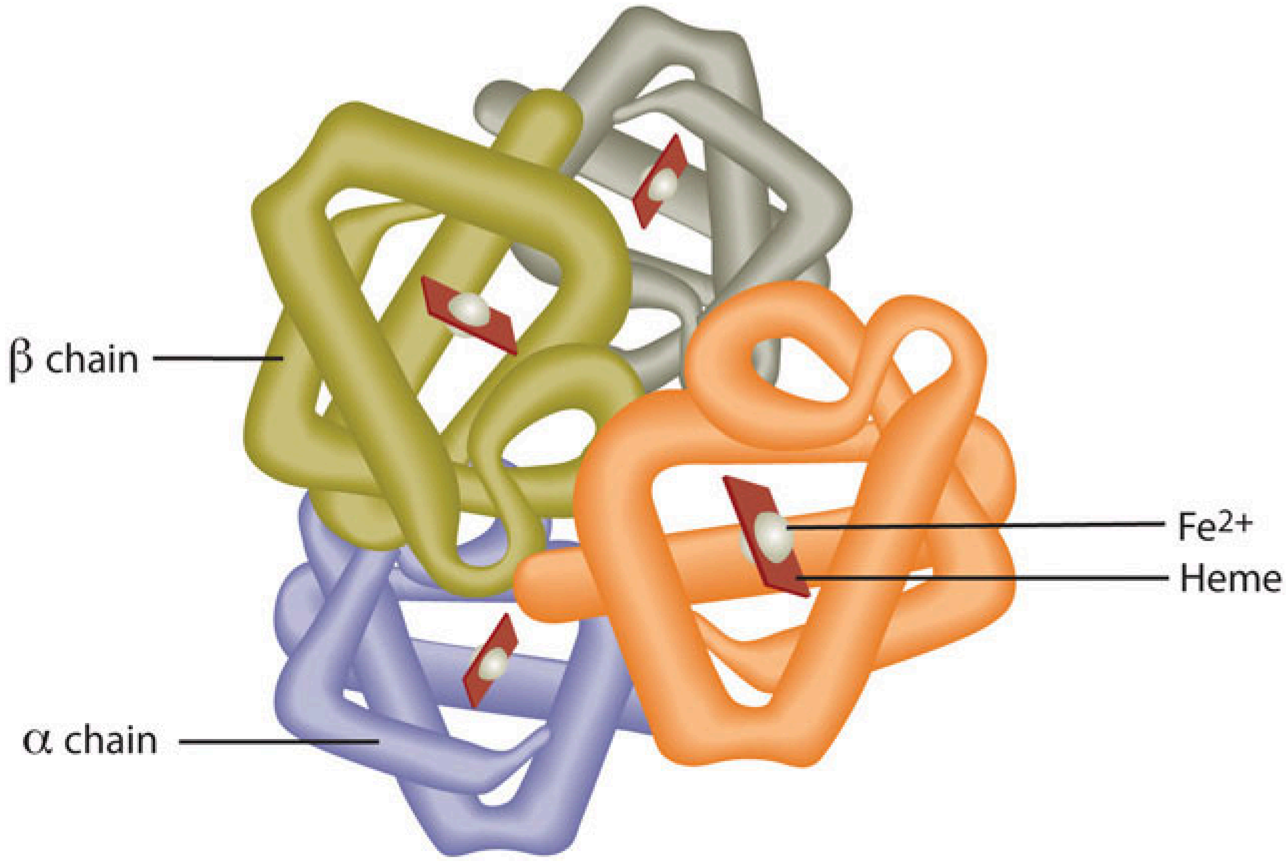

Figure 12.61 *The Structure of Hemoglobin. Hemoglobin is composed of four peptides. Each contains a heme group with iron in the center.*

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 careful meal planning does prevent its development. Iron deficiency is the most common of all micronutrient deficiencies.

Table 12.61 Enhancers and Inhibitors of Iron Absorption

Enhancers	Meat, Fish, Poultry, Seafood, Stomach acid, Vitamin C
Inhibitors	Phosphate, Calcium, Tea, Coffee, Colas, Soy protein, High doses of minerals (antacids), Bran/fiber, Phytates, Oxalates, Polyphenols

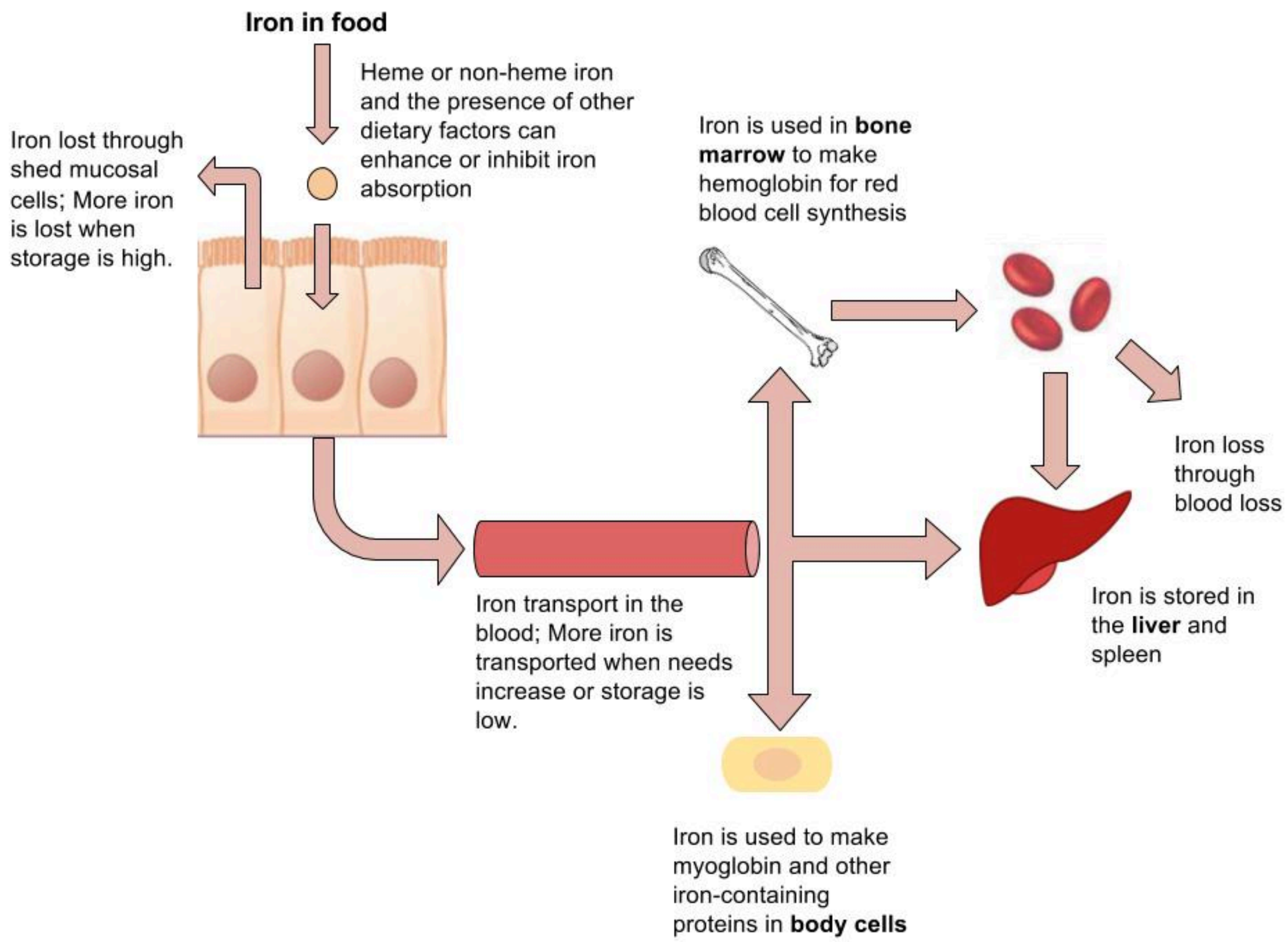

Figure 12.62 *Iron Absorption, Functions, and Loss. Image by Allison Calabrese / CC BY 4.0*

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 National Academy of Medicine has set tolerable upper intake levels of iron (Table 12.62 "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 12.62 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 12.63 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. See Table 12.61 "Enhancers and Inhibitors of Iron Absorption" for more enhancers and inhibitors for iron absorption.

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-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.

Preventing Iron-Deficiency Anemia

In young children iron-deficiency anemia can cause significant motor, mental, and behavioral abnormalities that are long-lasting. In the United States, the high incidence of iron-deficiency anemia in infants and children was a major public-health problem prior to the early 1970s, but now the incidence has been greatly reduced. This achievement was accomplished by implementing the screening of infants for iron-deficiency anemia in the health sector as a common practice, advocating the **fortification** of infant formulas and cereals with iron, and distributing them in supplemental food programs, such as that within **Women, Infants, and Children (WIC)**. Breastfeeding, iron supplementation, and delaying the introduction of cow's milk for at least the first twelve months of life were also encouraged. These practices were implemented across the socioeconomic spectrum and by the 1980s iron-deficiency anemia in infants had significantly declined. Other solutions had to be introduced in young children, who no longer were fed breast milk or fortified formulas and were consuming cow's milk. The following solutions were introduced to parents: provide a diet rich in sources of iron and vitamin C, limit cow's milk consumption to less than twenty-four ounces per day, and a multivitamin containing iron.

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.

Notes

1. Centers for Disease Control and Prevention. "Iron and Iron Deficiency." Accessed October 2, 2011. http://www.cdc.gov/nutrition/everyone/basics/vitamins/iron.html.
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.
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.
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.

12.7 Zinc

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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 12.71 Dietary Reference Intakes for Zinc[2]

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		

Dietary Sources of Zinc

Table 12.72 Zinc Content of Various Foods[3]

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

Notes

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.
2. 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.
3. 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.

12.8 Copper

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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.

Dietary Reference Intakes for Copper

Table 12.81 Dietary Reference Intakes for Copper[1]

Age Group	RDA, Males and Females (mcg/day)	UL (mcg/day)
Infants (0–6 mon.)	200 (AI)	–
Infants (7–12 mon.)	220 (AI)	–
Children (1–3 years)	340	1000
Children (4–8 years)	440	3000
Children (9–13 yrs)	700	5000
Adolescents (14–18 yrs)	890	8000
Adults (> 19 years)	900	10000

Dietary Sources of Copper

Table 12.82 Some Food Sources of Copper[2]

Food	Serving	Copper (mcg)
Liver (beef), cooked, pan-fried	1 ounce	4,128
Mollusks, oysters, eastern, wild, cooked, moist heat	6 medium oysters	2,397
Crab meat, Alaskan king, cooked	3 ounces	1,005
Crab meat, blue, cooked, moist heat	3 ounces	692
Mollusks, clams, mixed species, cooked, moist heat	3 ounces	585
Cashews nuts, raw	1 ounce	622
Sunflower seed kernels, dry roasted	1 ounce	519
Hazelnuts, dry roasted	1 ounce	496
Almonds	1 ounce	292
Peanut butter, chunk style, without salt	2 tablespoons	185
Lentils, mature seeds, cooked, boiled, without salt	1 cup	497
Mushrooms, white, raw	1 cup (sliced)	223
Shredded wheat cereal	2 biscuits	167
Chocolate (semisweet)	1 ounce	198

Notes

1. Source: Micronutrient Information Center: Manganese. Oregon State University, Linus Pauling Institute. https://lpi.oregonstate.edu/mic/minerals/copper. Updated in December 2013. Accessed September 02, 2020.
2. Source: Micronutrient Information Center: Manganese. Oregon State University, Linus Pauling Institute. https://lpi.oregonstate.edu/mic/minerals/copper. Updated in December 2013. Accessed September 02, 2020.

12.9 Vitamin A

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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, the layer of cells at the back of the eye that detect light. The retinoids 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.

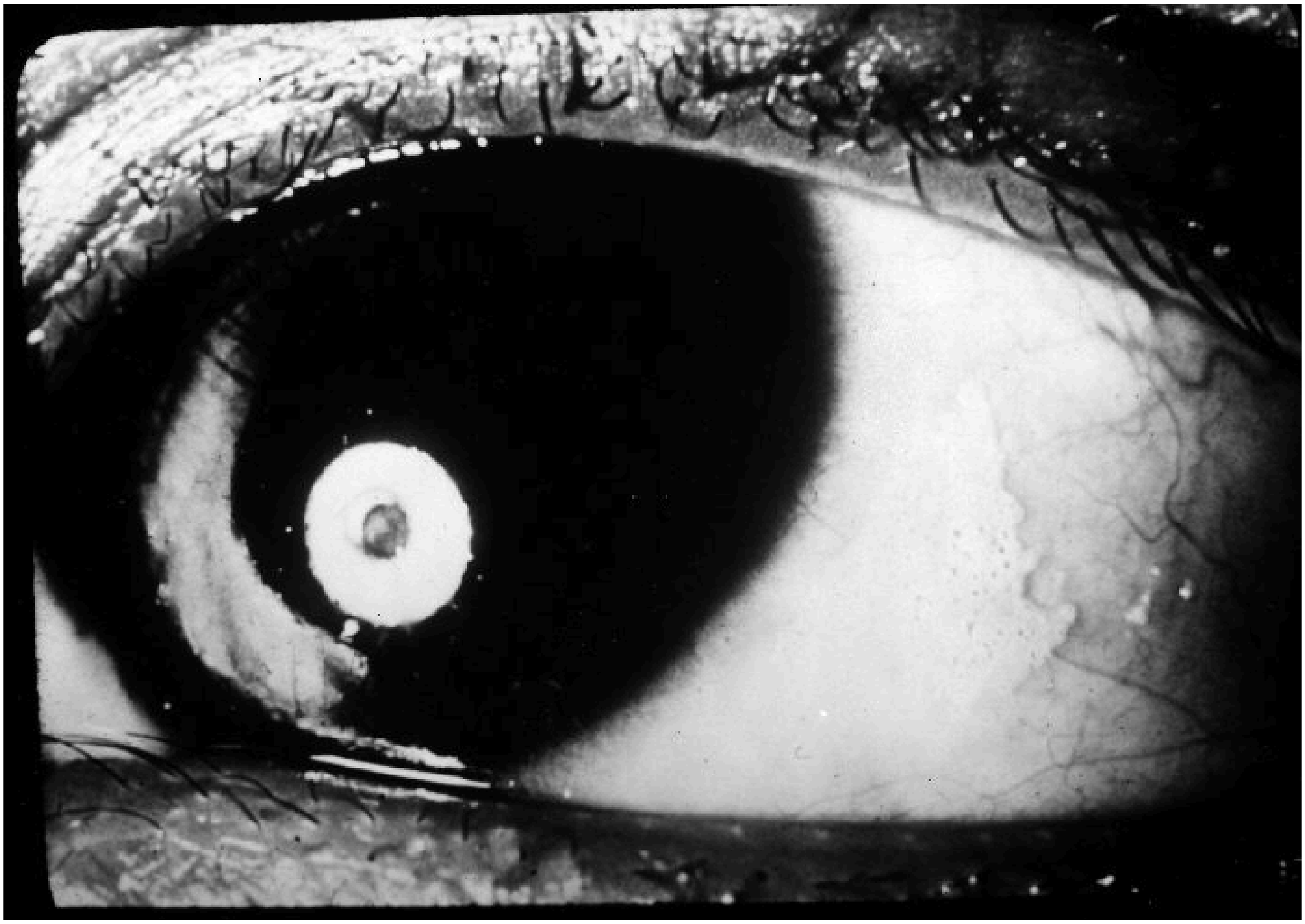

Figure 12.91 *Bitot Spot caused by vitamin A deficiency. Credit: Malnutrition-Bitot's Spots/ Bitot's Spots caused by vitamin A deficiency by CDC / Nutrition Program*

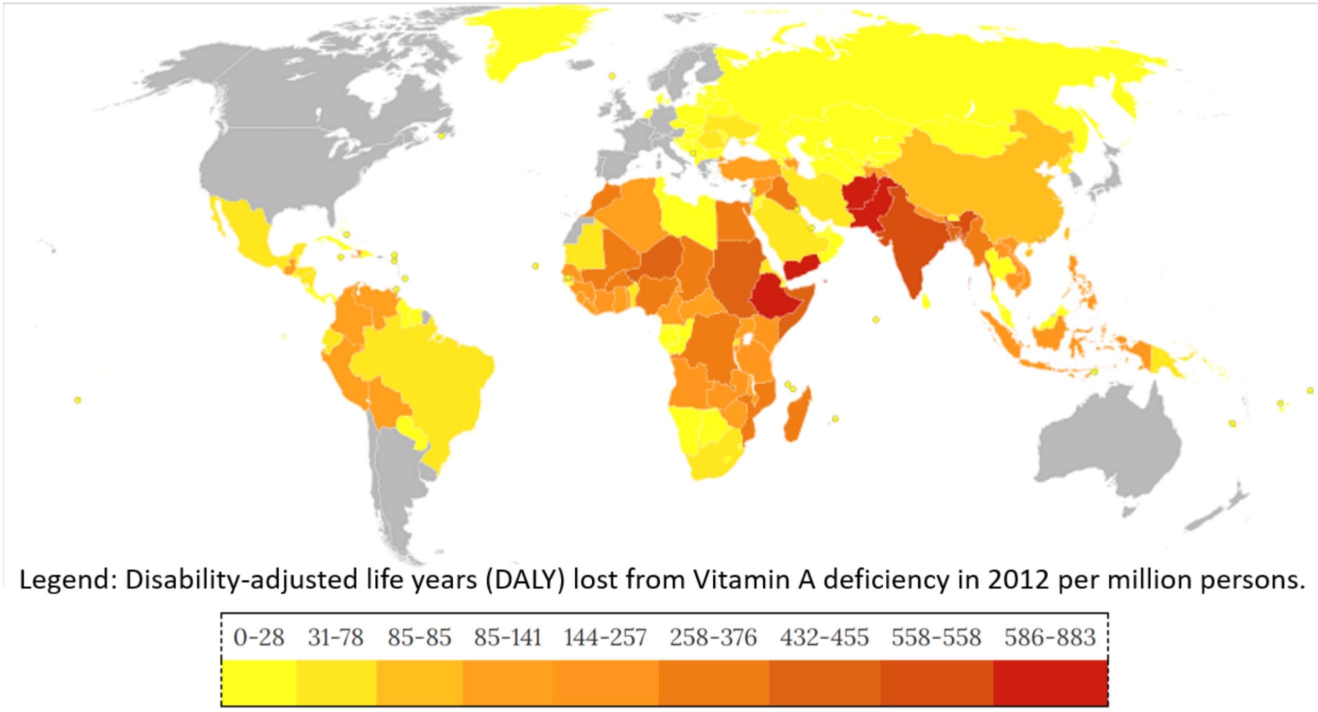

Figure 12.92 *Vitamin A Deficiency World Map. Map by Wikipedia user Chris55 / CC BY-SA 4.0*

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.

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-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 system function while maintaining adequate stores (good for four months) in the liver.

Table 12.91 Dietary Reference Intakes for Vitamin A[4]

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		

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 12.92 "Vitamin A Content of Various Foods"). The dietary sources of carotenoids will be given in the following text.

Table 12.92 Vitamin A Content of Various Foods[5]

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

In the United States, the most consumed carotenoids are alpha-carotene, beta-carotene, beta-cryptoxanthin, lycopene, lutein, and zeaxanthin. See Table 12.93 "Alpha- and Beta-Carotene Content of Various Foods" for the carotenoid content of various foods.

Table 12.93 Alpha- and Beta-Carotene Content of Various Foods[6]

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

Notes

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.
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.

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.
4. 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.
5. 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.
6. 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.

CHAPTER XIII

CHAPTER 13: WATER AND ELECTROLYTES

In this chapter, we'll be talking about water and the **minerals** that are essential for regulating **fluid balance** in the body: the electrolytes. At the end of the chapter, we'll briefly discuss hypertension (high blood pressure), a disorder in which fluid balance and electrolytes play a very important part.

Sections:

- 13.0 Introduction to Water and Electrolytes
- 13.1 Overview of Fluid and Electrolyte Balance
- 13.2 Water's Importance to Vitality
- 13.3 Regulation of Water Balance
- 13.4 Consequences of Water Deficiency or Excess
- 13.5 Sodium
- 13.6 Chloride
- 13.7 Potassium
- 13.8 Magnesium
- 13.9 Hypertension, Salt-Sensitivity, & the DASH Diet

Chapter 13 is adapted primarily from Fialkowski Revilla, et al. *Human Nutrition.*

Additional material in section 13.9 is adapted from Jellum, et al. *Principles of Nutrition.*

13.0 Introduction to Water and Electrolytes

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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.

The latest National Health and Nutrition Examination Survey, covering the period from 2005 to 2008, reports that about 50 percent of Americans consume sugary drinks daily.[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.

Notes

1. Ogden C, Kit B, et al. Consumption of Sugar Drinks in the United States, 2005–2008. Centers for Disease Control and Prevention. NCHS Data Brief no. 71. http://www.cdc.gov/nchs/data/databriefs/db71.htm [inactive]. Published August 2011. Accessed September 22, 2017.

13.1 Overview of Fluid and Electrolyte Balance

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Water is made up of 2 hydrogen atoms and 1 oxygen atom (Figure 13.11 "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 conducted at the Fred Hutchinson Cancer Research Center in Seattle found that women who drank more than five glasses of water each day had a significantly decreased risk for developing colon cancer.[1]

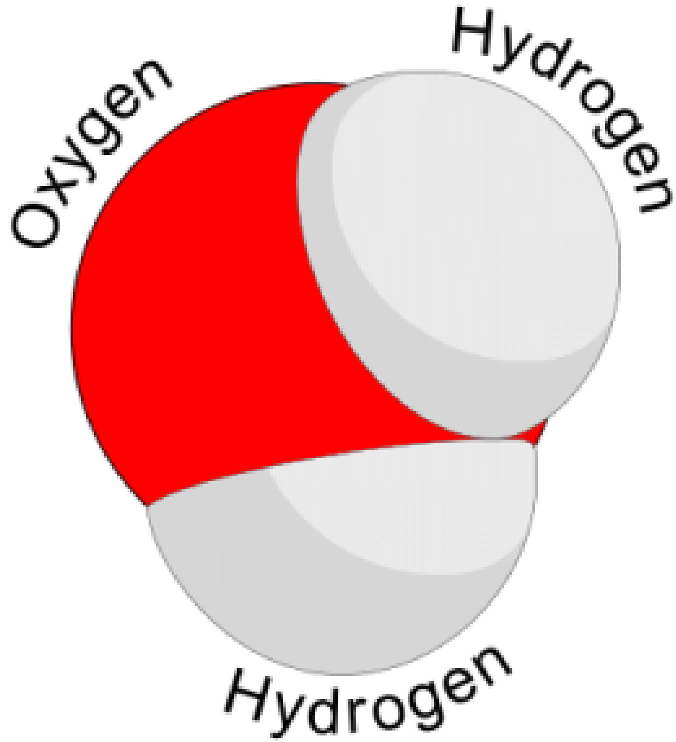

Figure 13.11 *The Water Molecule. Credit: "Water Molecule" by Chris Martin / Public Domain*

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 into interstitial fluid (in the spaces between cells), blood plasma, and other bodily fluids such as the cerebrospinal fluid which surrounds and protects the brain and spinal cord (Figure 13.12 "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.

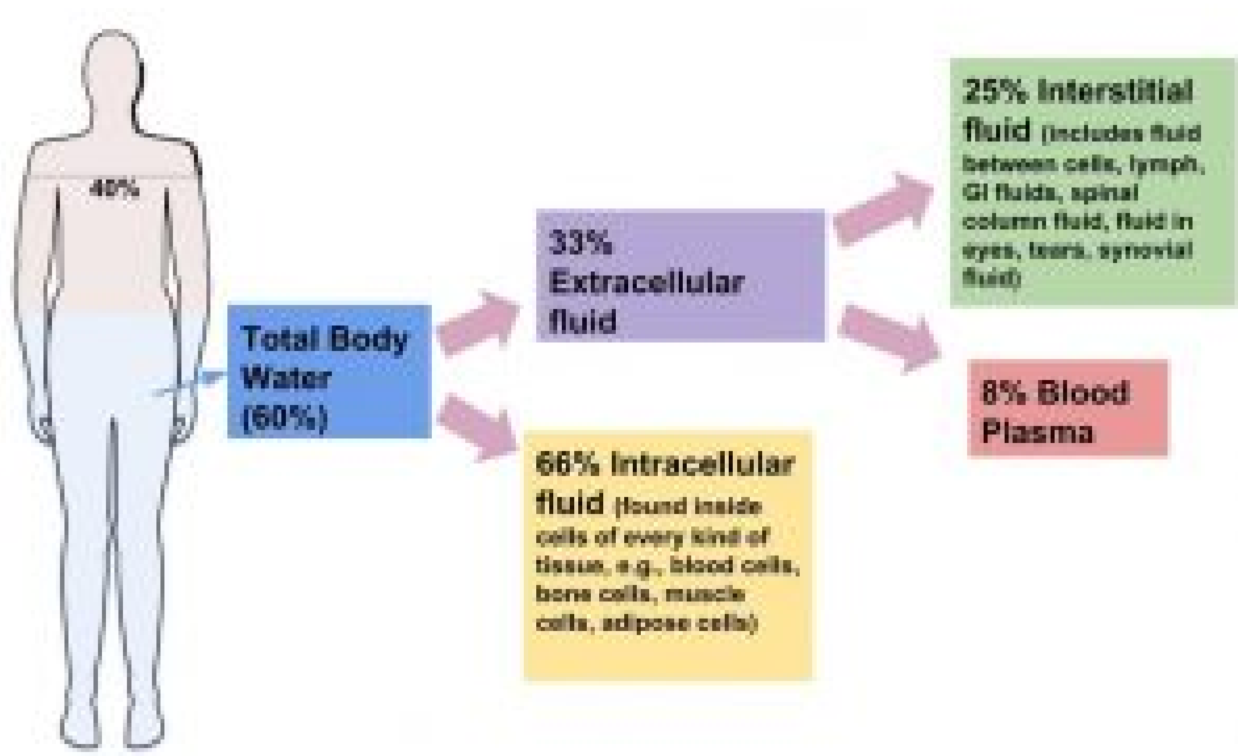

***Figure* 13.12** *Distribution of Body Water. Image by Allison Calabrese / CC BY 4.0*

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 13.13 "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.

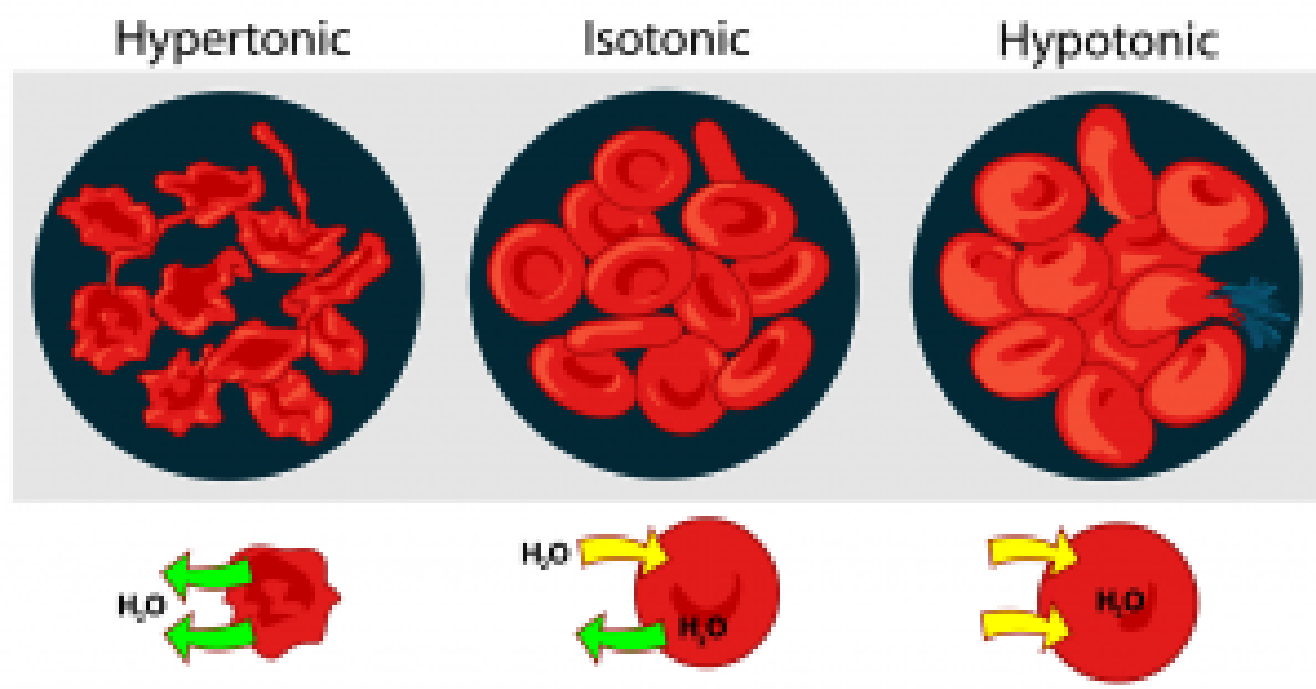

Figure 13.13 *Osmoregulation. Credit: "Osmosis" by Mariana Ruiz / Public Domain*

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.

Notes

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.

13.2 Water's Importance to Vitality

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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 (H_2O) 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 13.21 "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.

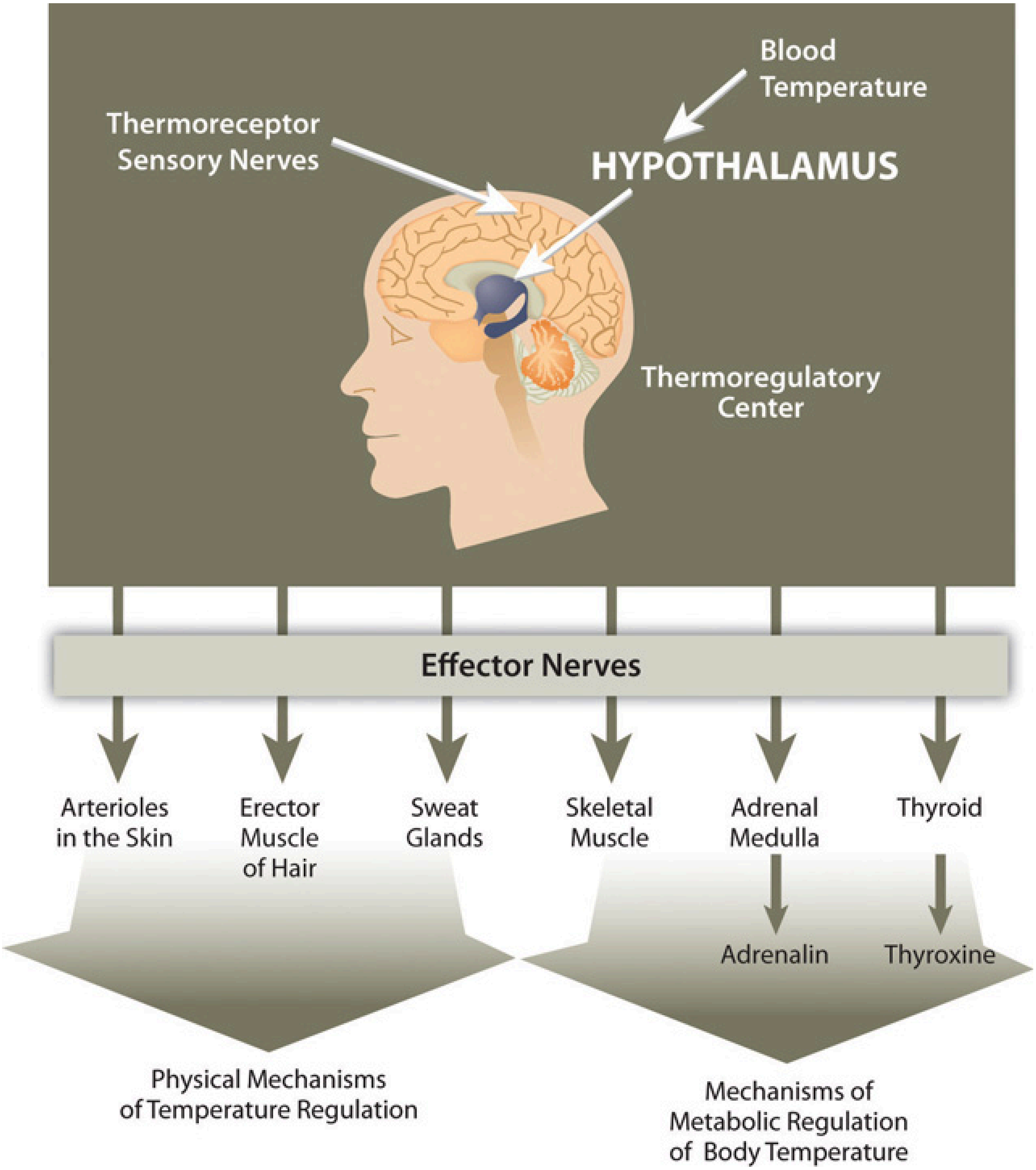

Figure 13.21 *Thermoregulatory Center. Thermoregulation is the ability of an organism to maintain body temperature despite changing environmental temperatures.*

13.3 Regulation of Water Balance

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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.

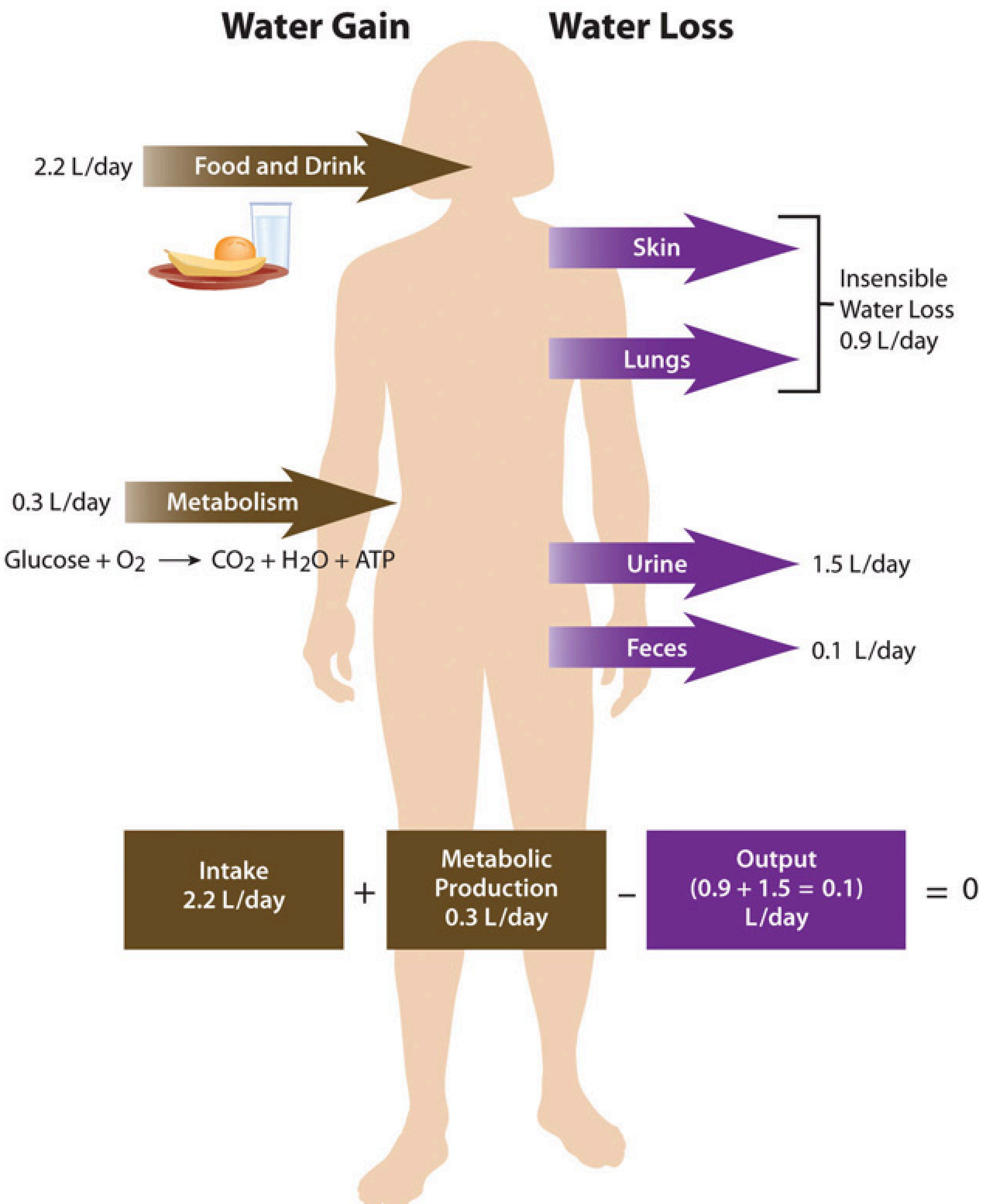

Figure 13.31 *Daily Fluid Loss and Gain*

Dietary Gain of Water

The Food and Nutrition Board of the Institute of Medicine (IOM) has set 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. In America, approximately 20 percent of dietary water comes from solid foods. See Table 13.31 "Water Content in Foods" for the range of water contents for selected food items. Beverages includes water, tea, coffee, sodas, and juices.

Table 13.31 Water Content in Foods[2]

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

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.

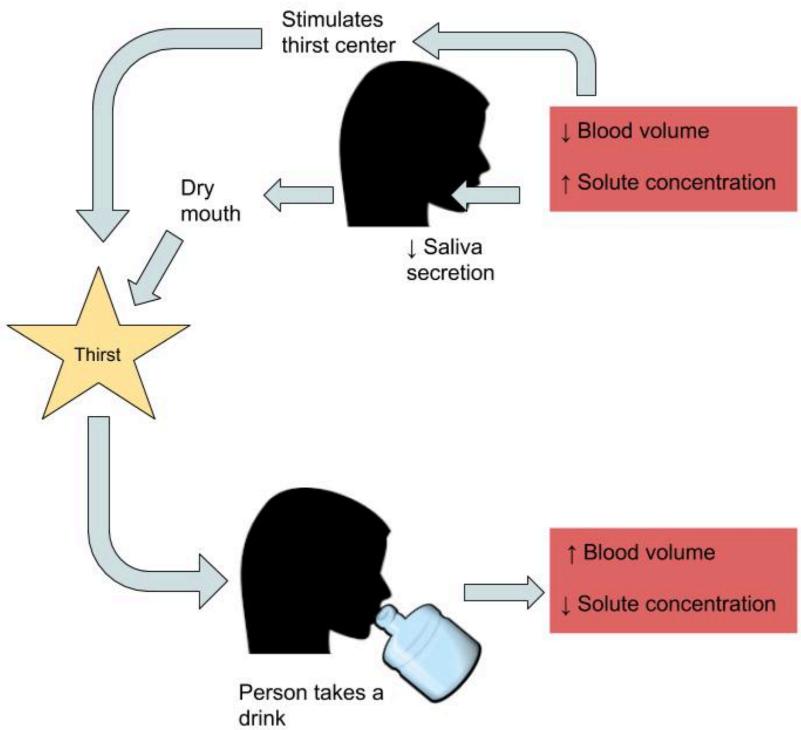

Figure 13.32 *Regulating Water Intake. Image by Allison Calabrese / CC BY 4.0*

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.

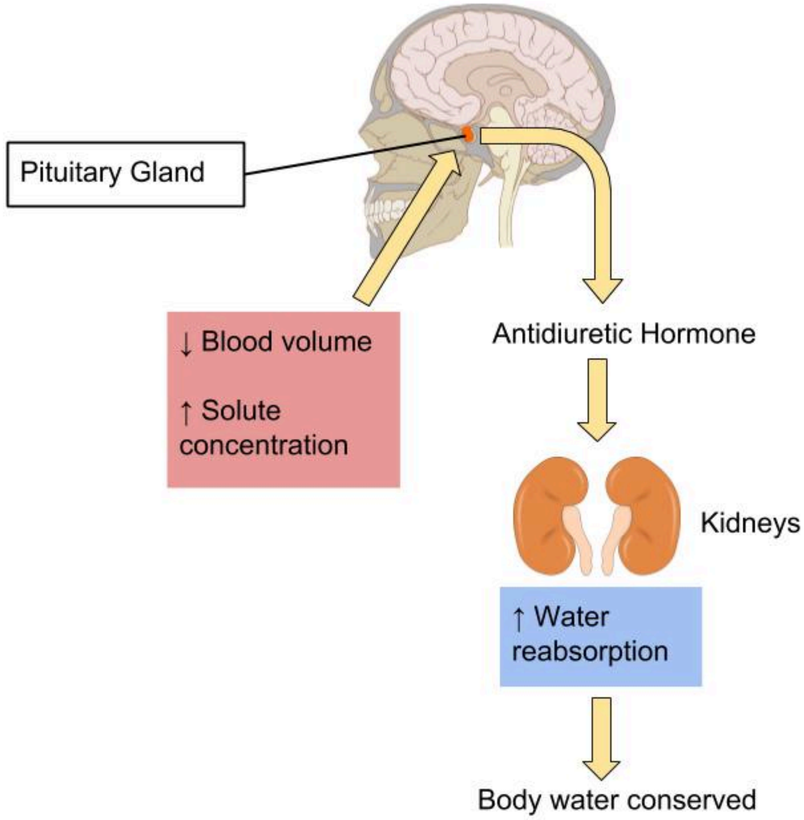

***Figure 13.33** Regulating Water Output. Image by Allison Calabrese / CC BY 4.0*

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.

Notes

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.
2. 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.

13.4 Consequences of Water Deficiency or Excess

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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. However, if the rate of water consumption exceeds the kidneys' ability to remove the excess, serious complications can arise. 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.

The symptoms of water intoxication are caused by dilution of sodium in the body (hyponatremia), and so will be discussed in more detail in section 13.5.

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.

13.5 Sodium

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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 IOM has set an AI level for sodium for healthy adults between the ages of nineteen and fifty at 1,500 milligrams (Table 13.51 "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 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). The National Academy of Medicine estimates that greater than 95 percent of men and 75 percent of women in America consume salt in excess of the UL. 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. The IOM recommends that people over fifty, African Americans, diabetics, and those with chronic kidney disease should consume no more than 1,500 milligrams of sodium per day. The American Heart Association (AHA) states that all Americans, not just those listed, should consume less than 1,500 milligrams of sodium per day to prevent cardiovascular disease. The AHA recommends this because millions of people have risk factors for hypertension and there is scientific evidence supporting that lower-sodium diets are preventive against hypertension.

Table 13.51 Dietary Reference Intakes for Sodium[2]

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		

Food Sources for Sodium

Most sodium in the typical American 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 13.52 “Sodium Contents of Selected Foods”.

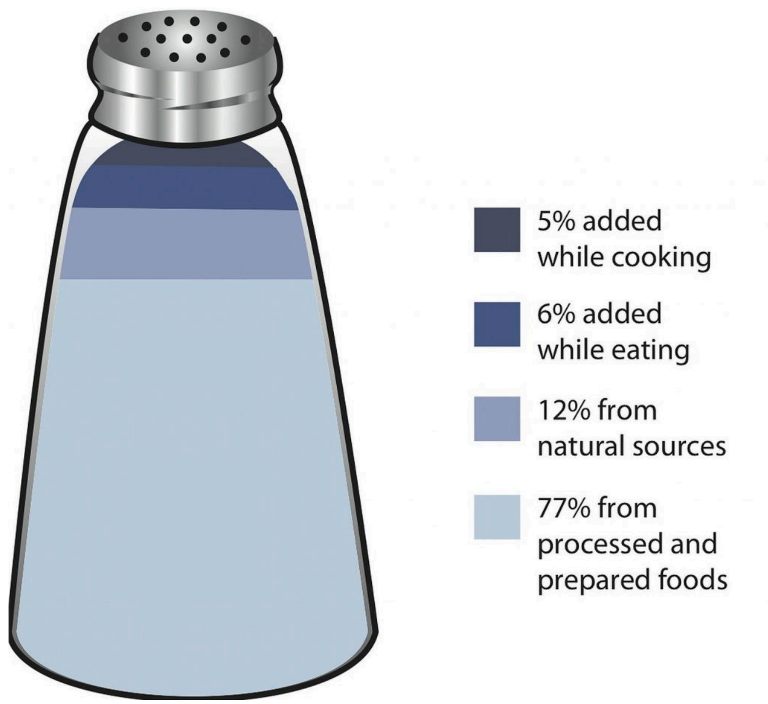

Figure 13.51 *Dietary Sources of Sodium*

Table 13.52 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

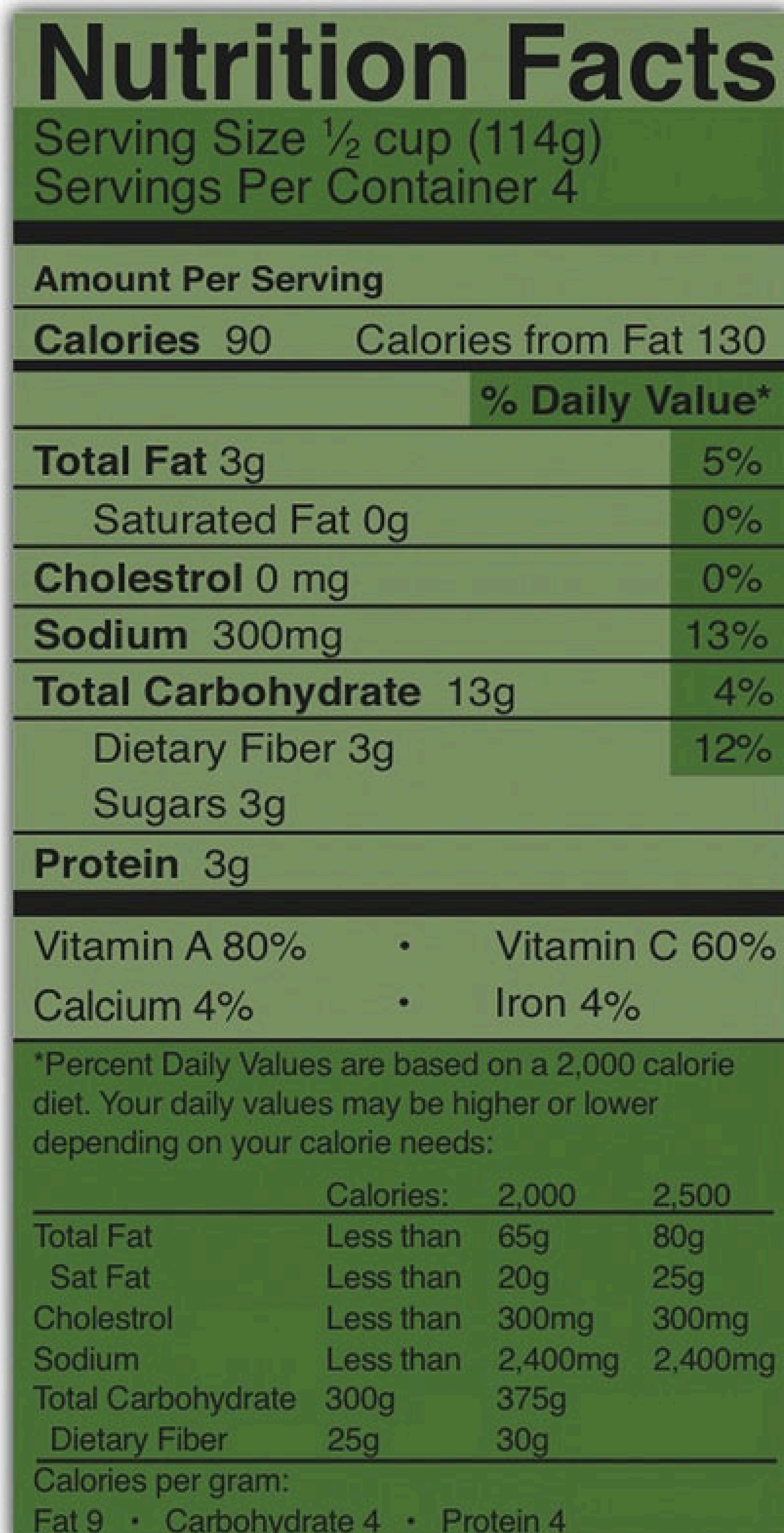

Figure 13.52 *Sodium levels in milligrams is a required listing on a Nutrition Facts label.*

The **Nutrition Facts panel** displays the amount of sodium (in milligrams) per serving of the food in question (Figure 13.52 "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. Various claims about the sodium content in foods must be in accordance with **Food and Drug Administration (FDA)** regulations (Table 13.53 "Food Packaging Claims Regarding Sodium").

Table 13.53 Food Packaging Claims Regarding Sodium[3]

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	

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 13.54 "Salt Substitutes" displays the sodium and potassium amounts in some salt substitutes.

Table 13.54 Salt Substitutes[4]

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

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 13.55 "Salt Alternatives" for an American Heart Association list of alternative food seasonings.

Table 13.55 Salt Alternatives[5]

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

Seasoning	Foods
Thyme	Lean meats (especially veal and lean pork), sauces, soups, onions, peas, tomatoes, salads
Turmeric	Lean meats, fish, sauces, rice

Notes

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.
2. 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.
3. 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.
4. 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.
5. 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.

13.6 Chloride

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Chloride is the primary negatively-charged ion 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 National Academy of Medicine, 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 13.61 "Adequate Intakes for Chloride".

Table 13.61 Adequate Intakes for Chloride[1]

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

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.

Notes

1. 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.

13.7 Potassium

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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 IOM based their AIs for potassium 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 mg per day. The AIs for other age groups are listed in Table 13.71 "Adequate Intakes for Potassium".

Table 13.71 Adequate Intakes for Potassium[1]

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

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 section 13.9.

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.

Notes

1. 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.

13.8 Magnesium

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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 **bone mineral density (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 essential for nerve conduction and muscle contraction. Another health benefit of magnesium is that it may decrease blood pressure.

Many Americans 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 13.81 Dietary Reference Intakes for Magnesium[2]

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		

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 in America 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 13.82 Magnesium Content of Various Foods[3]

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

Notes

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 Clin Nutr*. 1999; 69(4), 727–36. http://www.ajcn.org/cgi/pmidlookup?view=long&pmid=10197575. Accessed October 6, 2017.
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.
3. 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.

13.9 Hypertension, Salt-Sensitivity, & the DASH Diet

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. The **Centers for Disease Control and Prevention (CDC)** reported that in 2007–2008 approximately 33 percent of Americans were hypertensive.[1]The percentage of people with hypertension increases to over 60 percent in people over the age of sixty.

Figure 13.91 *Measuring Blood Pressure. Credit: Testing a GI's blood pressure at Guantanamo by Charlie Helmholt / Public Domain*

Approximately 27% of American adults have hypertension (high blood pressure), which increases their risk of developing cardiovascular disease.[2]

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.[34]

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.[5]

While some other large studies have demonstrated little or no significant relationship between sodium intake and blood pressure, the weight of scientific evidence demonstrating low-sodium diets as effective preventative and treatment measures against hypertension led the US government to pass a focus on salt within the Consolidated Appropriations Act of 2008. A part of this act tasked the CDC, under guidance from the National Academy of Medicine (formerly Institute of Medicine), to make recommendations for Americans to reduce dietary sodium intake. This task is ongoing and involves "studying government approaches (regulatory and legislative actions), food supply approaches (new product development, food reformulation), and information/education strategies for the public and professionals."[6]

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. Salt-sensitive means that a person's blood pressure increases with increased salt intake and decreases with decreased salt intake. Approximately 25% of normotensive (normal blood pressure) individuals and 50% of hypertensive individuals are salt-sensitive.[7] Most others are salt-insensitive, and in a small portion of individuals, low salt consumption actually increases blood pressure.[8] Unfortunately, there isn't a clinical method to determine whether a person is salt-sensitive. There are some known characteristics that increase the likelihood of an individual being salt-sensitive. They are:[9]

- Elderly
- Female
- African-American
- Hypertensive
- Diabetic
- Chronic Kidney Disease

There is some evidence now suggesting that there may be negative effects in some people who restrict their sodium intakes to the levels recommended by some organizations. The second link describes a couple of studies that had conflicting outcomes as it relates to the importance of salt reduction in decreasing blood pressure and cardiovascular disease. The third link is to a study that found that higher potassium consumption, not lower sodium consumption, was associated with decreased blood pressure in adolescent teenage girls.

Web Links:

Report Questions Reducing Salt Intake Too Dramatically

Pour on the Salt? New Research Suggests More Is OK

For Teenagers, Potassium May Matter More Than Salt

The DASH Diet

To combat hypertension, the Dietary Approaches to Stop Hypertension (DASH) diet was developed. 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 a clinical trial, 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.[10]

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

The daily goals for the DASH diet are shown in the figure below.

BOX 2

Daily Nutrient Goals Used in the DASH Studies
(for a 2,100 Calorie Eating Plan)

Total fat	27% of calories	**Sodium**	2,300 mg*
Saturated fat	6% of calories	**Potassium**	4,700 mg
Protein	18% of calories	**Calcium**	1,250 mg
Carbohydrate	55% of calories	**Magnesium**	500 mg
Cholesterol	150 mg	**Fiber**	30 g

* *1,500 mg sodium was a lower goal tested and found to be even better for lowering blood pressure. It was particularly effective for middle-aged and older individuals, African Americans, and those who already had high blood pressure.*
g = grams; mg = milligrams

Figure 13.92 *DASH daily nutrient goals. Source*

To get an idea of what types of foods and how much would be consumed in the diet, an eating plan is shown below.

BOX 4

DASH Eating Plan— Number of Daily Servings for Other Calorie Levels

Food Groups	Servings/Day 1,600 calories/day	2,600 calories/day	3,100 calories/day
Grains*	6	10–11	12–13
Vegetables	3–4	5–6	6
Fruits	4	5–6	6
Fat-free or low-fat milk and milk products	2–3	3	3–4
Lean meats, poultry, and fish	3–6	6	6–9
Nuts, seeds, and legumes	3/week	1	1
Fats and oils	2	3	4
Sweets and added sugars	0	≤2	≤2

* *Whole grains are recommended for most grain servings as a good source of fiber and nutrients.*

Figure 13.93 *DASH eating plan. Source*

The DASH diet has been shown to be remarkably effective in decreasing blood pressure in those with hypertension. Nevertheless, most people with hypertension aren't following the DASH diet. In fact, evidence from the National Health and Nutrition Examination Survey found that significantly fewer hypertensive individuals were following the DASH diet in 1999-2004 than during 1988-1994.[11]

For more information on the DASH diet, see the fact sheet prepared by the National Heart, Lung, and Blood Institute at the web link below:

Web Link: Your Guide to Lowering Blood Pressure

Notes

1. Centers for Disease Control and Prevention. "FastStats—Hypertension." Accessed October 2, 2011. https://www.cdc.gov/nchs/fastats/hypertension.htm.
2. McGuire M, Beerman KA. (2011) *Nutritional sciences: From fundamentals to food*. Belmont, CA: Wadsworth Cengage Learning.
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4. 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.
5. 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.
6. Henney JE, Taylor CL, Boon CS. Strategies to Reduce Sodium Intake in the United States, by Committee on Strategies to Reduce Sodium Intake, Institute of Medicine. Washington, D.C.: National Academies Press; 2010. http://www.nap.edu/openbook.php?record_id=12818&page=19#p2001bcf59960019001. Accessed September 22, 2017.
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CHAPTER XIV

CHAPTER 14: DIET AND HEALTH

Nutritional needs for certain chronic and infectious diseases may be different from that of the normal, balanced person since many diseases are caused by lifestyle choices including poor nutrition. This chapter will address cardiovascular disease, hypertension, diabetes mellitus, cancer, and obesity, including nutritional recommendations for each.

Subsections:

Chapter 14 is adapted from Jellum, et al, *Principles of Nutrition.* Acknowledgements therein:

- Section 14.1 & 14.2: from https://www.cdc.gov/chronicdisease/index.htm. Accessed on December 12, 2017
- Section 14.3:
  - Adapted from: Zimmerman and Snow. "An Introduction to Nutrition" v. 1.0. Accessed on December 4, 2017. https://2012books.lardbucket.org/books/an-introduction-to-nutrition/
  - Also includes selected sections from: Lindshield, B. L. Kansas State University Human Nutrition (FNDH 400) Flexbook. Accessed on December 4, 2017. goo.gl/vOAnR
- Section 14.4:
  - From: https://www.cdc.gov/diabetes/basics/diabetes.html Accessed on December 12,2017
  - Also includes selected sections from: Lindshield, B. L. Kansas State University Human Nutrition (FNDH 400) Flexbook. Accessed on December 4, 2017. goo.gl/

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- Section 14.5:
    - From https://www.cdc.gov/nccdphp/dnpao/index.html; https://www.cdc.gov/chronicdisease/
    - Also includes selected sections from: Lindshield, B. L. Kansas State University Human Nutrition (FNDH 400) Flexbook. Accessed on December 12, 2017. goo.gl/vOAnR
- Section 14.6:
    - Adapted from: http://www.merckmanuals.com/professional/nutritional-disorders/obesity-and-the-metabolic-syndrome/obesity. Accessed December 12, 2017.
    - Also contains material from https://www.cdc.gov/obesity/adult/causes.html Accessed December 12, 2017

14.1 Chronic Disease Overview

According to the Centers for Disease Control, chronic diseases are the leading causes of death and disability in the United States. Chronic diseases and conditions—such as **heart disease**, stroke, cancer, type 2 diabetes, **obesity**, chronic lung diseases, and arthritis—are among the most common, costly, and preventable of all health problems.

Chronic diseases and conditions—such as heart disease, stroke, cancer, type 2 diabetes, obesity, and arthritis—are among the most common, costly, and preventable of all health problems.

- As of 2012, about half of all adults—117 million people—had one or more chronic health conditions. One in four adults had two or more chronic health conditions.[1]
- Seven of the top 10 causes of death in 2014 were chronic diseases. Two of these chronic diseases—heart disease and cancer—together accounted for nearly 46% of all deaths.[2]
- Obesity is a serious health concern. During 2011–2014, more than one-third of adults (36%), or about 84 million people, were obese (defined as body mass index [BMI] ≥30 kg/m^2). About one in six youths (17%) aged 2 to 19 years was obese (BMI ≥95th percentile).[3]
- Arthritis is the most common cause of disability.[4] Of the 54 million adults with doctor- diagnosed arthritis, more than 23 million say they have trouble with their usual activities because of arthritis.[5]
- Diabetes is the leading cause of kidney failure, lower-limb amputations other than those caused by injury, and new cases of blindness among adults.[6]

Health Risk Behaviors that Cause Chronic Diseases

Health risk behaviors are unhealthy behaviors you can change are listed below; most American adults have more than one of these risk factors:

- High blood pressure.
- Tobacco use and exposure to secondhand smoke.

- Obesity (high body mass index).
- Physical inactivity.
- Excessive alcohol use.
- Diets low in fruits and vegetables.
- Diets high in sodium and saturated fats.

Four of these risk factors – lack of exercise or physical activity, poor nutrition, tobacco use, and drinking too much alcohol are health risk behaviors that cause much of the illness, suffering, and early death related to chronic diseases and conditions. Consider the following statistics:

- In 2015, 50% of adults aged 18 years or older did not meet recommendations for aerobic physical activity. In addition, 79% did not meet recommendations for both aerobic and muscle-strengthening physical activity.[7]
- More than 1 in 3 adults (about 92.1 million) have at least one type of cardiovascular disease.[8] About 90% of Americans aged 2 years or older consume too much sodium, which can increase their risk of high blood pressure.[9]
- In 2015, more than 37% of adolescents and 40% of adults said they ate fruit less than once a day, while 39% of adolescents and 22% of adults said they ate vegetables less than once a day.[10]
- An estimated 36.5 million adults in the United States (15.1%) said they currently smoked cigarettes in 2015.[11] Cigarette smoking accounts for more than 480,000 deaths each year.[12] Each day, more than 3,200 youth younger than 18 years smoke their first cigarette, and another 2,100 youth and young adults who smoke every now and then become daily smokers.[12]
- Drinking too much alcohol is responsible for 88,000 deaths each year, more than half of which are due to binge drinking.[13,14] US adults report binge drinking an average of 4 times a month, and have an average of 8 drinks per binge, yet most binge drinkers are not alcohol dependent.[15, 16]

The Cost of Chronic Diseases and Health Risk Behaviors

In the United States, chronic diseases and conditions and the health risk behaviors that cause them account for most health care costs.

- Eighty-six percent of the nation's $2.7 trillion annual health care expenditures are for people with chronic and mental health conditions. These costs can be reduced.[17]
- Total annual cardiovascular disease costs to the nation averaged $316.1 billion in 2012– 2013. Of this amount, $189.7 billion was for direct medical expenses and $126.4 billion was for lost productivity costs (from premature death).[18]
- Cancer care cost $157 billion in 2010 dollars.[19]
- The total estimated cost of diagnosed diabetes in 2012 was $245 billion, including $176 billion in direct medical costs and $69 billion in decreased productivity. Decreased productivity includes costs associated with people being absent from work, being less productive while at work, or not being able to work at all because of diabetes.[20]
- The total cost of arthritis and related conditions was about $128 billion in 2003. Of this amount, nearly $81 billion was for direct medical costs and $47 billion was for indirect costs associated with lost earnings.[21]
- Medical costs linked to obesity were estimated to be $147 billion in 2008. Annual medical costs for people who were obese were $1,429 higher than those for people of normal weight in 2006.[22]
- For the years 2009–2012, economic cost due to smoking is estimated to be at least $300 billion a year. This cost includes nearly $170 billion in direct medical care for adults and more than $156 billion for lost productivity from premature death estimated from 2005 through 2009.[12]
- The economic costs of drinking too much alcohol were estimated to be $249 billion, or

$2.05 a drink, in 2010. Most of these costs were due to binge drinking and resulted from losses in workplace productivity, health care expenses, and crimes related to excessive drinking.[23]

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14.2 Diet and Heart Disease

Heart disease is the leading cause of death in the United States, killing more than 600,000 people each year.[1]

Heart disease is the leading cause of death in the United States for both men and women and for people of most ethnicities in the United States, including whites, African Americans, and Hispanics[1]. For American Indians or Alaska Natives and Asians or Pacific Islanders, heart disease is second only to cancer. Approximately 610,000 Americans die of heart disease each year.

That's one in every four deaths in this country from heart disease.[1]

The term "heart disease" refers to several types of heart conditions. The most common type is coronary artery disease, which can cause a heart attack. Other kinds of heart disease may involve the valves in the heart, or the heart may not pump well and cause heart failure. Some people are born with heart problems that lead to heart attack.

Key Definitions

- **Coronary artery disease** is a type of heart disease that occurs when a substance called plaque builds up in the arteries that supply blood to the heart.
- **Plaque** is made up of cholesterol deposits, which can accumulate in your arteries.
- **Atherosclerosis** is a condition that occurs when too much plaque builds up in your arteries, causing them to narrow.
- **Cholesterol** is a fat-like substance in the body. High levels in the blood can lead to heart disease and stroke.
- **Diabetes** is a disease that affects the body's use of **insulin**. Insulin tells the body to remove sugar from the blood. People with diabetes either don't make enough insulin, can't use their own insulin as well as they should, or both.
- **Obesity** is excess body fat.

Signs and Symptoms of Heart Attack

Anyone can develop heart disease (including children). Heart attacks occur when plaque builds up in the arteries, causing the arteries to narrow over time. This narrowing of the arteries reduces blood flow to the heart, eventually causing a heart attack. Cells in the heart muscle that do not receive enough oxygenated blood begin to die and the more time that passes without restored blood flow, the greater the damage to the heart. Symptoms of a heart attack vary depending on the type of heart disease. For many suffering a heart attack, the first sign is chest discomfort. Some heart attack sufferers may experience several symptoms. The National Heart Attack Alert Program notes these major signs of a heart attack:

- **Chest pain or discomfort.** Most heart attacks involve discomfort in the center or left side of the chest that lasts for more than a few minutes, or that goes away and comes back. The discomfort can feel like uncomfortable pressure, squeezing, fullness, or pain.
- **Discomfort in other areas of the body.** Can include pain or discomfort in one or both arms, the jaw, neck, back, or stomach.
- **Shortness of breath.** Often comes along with chest discomfort. But it also can occur before chest discomfort.
- **Other symptoms.** May include breaking out in a cold sweat, shortness of breath, nausea (feeling sick to your stomach), weakness or light-headedness.

Web Link: Warning Signs of a Heart Attack

If you think that you or someone you know is having a heart attack, you should call 911 immediately.

High blood pressure, high cholesterol, and smoking are key risk factors for heart disease. About half of Americans (47%) have at least one of these three risk factors.

Several other medical conditions and lifestyle choices can also put people at a higher risk for heart disease, including:

- Diabetes

- Overweight and obesity
- Poor diet
- Physical inactivity
- Excessive alcohol use

Preventing Heart Disease

By living a healthy lifestyle, you can help keep your blood pressure, cholesterol, and sugar normal and lower your risk for heart disease and heart attack. A healthy lifestyle includes the following:

- Eating a healthy diet.
- Maintaining a healthy weight.
- Getting enough physical activity.
- Not smoking or using other forms of tobacco.
- Limiting alcohol use.

Healthy Diet

Choosing healthy meal and snack options can help you avoid heart disease and its complications. Be sure to eat plenty of fresh fruits and vegetables and avoid or limit all processed foods.

Eating foods low in saturated fats, trans fat, and cholesterol and high in fiber can help prevent high cholesterol. Limiting sugar in your diet can lower you blood sugar level to prevent or help control diabetes.

Healthy Weight

Being overweight or obese increases your risk for heart disease. To determine if your weight is in a healthy range, doctors often calculate your body mass index (BMI) by your height and weight. BMI can be an accurate reflection of a person's body fat composition for some, but for others it can be an inaccurate measurement, because those with significant muscle mass may have a higher BMI calculation because of the density of muscle versus fat (so they will have a heavier weight even if their body fat is in a healthy range). Body composition analysis (total amount of body fat versus blood, muscle, bone, **organs**, etc.) is a much more accurate determination of obesity.

Physical Activity

Physical activity can help you maintain a healthy weight and lower your blood pressure, cholesterol, and sugar levels. For adults, the Surgeon General recommends 2 hours and 30 minutes of moderate-intensity exercise, like brisk walking or bicycling, every week. Children and adolescents should get 1 hour of physical activity every day.

Cigarette Smoking

Cigarette smoking greatly increases your risk for heart disease. If you don't smoke, don't start. If you do smoke, quitting will lower your risk for heart disease. Your doctor can suggest ways to help you quit.

Alcohol Consumption

Avoid drinking too much alcohol, which can raise your blood pressure. Men should have no more than two drinks per day, and women should limit their alcohol intake to no more than one drink daily.

Video Link: Diet Can Reverse Heart Disease

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14.3 Diet and High Blood Pressure

High Blood Pressure

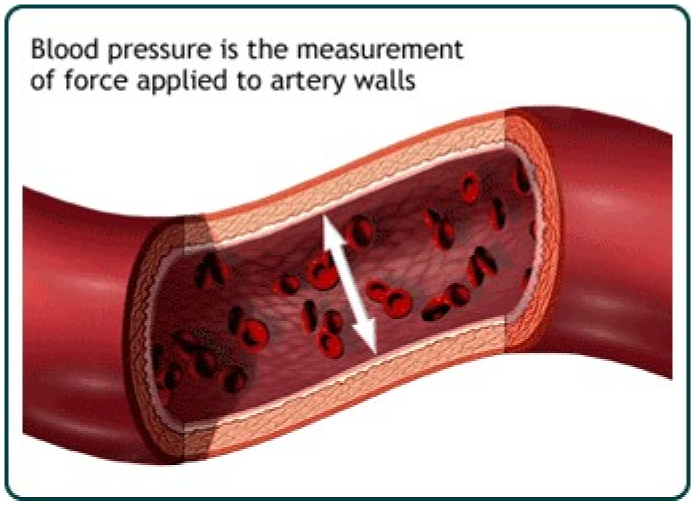

Figure 14.31 *Blood pressure is the force felt by artery walls due to blood flowing through.*

Blood pressure is the force of blood pushing against the walls of your arteries, which carry blood from your heart to other parts of your body, and back to the heart. Blood pressure normally rises and falls throughout the day. But if it stays high for a long time, it can damage your heart and lead to health problems.

High blood pressure is a common and dangerous condition, putting you at risk for heart disease and stroke, two of the leading causes of death in in the United States.[1]

About 1 of every 3 American adults—or about 75 million people—have high blood pressure. Only about half (54%) of these people have their high blood pressure under control.[1]

High blood pressure is called the "silent killer" because it often has no warning signs or symptoms, and many people do not know they have it. That's why it is important to check your blood pressure regularly.

The good news is that you can take steps to prevent high blood pressure or to control it if your blood pressure is already high.

Preventing High Blood Pressure

By living a healthy lifestyle, you can help keep your blood pressure in a healthy range and lower your risk for heart disease and stroke. A healthy lifestyle includes:

- Eating a healthy diet.
- Maintaining a healthy weight.
- Getting enough physical activity.
- Not smoking.
- Limiting alcohol use.

The Dietary Approaches to Stop **Hypertension** (DASH) diet was developed specifically for patients with hypertension. You can learn more about this diet in section 13.9 or at the link below.

> **Web Link:** DASH diet – Mayo Clinic

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14.4 Diet and Diabetes

Diabetes

Diabetes was previously discussed in chapter 5, so this chapter will focus on health risks associated with diabetes and how to prevent and manage diabetes.

Diabetes is a chronic disease that affects how your body turns food into energy.

Most of the food you eat is broken down into sugar (glucose) and released into your bloodstream. Your pancreas makes a **hormone** called insulin, which acts like a key to let the blood sugar into your body's cells for use as energy.

If you have diabetes, your body either doesn't make enough insulin or can't use the insulin it makes as well as it should. When there isn't enough insulin, or the cells stop responding to insulin, too much sugar stays in your bloodstream, which over time can cause serious health problems, such as heart disease, kidney disease, and loss of vision.

Diabetes by the Numbers

- **Over 30 million** US adults have diabetes, and 1 in 4 of them don't know they have it.
- Diabetes is the **seventh leading cause** of death in the US.
- Diabetes is the **No. 1** cause of kidney failure, lower-limb amputations, and adult-onset blindness.
- In the last **20 years**, the number of adults diagnosed with diabetes has more than **tripled** as the American population has aged and become more overweight or obese.

Web Link: Statistics about Diabetes
Video Link: The State of Diabetes in the US 2017

Types of Diabetes:

There are three main types of diabetes: type 1, type 2, and gestational diabetes (diabetes while pregnant).

Type 1 diabetes is caused by an autoimmune reaction that stops your body from making insulin. About 5% of the people who have diabetes have this type. Symptoms of type 1 diabetes often develop quickly. It's usually diagnosed in children, teens, and young adults. If you have type 1 diabetes, you'll need to take insulin every day.

With **Type 2 diabetes**, your body doesn't use insulin well and is unable to keep blood sugar at normal levels. Most people with diabetes have this type. It usually develops over many years and is usually diagnosed in adults (though increasingly in children, teens, and young adults due to the high rates of overweight and obesity in children). Type 2 diabetes can be prevented, delayed, and reversed with healthy lifestyle changes, such as losing weight if you're overweight, healthy eating, and getting regular physical activity.

Gestational diabetes develops in pregnant women who have never had diabetes. If you have gestational diabetes, your baby could be at higher risk for health complications. Gestational diabetes usually goes away after your baby is born but increases your risk for type 2 diabetes later in life. Your baby is more likely to become obese as a child or teen, and more likely to develop type 2 diabetes later in life too.

Prediabetes

In the United States, 84.1 million adults—more than 1 in 3—have prediabetes, and 90% of them don't know they have it. Prediabetes is a serious health condition where blood sugar levels are higher than normal, but not high enough yet to be diagnosed as diabetes. Prediabetes increases your risk for type 2 diabetes, heart disease, and stroke.

Diet for Diabetes

Avoid foods high in saturated fats or trans fats, sugar, and artificial additives such as:

- Fatty cuts of meat
- Fried foods
- Whole milk and dairy products made from whole milk.
- Sweets such as cakes, candy, cookies, pastries and cakes/pies
- Salad dressings
- Lard, shortening, stick margarine, and nondairy creamers
- Processed and refined foods
- Fruit-flavored drinks
- Sodas
- Tea or coffee sweetened with sugar

Eat more fiber found in all plant foods such as fruits, vegetables, beans, peas, legumes, and whole-grains.

Eat a variety of fruits and vegetables every day. Choose fresh, frozen, canned, or dried fruit and 100% fruit juices most of the time. Eat plenty of veggies like these:

- Dark green veggies (e.g., broccoli, spinach, brussels sprouts)
- Orange veggies (e.g., carrots, sweet potatoes, pumpkin, winter squash)
- Beans and peas (e.g., black beans, garbanzo beans, kidney beans, pinto beans, split peas, lentils)

Physical Activity

Physical activity can help you control your blood glucose, weight, and blood pressure, as well as raise your "good" cholesterol and lower your "bad" cholesterol. It can also help prevent heart and blood flow problems, reducing your risk of heart disease and nerve damage, which are often problems for people with diabetes.

Experts recommend moderate-intensity physical activity for at least 30 minutes on five or more days of the week. Some examples of moderate-intensity physical activity are walking briskly, mowing the lawn, dancing, swimming, or bicycling.

14.5 Diet and Cancer

Cancer

Cancer is a term used for diseases in which abnormal cells divide without control. Cancer cells can spread to other parts of the body through the blood and lymph systems. There are more than 100 kinds of cancer.

Cigarette Smoking

Lung cancer is the leading cause of cancer death, and cigarette smoking causes almost all cases. Compared to nonsmokers, current smokers are about 25 times more likely to die from lung cancer. Smoking causes about 80% to 90% of lung cancer deaths. Smoking also causes cancer of the mouth and throat, esophagus, stomach, colon, rectum, liver, pancreas, larynx, trachea, bronchus, kidney and renal pelvis, urinary bladder, and cervix, and causes acute myeloid leukemia.[1,2]

Secondhand Smoke

Adults who are exposed to secondhand smoke at home or at work increase their risk of developing lung cancer by 20% to 30%. Concentrations of many cancer-causing and toxic chemicals are higher in secondhand smoke than in the smoke inhaled by smokers.[3]

Protecting Your Skin

Skin cancer is the most common kind of cancer in the United States. Exposure to ultraviolet rays from the sun and tanning beds appears to be the most important environmental factor involved with developing skin cancer. To help prevent skin cancer while still having fun outdoors, protect yourself by seeking shade, applying sunscreen, and wearing sun-protective clothing, a hat, and sunglasses.

Limit Alcohol Intake

Drinking alcohol raises the risk of some cancers. Drinking any kind of alcohol can contribute to cancers of the mouth and throat, larynx, esophagus, colon and rectum, liver, and breasts. The less alcohol you drink, the lower the risk of cancer.

Studies around the world have shown that drinking alcohol regularly increases the risk of getting mouth, voice box, and throat cancers.A large number of studies provide strong evidence that drinking alcohol is a risk factor for primary liver cancer, and more than 100 studies have found an increased risk of breast cancer with increasing alcohol intake. The link between alcohol consumption and colorectal (colon) cancer has been reported in more than 50 studies.[4]

Healthy Weight

Research has shown that being overweight or obese substantially raises a person's risk of getting endometrial, breast, prostate, and colorectal cancers.[4,5]

Diet and Cancer Prevention

A healthy lifestyle involves many choices. Among them, choosing a **balanced diet**. According to the *Dietary Guidelines for Americans* 2015-2020, a healthy eating plan:

- Emphasizes fruits, vegetables, whole grains, and fat-free or low-fat milk and milk products
- Includes **lean meats**, poultry, fish, beans, eggs, and nuts
- Is low in saturated fats, *trans* fats, cholesterol, salt (sodium), and added sugars

- Stays within your daily **calorie** needs

Web Link: Let Food Be Your Medicine

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14.6 Diet and Obesity

Obesity and energy balance have already been covered in depth in chapter 9. Here we will summarize and focus on causes and health effects or complications of obesity.

Obesity

Overweight and obesity have become one of America's national epidemics. According to the National Institutes of Health, over two-thirds of American adults are overweight, and one in three is obese. Obesity puts people at risk for a host of health problems, including Type 2 diabetes, heart disease, high cholesterol, hypertension, osteoarthritis, and some forms of cancer. The more overweight a person is, the greater his or her risk of developing life- threatening complications. There is no single cause of obesity and no single way to treat it.

Obesity results from a combination of causes and contributing factors, including individual factors such as behavior and genetics. Behaviors can include dietary patterns, physical activity, inactivity, medication use, and other exposures. Additional contributing factors in our society include the food and physical activity environment, education and skills, and food marketing and promotion.

Obesity is a serious concern because it is associated with poorer mental health outcomes, reduced quality of life, and the leading causes of death in the U.S. and worldwide, including diabetes, heart disease, stroke, and some types of cancer. However, a healthy, nutritious diet is generally the first step, including consuming more fruits and vegetables, whole grains, and lean meats and dairy products.

Healthy behaviors include a healthy diet pattern and regular physical activity. Energy balance of the number of **calories** consumed from foods and beverages with the number of calories the body uses for activity plays a role in preventing excess weight gain. A healthy diet pattern follows the Dietary Guidelines for Americans which emphasizes eating whole grains, fruits, vegetables, lean protein, low-fat and fat-free dairy products and drinking water. The Physical Activity Guidelines for Americans recommends adults do at least 150 minutes of moderate intensity activity or 75 minutes of vigorous intensity activity, or a combination of both, along with 2 days of strength training per week.

Having a healthy diet pattern and regular physical activity is also important for long term health benefits and prevention of chronic diseases such as Type 2 diabetes and heart disease.

Obesity is having excess body weight and is influenced by a combination of factors, which usually results in consuming more calories than the body needs. These factors may include:

- physical inactivity
- diet
- **genes**
- lifestyle
- ethnic and socioeconomic background
- exposure to certain chemicals, certain conditions, and use of certain drugs.

Some strategies to treating obesity include:

- Increasing activity and reducing caloric intake are essential to treating obesity, but some people benefit from also taking drugs.
- Losing as little as 5 to 10% of body weight can help lessen weight-related problems, such as diabetes, high blood pressure, and high cholesterol levels.
- People who are obese or overweight and have weight-related problems (such as diabetes) may be treated with weight-loss drugs.
- People who are very obese and who have serious weight-related problems may benefit from weight-loss surgery.

Obesity has become increasingly common throughout the world. In the United States, obesity is very common. More than one third (36.5%) of adults are obese, and more than 25% of children and adolescents are overweight or obese. Also, severe obesity has become more common.

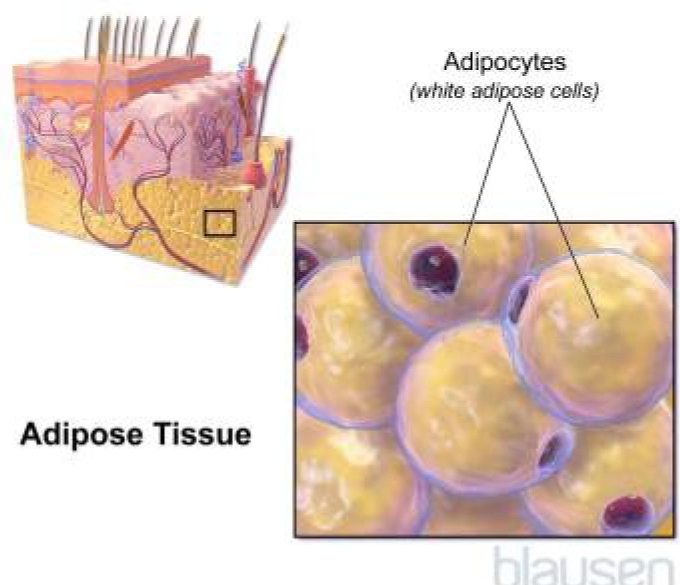
Obesity is much easier to prevent than treat. Once people gain excess weight, the body resists losing weight. For example, when people diet or reduce the number of calories they consume, the body compensates by increasing appetite and reducing the number of calories burned during rest.

Causes

Obesity results from a combination of factors, including the reduced opportunity for physical activity, the increased availability of high-calorie foods, and the presence of genes that make obesity more likely. But ultimately, obesity results from consuming more calories than the body needs over a long period of time.

Excess calories are stored in the body as fat (adipose tissue). The number of calories needed varies from person to person, depending on age, sex, activity level, and metabolic rate. A person's **resting (basal) metabolic rate**—the amount of calories the body burns while at rest—is determined by the amount of muscle (lean) tissue a person has and the person's total body weight. The more muscle people have, the higher their metabolic rate.

Changes in the bacteria that are normally present in the digestive system (called gut flora) may increase the risk of obesity. Normally, these bacteria help the body by helping it digest food (among other things). Changes in the number and types of bacteria in the digestive system may change how the body processes food.



14.61 *Adipocytes are the cells within adipose tissue that store [pb_glossary id="4263"]triglycerides[/pb_glossary].*

Physical inactivity

In developed countries, lack of physical activity is common and contributes to the increase in obesity. Opportunities for physical activity have been engineered away by technological advances, such as elevators, cars, and remote controls. More time is spent doing sedentary activities, such as using the computer, watching television, and playing video games. Also, people's jobs have become more sedentary as office or desk jobs have replaced manual labor. Sedentary people use fewer calories than more active people and thus require fewer calories in the diet. If caloric intake is not reduced accordingly, people gain weight.

Diet

The diet in developed countries is energy dense. That is, it consists of foods that have a large number of calories in a relatively small amount (volume). Most of these foods contain more processed **carbohydrates**, more fat, and less fiber. Fats, by nature, are energy dense. Fat has 9 calories per gram, but carbohydrates and proteins have 4 calories per gram.

Convenience foods, such as energy-dense snacks offered at vending machines and fast food restaurants, contribute to the increase in obesity. High-calorie beverages, including soda, juices, many coffee drinks, and alcohol, also contribute significantly. For example, a 12-ounce soda or bottle of beer has 150 calories, and a 12-ounce coffee beverage (containing dairy and sugar) or fruit smoothie can have 500 or more calories. **High-fructose corn syrup** (used to sweeten many bottled beverages) is often singled out as being particularly likely to cause obesity. Larger portion sizes at restaurants and in packaged foods and beverages encourage people to overeat. Also, restaurant and packaged foods are often prepared in ways that add calories. As a result, people may consume more calories than they realize.

Genes

Obesity tends to run in families. However, families share not only genes but also environment, and separating the two influences is difficult. Genes can affect how quickly the body burns calories at rest and during exercise. They can also affect appetite and thus how much food is consumed. Genes may have a greater effect on where body fat accumulates, particularly fat around the waist and in the abdomen, than on how much body fat accumulates.

Many genes influence weight, but each gene has only a very small effect. Obesity rarely results when only one gene is abnormal.

Pregnancy and menopause

Gaining weight during **pregnancy** is normal and necessary. However, pregnancy can be the beginning of weight problems if women do not return to their pre-pregnancy weight. About 15% of women permanently gain 20 pounds or more with each pregnancy. Having several children close together may compound the problem. Breastfeeding can help women return to their pre-pregnancy weight.

If a pregnant woman is obese or smokes, weight regulation in the child may be disturbed, contributing to weight gain during childhood and later.

After **menopause**, many women gain weight. This weight gain may result from reduced activity. Hormonal changes may cause fat to be redistributed and accumulate around the waist. Fat in this location increases the risk of health problem.

Aging

Obesity becomes more common as people age. As people age, body composition may change as muscle tissue decreases. The result is a higher percentage of body fat and a lower basal metabolic rate (because muscle burns more calories).

Other Lifestyle Factors

Sleep deprivation or lack of sleep (usually considered less than 6 to 8 hours per night) can result in weight gain. Sleeplessness results in hormonal changes that increase appetite and cravings for energy-dense foods.

Stopping smoking often results in weight gain. Nicotine decreases appetite and increases the metabolic rate. When nicotine is stopped, people may eat more food, and their metabolic rate decreases, so that fewer calories are burned. As a result, body weight may increase by 5 to 10%.

Hormones

Hormonal disorders rarely cause obesity. The following are among the most common:

- **Cushing syndrome** is caused by excessive levels of cortisol in the body. The syndrome can result from a benign tumor in the pituitary gland (pituitary adenoma) or from a tumor in the adrenal gland or elsewhere, such as in the lungs. Cushing syndrome typically causes fat to accumulate in the face, making it look full (called moon face), and behind the neck (called a buffalo hump).
- **Polycystic ovary syndrome** affects about 5 to 10% of women. Affected women tend to be overweight or obese. Levels of testosterone and other male hormones are increased, causing fat to accumulate in the waist and abdomen, which is more harmful than the fat that is distributed throughout the body.

Drugs

Many drugs used to treat common disorders promote weight gain. These drugs include some drugs used to treat psychiatric disorders including depression, some drugs used to treat seizures, some drugs used to treat high blood pressure (antihypertensives, such as beta- blockers), corticosteroids, and some drugs used to treat diabetes mellitus.

Complications

Being obese increases the risk of many health problems. Virtually every **organ system** can be affected. These weight-related health problems can cause symptoms, such as shortness of breath, difficulty breathing during activity, snoring, skin abnormalities including stretch marks, and joint and back pain.

Obesity increases the risk of the following:

- Abnormal levels of cholesterol and other fats (lipids), called dyslipidemia
- High blood pressure (hypertension)
- Metabolic syndrome, which includes resistance to the effects of insulin (called insulin resistance), abnormal levels of cholesterol and other fats in the blood, and high blood pressure
- Coronary artery disease
- Heart failure
- Diabetes or a high blood sugar level that is not high enough to be considered diabetes (**prediabetes**)
- Cancer of the breast, uterus, ovaries, colon, prostate, kidneys, or pancreas
- **Gallstones** and other **gallbladder** disorders
- **Gastroesophageal reflux (GERD)**
- A low testosterone level, erectile dysfunction, and reduced fertility in men
- Menstrual disorders, infertility, and increased risk of miscarriage in women
- Skin infections
- Varicose veins
- Fatty liver and cirrhosis
- Blood clots (deep vein thrombosis and pulmonary embolism)
- Obstructive sleep apnea
- Arthritis, **gout**, low back pain, and other joint disorders
- Depression and anxiety

Obstructive sleep apnea can develop if excess fat in the neck compresses the airway during sleep. Breathing stops for a few moments, as often as hundreds of times a night. This disorder is often undiagnosed. It can cause loud snoring and excessive daytime sleepiness and increases the risk of high blood pressure, abnormal heart rhythms, metabolic syndrome, heart attacks, heart failure, and strokes.

Obesity can increase the risk of early death. The more severe the obesity, the higher the risk. In the United States, 300,000 deaths a year are attributed to obesity. It is the second most common cause of preventable death (cigarette smoking is the most common).

Obesity can lead to social, economic, and psychologic problems. For example, obese people may be underemployed or unemployed, or they may have a poor body image and low self- esteem.

Video: CDC: The Obesity Epidemic

CHAPTER XV

CHAPTER 15: PREGNANCY AND NUTRITION

It is crucial to consume healthy foods at every phase of life, beginning in the womb. Good nutrition is vital for any pregnancy and not only helps an expectant mother remain healthy, but also impacts the development of the fetus and ensures that the baby thrives in infancy and beyond. During pregnancy, a woman's needs increase for certain **nutrients** more than for others. If these nutritional needs are not met, infants could suffer from low birth weight (a birth weight less than 5.5 pounds, which is 2,500 grams), among other developmental problems. Therefore, it is crucial to make careful dietary choices.

Sections:

Sections 15.1 & 15.2: Adapted from Fialkowski Revilla, et al. *Human Nutrition*.

Sections 15.3-15.5: Adapted from Jellum et al., *Principles of Nutrition*. Acknowledgements therein:

- Adapted from: Zimmerman and Snow. "An Introduction to Nutrition" v. 1.0. Accessed on December 4, 2017. https://2012books.lardbucket.org/books/an-introduction-to-nutrition/s16-02-pregnancy-and-nutrition.html

15.1 The Human Life Cycle

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Learning Objectives

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

- Describe the physiological basis for nutrient requirements during pregnancy

The Human Life Cycle

Human bodies change significantly over time, and food is the fuel for those changes.

People of all ages need the same basic nutrients—essential amino acids, carbohydrates, essential fatty acids, and twenty-eight **vitamins** and **minerals**—to sustain life and health. However, the amounts of nutrients needed differ. Throughout the human life cycle, the body constantly changes and goes through different periods known as stages. This chapter will focus on **nutrition** during pregnancy. Chapter 16 will focus on nutrition throughout the lifespan. The major stages of the human life cycle are defined as follows:

- **Pregnancy.** The development of a **zygote** into an embryo and then into a fetus in preparation for childbirth.
- **Infancy.** The earliest part of childhood. It is the period from birth through age one.
- **Toddler years.** Occur during ages two and three and are the end of early childhood.
- **Childhood.** Takes place from ages four to eight.
- **Puberty.** The period from ages nine to thirteen, which is the beginning of adolescence.
- **Older adolescence.** The stage that takes place between ages fourteen and eighteen.
- **Adulthood.** The period from adolescence to the end of life and begins at age

nineteen.

- **Middle age.** The period of adulthood that stretches from age thirty-one to fifty.
- **Senior years, or old age**. Extend from age fifty-one until the end of life.

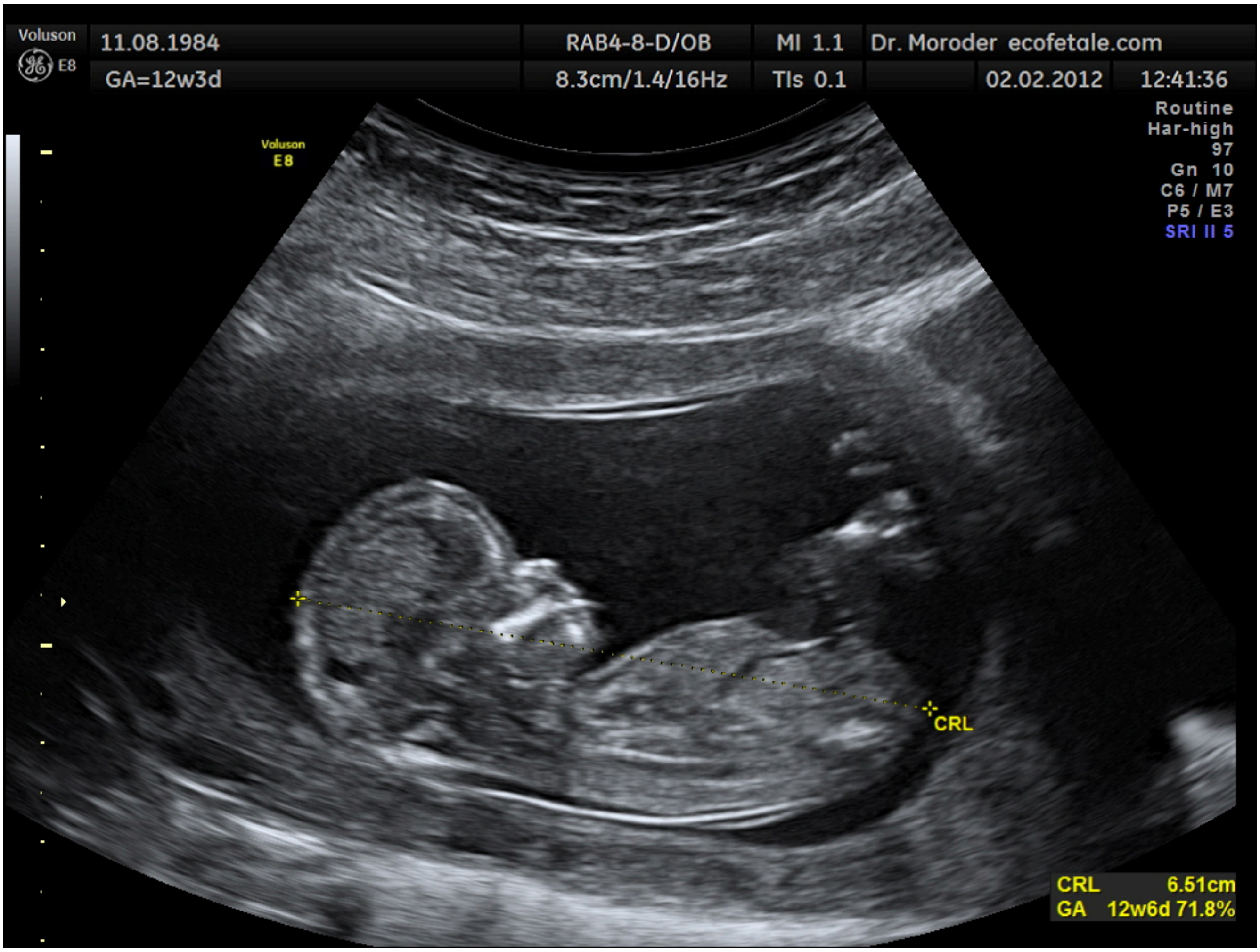

Figure 15.11 *Ultrasound image of a four-month-old fetus.. Image by Wolfgang Moroder / CC BY-SA 3.0*

We begin with pregnancy, a developmental marathon that lasts about forty weeks. It begins with the first trimester (weeks one to week twelve), extends into the second trimester (weeks thirteen to week twenty-seven), and ends with the third trimester (week twenty-eight to birth). At conception, a sperm cell fertilizes an egg cell, creating a zygote. The zygote rapidly divides into multiple **cells** to become an embryo and implants itself in the uterine wall, where it develops into a fetus. Some of the major changes that occur include the branching of nerve cells to form primitive neural pathways at eight weeks. At the twenty-week mark, physicians typically perform an ultrasound to acquire information about the fetus and check for abnormalities. By this time, it is possible to know the sex of the baby. At twenty-eight weeks, the unborn baby begins to add body fat in preparation for life outside of the womb[1].

Throughout this entire process, a pregnant woman's nutritional choices affect not only fetal development, but also her own health and the future health of her newborn.

Notes

1. Polan EU, Taylor DR. Journey Across the LifeSpan: Human Development and Health Promotion. Philadelphia: F.A. Davis Company; 2003, 81–82.

15.2 Early Days of Pregnancy

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The Early Days of Pregnancy

For medical purposes, pregnancy is measured from the first day of a woman's last menstrual period until childbirth, and typically lasts about forty weeks. Major changes begin to occur in the earliest days, often weeks before a woman even knows that she is pregnant. During this period, adequate nutrition supports cell division, tissue differentiation, and organ development. As each week passes, new milestones are reached. Therefore, women who are trying to conceive should make proper dietary choices to ensure the delivery of a healthy baby. Fathers-to-be should also consider their eating habits. A sedentary lifestyle and a diet low in fresh fruits and vegetables may affect male fertility. Men who drink too much alcohol may also damage the quantity and quality of their sperm[1].

For both men and women, adopting healthy habits also boosts general well-being and makes it possible to meet the demands of parenting.

Folate

A pregnancy may happen unexpectedly. Therefore, it is important for all women of childbearing age to get 400 micrograms of folate per day prior to pregnancy and 600 micrograms per day during pregnancy. Recall from chapter 11 that folate, which is also known as folic acid, is crucial for the production of DNA and RNA and the synthesis of cells. A deficiency can cause **megaloblastic anemia**, or the development of abnormal red blood cells, in pregnant women. It can also have a profound affect on the unborn baby. Typically, folate intake has the greatest impact during the first eight weeks of pregnancy, when the **neural tube** closes. The neural tube develops into the fetus's brain, and adequate folate reduces the risk of brain abnormalities or neural tube defects, which occur in one in a thousand pregnancies in North America each year. This vital nutrient also supports the spinal cord and its protective coverings. Inadequate folic acid can result in birth defects, such as spina bifida, which is the failure of the spinal column to close. The name "folate" is derived from the Latin word folium for leaf, and leafy green vegetables such as spinach and kale are excellent sources of it. Folate is also found in legumes, liver, and oranges. Additionally, since 1998, food manufacturers have been required to add folate to cereals and other grain products[2].

Notes

1. Healthy Sperm: Improving Your Fertility. Mayo Clinic. 1998–2012 Mayo Foundation for Medical Education and Research. http://www.mayoclinic.com/health/fertility/MC00023. Accessed February 21, 2012.
2. Folic Acid. MedlinePlus, a service of the National Institutes of Health. 1995–2012 http://www.nlm.nih.gov/medlineplus/druginfo/natural/1017.html. Updated August 7, 2011. Accessed November 22, 2017.

15.3 Weight During Pregnancy

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Weight Gain during Pregnancy

During pregnancy, a mother's body changes in many ways. One of the most notable and significant changes is weight gain. If a pregnant woman does not gain enough weight, her unborn baby will be at risk. Poor weight gain, especially in the third trimester, could result not only in low birth weight, but also infant mortality and intellectual disabilities. Therefore, it is vital for a pregnant woman to maintain a healthy weight, and her weight prior to pregnancy has a major effect. Infant birth weight is one of the best indicators of a baby's future health. Pregnant women of normal weight should gain between 25 and 35 pounds in total through the entire pregnancy. The precise amount that a mother should gain usually depends on her beginning body mass index (BMI). See Table 15.31 "Body Mass Index and Pregnancy" for The Institute of Medicine (IOM) recommendations.

Table 15.31 Body Mass Index and Pregnancy[1]

Prepregnancy BMI	Weight Category	Recommended Weight Gain
Below 18.5	Underweight	28–40 lbs.
18.5–24.9	Normal	25–35 lbs.
25.0–29.9	Overweight	15–25 lbs.
Above 30.0	Obese (all classes)	11–20 lbs.

Starting weight below or above the normal range can lead to different complications. Pregnant women with a prepregnancy BMI below twenty are at a higher risk of a preterm delivery and an underweight infant. Pregnant women with a prepregnancy BMI above thirty have an increased risk of the need for a cesarean section during delivery. Therefore, it is optimal to have a BMI in the normal range prior to pregnancy.

Generally, women gain 2 to 5 pounds in the first trimester. After that, it is best not to gain more than one pound per week. Some of the new weight is due to the growth of the fetus, while some is due to changes in the mother's body that support the pregnancy. Weight gain often breaks down in the following manner as shown in Figure 15.31 6 to 8 pounds of fetus, 1 to 2 pounds for the placenta (which supplies nutrients to the fetus and removes waste products), 2 to 3 pounds for the amniotic sac (which contains fluids that surround and cushion the fetus), 1 to 2 pounds in the breasts, 1 to 2 pounds in the uterus, 3 to 4 pounds of maternal blood, 3 to 4 pounds maternal fluids, and 8 to 10 pounds of extra maternal fat stores that will be needed for breastfeeding and delivery. Women who are pregnant with more than one fetus are advised to gain even more weight to ensure the health of their unborn babies.

Figure 15.31 *Areas of weight gain for pregnant women*

The weight an expectant mother gains during pregnancy is almost all lean tissue, including the placenta and fetus. Weight gain is not the only major change. A pregnant woman also will find that her breasts enlarge and that she has a tendency to retain water[2].

The pace of weight gain is also important. If a woman puts on weight too slowly, her physician may recommend nutritional counseling. If she gains weight too quickly, especially in the third trimester, it may be the result of edema, or swelling due to excess fluid accumulation. Rapid weight gain may also result from increased **calorie** consumption or a lack of exercise.

Weight Loss after Pregnancy

During labor, new mothers lose some of the weight they gained during pregnancy with the delivery of their child. In the following weeks, they continue to shed weight as they lose accumulated fluids and their blood volume returns to normal. Some studies have hypothesized that breastfeeding also helps a new mother lose some of the extra weight, although research is ongoing[3].

New mothers who gain a healthy amount of weight and participate in regular physical activity during their pregnancies also have an easier time shedding weight post-pregnancy. However, women who gain more weight than needed for a pregnancy typically retain that excess weight as body fat. If those few pounds increase a new mother's BMI by a unit or more, that could lead to complications such as **hypertension** or Type 2 diabetes in future pregnancies or later in life.

Notes

1. Weight Gain during Pregnancy: Reexamining the Guidelines. Institute of Medicine. https://www.nap.edu/resource/12584/Report-Brief---Weight-Gain-During-Pregnancy.pdf
2. Weight Gain during Pregnancy. Utah Department of Health, Baby Your Baby. http://www.babyyourbaby.org/pregnancy/during. Published 2012. Accessed November 22, 2017.
3. Stuebe AM, Rich-Edwards JW. The Reset Hypothesis: Lactation and Maternal Metabolism, *Am J Perinatol.* 2009; 26(1), 81–88.

15.4 Nutritional Requirements During Pregnancy

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As a mother's body changes, so do her nutritional needs. Pregnant women must consume more calories and nutrients in the second and third trimesters than other adult women. However, the average recommended daily caloric intake can vary depending on activity level and the mother's normal weight. Also, pregnant women should choose a high-quality, diverse diet, consume fresh foods, and prepare nutrient-rich meals. Steaming is the best way to cook vegetables. Vitamins are destroyed by overcooking, whereas uncooked vegetables and fruits have the highest vitamin content. It is also standard for pregnant women to take prenatal supplements to ensure adequate intake of the needed **micronutrients**.

Energy and Macronutrients

During the first trimester, a pregnant woman has the same energy requirements as normal and should consume the same number of calories as usual. However, as the pregnancy progresses, a woman must increase her caloric intake. According to the National Academy of Medicine, she should consume an additional 340 calories per day during the second trimester, and an additional 450 calories per day during the third trimester. This is partly due to an increase in **metabolism**, which rises during pregnancy and contributes to increased energy needs. A woman can easily meet these increased needs by consuming more nutrient-dense foods.

The recommended daily allowance, or RDA, of **carbohydrates** during pregnancy is about 175 to 265 grams per day to fuel fetal brain development. The best food sources for pregnant women include whole-grain breads and cereals, brown rice, root vegetables, legumes, and fruits. These and other unrefined carbohydrates provide nutrients, **phytochemicals**, antioxidants, and the extra 3 mg/day of fiber that is recommended during pregnancy. These foods also help to build the placenta and supply energy for the growth of the unborn baby.

During pregnancy, extra protein is needed for the synthesis of new maternal and fetal tissues. Protein builds muscle and other **tissues**, enzymes, antibodies, and **hormones** in both the mother and the unborn baby. Additional protein also supports increased blood volume and the production of amniotic fluid. The RDA of protein during pregnancy is 71 grams per day, which is 25 grams above the normal recommendation. Protein should be derived from healthy sources, such as **lean red meat**, white-meat poultry, legumes, nuts, seeds, eggs, and fish. Low-fat milk and other dairy products also provide protein, along with calcium and other nutrients.

There are no specific recommendations for fats in pregnancy, apart from following normal dietary guidelines. Although this is the case, it is recommended to increase the amount of essential fatty acids linoleic acid and ∝-linolenic acid because they are incorporated into the placenta and fetal tissues. Fats should make up 25 to 35 percent of daily calories, and those calories should come from healthy fats, such as avocados. It is not recommended for pregnant women to be on a very low-fat diet, since it would be hard to meet the needs of essential fatty acids and **fat-soluble** vitamins. Fatty acids are important during pregnancy because they support the baby's brain and eye development.

Fluids

Fluid intake must also be monitored. According to the IOM, pregnant women should drink 2.3 liters (about 10 cups) of liquids per day to provide enough fluid for blood production. It is also important to drink liquids during physical activity or when it is hot and humid outside, to replace fluids lost to perspiration. The combination of a high-fiber diet and lots of liquids also helps to eliminate waste.
[1]

Vitamins and Minerals

The daily requirements for non-pregnant women change with the onset of a pregnancy.

Taking a daily prenatal supplement or multivitamin helps to meet many nutritional needs. However, most of these requirements should be fulfilled with a healthy diet. The following table compares the normal levels of required vitamins and minerals to the levels needed during pregnancy. For pregnant women, the RDA of nearly all vitamins and minerals increases.

Table 15.41 Recommended Nutrient Intakes during Pregnancy[2]

Nutrient	Non-pregnant Women	Pregnant Women
Vitamin A (mcg)	700.0	770.0
Vitamin B6 (mg)	1.5	1.9
Vitamin B12 (mcg)	2.4	2.6
Vitamin C (mg)	75.0	85.0
Vitamin D (mcg)	5.0	5.0
Vitamin E (mg)	15.0	15.0
Calcium (mg)	1,000.0	1,000.0
Folate (mcg)	400.0	600
Iron (mg)	18.0	27.0
Magnesium (mg)	320.0	360.0
Niacin (B3) (mg)	14.0	18.0
Phosphorus	700.0	700.0
Riboflavin (B2) (mg)	1.1	1.4
Thiamine (B1) (mg)	1.1	1.4
Zinc (mg)	8.0	11.0

The micronutrients involved with building the skeleton—vitamin D, calcium, phosphorus, and magnesium—are crucial during pregnancy to support fetal bone development. Although the levels are the same as those for non-pregnant women, many women do not typically consume adequate amounts and should make an extra effort to meet those needs.

There is an increased need for all B vitamins during pregnancy. Adequate vitamin B_6 supports the metabolism of **amino acids**, while more vitamin B_{12} is needed for the synthesis of red blood cells and DNA. Additional zinc is crucial for cell development and protein synthesis. The need for vitamin A also increases, and extra iron intake is important because of the increase in blood supply during pregnancy and to support the fetus and placenta. Iron is the one micronutrient that is almost impossible to obtain in adequate amounts from food sources only. Therefore, even if a pregnant woman consumes a healthy diet, there still is a need to take an iron supplement, in the form of ferrous salts. Also remember that folate needs increase during pregnancy to 600 micrograms per day to prevent neural tube defects. This micronutrient is crucial for fetal development because it helps produce the extra blood a woman's body requires during pregnancy.

For most other minerals, recommended intakes are similar to those for non-pregnant women, although it is crucial for pregnant women to make sure to meet the RDAs to reduce the risk of birth defects. In addition, pregnant mothers should avoid exceeding any recommendations. Taking megadose supplements can lead to excessive amounts of certain micronutrients, such as vitamin A and zinc, which may produce toxic effects that can also result in birth defects.

Notes

1. Pregnancy: Body Changes and Discomforts. US Department of Health and Human Services, Office on Women's Health. http://www.womenshealth.gov/pregnancy/you-are-pregnant/body-changes -discomforts.cfm. Updated September 27, 2010. Accessed December 2, 2017.
2. Source: Nutrition during Pregnancy: Part I: Weight Gain, Part II: Nutrient Supplements. Institute of Medicine. http://iom.edu/Reports/1990/Nutrition-During-Pregnancy-Part-I-Weight-Gain-Part-II-Nutrient-Supplements.aspx. Published January 1, 1990. Accessed November 22, 2017.

15.5 Guide to Eating During Pregnancy

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While pregnant women have an increased need for energy, vitamins, and minerals, energy increases are proportionally less than other **macronutrient** and micronutrient increases. So, nutrient-dense foods, which are higher in proportion of macronutrients and micronutrients relative to calories, are essential to a healthy diet. Examples of nutrient-dense foods include fruits, vegetables, whole grains, peas, beans, reduced-fat dairy, and lean meats. Pregnant women should be able to meet almost all of their increased needs via a healthy diet. However, expectant mothers should take a prenatal supplement to ensure an adequate intake of iron and folate. Here are some additional dietary guidelines for pregnant women[1]:

- Eat iron-rich or iron-fortified foods, including meat or meat alternatives, breads, and cereals, to help satisfy increased need for iron and prevent **anemia**.
  Include vitamin C-rich foods, such as orange juice, broccoli, or strawberries, to enhance iron **absorption**.
- Eat a **well-balanced diet**, including fruits, vegetables, whole grains, calcium-rich foods, lean meats, and a variety of cooked seafood (excluding fish that are high in mercury, such as swordfish and shark).
- Drink additional fluids, water especially.

Foods to Avoid

A number of substances can harm a growing fetus. Therefore, it is vital for women to avoid them throughout a pregnancy. Some are so detrimental that a woman should avoid them even if she suspects that she might be pregnant. For example, consumption of alcoholic beverages results in a range of abnormalities that fall under the umbrella of fetal alcohol spectrum disorders. They include learning and attention deficits, heart defects, and abnormal facial features (See figure below). Alcohol enters the unborn baby via the umbilical cord and can slow fetal growth, damage the brain, or even result in miscarriage. The effects of alcohol are most severe in the first trimester, when the **organs** are developing. As a result, there is no safe amount of alcohol that a pregnant woman can consume. Although pregnant women in the past may have participated in behavior that was not known to be risky at the time, such as drinking alcohol or smoking cigarettes, today we know that it is best to avoid those substances completely to protect the health of the unborn baby.

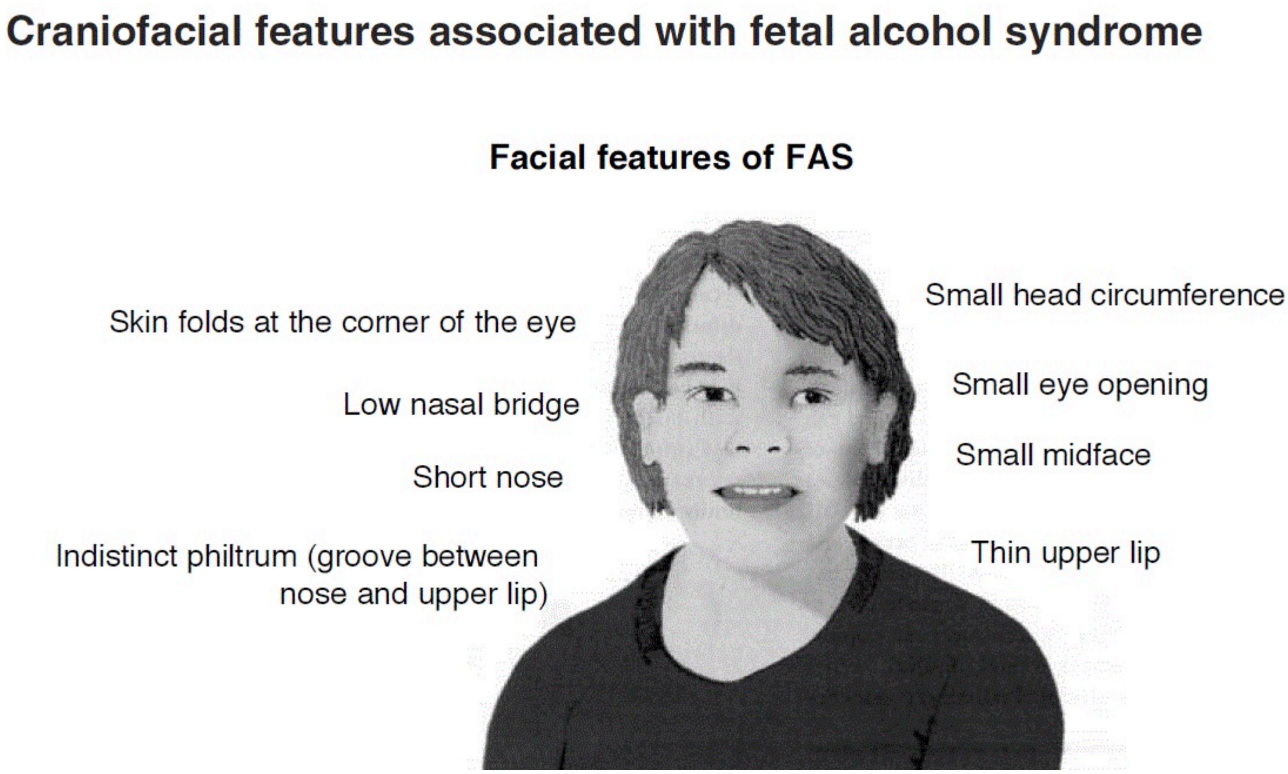

Figure 15.51 *Craniofacial features associated with fetal alcohol syndrome. Figure by NIH/National Institute on Alcohol Abuse and Alcoholism / Public Domain*

Pregnant women should also limit caffeine intake, which is found not only in coffee, but also tea, colas, cocoa, chocolate, and some over-the-counter painkillers. Some studies suggest that very high amounts of caffeine have been linked to babies born with low birth weights. The American Journal of Obstetrics and Gynecology released a report, which found that women who consume 200 milligrams or more of caffeine a day (which is the amount in 10 ounces of coffee or 25 ounces of tea) increase the risk of miscarriage[2].

Consuming large quantities of caffeine affects the pregnant mother as well, leading to irritability, anxiety, and insomnia. Most experts agree that small amounts of caffeine each day are safe (about one 8-ounce cup of coffee a day or less)[3]. However, that amount should not be exceeded.

Foodborne Illness

For both mother and child, foodborne illness can cause major health problems. For example, the foodborne illness caused by the bacteria *Listeria monocytogenes* can cause spontaneous abortion and fetal or newborn meningitis. According to the **CDC**, pregnant women are twenty times more likely to become infected with this disease, which is known as listeriosis, than nonpregnant, healthy adults. Symptoms include headaches, muscle aches, nausea, vomiting, and fever. If the infection spreads to the nervous system, it can result in a stiff neck, convulsions, or a feeling of disorientation[4].

Foods more likely to contain the bacteria that should be avoided are unpasteurized dairy products, especially soft cheeses, and also smoked seafood, hot dogs, paté, cold cuts, and uncooked meats. To avoid consuming contaminated foods, women who are pregnant or breastfeeding should take the following measures:

- Thoroughly rinse fruits and vegetables before eating them
- Keep cooked and ready-to-eat food separate from raw meat, poultry, and seafood
- Store food at 40° F (4° C) or below in the refrigerator and at 0° F (−18° C) in the freezer
- Refrigerate perishables, prepared food, or leftovers within two hours of preparation or eating
- Clean the refrigerator regularly and wipe up any spills right away
- Check the expiration dates of stored food once per week
- Cook hot dogs, cold cuts (e.g., deli meats/luncheon meat), and smoked seafood to 160° F

It is always important to avoid consuming contaminated food to prevent food poisoning. This is especially true during pregnancy. Heavy metal contaminants, particularly mercury, lead, and cadmium, pose risks to pregnant mothers. As a result, vegetables should be washed thoroughly or have their skins removed to avoid heavy metals.

Pregnant women can eat fish, ideally 8 to 12 ounces of different types each week.

Expectant mothers are able to eat cooked shellfish such as shrimp, farm-raised fish such as salmon, and a maximum of 6 ounces of albacore, or white, tuna. However, they should avoid fish with high methylmercury levels, such as shark, swordfish, tilefish, and king mackerel. Pregnant women should also avoid consuming raw shellfish to avoid foodborne illness. The Environmental Defense Fund eco-rates fish to provide guidelines to consumers about the safest and most environmentally friendly choices. You can find ratings for fish and seafood at http://www.edf.org.

Notes

1. Staying Healthy and Safe. US Department of Health and Human Services, Office on Women's Health. Last updated March 5, 2009. https://www.womenshealth.gov/pregnancy/youre-pregnant-now-what/staying-healthy-and-safe. Updated February 1, 2017. Accessed November 30, 2017.
2. Weng X, Odouli R, Li DK. Maternal caffeine consumption during pregnancy and the risk of miscarriage: a prospective cohort study. *Am J Obstet Gynecol* 2008;198, 279.e1-279.e8.
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4. Listeria and Pregnancy. American Pregnancy Association. http://www.americanpregnancy.org/pregnancycomplications/listeria.html. Updated March 10, 2017. Accessed November 29, 2017.

15.6 Physical Activity During Pregnancy

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For most pregnant women, physical activity is a must and is recommended in the 2015 **Dietary Guidelines for Americans**. Regular exercise of moderate intensity, about thirty minutes per day most days of the week, keeps the heart and lungs healthy. It also helps to improve sleep and boosts mood and energy levels. In addition, women who exercise during pregnancy report fewer discomforts and may have an easier time losing excess weight after childbirth. Brisk walking, swimming, or an aerobics class geared toward expectant mothers are all great ways to get exercise during a pregnancy. Healthy women who already participate in vigorous activities, such as running, can continue doing so during pregnancy provided they discuss an exercise plan with their physicians.

However, pregnant women should avoid pastimes that could cause injury, such as soccer, football, and other contact sports, or activities that could lead to falls, such as horseback riding and downhill skiing. It may be best for pregnant women not to participate in certain sports, such as tennis, that require you to jump or change direction quickly. Scuba diving should also be avoided because it might result in the fetus developing decompression sickness. This potentially fatal condition results from a rapid decrease in pressure when a diver ascends too quickly[1].

Notes

1. Should I Exercise During My Pregnancy?. National Institutes of Health, and Friends of the National Library of Medicine. NIH Medline Plus. 2008; 3(1), 26. http://www.nlm.nih.gov/medlineplus/magazine/issues/winter08/articles/winter08pg26.html. Accessed December 2, 2017.

15.7 Common Discomforts During Pregnancy

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Pregnancy can lead to certain discomforts, from back strain to swollen ankles. Also, a pregnant woman is likely to experience constipation because increased hormone levels can slow digestion and relax muscles in the bowels. Constipation and pressure from growth of the uterus can result in **hemorrhoids**, which are another common discomfort.[1] Getting mild to moderate exercise and drinking enough fluids can help prevent both conditions. Also, eating a high-fiber diet softens the stools and reduces the pressure on hemorrhoids.

Heartburn can occur during the early months of pregnancy due to an increase in the hormone progesterone, and during the later months due to the expanding size of the fetus, which limits stomach contraction. Avoiding chocolate, mint, and greasy foods, and remaining upright for an hour after meals can help pregnant women avoid heartburn. In addition, it can be helpful to drink fluids between meals, instead of with food.

Other common complaints can include leg cramps and bloating. Regular exercise can help to alleviate these discomforts. A majority of pregnant women develop gastrointestinal issues, such as nausea and vomiting. Many also experience food cravings and aversions. All of these can impact a pregnant woman's nutritional intake and it is important to protect against adverse effects.

Nausea and Vomiting

Nausea and vomiting are gastrointestinal issues that strike many pregnant women, typically in the first trimester. Nausea tends to occur more frequently than vomiting. These conditions are often referred to as "**morning sickness**," although that's something of a misnomer because nausea and vomiting can occur all day long, although it is often the worst in the first part of the day.

Increased levels of the pregnancy hormone human chorionic gonadotropin may cause nausea and vomiting, although that is speculative. Another major suspect is estrogen because levels of this hormone also rise and remain high during pregnancy. Given that a common side effect of estrogen-containing oral contraceptives is nausea this hormone likely has a role. Nausea usually subsides after sixteen weeks, possibly because the body becomes adjusted to higher estrogen levels.

It can be useful for pregnant women to keep a food diary to discover which foods trigger nausea, so they can avoid them in the future. Other tips to help avoid or treat nausea and vomiting include the following:

- Avoid spicy foods
- Avoid strong or unusual odors
- Eat dry cereal, toast, or crackers
- Eat frequent, small meals
- Consume more unrefined carbohydrates
- Get moderate **aerobic exercise**
- Drink ginger tea, which aids in stomach upset
- Seek fresh air when a bout of nausea comes on

A severe form of nausea and vomiting is a condition known as hyperemesis gravidarum. It is marked by prolonged vomiting, which can result in dehydration and require hospitalization. This disorder is relatively rare and impacts only 0.3 to 2 percent of all pregnant women.[2]

Food Cravings and Aversions

Food aversions and cravings do not have a major impact unless food choices are extremely limited. The most common food aversions are milk, meats, pork, and liver. For most women, it is not harmful to indulge in the occasional craving, such as the desire for pickles and ice cream. However, a medical disorder known as **pica** is willingly consuming foods with little or no nutritive value, such as dirt, clay, and laundry starch. In some places this is a culturally accepted practice. However, it can be harmful if these substances take the place of nutritious foods or contain toxins.

Notes

1. US Department of Health and Human Services, Office on Women's Health. "Pregnancy: Body Changes and Discomforts." Last updated September 27, 2010. http://www.womenshealth.gov/pregnancy/you-are-pregnant/body- changes -discomforts.cfm.
2. Eliakim, R., O. Abulafia, and D. M. Sherer. "Hyperemesis Gravidarum: A Current Review." *Am J Perinatol* 17, no. 4 (2000): 207–18.

15.8 Complications During Pregnancy

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Expectant mothers may face different complications during the course of their pregnancy. They include certain medical conditions that could greatly impact a pregnancy if left untreated, such as **gestational hypertension** and **gestational diabetes**, which have diet and nutrition implications.

Gestational Hypertension

Gestational hypertension is a condition of high blood pressure during the second half of pregnancy. Also referred to as pregnancy-induced hypertension, this condition affects about 6 to 8 percent of all pregnant women. First-time mothers are at a greater risk, along with women who have mothers or sisters who had gestational hypertension, women carrying multiple fetuses, women with a prior history of high blood pressure or kidney disease, and women who are overweight or obese when they become pregnant.

Hypertension can prevent the placenta from getting enough blood, which would result in the baby getting less oxygen and nutrients. This can result in low birth weight, although most women with gestational hypertension can still deliver a healthy baby if the condition is detected and treated early. Some risk factors can be controlled, such as diet, while others cannot, such as family history. If left untreated, gestational hypertension can lead to a serious complication called preeclampsia, which is sometimes referred to as toxemia. This disorder is marked by elevated blood pressure and protein in the urine and is associated with swelling. To prevent preeclampsia, the WHO recommends increasing calcium intake for women consuming diets low in that micronutrient, administering a low dosage of aspirin (75 milligrams), and increasing prenatal checkups.[1]

Gestational Diabetes

About 4 percent of pregnant women suffer from a condition known as gestational diabetes, which is abnormal glucose tolerance during pregnancy. The body becomes resistant to the hormone insulin, which enables cells to transport glucose from the blood. Gestational diabetes is usually diagnosed around twenty-four to twenty-six weeks, although it is possible for the condition to develop later into a pregnancy. **Signs and symptoms** of this disease include extreme **hunger**, **thirst**, or fatigue. If blood sugar levels are not properly monitored and treated, the baby might gain too much weight and require a cesarean delivery. Diet and regular physical activity can help to manage this condition. Most patients who suffer from gestational diabetes also require daily insulin injections to boost the absorption of glucose from the bloodsteam and promote the storage of glucose in the form of glycogen in liver and muscle cells. Gestational diabetes usually resolves after childbirth, although some women who suffer from this condition develop Type 2 diabetes later in life, particularly if they are overweight.

Notes

1. World Health Organization. "WHO Recommendations for Prevention and Treatment of Pre-eclampsia and Eclampsia." 2011. Accessed June 8, http://whqlibdoc.who.int/publications/2011/9789241548335_eng.pdf.

15.9 Key Takeaways

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- During pregnancy, it is imperative that a woman meet the nutritional needs both she and her unborn child require, which includes an increase in certain micronutrients, such as iron and folate.
- Starting BMI determines how much weight a woman needs to gain throughout her pregnancy. In an average pregnancy, a woman gains an extra 30 pounds.
- During the second and third trimesters, a woman's energy requirements increase by 340 calories per day for the second trimester and 450 calories per day for the third trimester.
- Common discomforts that can impact nutritional intake during pregnancy include nausea and vomiting, heartburn, and constipation.
- Gestational hypertension is a condition that impacts about 6 to 8 percent of pregnant women and results in a rise of blood pressure levels. This condition can lead to **preeclampsia** during a pregnancy.
- Gestational diabetes is a condition that impacts about 4 percent of pregnant women and results in a rise of blood glucose levels. This condition can lead to Type 2 diabetes later in life.

CHAPTER XVI

CHAPTER 16: LIFESPAN NUTRITION

In chapter 15, we discussed the human life cycle and all the ways in which pregnancy affects the mother's nutritional needs. In this chapter, we will look at how nutritional needs change across the lifespan, from infancy through childhood and adolescence, and then into middle and old age. Throughout all stages of life, the same basic nutrition principles still apply, but there are special considerations as bodies change near the beginning and end of the life cycle that we have not yet discussed.

Sections:

Chapter 16 is adapted from Jellum, et al., *Principles of Nutrition.* Acknowledgement therein:

- Adapted from: Zimmerman and Snow. "An Introduction to Nutrition" v. 1.0. and accessed at https://2012books.lardbucket.org/books/an-introduction-to-nutrition/

16.1 Infancy (Birth to Age One)

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for infants.
- Describe the physiologic basis for lactation and the specific components of breast milk.
- Discuss the benefits and barriers related to breastfeeding.
- Examine feeding problems that parents and caregivers may face with their infants.

Diet and **nutrition** have a major impact on a child's development from **infancy** into the adolescent years. A healthy diet not only affects growth, but also immunity, intellectual capabilities, and emotional well-being. One of the most important jobs of parenting is making sure that children receive an adequate amount of needed **nutrients** to provide a strong foundation for the rest of their lives.

The term infant is derived from the Latin word *infans*, which means "unable to speak." Healthy infants grow steadily, but not always at an even pace. For example, during the first year of life, height increases by 50 percent, while weight triples. Physicians and other health professionals can use growth charts to track a baby's development process. Because infants cannot stand, length is used instead of height to determine the rate of a child's growth. Other important developmental measurements include head circumference and weight. All of these must be tracked and compared against standard measurements for an infant's age. Nationally accepted growth charts are based on data collected by the National Center for Health Statistics. These charts allow for tracking trends over time and comparing with other infants among percentiles within the United States. Growth charts may provide warnings that a child has a medical problem or is malnourished. Insufficient weight or height gain during infancy may indicate a condition known as failure-to-thrive (FTT), which is characterized by poor growth. FTT can happen at any age, but in infancy, it typically occurs after six months. Some causes include poverty, lack of enough food, feeding inappropriate foods, and excessive intake of fruit juice.

Nutritional Requirements

Requirements for **macronutrients** and **micronutrients** on a per-kilogram basis are higher during infancy than at any other stage in the human life cycle. These needs are affected by the rapid cell division that occurs during growth, which requires energy and protein, along with the nutrients that are involved in DNA synthesis. During this period, children are entirely dependent on their parents or other caregivers to meet these needs. For almost all infants six months or younger, breast milk is the best source to fulfill nutritional requirements. An infant may require feedings eight to twelve times a day or more in the beginning. After six months, infants can gradually begin to consume solid foods to help meet nutrient needs.

Energy

Energy needs relative to size are much greater in an infant than an adult. A baby's resting metabolic rate is two times that of an adult. The RDA to meet energy needs changes as an infant matures and puts on more weight. The National Academy of Medicine uses a set of equations to calculate the **total energy expenditure** and resulting energy needs. For example, the equation for the first three months of life is:

(89 x weight [kg] −100) + 175 kcal.

Based on these equations, the estimated energy requirement for infants from zero to six months of age is 472 to 645 **kilocalories** per day for boys and 438 to 593 kilocalories per day for girls. For infants ages six to twelve months, the estimated requirement is 645 to 844 kilocalories per day for boys and 593 to 768 kilocalories per day for girls. From the age one to age two, the estimated requirement rises to 844–1,050 kilocalories per day for boys and 768–997 kilocalories per day for girls.[1] How often an infant wants to eat will also change over time due to growth spurts, which typically occur at about two weeks and six weeks of age, and again at about three months and six months of age.

Macronutrients

The dietary recommendations for infants are based on the nutritional content of human breast milk. **Carbohydrates** make up about 45 to 65 percent of the caloric content in breast milk, which amounts to a RDA of about 130 grams. Almost all of the carbohydrate in human milk is lactose, which infants digest and tolerate well. In fact, lactose intolerance is practically nonexistent in infants. Protein makes up about 5 to 20 percent of the caloric content of breast milk, which amounts to 13 grams per day. Infants have a high need for protein to support growth and development, though excess protein (which is only a concern with bottle-feeding) can cause dehydration, diarrhea, fever, and acidosis in premature infants. About 30 to 40 percent of the caloric content in breast milk is made up of fat. A high-fat diet is necessary to encourage the development of neural pathways in the brain and other parts of the body. However, saturated fats and **trans fatty acids** inhibit this growth. Infants who are over the age of six months, which means they are no longer exclusively breastfed, should not consume foods that are high in these types of fats.

Micronutrients

Almost all of the nutrients that infants require can be met if they consume an adequate amount of breast milk. There are a few exceptions, though. Human milk is low in vitamin D, which is needed for calcium absorption and building bone, among other things.

Therefore, breastfed children often need to take a vitamin D supplement in the form of drops. Infants at the highest risk for vitamin D deficiency are those with darker skin and no exposure to sunlight. Breast milk is also low in vitamin K, which is required for blood clotting, and deficits could lead to bleeding or hemorrhagic disease. Babies are born with limited vitamin K, so supplementation may be needed initially and some states require a vitamin K injection after birth. Also, breast milk is not high in iron, but the iron in breast milk is well absorbed by infants. After four to six months, however, an infant needs an additional source of iron other than breast milk.

Fluids

Infants have a high need for fluids, 1.5 milliliters per kilocalorie consumed compared to 1.0 milliliters per kilocalorie consumed for adults. This is because children have larger body surface area per unit of body weight and a reduced capacity for perspiration. Therefore, they are at greater risk of dehydration. However, parents or other caregivers can meet an infant's fluid needs with breast milk or formula. As solids are introduced, parents must make sure that young children continue to drink fluids throughout the day.

Breastfeeding

After the birth of the baby, nutritional needs must be met to ensure that an infant not only survives, but thrives from infancy into childhood. Breastfeeding provides the fuel a newborn needs for rapid growth and development. As a result, the WHO recommends that breastfeeding be done exclusively for the first six months of an infant's life. New mothers must also pay careful consideration to their own nutritional requirements to help their bodies recover in the wake of the pregnancy. This is particularly true for women who breastfeed their babies, which calls for an increased need in certain nutrients.

Lactation

Lactation is the process that makes breastfeeding possible, and is the synthesis and secretion of breast milk. Early in a woman's **pregnancy**, her mammary glands begin to prepare for milk production. **Hormones** play a major role in this, particularly during the second and third trimesters. At that point, levels of the hormone prolactin increase to stimulate the growth of the milk duct system, which initiates and maintains milk production. Levels of the hormone oxytocin also rise to promote the release of breast milk when the infant suckles, which is known as the milk ejection reflex. However, levels of the hormone progesterone need to decrease for successful milk production, because progesterone inhibits milk secretion. Shortly after birth, the expulsion of the placenta triggers progesterone levels to fall, which activates lactation. [2]

New mothers need to adjust their caloric and fluid intake to make breastfeeding possible. The RDA is 330 additional calories during the first six months of lactation and 400 additional calories during the second six months of lactation. The energy needed to support breastfeeding comes from both increased intake and from stored fat. For example, during the first six months after her baby is born, the daily caloric cost for a lactating mother is 500 calories, with 330 calories derived from increased intake and 170 calories derived from maternal fat stores. This helps explain why breastfeeding may promote weight loss in new mothers. Lactating women should also drink 3.1 liters of liquids per day (about 13 cups) to maintain milk production, according to the Institute of Medicine. As is the case during pregnancy, the RDA of nearly all **vitamins** and **minerals** increases for women who are breastfeeding their babies. The following table compares the recommended vitamins and minerals for lactating women to the levels for non-pregnant and pregnant women:

Recommended Nutrient Intakes during Lactation

Table 16.11 Recommended Nutrient Intakes in Non-Pregnant, Pregnant, and Lactating Women.[3]

Nutrient	Non-pregnant Women	Pregnant Women	Lactating Women
Vitamin A (mcg)	700	770	1300
Vitamin B6 (mg)	1.5	1.9	2.0
Vitamin B12 (mcg)	2.4	2.6	2.8
Vitamin C (mg)	75	85	120
Vitamin D (mcg)	5	5	5
Vitamin E (mg)	15	15	19
Calcium (mg)	1000	1000	1000
Folate (mcg)	400	600	500
Iron (mg)	18	27	9
Magnesium (mg)	320	360	310
Niacin (mg)	14	18	17
Phosphorus (mg)	700	700	700
Riboflavin (mg)	1.1	1.5	1.6
Thiamin (mg)	1.1	1.4	1.4
Zinc (mg)	8	11	12

Calcium requirements do not change during breastfeeding because of more efficient absorption, which is the case during pregnancy, too. However, the reasons for this differ. During pregnancy, there is enhanced absorption within the gastrointestinal tract. During lactation, there is enhanced retention by the kidneys. The RDA for phosphorus, fluoride, and molybdenum also remains the same.

Components of Breast Milk

Human breast milk not only provides adequate nutrition for infants, it also helps to protect newborns from disease. In addition, breast milk is rich in cholesterol, which is needed for brain development. It is helpful to know the different types and components of breast milk, along with the nutrients they provide to enable an infant survive and thrive.

Colostrum

Colostrum is produced immediately after birth, prior to the start of milk production, and lasts for several days after the arrival of the baby. Colostrum is thicker than breast milk, and is yellowish or creamy in color. This protein-rich liquid fulfills an infant's nutrient needs during those early days. Although low in volume, colostrum is packed with concentrated nutrition for newborns. This special milk is high in **fat-soluble** vitamins, minerals, and immunoglobulins (**antibodies**) that pass from the mother to the baby. Immunoglobulins provide passive immunity for the newborn and protect the baby from bacterial and viral diseases.[4]

Transitional Milk

Two to four days after birth, colostrum is replaced by transitional milk. Transitional milk is a creamy liquid that lasts for approximately two weeks and includes high levels of fat, lactose, and **water-soluble** vitamins. It also contains more calories than colostrum. After a new mother begins to produce transitional milk, she typically notices a change in the volume and type of liquid secreted and an increase in the weight and size of her breasts.[5]

Mature Milk

Mature milk is the final fluid that a new mother produces. In most women, it begins to secrete at the end of the second week postchildbirth. There are two types of mature milk that appear during a feeding. Foremilk occurs at the beginning and includes water, vitamins, and protein. Hind-milk occurs after the initial release of milk and contains higher levels of fat, which is necessary for weight gain. Combined, these two types of milk ensure that a baby receives adequate nutrients to grow and develop properly.[6]

About 90 percent of mature milk is water, which helps an infant remain hydrated. The other 10 percent contains carbohydrates, proteins, and fats, which support energy and growth. Similar to cow's milk, the main carbohydrate of mature breast milk is lactose. Breast milk contains vital fatty acids, such as docosahexaenoic acid (DHA) and arachidonic acid (ARA). In terms of protein, breast milk contains more whey than casein (which is the reverse of cow's milk). Whey is much easier for infants to digest than casein. Complete protein, which means all of the essential amino acids, is also present in breast milk. Complete protein includes lactoferrin, an iron-gathering compound that helps to absorb iron into an infant's bloodstream.

In addition, breast milk provides adequate vitamins and minerals. Although absolute amounts of some micronutrients are low, they are more efficiently absorbed by infants. Other essential components include digestive enzymes that help a baby digest the breast milk. Human milk also provides the hormones and growth factors that help a newborn to develop.

Diet and Milk Quality

A mother's diet can have a major impact on milk production and quality. As during pregnancy, lactating mothers should avoid illegal substances and cigarettes. Some legal drugs and herbal products can be harmful as well, so it is helpful to discuss them with a health-care provider. Some mothers may need to avoid certain things, such as spicy foods, that can produce gas in sensitive infants. Lactating women can drink alcohol, though they must avoid breastfeeding until the alcohol has completely cleared from their milk. Typically, this takes two to three hours for 12 ounces of beer, 5 ounces of wine, or 1.5 ounces of liquor, depending on a woman's body weight.[7] Precautions are necessary because exposure to alcohol can disrupt an infant's sleep schedule.

Benefits of Breastfeeding

Breastfeeding has a number of benefits, both for the mother and for the child. Breast milk contains immunoglobulins, enzymes, immune factors, and white blood cells. As a result, breastfeeding boosts the baby's immune system and lowers the incidence of diarrhea, along with respiratory diseases, gastrointestinal problems, and ear infections. Breastfed babies also are less likely to develop asthma and allergies, and breastfeeding lowers the risk of sudden infant death syndrome. In addition, human milk encourages the growth of healthy bacteria in an infant's intestinal tract. All of these benefits remain in place after an infant has been weaned from breast milk. Some studies suggest other possible long- term effects. For example, breast milk may improve an infant's intelligence and protect against Type 1 diabetes and **obesity**, although research is ongoing in these areas.[8]

Breastfeeding has a number of other important benefits. It is easier for babies to digest breast milk than bottle formula, which contains proteins made from cow's milk that require an adjustment period for infant digestive systems. Breastfed infants are sick less often than bottle-fed infants. Breastfeeding is more sustainable and results in less plastic waste and other trash. Breastfeeding can also save families money because it does not incur the same cost as purchasing formula. Other benefits include that breast milk is always ready. It does not have to be mixed, heated, or prepared. Also, breast milk is sterile and is always at the right temperature.

In addition, the skin-to-skin contact of breastfeeding promotes a close bond between mother and baby, which is an important emotional and psychological benefit. The practice also provides health benefits for the mother. Breastfeeding helps a woman's bones stay strong, which protects against fractures later in life. Studies have also shown that breastfeeding reduces the risk of breast and ovarian cancers.[9]

The Baby-Friendly Hospital Initiative In 1991, the WHO and UNICEF launched the Baby-Friendly Hospital Initiative (BFHI), which works to ensure that all maternities, including hospitals and freestanding facilities, become centers of breastfeeding support. A maternity can be denoted as "baby-friendly" when it does not accept substitutes to human breast milk and has implemented ten steps to support breastfeeding. These steps include having a written policy on breastfeeding communicated to health-care staff on a routine basis, informing all new mothers about the benefits and management of breastfeeding, showing new mothers how to breastfeed their infants, and how to maintain lactation, and giving newborns no food or drink other than breast milk, unless medically indicated. Since the BFHI began, more than fifteen thousand facilities in 134 countries, from Benin to Bangladesh, have been deemed "baby friendly." As a result, more mothers are breastfeeding their newborns and infant health has improved, in both the developed world and in developing nations.[10]

Barriers to Breastfeeding

Although breast milk is ideal for almost all infants, there are some challenges that nursing mothers may face when starting and continuing to breastfeed their infants. These obstacles include painful engorgement or fullness in the breasts, sore and tender nipples, lack of comfort or confidence in public, and lack of accommodation to breastfeed or express milk in the workplace.

One of the first challenges nursing mothers face is learning the correct technique. It may take a little time for a new mother to help her baby properly latch on to her nipples.

Improper latching can result in inadequate intake, which could slow growth and development. However, International Board Certified Lactation Consultants (IBCLCs), OB nurses, and registered dietitians are all trained to help new mothers learn the proper technique. Education, the length of maternity leave, and laws to protect public breastfeeding, among other measures, can all help to facilitate breastfeeding for many lactating women and their newborns.

Contraindications to Breastfeeding

Although there are numerous benefits to breastfeeding, in some cases there are also risks that must be considered. In the developed world, a new mother with HIV should not breastfeed, because the infection can be transmitted through breast milk. These women typically have access to bottle formula that is safe, and can be used as a replacement for breast milk. However, in developing nations where HIV infection rates are high and acceptable infant formula can be difficult to come by, many newborns would be deprived of the nutrients they need to develop and grow. Also, inappropriate or contaminated bottle formulas cause 1.5 million infant deaths each year. As a result, the WHO recommends that women infected with HIV in the developing world should nurse their infants while taking antiretroviral medications to lower the risk of transmission.[11]

Breastfeeding also is not recommended for women undergoing radiation or chemotherapy treatment for cancer. Additionally, if an infant is diagnosed with galactosemia, meaning an inability to process the simple sugar galactose, the child must be on a galactose-free diet, which excludes breast milk. This genetic disorder is a very rare condition, however, and only affects 1 in thirty- to sixty thousand newborns.[12] When breastfeeding is contraindicated for any reason, feeding a baby formula enables parents and caregivers to meet their newborn's nutritional needs.

Bottle-Feeding

Most women can and should breastfeed when given sufficient education and support. However, as discussed, a small percentage of women are unable to breastfeed their infants, while others choose not to. For parents who choose to bottle-feed, infant formula provides a balance of nutrients. However, not all formulas are the same and there are important considerations that parents and caregivers must weigh. Standard formulas use cow's milk as a base. They have 20 calories per fluid ounce, similar to breast milk, with vitamins and minerals added. Soy-based formulas are usually given to infants who develop diarrhea, constipation, vomiting, **colic**, or abdominal pain, or to infants with a cow's milk protein allergy. Hypoallergenic protein hydrolysate formulas are usually given to infants who are allergic to cow's milk and soy protein. This type of formula uses hydrolyzed protein, meaning that the protein is broken down into amino acids and small peptides, which makes it easier to digest. Preterm infant formulas are given to low birth weight infants, if breast milk is unavailable. Preterm infant formulas have 24 calories per fluid ounce and are given until the infant reaches a desired weight.

Infant formula comes in three basic types:

- Powder that requires mixing with water. This is the least expensive type of formula.
- Concentrates, which are liquids that must be diluted with water. This type is slightly more expensive.
- Ready-to-use liquids that can be poured directly into bottles. This is the most expensive type of formula.

However, it requires the least amount of preparation. Ready-to-use formulas are also convenient for traveling. Most babies need about 2.5 ounces of formula per pound of body weight each day. Therefore, the average infant should consume about 24 fluid ounces of breast milk or formula per day. When preparing formula, parents and caregivers should carefully follow the safety guidelines, since an infant has an immature immune system. All equipment used in formula preparation should be sterilized.

Prepared, unused formula should be refrigerated to prevent bacterial growth. Parents should make sure not to use contaminated water to mix formula in order to prevent foodborne illnesses. Follow the instructions for powdered and concentrated formula carefully—formula that is over-diluted would not provide adequate calories and protein, while over-concentrated formula provides too much protein and too little water which can impair kidney function.

Breast Milk versus Bottle Formula

It is important to note again that both the American Academy of Pediatrics and the WHO state that breast milk is far superior to infant formula. The table below compares the advantages of giving a child breast milk to the disadvantages of using bottle formula.

Table 16.12 Comparison of breast milk and bottle formula[13]

Breast Milk	Bottle Formula
Antibodies and lactoferrin in breast milk protect infants.	Formula does not contain immunoprotective factors.
The iron in breast milk is absorbed more easily.	Formula contains more iron than breast milk, but it is not absorbed as easily.
The feces that babies produce do not smell because breastfed infants have different bacteria in the gut.	The feces that bottle-fed infants produce tends to have a foul-smelling odor.
Breast milk is always available and is always at the correct temperature.	Formula must be prepared, refrigerated for storage, and warmed before it is given to an infant.
Breastfed infants are less likely to have constipation.	Bottle-fed infants are more likely to have constipation.
Breastfeeding ostensibly is free, though purchasing a pump and bottles to express milk does require some expense.	Formula must be purchased and is expensive.
Breast milk contains the fatty acids DHA and ARA, which are vital for brain and vision development.	Some formulas contain DHA and ALA.

Introducing Solid Foods

Infants should be breastfed or bottle-fed exclusively for the first six months of life according to the WHO. (The American Academy of Pediatrics recommends breast milk or bottle formula exclusively for at least the first four months, but ideally for six months.). Infants should not consume solid foods prior to six months because solids do not contain the right nutrient mix that infants need. Also, eating solids may mean drinking less breast milk or bottle formula. If that occurs, an infant may not consume the right quantities of various nutrients. If parents try to feed an infant who is too young or is not ready, their tongue will push the food out, which is called an ***extrusion reflex***. After six months, the suck-swallow reflexes are not as strong, and infants can hold up their heads and move them around, both of which make eating solid foods more feasible.

Solid baby foods can be bought commercially or prepared from regular food using a food processor, blender, food mill, or grinder at home. Usually, an infant cereal can be offered from a spoon between four to six months. By nine months to a year, infants are able to chew soft foods and can eat solids that are well chopped or mashed. Infants who are fed solid foods too soon are susceptible to developing food allergies.

Therefore, as parents and caregivers introduce solids, they should feed their child only one new food at a time (starting with rice cereal, followed by fruits or vegetables), to help identify allergic responses or **food intolerances**. An iron supplement or iron-fortified cereal is also recommended at this time.

Learning to Self-Feed

With the introduction of solid foods, young children begin to learn how to handle food and how to feed themselves. At six to seven months, infants can use their whole hand to pick up items (this is known as the ***palmar grasp***). They can lift larger items, but picking up smaller pieces of food is difficult. At eight months, a child might be able to use a ***pincer grasp***, which uses fingers to pick up objects. After the age of one, children slowly begin to use utensils to handle their food. Unbreakable dishes and cups are essential, since very young children may play with them or throw them when they become bored with their food.

Feeding Problems during Infancy

Parents and caregivers should be mindful of certain diet-related problems that may arise during infancy. Certain foods are choking hazards, including foods with skins or foods that are very small, such as grapes. Other examples of potential choking hazards include raw carrots and apples, raisins, and hard candy. Parents should also avoid adding salt or seasonings to an infant's food.

Heating an infant's food presents a risk of accidental injury or burns, which may occur if the food is heated unevenly or excessively. Keep in mind that an infant cannot communicate that the food is too hot. Also, parents and caregivers should never leave a baby alone at mealtime, because an infant can accidentally choke on pieces of food that are too big or have not been adequately chewed. Raw honey and corn syrup both contain spores of *Clostridium botulinum*. They produce a poisonous toxin in a baby's intestines, which can cause the foodborne illness botulism. After the age of one, it is safe to give an infant honey or corn syrup. However, honey as an ingredient in food, such as in cereal, is safe for all ages because it has been adequately heat-treated.

Overnutrition

Overnutrition during infancy is a growing problem. Overfed infants may develop dietary habits and metabolic characteristics that last a lifetime. According to the American Journal of Clinical Nutrition, the consequences of overnutrition and growth acceleration in infancy include long-term obesity, along with Type 2 diabetes and cardiovascular disease later in life. [14] Therefore, parents and other caregivers should restrain from overfeeding, and ideally give their infants breast milk to promote health and wellbeing.

Food Allergies

Food **allergies** impact four to six percent of young children in America. Common food allergens that can appear just before or after the first year include peanut butter, egg whites, wheat, cow's milk, and nuts. For infants, even a small amount of a dangerous food can prove to be life-threatening. If there is a family history of food allergies, it is a good idea to delay giving a child dairy products until one year of age, eggs until two years of age, and shellfish, fish, and nuts until three years of age.

However, lactating women should not make any changes to their diets. Research shows that nursing mothers who attempt to ward off allergies in their infants by eliminating certain foods may do more harm than good. According to the American Academy of Allergy, Asthma, and Immunology, mothers who avoided certain dairy products showed decreased levels in their breast milk of an immunoglobulin specific to cow's milk. This antibody is thought to protect against the development of allergies in children. Even when an infant is at higher risk for food allergies, there is no evidence that alterations in a mother's diet make a difference.[15]

Early Childhood Caries

Primary teeth are at risk for a disorder known as early childhood caries from breast milk, formula, juice, or other drinks fed through a bottle. (Caries is a clinical term for tooth decay.) Liquids can build up in a baby's mouth, and the natural or added sugars lead to tooth decay. Early childhood caries is caused not only by the kinds of liquids given to an infant, but also by the frequency and length of time that fluids are given. Giving a child a bottle of juice or other sweet liquids several times each day, or letting a baby suck on a bottle longer than a mealtime, either when awake or asleep, can also cause early childhood caries. In addition, this practice affects the development and position of the teeth and the jaw. The risk of early childhood caries continues into the **toddler** years as children begin to consume more foods with a high sugar content. Therefore, parents should avoid giving their children sugary snacks and beverages.

Gastroesophageal Reflux

Small amounts of spitting up during a feeding is normal. However, there is cause for concern if it is too difficult to feed an infant due to gastroesophageal reflux. This condition occurs when stomach muscles open at the wrong times and allow milk or food to back up into the esophagus. Symptoms of gastroesophageal reflux in infants include severe spitting up, projectile vomiting, arching of the back as though in pain, refusal to eat or pulling away from the breast during feedings, gagging or problems with swallowing, and slow weight gain. For most infants, making adjustments in feeding practices addresses the issue. For example, a parent can feed their baby in an upright position, wait at least an hour after eating for play time, burp more often, or give a child smaller, more frequent feedings.

Diarrhea and Constipation

Diarrhea is often caused by a gastrointestinal infection and can dehydrate an infant. It is characterized by stool frequency and consistency that deviates substantially from the norm. If an infant has had several bouts of this condition, they will need to replace lost fluids and electrolytes. A common recommendation is to give a child an oral rehydration solution. Because of the immunoprotective factors in breast milk, breastfed infants are less likely to contract gastrointestinal viral illness and experience diarrhea.

Infant constipation—which is the passage of hard, dry bowel movements, but not necessarily the absence of daily bowel movements—is another common problem. This condition frequently begins when a baby transitions from breast milk to formula or begins eating solid foods. Pediatricians can provide the best guidance for handling the problem. Common recommendations include applying a small amount of water-based lubricant to an infant's anus to ease the passage of hard stools, and feeding an infant on solid foods pureed pears or prunes, or providing barley cereal in place of rice cereal.[16] Parents can also offer their child a little more water in between feedings to help alleviate the condition.

Colic

Colic is a common problem during infancy, characterized by crankiness and crying jags. It is defined as crying that lasts longer than three hours per day for at least three days per week and for at least three weeks (which is commonly known as the "rule of 3's"), and is not caused by a medical problem. About one-fifth of all infants develop colic, usually between the second and third weeks. Crying spells can occur around the clock, but often worsen in the early evening. Also, colicky babies may have stomachs that are enlarged or distended with gas.

There is no definitive explanation for colic. Often, colic occurs when a child is unusually sensitive to stimulation. In breastfeeding babies, colic can be a sign of sensitivity to the mother's diet. Lactating mothers can try to eliminate caffeine, chocolate, and any other potentially irritating foods from their meals.[17] However, since colic usually subsides over time, any improvement that occurs with food elimination may conincide with the natural healing process.

Parents and caregivers who are feeding bottle formula to colicky babies should talk with pediatricians about replacing it with a protein hydrolysate formula.[18] Whether breastfeeding or bottlefeeding, it is also important not to overfeed infants, which could make them uncomfortable and more likely to have crying fits. In general, it is best to wait between two and three hours from the start of one feeding to the start of the next. If food sensitivity is the cause, colic should cease within a few days of making changes. Eventually, the problem goes away. Symptoms usually begin to dissipate after six weeks and are gone by twelve weeks.[19]

Newborn Jaundice

Newborn jaundice is another potential problem during infancy. This condition can occur within a few days of birth and is characterized by yellowed skin or yellowing in the whites of the eyes, which can be harder to detect in dark-skinned babies. Jaundice typically appears on the face first, followed by the chest, abdomen, arms, and legs. This disorder is caused by elevated levels of bilirubin in a baby's bloodstream. Bilirubin is a substance created by the breakdown of red blood cells and is removed by the liver. Jaundice develops when a newborn's liver does not efficiently remove bilirubin from the blood. There are several types of jaundice associated with newborns:

- Physiologic jaundice. The most common type of newborn jaundice and can affect up to 60 percent of full-term babies in the first week of life.
- Breast-milk jaundice. The name for a condition that persists after physiologic jaundice subsides in otherwise healthy babies and can last for three to twelve weeks after birth. Breast-milk jaundice tends to be genetic and there is no known cause, although it may be linked to a substance in the breast milk that blocks the breakdown of bilirubin. However, that does not mean breastfeeding should be stopped. As long as bilirubin levels are monitored, the disorder rarely leads to serious complications.
- Breastfeeding jaundice. Occurs when an infant does not get enough milk. This may happen because a newborn does not get a good start breastfeeding, does not latch

on to the mother's breast properly, or is given other substances that interfere with breastfeeding (such as juice). Treatment includes increased feedings, with help from a lactation consultant to ensure that the baby takes in adequate amounts.

Newborn jaundice is more common in a breastfed baby and tends to last a bit longer. If jaundice is suspected, a pediatrician will run blood tests to measure the amount of bilirubin in an infant's blood. Treatment often involves increasing the number of feedings to increase bowel movements, which helps to excrete bilirubin. Within a few weeks, as the baby begins to mature and red blood cell levels diminish, jaundice typically subsides with no lingering effects.[20]

Notes

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16.2 Nutrition in the Toddler Years

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for toddlers.
- Explore the introduction of solid foods into a toddler's diet.
- Examine feeding problems that parents and caregivers may face with their toddlers.

By the age of two, children have advanced from infancy and are on their way to becoming school-aged children. Their physical growth and motor development slows compared to the progress they made as infants. However, toddlers experience enormous intellectual, emotional, and social changes. Of course, food and nutrition continue to play an important role in a child's development. During this stage, the diet completely shifts from breastfeeding or bottle-feeding to solid foods along with healthy juices and other liquids. Parents of toddlers also need to be mindful of certain nutrition-related issues that may crop up during this stage of the human life cycle. For example, fluid requirements relative to body size are higher in toddlers than in adults because children are at greater risk of dehydration. Toddlers should drink about 1.3 liters of fluids per day, ideally liquids that are low in sugar.

The Toddler Years (Ages Two to Three)

During this phase of human development, children are mobile and grow more slowly than infants, but are much more active. The toddler years pose interesting challenges for parents or other caregivers, as children learn how to eat on their own and begin to develop personal preferences. However, with the proper diet and guidance, toddlers can continue to grow and develop at a healthy rate.

Nutritional Requirements

MyPlate may be used as a guide for the toddler's diet. A toddler's serving sizes should be approximately one-quarter that of an adult's. One way to estimate serving sizes for young children is one tablespoon for each year of life. For example, a two-year-old child would be served 2 tablespoons of fruits or vegetables at a meal, while a four-year-old would be given 4 tablespoons, or a quarter cup. Here is an example of a toddler-sized meal:

- 1 ounce of meat or chicken, or 2 to 3 tablespoons of beans
- One-quarter slice of whole-grain bread
- 1 to 2 tablespoons of cooked vegetable
- 1 to 2 tablespoons of fruit

Web Link: MyPlate-Preschoolers

Energy

The energy requirements for ages two to three are about 1,000 to 1,400 calories a day. In general, a toddler needs to consume about 40 calories for every inch of height. For example, a young child who measures 32 inches should take in an average of 1,300 calories a day. However, the recommended caloric intake varies with each child's level of activity. Toddlers require small, frequent, nutritious snacks and meals to satisfy energy requirements. The amount of food a toddler needs from each food group depends on daily calorie needs. See the following table for some examples:

Table 16.21 Serving Sizes for Toddlers[1]

Food Group	Daily Serving	Examples
Grains	About 3 ounces of grains per day, ideally whole grains	3 slices of bread 1 slice of bread, plus ⅓ cup of cereal, and ¼ cup of cooked whole-grain rice or pasta
Proteins	2 ounces of meat, poultry, fish, eggs, or legumes	1 ounce of lean meat or chicken, plus one egg 1 ounce of fish, plus ¼ cup of cooked beans
Fruits	1 cup of fresh, frozen, canned, and/or dried fruits, or 100 percent fruit juice	1 small apple cut into slices 1 cup of sliced or cubed fruit 1 large banana
Vegetables	1 cup of raw and/or cooked vegetables	1 cup of pureed, mashed, or finely chopped vegetables (such as mashed potatoes, chopped broccoli, or tomato sauce)
Dairy Products	2 cups per day	2 cups of fat-free or low- fat milk 1 cup of fat-free or low-fat milk, plus 2 slices of cheese 1 cup of fat-free or low-fat milk, plus 1 cup of yogurt

Macronutrients

For carbohydrate intake, the **Acceptable Macronutrient Distribution Range (AMDR)** is 45 to 65 percent of daily calories (113 to 163 grams for 1,000 daily calories). Toddlers' needs increase to support their body and brain development. Brightlycolored unrefined carbohydrates, such as peas, orange slices, tomatoes, and bananas are not only nutrient-dense, they also make a plate look more appetizing and appealing to a young child. The RDA of protein is 5 to 20 percent of daily calories (13 to 50 grams for 1,000 daily calories). The AMDR for fat for toddlers is 30 to 40 percent of daily calories (33 to 44 grams for 1,000 daily calories). Essential fatty acids are vital for the development of the eyes, along with nerve and other types of tissue. However, toddlers should not consume foods with high amounts of trans fats and saturated fats. Instead, young children require the equivalent of 3 teaspoons of healthy oils, such as canola oil, each day.

Micronutrients

As a child grows bigger, the demands for micronutrients increase. These needs for vitamins and minerals can be met with a **balanced diet**, with a few exceptions. As toddlers mature, they become more comfortable handling dishes and utensils. According to the American Academy of Pediatrics, toddlers and children of all ages need 600 international units of vitamin D per day. Vitamin D-fortified milk and cereals can help to meet this need. However, toddlers who do not get enough of this micronutrient should receive a supplement. Pediatricians may also prescribe a **fluoride** supplement for toddlers who live in areas with fluoride-poor water. Iron deficiency is also a major concern for children between the ages of two and three. You will learn about iron-deficiency **anemia** later in this section.

Learning How to Handle Food

As children grow older, they enjoy taking care of themselves, which includes self- feeding. During this phase, it is important to offer children foods that they can handle on their own and that help them avoid choking and other hazards. Examples include fresh fruits that have been sliced into pieces, orange or grapefruit sections, peas or potatoes that have been mashed for safety, a cup of yogurt, and whole-grain bread or bagels cut into pieces. Even with careful preparation and training, the learning process can be messy. As a result, parents and other caregivers can help children learn how to feed themselves by providing the following:

- small utensils that fit a young child's hand
- small cups that will not tip over easily
- plates with edges to prevent food from falling off
- small servings on a plate
- high chairs, booster seats, or cushions to reach a table

Feeding Problems in the Toddler Years

During the toddler years, parents may face a number of problems related to food and nutrition. Possible obstacles include difficulty helping a young child overcome a fear of new foods, or fights over messy habits at the dinner table. Even in the face of problems and confrontations, parents and other caregivers must make sure their preschooler has nutritious choices at every meal. For example, even if a child stubbornly resists eating vegetables, parents should continue to provide them. Before long, the child may change their mind, and develop a taste for foods once abhorred. It is important to remember this is the time to establish or reinforce healthy habits.

Nutritionist Ellyn Satter states that feeding is a responsibility that is split between parent and child. According to Satter, parents are responsible for what their infants eat, while infants are responsible for how much they eat. In the toddler years and beyond, parents are responsible for what children eat, when they eat, and where they eat, while children are responsible for how much food they eat and whether they eat. Satter states that the role of a parent or a caregiver in feeding includes the following:[2]

- selecting and preparing food
- providing regular meals and snacks
- making mealtimes pleasant
- showing children what they must learn about mealtime behavior
- avoiding letting children eat in between meal- or snack-times

High-Risk Choking

Foods Certain foods are difficult for toddlers to manage and pose a high risk of choking. Big chunks of food should not be given to children under the age of four. Also, globs of peanut butter can stick to a younger child's palate and choke them. Popcorn and nuts should be avoided as well, because toddlers are not able to grind food and reduce it to a consistency that is safe for swallowing. Certain raw vegetables, such as baby carrots, whole cherry tomatoes, whole green beans, and celery are also serious choking hazards. However, there is no reason that a toddler cannot enjoy well-cooked vegetables cut into bite-size pieces.

Picky Eaters

The parents of toddlers are likely to notice a sharp drop in their child's appetite. Children at this stage are often picky about what they want to eat. They may turn their heads away after eating just a few bites. Or, they may resist coming to the table at mealtimes. They also can be unpredictable about what they want to consume for specific meals or at particular times of the day. Although it may seem as if toddlers should increase their food intake to match their level of activity, there is a good reason for picky eating. A child's growth rate slows after infancy, and toddlers ages two and three do not require as much food.

Food Jags

For weeks, toddlers may go on ***a food jag*** and eat one or two preferred foods—and nothing else. It is important to understand that preferences will be inconsistent as a toddler develops eating habits. This is one way that young children can assert their individuality and independence. However, parents and caregivers should be concerned if the same food jag persists for several months, instead of several weeks. Options for addressing this problem include rotating acceptable foods while continuing to offer diverse foods, remaining low-key to avoid exacerbating the problem, and discussing the issue with a pediatrician. Also, children should not be forced to eat foods that they do not want. It is important to remember that food jags do not have a long-term effect on a toddler's health, and are usually temporary situations that will resolve themselves.

Toddler Obesity

Another potential problem during the early childhood years is toddler obesity. According to the US Department of Health and Human Services, in the past thirty years, obesity rates have more than doubled for all children, including infants and toddlers.[3] Almost 10 percent of infants and toddlers weigh more than they should considering their length, and slightly more than 20 percent of children ages two to five are overweight or obese.[4]

Obesity during early childhood tends to linger as a child matures and cause health problems later in life.

There are a number of reasons for this growing problem. One is a lack of time. Parents and other caregivers who are constantly on the go may find it difficult to fit home-cooked meals into a busy schedule and may turn to fast food and other conveniences that are quick and easy, but not nutritionally sound. Another contributing factor is a lack of access to fresh fruits and vegetables. This is a problem particularly in low-income neighborhoods where local stores and markets may not stock fresh produce or may have limited options. Physical inactivity is also a factor, as toddlers who live a sedentary lifestyle are more likely to be overweight or obese. Another contributor is a lack of breastfeeding support. Children who were breastfed as infants show lower rates of obesity than children who were bottle-fed.

To prevent or address toddler obesity parents and caregivers can do the following:

- Eat at the kitchen table instead of in front of a television to monitor what and how much a child eats.
- Offer a child healthy portions. The size of a toddler's fist is an appropriate serving size.
- Plan time for physical activity, about sixty minutes or more per day. Toddlers should have no more than sixty minutes of sedentary activity, such as watching television, per day.

Early Childhood Caries

Early childhood caries remains a potential problem during the toddler years. The risk of early childhood caries continues as children begin to consume more foods with a high sugar content. According to the National Health and Nutrition Examination Survey, children between ages of two and five consume about 200 calories of added sugar per day.[5]

Therefore, parents with toddlers should avoid processed foods, such as snacks from vending machines, and sugary beverages, such as soda. Parents also need to instruct a child on brushing their teeth at this time to help a toddler develop healthy habits and avoid tooth decay.

Iron-Deficiency Anemia

An infant who switches to solid foods, but does not eat enough iron-rich foods, can develop **iron-deficiency anemia.** This condition occurs when an iron-deprived body cannot produce enough hemoglobin, a protein in red blood cells that transports oxygen throughout the body. The inadequate supply of hemoglobin for new blood cells results in anemia. Iron-deficiency anemia causes a number of problems including weakness, pale skin, shortness of breath, and irritability. It can also result in intellectual, behavioral, or motor problems. In infants and toddlers, iron-deficiency anemia can occur as young children are weaned from iron-rich foods, such as breast milk and iron-fortified formula. They begin to eat solid foods that may not provide enough of this nutrient. As a result, their iron stores become diminished at a time when this nutrient is critical for brain growth and development.

There are steps that parents and caregivers can take to prevent iron-deficiency anemia, such as adding more iron-rich foods to a child's diet, including lean meats, fish, poultry, eggs, legumes, and iron-enriched whole-grain breads and cereals. A toddler's diet should provide 7 to 10 milligrams of iron daily. Although milk is critical for the bone-building calcium that it provides, intake should not exceed the RDA to avoid displacing foods rich with iron. Children may also be given a daily supplement, using infant vitamin drops with iron or ferrous sulfate drops. If iron deficiency anemia does occur, treatment includes a dosage of 3 milligrams per kilogram once daily before breakfast, usually in the form of a ferrous sulfate syrup. Consuming vitamin C, such as orange juice, can also help to improve iron absorption.[6]

Toddler Diarrhea

As with adults, a variety of conditions or circumstances may give a toddler diarrhea. Possible causes include bacterial or viral infections, food allergies, or lactose intolerance, among other medical conditions. Excessive fruit juice consumption (more than one 6-ounce cup per day) can also lead to diarrhea.[7] Diarrhea presents a special concern in young children because their small size makes them more vulnerable to dehydration. Parents should contact a pediatrician if a toddler has had diarrhea for more than twenty-four hours, if a child is also vomiting, or if they exhibit signs of dehydration, such as a dry mouth or tongue, or sunken eyes, cheeks, or abdomen. Preventing or treating dehydration in toddlers includes the replacement of lost fluids and electrolytes (sodium and potassium). Oral rehydration therapy, or giving special fluids by mouth, is the most effective measure.

Developing Habits

Eating habits develop early in life. They are typically formed within the first few years and it is believed that they persist for years, if not for life. So it is important for parents and other caregivers to help children establish healthy habits and avoid problematic ones. Children begin expressing their preferences at an early age. Parents must find a balance between providing a child with an opportunity for self expression, helping a child develop healthy habits, and making sure that a child meets all of their nutritional needs. Following Ellyn Satter's division of responsibility in feeding (see above) can help a child eat the right amount of food, learn mealtime behavior, and grow at a healthy and predictable rate. Bad habits and poor nutrition have an accrual effect. The foods you consume in your younger years will impact your health as you age, from childhood into the later stages of life. As a result, good nutrition today means optimal health tomorrow.

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16.3 Nutrition in Childhood

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for school-aged children.
- Discuss the most important nutrition-related concerns during childhood.

Nutritional needs change as children leave the toddler years. From ages four to eight, school-aged children grow consistently, but at a slower rate than infants and toddlers. They also experience the loss of deciduous, or “baby,” teeth and the arrival of permanent teeth, which typically begins at age six or seven. As new teeth come in, many children have some malocclusion, or malposition, of their teeth, which can affect their ability to chew food. Other changes that affect nutrition include the influence of peers on dietary choices and the kinds of foods offered by schools and afterschool programs, which can make up a sizable part of a child’s diet. Food-related problems for young children can include tooth decay, food sensitivities, and malnourishment. Also, excessive weight gain early in life can lead to obesity into adolescence and adulthood.

Childhood (Ages Four to Eight)

At this life stage, a healthy diet facilitates physical and mental development and helps to maintain health and wellness. School-aged children experience steady, consistent growth, with an average growth rate of 2–3 inches (5–7 centimeters) in height and 4.5–6.5 pounds (2–3 kilograms) in weight per year. In addition, the rate of growth for the extremities is faster than for the trunk, which results in more adult-like proportions. Long-bone growth stretches muscles and ligaments, which results in many children experiencing “growing pains,” at nighttime in particular.[1]

Energy

Children's energy needs vary, depending on their growth and level of physical activity. Energy requirements also vary according to gender. Girls ages four to eight require 1,200 to 1,800 calories a day, while boys need 1,200 to 2,000 calories daily, and, depending on their activity level, maybe more. Also, recommended intakes of macronutrients and most micronutrients are higher relative to body size, compared with nutrient needs during adulthood. Therefore, children should be provided nutrient-dense food at meal- and snack-time. However, it is important not to overfeed children, as this can lead to childhood obesity, which is discussed in the next section. Parents and other caregivers can turn to the MyPlate website for guidance: http://www.choosemyplate.gov/.

Macronutrients

For carbohydrates, the **Acceptable Macronutrient Distribution Range (AMDR)** is 45–65 percent of daily calories (which is a recommended daily allowance of 135–195 grams for 1,200 daily calories). Carbohydrates high in fiber should make up the bulk of intake. The AMDR for protein is 10–30 percent of daily calories (30–90 grams for 1,200 daily calories). Children have a high need for protein to support muscle growth and development. High levels of essential fatty acids are needed to support growth (although not as high as in infancy and the toddler years). As a result, the AMDR for fat is 25–35 percent of daily calories (33–47 grams for 1,200 daily calories). Children should get 17– 25 grams of fiber per day.

Micronutrients

Micronutrient needs should be met with foods first. Parents and caregivers should select a variety of foods from each food group to ensure that nutritional requirements are met. Because children grow rapidly, they require foods that are high in iron, such as **lean meats**, legumes, fish, poultry, and iron-enriched cereals. Adequate fluoride is crucial to support strong teeth. One of the most important micronutrient requirements during childhood is adequate calcium and vitamin D intake. Both are needed to build dense bones and a strong skeleton. Children who do not consume adequate vitamin D should be given a supplement of 10 micrograms (400 international units) per day. The table below shows the micronutrient recommendations for school-aged children. (Note that the recommendations are the same for boys and girls. As we progress through the different stages of the human life cycle, there will be some differences between males and females regarding micronutrient needs.)

Table 16.31 Recommended Micronutrient Levels during Childhood[2]

Nutrient	Children, Ages 4–8
Vitamin A (mcg)	400.0
Vitamin B_6 (mcg)	600.0
Vitamin B_{12} (mcg)	1.2
Vitamin C (mg)	25.0
Vitamin D (mcg)	5.0
Vitamin E (mg)	7.0
Vitamin K (mcg)	55.0
Calcium (mg)	800.0
Folate (mcg)	200.0
Iron (mg)	10.0
Magnesium (mg)	130.0
Niacin (B_3) (mg)	8.0
Phosphorus (mg)	500.0
Riboflavin (B_2) (mcg)	600.0
Selenium (mcg)	30.0
Thiamine (B_1) (mcg)	600.0
Zinc (mg)	5.0

Factors Influencing Intake

A number of factors can influence children's eating habits and attitudes toward food. Family environment, societal trends, taste preferences, and messages in the media all impact the emotions that children develop in relation to their diet. Television commercials can entice children to consume sugary products, fatty fast-foods, excess calories, refined ingredients, and sodium. Therefore, it is critical that parents and caregivers direct children toward healthy choices.

One way to encourage children to eat healthy foods is to make meal- and snack-time fun and interesting. Parents should include children in food planning and preparation, for example selecting items while grocery shopping or helping to prepare part of a meal, such as making a salad. At this time, parents can also educate children about kitchen safety. It might be helpful to cut sandwiches, meats, or pancakes into small or interesting shapes. In addition, parents should offer nutritious desserts, such as fresh fruits, instead of calorie-laden cookies, cakes, salty snacks, and ice cream. Also, studies show that children who eat family meals on a frequent basis consume more nutritious foods.[3]

Children and Malnutrition

Malnutrition is a problem many children face, in both developing nations and the developed world. Even with the wealth of food in North America, many children grow up malnourished, or even hungry. The US Census Bureau characterizes households into the following groups:

- food secure
- food insecure without hunger
- food insecure with moderate hunger
- food insecure with severe hunger

Millions of children grow up in food-insecure households with inadequate diets due to both the amount of available food and the quality of food. In the United States, about 20 percent of households with children are food insecure to some degree. In half of those, only adults experience food insecurity, while in the other half both adults and children are considered to be food insecure, which means that children did not have access to adequate, nutritious meals at times.[4]

Growing up in a food-insecure household can lead to a number of problems. Deficiencies in iron, zinc, protein, and vitamin A can result in stunted growth, illness, and limited development. Federal programs, such as the **National School Lunch Program**, the School Breakfast Program, and Summer Feeding Programs, work to address the risk of hunger and malnutrition in school-aged children. They help to fill the gaps and provide children living in food-insecure households with greater access to nutritious meals.

The National School Lunch Program

Beginning with preschool, children consume at least one of their meals in a school setting. Many children receive both breakfast and lunch outside of the home. Therefore, it is important for schools to provide meals that are nutritionally sound. In the United States, more than thirty-one million children from low-income families are given meals provided by the National School Lunch Program. This federally-funded program offers low-cost or free lunches to schools, and also snacks to afterschool facilities. School districts that take part receive subsidies from the **US Department of Agriculture (USDA)** for every meal they serve. School lunches must meet the current ***Dietary Guidelines for Americans*** and need to provide one-third of the RDAs for protein, vitamin A, vitamin C, iron, and calcium. However, local authorities make the decisions about what foods to serve and how they are prepared.[5]

The Healthy School Lunch Campaign works to improve the food served to children in school and to promote children's short- and long-term health by educating government officials, school officials, food-service workers, and parents. Sponsored by the Physicians Committee for Responsible Medicine, this organization encourages schools to offer more low-fat, cholesterol-free options in school cafeterias and in vending machines.[6]

Children and Vegetarianism

Another issue that some parents face with school-aged children is the decision to encourage a child to become a vegetarian or a **vegan**. Some parents and caregivers decide to raise their children as vegetarians for health, cultural, or other reasons. Preteens and teens may make the choice to pursue vegetarianism on their own, due to concerns about animals or the environment. No matter the reason, parents with vegetarian children must take care to ensure vegetarian children get healthy, nutritious foods that provide all the necessary nutrients.

Types of Vegetarian Diets

There are several types of vegetarians, each with certain restrictions in terms of diet:

- **Ovo-vegetarians.** Ovo-vegetarians eat eggs, but do not eat any other animal products.
- **Lacto-ovo-vegetarians.** Lacto-ovo-vegetarians eat eggs and dairy products, but do not eat any meat.
- **Lacto-vegetarians.** Lacto-vegetarians eat dairy products, but do not eat any other animal products.
- **Vegans.** Vegans eat food only from plant sources, no animal products at all.

Children who consume some animal products, such as eggs, cheese, or other forms of dairy, can meet their nutritional needs. For a child following a strict vegan diet, planning is needed to ensure adequate intake of protein, iron, calcium, vitamin B_{12}, and vitamin D. Legumes and nuts can be eaten in place of meat, soy milk fortified with calcium and vitamins D and B_{12} can replace cow's milk.

Food Allergies and Food Intolerance

Recent studies show that three million children under age eighteen are allergic to at least one type of food.[7] Some of the most common allergenic foods include peanuts, milk, eggs, soy, wheat, and shellfish. An **allergy** occurs when a protein in food triggers an immune response, which results in the release of antibodies, histamine, and other defenders that attack foreign bodies. Possible symptoms include itchy skin, hives, abdominal pain, vomiting, diarrhea, and nausea. Symptoms usually develop within minutes to hours after consuming a food allergen. Children can outgrow a food allergy, especially allergies to wheat, milk, eggs, or soy.

Anaphylaxis is a life-threatening reaction that results in difficulty breathing, swelling in the mouth and throat, decreased blood pressure, shock, or even death. Milk, eggs, wheat, soybeans, fish, shellfish, peanuts, and tree nuts are the most likely to trigger this type of response. A dose of the drug epinephrine is often administered via a "pen" to treat a person who goes into anaphylactic shock.[8]

Some children experience a food intolerance, which does not involve an immune response. A food intolerance is marked by unpleasant symptoms that occur after consuming certain foods. Lactose intolerance, though rare in very young children, is one example. Children who suffer from this condition experience an adverse reaction to the lactose in milk products. It is a result of the small intestine's inability to produce enough of the enzyme **lactase**, which is produced by the small intestine. Symptoms of lactose intolerance usually affect the GI tract and can include bloating, abdominal pain, gas, nausea, and diarrhea. An intolerance is best managed by making dietary changes and avoiding any foods that trigger the reaction.[9]

The Threat of Lead Toxicity

There is a danger of lead toxicity, or lead poisoning, among school-aged children. Lead is found in plumbing in old homes, in lead-based paint, and occasionally in the soil.

Contaminated food and water can increase exposure and result in hazardous lead levels in the blood. Children under age six are especially vulnerable. They may consume items tainted with lead, such as chipped, lead-based paint. Another common exposure is lead dust in carpets, with the dust flaking off of paint on walls. When children play or roll around on carpets coated with lead, they are in jeopardy. Lead is indestructible, and once it has been ingested it is difficult for the human body to alter or remove it. It can quietly build up in the body for months, or even years, before the onset of symptoms. Lead toxicity can damage the brain and central nervous system, resulting in impaired thinking, reasoning, and perception.

Treatment for lead poisoning includes removing the child from the source of contamination and extracting lead from the body. Extraction may involve chelation therapy, which binds with lead so it can be excreted in urine. Another treatment protocol, EDTA therapy, involves administering a drug called ethylenediaminetetraacetic acid

(EDTA) to remove lead from the bloodstream of patients with levels greater than 45 mcg/dL.[10] Fortunately, lead toxicity is highly preventable. It involves identifying potential hazards, such as lead paint and pipes, and removing them before children are exposed to them.

Notes

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8. National Institutes of Health, US Department of Health and Human Services. “Food Allergy Quick Facts.” Accessed March 5, 2012. http://www.niaid.nih.gov/topics/foodallergy/understanding/pages/quickfacts.aspx.
9. National Digestive Disease Information Clearinghouse, a service of National Institute of Diabetes and Digestive and Kidney Diseases, National Institutes of Health. “Lactose Intolerance.” *NIH Publication No.* 09– 2751 (June 2009). Last updated April 23, 2012. http://digestive.niddk.nih.gov/ddiseases/pubs/lactoseintolerance/.
10. Mayo Foundation for Medical Education and Research. “Lead poisoning.” ©1998–2012 Accessed March 5, 2012. http://www.mayoclinic.com/health/lead-poisoning/FL00068.

16.4 Puberty and Nutrition

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for preteens.
- Discuss the most important nutrition-related concerns at the onset of puberty.
- Discuss the growing rates of childhood obesity and the long-term consequences of it.

Puberty is the beginning of adolescence. The onset of puberty brings a number of changes, including the development of primary and secondary sex characteristics, growth spurts, an increase in body fat, and an increase in bone and muscle development. All of these changes must be supported with adequate intake and healthy food choices.

The Onset of Puberty (Ages Nine to Thirteen)

This period of physical development is divided into two phases. The first phase involves height increases from 20 to 25 percent. Puberty is second to the prenatal period in terms of rapid growth as the long bones stretch to their final, adult size. Girls grow 2–8 inches (5–20 centimeters) taller, while boys grow 4–12 inches (10–30 centimeters) taller. The second phase involves weight gain related to the development of bone, muscle, and fat tissue. Also in the midst of puberty, the sex hormones trigger the development of reproductive organs and secondary sexual characteristics, such as pubic hair. Girls also develop "curves," while boys become broader and more muscular.[1]

Energy

The energy requirements for preteens differ according to gender, growth, and activity level. For ages nine to thirteen, girls should consume about 1,400 to 2,200 calories per day and boys should consume 1,600 to 2,600 calories per day. Physically active preteens who regularly participate in sports or exercise need to eat a greater number of calories to account for increased energy expenditures.

Macronutrients

For carbohydrates, the **AMDR** is 45 to 65 percent of daily calories (which is a recommended daily allowance of 158–228 grams for 1,400–1,600 daily calories). Carbohydrates that are high in fiber should make up the bulk of intake. The AMDR for protein is 10 to 30 percent of daily calories (35–105 grams for 1,400 daily calories for girls and 40–120 grams for 1,600 daily calories for boys). The AMDR for fat is 25 to 35 percent of daily calories (39–54 grams for 1,400 daily calories for girls and 44–62 grams for 1,600 daily calories for boys), depending on caloric intake and activity level.

Micronutrients

Key vitamins needed during puberty include vitamins D, K, and B_{12}. Adequate calcium intake is essential for building bone and preventing **osteoporosis** later in life. Young females need more iron at the onset of menstruation, while young males need additional iron for the development of lean body mass. Almost all of these needs should be met with dietary choices, not supplements (iron is an exception). The table below shows the micronutrient recommendations for young adolescents.

Table 16.41 Recommended Micronutrient Levels during Puberty[2]

Nutrient	Preteens, Ages 9–13
Vitamin A (mcg)	600.0
Vitamin B_6 (mg)	1.0
Vitamin B_{12} (mcg)	1.8
Vitamin C (mg)	45.0
Vitamin D (mcg)	5.0
Vitamin E (mg)	11.0
Vitamin K (mcg)	60.0
Calcium (mg)	1,300.0
Folate (mcg)	300.0
Iron (mg)	8.0
Magnesium (mg)	240.0
Niacin (B_3) (mg)	12.0
Phosphorus (mg)	1,250.0
Riboflavin (B_2) (mcg)	900.0
Selenium (mcg)	40.0
Thiamine (B_1) (mcg)	900.0
Zinc (mg)	8.0

Childhood Obesity

Children need adequate caloric intake for growth, and it is important not to impose very restrictive diets. However, exceeding caloric requirements on a regular basis can lead to childhood obesity, which has become a major problem in North America. Nearly one of three US children and adolescents are overweight or obese.[3] In Canada, approximately 26 percent of children and adolescents are overweight or obese.[4]

There are a number of reasons behind this problem, including:

- larger portion sizes
- limited access to nutrient-rich foods
- increased access to fast foods and vending machines
- lack of breastfeeding support
- declining physical education programs in schools
- insufficient physical activity and a sedentary lifestyle
- media messages encouraging the consumption of unhealthy foods

Children who suffer from obesity are more likely to become overweight or obese adults. Obesity has a profound effect on self-esteem, energy, and activity level. Even more importantly, it is a major risk factor for a number of diseases later in life, including cardiovascular disease, Type 2 diabetes, stroke, **hypertension**, and certain cancers.[5]

A percentile for body mass index (BMI) specific to age and sex is used to determine if a child is overweight or obese. This is more appropriate than the BMI categories used for adults because the body composition of children varies as they develop, and differs between boys and girls. If a child gains weight inappropriate to growth, parents and caregivers should limit energy-dense, nutrient-poor snack foods. Also, children ages three and older can follow the National Cholesterol Education Program guidelines of no more than 35 percent of calories from fat (10 percent or less from saturated fat), and no more than 300 milligrams of cholesterol per day. In addition, it is extremely beneficial to increase a child's physical activity and limit sedentary activities, such as watching television, playing video games, or surfing the Internet.

Programs to address childhood obesity can include behavior modification, exercise counseling, psychological support or therapy, family counseling, and family meal-planning advice. For most, the goal is not weight loss, but rather allowing height to catch up with weight as the child continues to grow. Rapid weight loss is not recommended for preteens or younger children due to the risk of deficiencies and stunted growth.

Avoiding Added Sugars

One major contributing factor to childhood obesity is the consumption of added sugars. Added sugars include not only sugar added to food at the table, but also are ingredients in items such as bread, cookies, cakes, pies, jams, and soft drinks. The added sugar in store-bought items may be listed as white sugar, brown sugar, high-fructose corn syrup, honey, malt syrup, maple syrup, molasses, anhydrous dextrose, crystal dextrose, and concentrated fruit juice. (Not included are sugars that occur naturally in foods, such as the lactose in milk or the fructose in fruits.) In addition, sugars are often "hidden" in items added to foods after they're prepared, such as ketchup, salad dressing, and other condiments. According to the National Center for Health Statistics, young children and adolescents consume an average of 322 calories per day from added sugars, or about 16 percent of daily calories.[6] The primary offenders are processed and packaged foods, along with soda and other beverages. These foods are not only high in sugar, they are also light in terms of nutrients and often take the place of healthier options. Intake of added sugar should be limited to 100–150 calories per day to discourage poor eating habits.

Notes

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4. Childhood Obesity Foundation. "Statistics." Accessed March 5, 2012. http://www.childhoodobesityfoundation.ca/statistics.
5. World Health Organization. "Obesity and Overweight Fact Sheet." Last revised March 2011. http://www.who.int/mediacentre/factsheets/fs311/en/.
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16.5 Older Adolescence and Nutrition

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for teens.
- Discuss the most important nutrition-related concerns during adolescence.
- Discuss the effect of eating disorders on health and wellness.

In this section, we will discuss the nutritional requirements for young people ages fourteen to eighteen. One way that teenagers assert their independence is by choosing what to eat. They have their own money to purchase food and tend to eat more meals away from home. **Older adolescents** also can be curious and open to new ideas, which includes trying new kinds of food and experimenting with their diet. For example, teens will sometimes skip a main meal and snack instead. That is not necessarily problematic. Their choice of food is more important than the time or place. However, too many poor choices can make young people nutritionally vulnerable. Teens should be discouraged from eating fast food, which has a high fat and sugar content, or frequenting convenience stores and using vending machines, which typically offer poor nutritional selections. Other challenges that teens may face include obesity and eating disorders. At this life stage, young people still need guidance from parents and other caregivers about nutrition-related matters. It can be helpful to explain to young people how healthy eating habits can support activities they enjoy, such as skateboarding or dancing, or connect to their desires or interests, such as a lean figure, athletic performance, or improved cognition.

Adolescence (Ages Fourteen to Eighteen): Transitioning into Adulthood

As during puberty, growth and development during adolescence differs in males than in females. In teenage girls, fat assumes a larger percentage of body weight, while teenage boys experience greater muscle and bone increases. For both, primary and secondary sex characteristics have fully developed and the rate of growth slows with the end of puberty. Also, the motor functions of an older adolescent are comparable to those of an adult.[1] Again, adequate nutrition and healthy choices support this stage of growth and development.

Energy

Adolescents have increased appetites due to increased nutritional requirements. Nutrient needs are greater in adolescence than at any other time in the life cycle, except during pregnancy. The energy requirements for ages fourteen to eighteen are 1,800 to 2,400 calories for girls and 2,000 to 3,200 calories for boys, depending on activity level. The extra energy required for physical development during the teenaged years should be obtained from foods that provide nutrients instead of "**empty calories.**" Also, teens who participate in sports must make sure to meet their increased energy needs.

Macronutrients

Older adolescents are more responsible for their dietary choices than younger children, but parents and caregivers must make sure that teens continue to meet their nutrient needs. For carbohydrates, the **AMDR** is 45 to 65 percent of daily calories (203–293 grams for 1,800 daily calories). Adolescents require more servings of grain than younger children, and should eat whole grains, such as wheat, oats, barley, and brown rice. The Institute of Medicine recommends higher intakes of protein for growth in the adolescent population. The AMDR for protein is 10 to 30 percent of daily calories (45–135 grams for 1,800 daily calories), and lean proteins, such as meat, poultry, fish, beans, nuts, and seeds are excellent ways to meet those nutritional needs.

The AMDR for fat is 25 to 35 percent of daily calories (50–70 grams for 1,800 daily calories), and the AMDR for fiber is 25–34 grams per day, depending on daily calories and activity level. It is essential for young athletes and other physically active teens to intake enough fluids, because they are at a higher risk for becoming dehydrated.

Micronutrients

Micronutrient recommendations for adolescents are mostly the same as for adults, though children this age need more of certain minerals to promote bone growth (e.g., calcium and phosphorus, along with iron and zinc for girls). Again, vitamins and minerals should be obtained from food first, with supplementation for certain micronutrients only (such as iron).

The most important micronutrients for adolescents are calcium, vitamin D, vitamin A, and iron. Adequate calcium and vitamin D are essential for building bone mass. The recommendation for calcium is 1,300 milligrams for both boys and girls. Low-fat milk and cheeses are excellent sources of calcium and help young people avoid saturated fat and cholesterol. It can also be helpful for adolescents to consume products fortified with calcium, such as breakfast cereals and orange juice. Iron supports the growth of muscle and lean body mass. Adolescent girls also need to ensure sufficient iron intake as they start to menstruate. Girls ages twelve to eighteen require 15 milligrams of iron per day. Increased amounts of vitamin C from orange juice and other sources can aid in iron absorption. Also, adequate fruit and vegetable intake allows for meeting vitamin A needs. The table below shows the micronutrient recommendations for older adolescents, which differ slightly for males and females, unlike the recommendations for puberty.

Table 16.51 Recommended Micronutrient Levels during Older Adolescence[2]

Nutrient	Males, Ages 14–18	Females, Ages 14–18
Vitamin A (mcg)	900.0	700.0
Vitamin B_6 (mg)	1.3	1.2
Vitamin B_{12} (mcg)	2.4	2.4
Vitamin C (mg)	75.0	65.0
Vitamin D (mcg)	5.0	5.0
Vitamin E (mg)	15.0	15.0
Vitamin K (mcg)	75.0	75.0
Calcium (mg)	1,300.0	1,300.0
Folate (mcg)	400.0	400.0
Iron (mg)	11.0	15.0
Magnesium (mg)	410.0	360.0
Niacin (B_3) (mg)	16.0	14.0
Phosphorus (mg)	1,250.0	1,250.0
Riboflavin (B_2) (mg)	1.3	1.0
Selenium (mcg)	55.0	55.0
Thiamine (B_1) (mg)	1.2	1.0
Zinc (mg)	11.0	9.0

Eating Disorders

Many teens struggle with an eating disorder, which can have a detrimental effect on diet and health. A study published by North Dakota State University estimates that these conditions impact twenty-four million people in the United States and seventy million worldwide.[3] These disorders are more prevalent among adolescent girls, but have been increasing among adolescent boys in recent years. Because eating disorders often lead to malnourishment, adolescents with an eating disorder are deprived of the crucial nutrients their still- growing bodies need.

Eating disorders involve extreme behavior related to food and exercise. Sometimes referred to as "starving or stuffing," they encompass a group of conditions marked by undereating or overeating. Some of these conditions include:

- **Anorexia Nervosa.** Anorexia nervosa is a potentially fatal condition characterized by undereating and excessive weight loss. People with this disorder are preoccupied with dieting, calories, and food intake to an unhealthy degree. Anorexics have a poor body image, which leads to anxiety, avoidance of food, a rigid exercise regimen, fasting, and a denial of **hunger**. The condition predominantly affects females. Between 0.5 and 1 percent of American women and girls suffer from this eating disorder.
- **Binge-Eating Disorder.** People who suffer from binge-eating disorder experience regular episodes of eating an extremely large amount of food in a short period of time. Binge eating is a compulsive behavior, and people who suffer from it typically feel it is beyond their control. This behavior often causes feelings of shame and embarrassment, and leads to obesity, high blood pressure, high cholesterol levels, Type 2 diabetes, and other health problems. Both males and females suffer from binge-eating disorder. It affects 1 to 5 percent of the population.
- **Bulimia Nervosa.** Bulimia nervosa is characterized by alternating cycles of overeating and undereating. People who suffer from it partake in binge eating, followed by compensatory behavior, such as self-induced vomiting, laxative use, and compulsive exercise. As with anorexia, most people with this condition are female. Approximately 1 to 2 percent of American women and girls have this eating disorder.[4]

Eating disorders stem from stress, low self-esteem, and other psychological and emotional issues. It is important for parents to watch for **signs and symptoms** of these disorders, including sudden weight loss, lethargy, vomiting after meals, and the use of appetite suppressants. Eating disorders can lead to serious complications or even be fatal if left untreated. Treatment includes cognitive, behavioral, and nutritional therapy.

Notes

1. Elaine U. Polan, RNC, MS and Daphne R. Taylor, RN, MS, *Journey Across the Life Span: Human Development and Health Promotion* (Philadelphia: F. A. Davis Company, 2003), 171–173.

2. Source: National Academy of Medicine. http://www.nam.edu.
3. North Dakota State University. "Eating Disorder Statistics." Accessed March 5, 2012. http://www.ndsu.edu/fileadmin/counseling/Eating_Disorder_Statistics.pdf.
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16.6 Middle Age (Ages Thirty-One to Fifty): Aging Well

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for middle-aged adults.
- Discuss the most important nutrition-related concerns during middle age.
- Define "preventive nutrition" and give an applied example.

During this stage of the human life cycle, adults begin to experience the first outward signs of aging. Wrinkles begin to appear, joints ache after a highly active day, and body fat accumulates. There is also a loss of muscle tone and elasticity in the connective tissue.[1] Throughout the aging process, good nutrition can help middle-aged adults maintain their health and recover from any medical problems or issues they may experience.

Many people in their late thirties and in their forties notice a decline in endurance, the onset of wear-and-tear injuries (such as osteoarthritis), and changes in the digestive system. Wounds and other injuries also take longer to heal. Body composition changes due to fat deposits in the trunk. To maintain health and wellness during the middle-aged years and beyond, it is important to:

- maintain a healthy body weight
- consume nutrient-dense foods
- drink alcohol moderately or not at all
- be a nonsmoker
- engage in **moderate physical activity** at least 150 minutes per week

Energy

The energy requirements for ages thirty-one to fifty are 1,800 to 2,200 calories for women and 2,200 to 3,000 calories for men, depending on activity level. These estimates do not include women who are pregnant or breastfeeding. Middle-aged adults must rely on healthy food sources to meet these needs. In many parts of North America, typical dietary patterns do not match the recommended guidelines. For example, five foods— iceberg lettuce, frozen potatoes, fresh potatoes, potato chips, and canned tomatoes— account for over half of all vegetable intake.[2] Following the dietary guidelines in the middle-aged years provides adequate but not excessive energy, macronutrients, vitamins, and minerals.

Macronutrients and Micronutrients

The **AMDRs** for carbohydrates, protein, fat, fiber, and fluids remain the same from young adulthood into middle age. It is important to avoid putting on excess pounds and limiting an intake of solid fats, alcohols, and added sugars to help avoid cardiovascular disease, diabetes, and other chronic conditions.

There are some differences, however, regarding micronutrients. For men, the recommendation for magnesium increases to 420 milligrams daily, while middle-aged women should increase their intake of magnesium to 320 milligrams per day. Other key vitamins needed during the middle-aged years include folate and vitamins B_6 and B_{12} to prevent elevation of homocysteine, a byproduct of **metabolism** that can damage arterial walls and lead to **atherosclerosis**, a cardiovascular condition. Again, it is important to meet nutrient needs with food first, then supplementation, such as a daily multivitamin, if you can't meet your needs through food.

Preventive/Defensive Nutrition

During the middle-aged years, preventive nutrition can promote wellness and help **organ systems** to function optimally throughout aging. Preventive nutrition is defined as dietary practices directed toward reducing disease and promoting health and well-being. Healthy eating in general—such as eating unrefined carbohydrates instead of refined carbohydrates and avoiding trans fats and saturated fats—helps to promote wellness.

However, there are also some things that people can do to target specific concerns. One example is consuming foods high in antioxidants, such as strawberries, blueberries, and other colorful fruits and vegetables, to reduce the risk of cancer.

Phytochemicals are compounds in fruits and vegetables that act as defense systems for plants. Different phytochemicals are beneficial in different ways. For example, **carotenoids**, which are found in carrots, cantaloupes, sweet potatoes, and butternut squash, may protect against cardiovascular disease by helping to prevent the oxidation of cholesterol in the arteries, although research is ongoing.[3] According to the American Cancer Society, some studies suggest that a phytochemical found in watermelons and tomatoes called lycopene may protect against stomach, lung, and prostate cancer, although more research is needed.[4]

Omega-3 fatty acids can help to prevent coronary artery disease. These crucial nutrients are found in oily fish, including salmon, mackerel, tuna, herring, cod, and halibut. Other beneficial fats that are vital for healthy functioning include **monounsaturated fats**, which are found in plant oils, avocados, peanuts, and pecans.

Menopause

In the middle-aged years, women undergo a specific change that has a major effect on their health. They begin the process of menopause, typically in their late forties or early fifties. The ovaries slowly cease to produce estrogen and progesterone, which results in the end of menstruation. Menopausal symptoms can vary, but often include hot flashes, night sweats, and mood changes. The hormonal changes that occur during menopause can lead to a number of physiological changes as well, including alterations in body composition, such as weight gain in the abdominal area. Bone loss is another common condition related to menopause due to the loss of female reproductive hormones. Bone thinning increases the risk of fractures, which can affect mobility and the ability to complete everyday tasks, such as cooking, bathing, and dressing.[5] Recommendations for women experiencing menopause or perimenopause (the stage just prior to the end of the menstruation) include:

- consuming a variety of whole grains, and other nutrient-dense foods

- maintaining a diet high in fiber, low in fat, and low in sodium
- avoiding caffeine, spicy foods, and alcohol to help prevent hot flashes
- eating foods rich in calcium, or taking physician-prescribed calcium supplements and vitamin D
- doing stretching exercises to improve balance and **flexibility** and reduce the risk of falls and fractures

Notes

1. Elaine U. Polan, RNC, MS and Daphne R. Taylor, RN, MS, *Journey Across the Life Span: Human Development and Health Promotion*(Philadelphia: F. A. Davis Company, 2003), 212–213.
2. Adam Drewnowski and Nicole Darmon. "Food Choices and Diet Cost: an Economic Analysis." *The Journal of Nutrition*. © 2005 The American Society for Nutritional Sciences. Accessed March 5, 2012. http://jn.nutrition.org/content/135/4/900.full.
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16.7 Old Age and Nutrition

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for elderly adults.
- Discuss the most important nutrition-related concerns during the senior years.
- Discuss the influence of diet on health and wellness in old age.

Beginning at age fifty-one, requirements change once again and relate to the nutritional issues and health challenges that older people face. After age sixty, blood pressure rises and the immune system may have more difficulty battling invaders and infections. The skin becomes more wrinkled and hair has turned gray or white or fallen out, resulting in hair thinning. Older adults may gradually lose an inch or two in height. Also, short-term memory might not be as keen as it once was.[1]

In addition, many people suffer from serious health conditions, such as cardiovascular disease and cancer. Being either underweight or overweight is also a major concern for the elderly. However, many older adults remain in relatively good health and continue to be active into their golden years. Good nutrition is often the key to maintaining health later in life. In addition, the fitness and nutritional choices made earlier in life set the stage for continued health and happiness.

Older Adulthood (Ages Fifty-One and Older): The Golden Years

An adult's body changes during old age in many ways, including a decline in hormone production, muscle mass, and strength. Also in the later years, the heart has to work harder because each pump is not as efficient as it used to be. Kidneys are not as effective in excreting metabolic products such as sodium, acid, and potassium, which can alter water balance and increase the risk for over- or underhydration. In addition, immune function decreases and there is lower efficiency in the absorption of vitamins and minerals.

Older adults should continue to consume nutrient-dense foods and remain physically active. However, deficiencies are more common after age sixty, primarily due to reduced intake or malabsorption. The loss of mobility among frail, homebound elderly adults also impacts their access to healthy, diverse foods.

Energy

Due to reductions in lean body mass and metabolic rate, older adults require less energy than younger adults. The energy requirements for people ages fifty-one and over are 1,600 to 2,200 calories for women and 2,000 to 2,800 calories for men, depending on activity level. The decrease in physical activity that is typical of older adults also influences nutritional requirements.

Macronutrients

The **AMDRs** for carbohydrates, protein, and fat remain the same from middle age into old age. Older adults should substitute more unrefined carbohydrates for refined ones, such as whole grains and brown rice. Fiber is especially important in preventing constipation and **diverticulitis**, and may also reduce the risk of colon **cancer**. Protein should be lean, and healthy fats, such as omega-3 fatty acids, are part of any good diet.

Micronutrients

An increase in certain micronutrients can help maintain health during this life stage. The recommendations for calcium increase to 1,200 milligrams per day for both men and women to slow bone loss. Also to help protect bones, vitamin D recommendations increase to 10–15 micrograms per day for men and women. Vitamin B_6 recommendations rise to 1.7 milligrams per day for older men and 1.5 milligrams per day for older women to help lower levels of homocysteine and protect against cardiovascular disease. As adults age, the production of stomach acid can decrease and lead to an overgrowth of bacteria in the small intestine. This can affect the absorption of vitamin B_{12} and cause a deficiency. As a result, older adults need more B_{12} than younger adults, and require an intake of 2.4 micrograms per day, which helps promote healthy brain functioning. For elderly women, higher iron levels are no longer needed postmenopause and recommendations decrease to 8 milligrams per day. People over age fifty should eat foods rich with all of these micronutrients.

Nutritional Concerns for Older Adults

Dietary choices can help improve health during this life stage and address some of the nutritional concerns that many older adults face. In addition, there are specific concerns related to nutrition that affect adults in their later years. They include medical problems, such as disability and disease, which can impact diet and activity level. For example, dental problems can lead to difficulties with chewing and swallowing, which in turn can make it hard to maintain a healthy diet. The use of dentures or the preparation of pureed or chopped foods can help solve this problem. There also is a decreased **thirst** response in the elderly, and the kidneys have a decreased ability to concentrate urine, both of which can lead to dehydration.

Sensory Issues

At about age sixty, taste buds begin to decrease in size and number. As a result, the taste thresholdis higher in older adults, meaning that more of the same flavor must be present to detect the taste. Many elderly people lose the ability to distinguish between salty, sour, sweet, and bitter flavors. This can make food seem less appealing and decrease the appetite. An intake of foods high in sugar and sodium can increase due to an inability to discern those tastes. The sense of smell also decreases, which impacts attitudes toward food. Sensory issues may also affect the digestion because the taste and smell of food stimulates the secretion of digestive enzymes in the mouth, stomach, and pancreas.

Gastrointestinal Problems

A number of gastrointestinal issues can affect food intake and digestion among the elderly. Saliva production decreases with age, which affects chewing, swallowing, and taste. Digestive secretions decline later in life as well, which can lead to atrophic gastritis (inflammation of the lining of the stomach). This interferes with the absorption of some vitamins and minerals. Reduction of the digestive enzyme lactase results in a decreased tolerance for dairy products. Slower gastrointestinal motility can result in more constipation, gas, and bloating, and can also be tied to low fluid intake, decreased physical activity, and a diet low in fiber, fruits, and vegetables.

Dysphagia

Some older adults have difficulty getting adequate nutrition because of the disorder dysphagia, which impairs the ability to swallow. Any damage to the parts of the brain that control swallowing can result in dysphagia, therefore stroke is a common cause. Dysphagia is also associated with advanced dementia because of overall brain function impairment. To assist older adults suffering from dysphagia, it can be helpful to alter food consistency. For example, solid foods can be pureed, ground, or chopped to allow more successful and safe swallow. This decreases the risk of aspiration, which occurs when food flows into the respiratory tract and can result in pneumonia. Typically, speech therapists, physicians, and **dietitians** work together to determine the appropriate diet for dysphagia patients.

Obesity in Old Age

Similar to other life stages, obesity is a concern for the elderly. Adults over age sixty are more likely to be obese than young or middle-aged adults. As explained throughout this chapter, excess body weight has severe consequences. Being overweight or obese increases the risk for potentially fatal conditions that can afflict the elderly. They include cardiovascular disease, which is the leading cause of death in the United States, and Type

2 diabetes, which causes about seventy thousand deaths in the United States annually.[2] Obesity is also a contributing factor for a number of other conditions, including arthritis.

For older adults who are overweight or obese, dietary changes to promote weight loss should be combined with an exercise program to protect muscle mass. This is because dieting reduces muscle as well as fat, which can exacerbate the loss of muscle mass due to aging. Although weight loss among the elderly can be beneficial, it is best to be cautious and consult with a health-care professional before beginning a weight-loss program.

The Anorexia of Aging

In addition to concerns about obesity among senior citizens, being underweight can be a major problem. A condition known as the anorexia of aging is characterized by poor food intake, which results in dangerous weight loss. This major health problem among the elderly leads to a higher risk for immune deficiency, frequent falls, muscle loss, and cognitive deficits. Reduced muscle mass and physical activity mean that older adults need fewer calories per day to maintain a normal weight. It is important for health care providers to examine the causes for anorexia of aging among their patients, which can vary from one individual to another. Understanding why some elderly people eat less as they age can help health-care professionals assess the risk factors associated with this condition. Decreased intake may be due to disability or the lack of a motivation to eat. Also, many older adults skip at least one meal each day. As a result, some elderly people are unable to meet even reduced energy needs.

Nutritional interventions should focus primarily on a healthy diet. Remedies can include increasing the frequency of meals and adding healthy, high-calorie foods (such as nuts, potatoes, whole-grain pasta, and avocados) to the diet. Liquid supplements between meals may help to improve caloric intake.[3] Health care professionals should consider a patient's habits and preferences when developing a nutritional treatment plan. After a plan is in place, patients should be weighed on a weekly basis until they show improvement.

Vision Problems

Many older people suffer from vision problems and a loss of vision. Age-related macular degeneration is the leading cause of blindness in Americans over age sixty.[4] This disorder can make food planning and preparation extremely difficult and people who suffer from it often must depend on caregivers for their meals. Self-feeding also may be difficult if an elderly person cannot see his or her food clearly. Friends and family members can help older adults with shopping and cooking. Food-assistance programs for older adults (such as Meals on Wheels) can also be helpful.

Diet may help to prevent macular degeneration. Consuming colorful fruits and vegetables increases the intake of lutein and zeaxanthin. Several studies have shown that these antioxidants provide protection for the eyes. Lutein and zeaxanthin are found in green, leafy vegetables such as spinach, kale, and collard greens, and also corn, peaches, squash, broccoli, Brussels sprouts, orange juice, and honeydew melon.[5]

Neurological Conditions

Elderly adults who suffer from dementia may experience memory loss, agitation, and delusions. One in eight people over the age sixty-four and almost half of all people over eighty-five suffer from Alzheimer's, which is the most common form of dementia. These conditions can have serious effects on diet and nutrition as a person increasingly becomes incapable of caring for himself or herself, which includes the ability to buy and prepare food, and to self-feed.

Longevity and Nutrition

The foods you consume in your younger years influence your health as you age. Good nutrition and regular physical activity can help you live longer and healthier. Conversely, poor nutrition and a lack of exercise can shorten your life and lead to medical problems. The right foods provide numerous benefits at every stage of life. They help an infant grow, an adolescent develop mentally and physically, a young adult achieve his or her physical peak, and an older adult cope with aging. Nutritious foods form the foundation of a healthy life at every age.

Notes

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CHAPTER XVII

CHAPTER 17: FITNESS AND NUTRITION

Physical activity is an important part of living a healthy lifestyle, and it goes beyond helping with energy balance. In this chapter, we'll introduce different components of physical fitness, and why they're important. We'll also discuss how physical activity affects the body's nutritional needs.

Sections:

Adapted from Fialkowski Revilla, et al. *Human Nutrition.*

17.0 Introduction to Physical Fitness

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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.

17.1 The Essential Elements of Physical Fitness

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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 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 17.11** VO_2 Max Test. 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 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 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 17.12 "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.

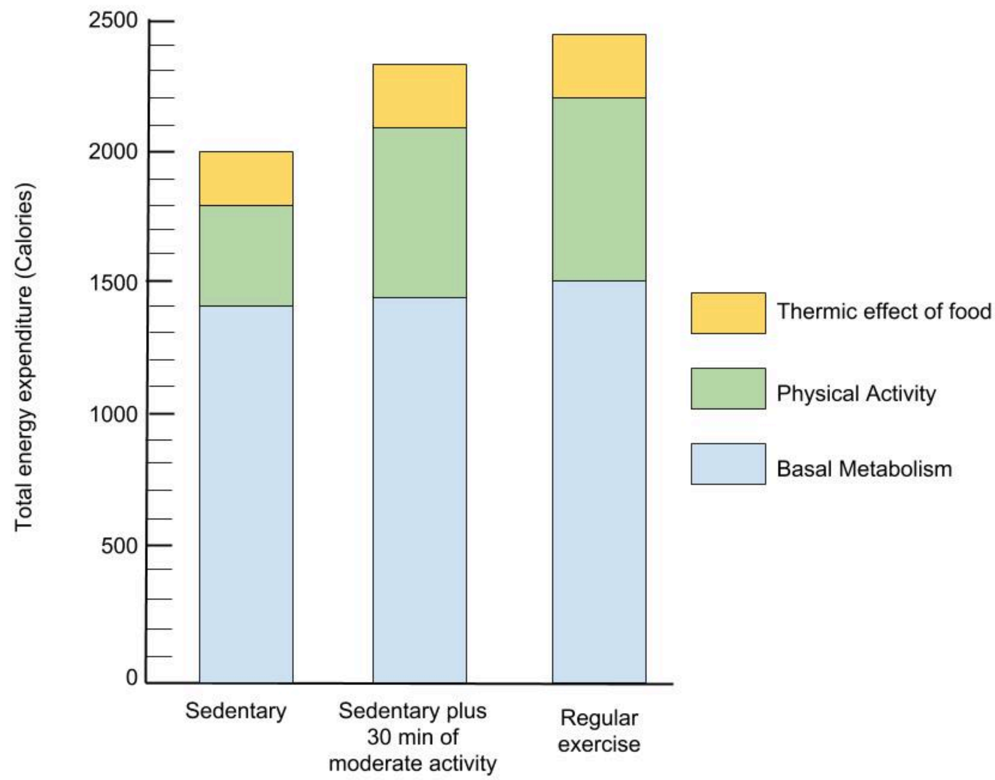

Figure 17.12 *The Effect of Physical Activity on Energy Expenditure. Image by Allison Calabrese / CC BY 4.0*

Physical Activity Recommendations

The **CDC** along with the American College of Sports Medicine (ACSM) have evidence based recommendations and guidelines for individuals to follow in order to obtain or maintain a healthy lifestyle. 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 by the ACSM 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 CDC website and the ACSM website.

Notes

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.
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17.2 The Benefits of Physical Activity

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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 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.

Notes

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.

17.3 Fuel Sources

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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 a 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

Recall from chapter 8 that anaerobic metabolism occurs in the cytosol of muscle cells. As seen in Figure 17.31 "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.

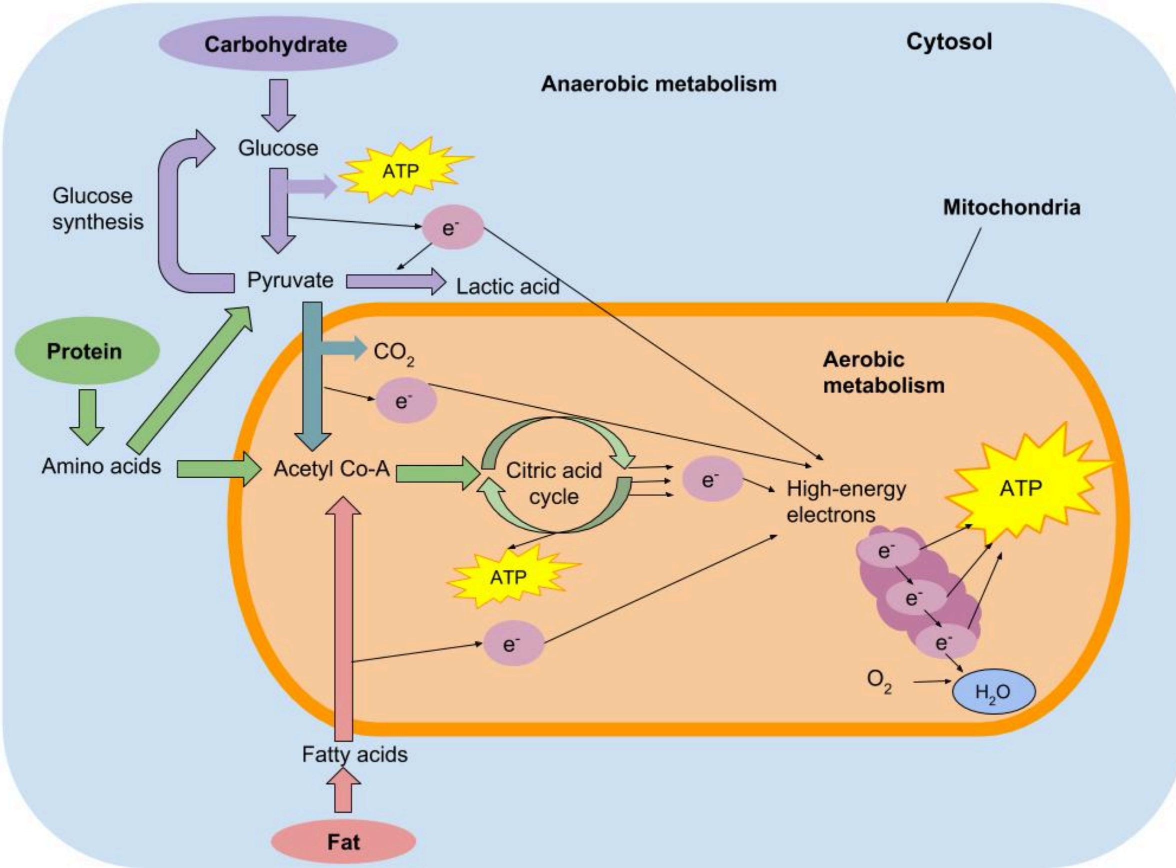

Figure 17.31 *Anaerobic versus Aerobic Metabolism. Image by Allison Calabrese / CC BY 4.0*

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 through this pathway.

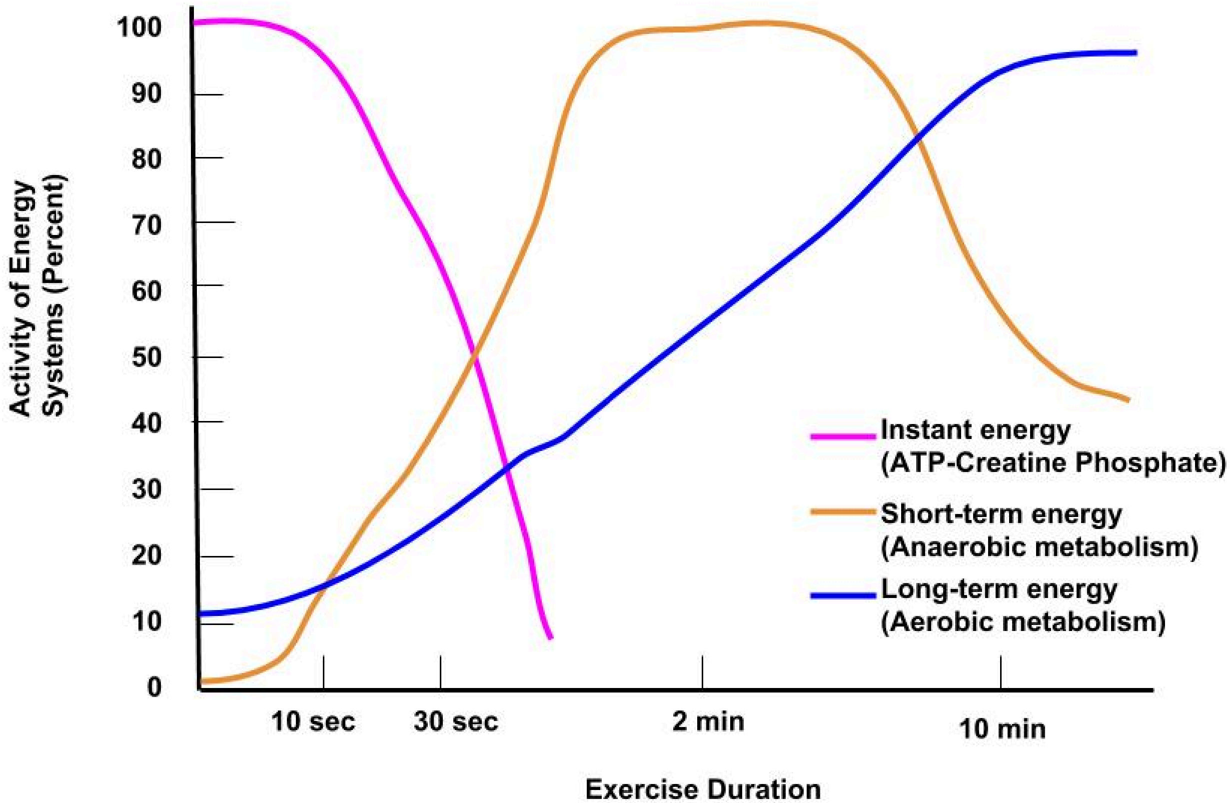

Figure 17.32 *The Effect of Exercise Duration on Energy Systems. Image by Allison Calabrese / CC* BY 4.0

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.

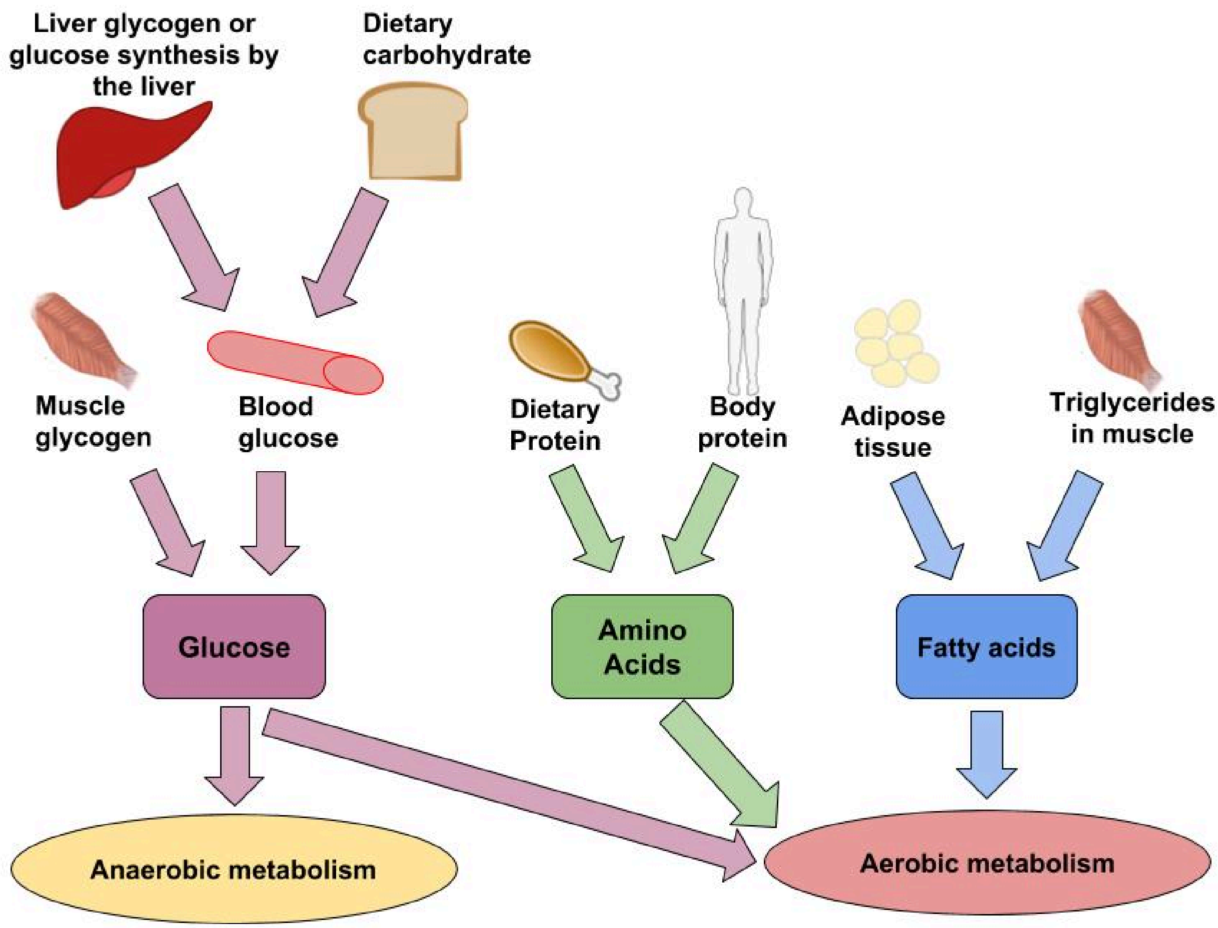

***Figure* 17.33** *Fuel Sources for Anaerobic and Aerobic Metabolism. Image by Allison Calabrese /* CC BY 4.0

Physical Activity Intensity and Fuel Use

The exercise intensity determines the contribution of the type of fuel source used for ATP production(see Figure 17.34 "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 and less oxygen is available 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.

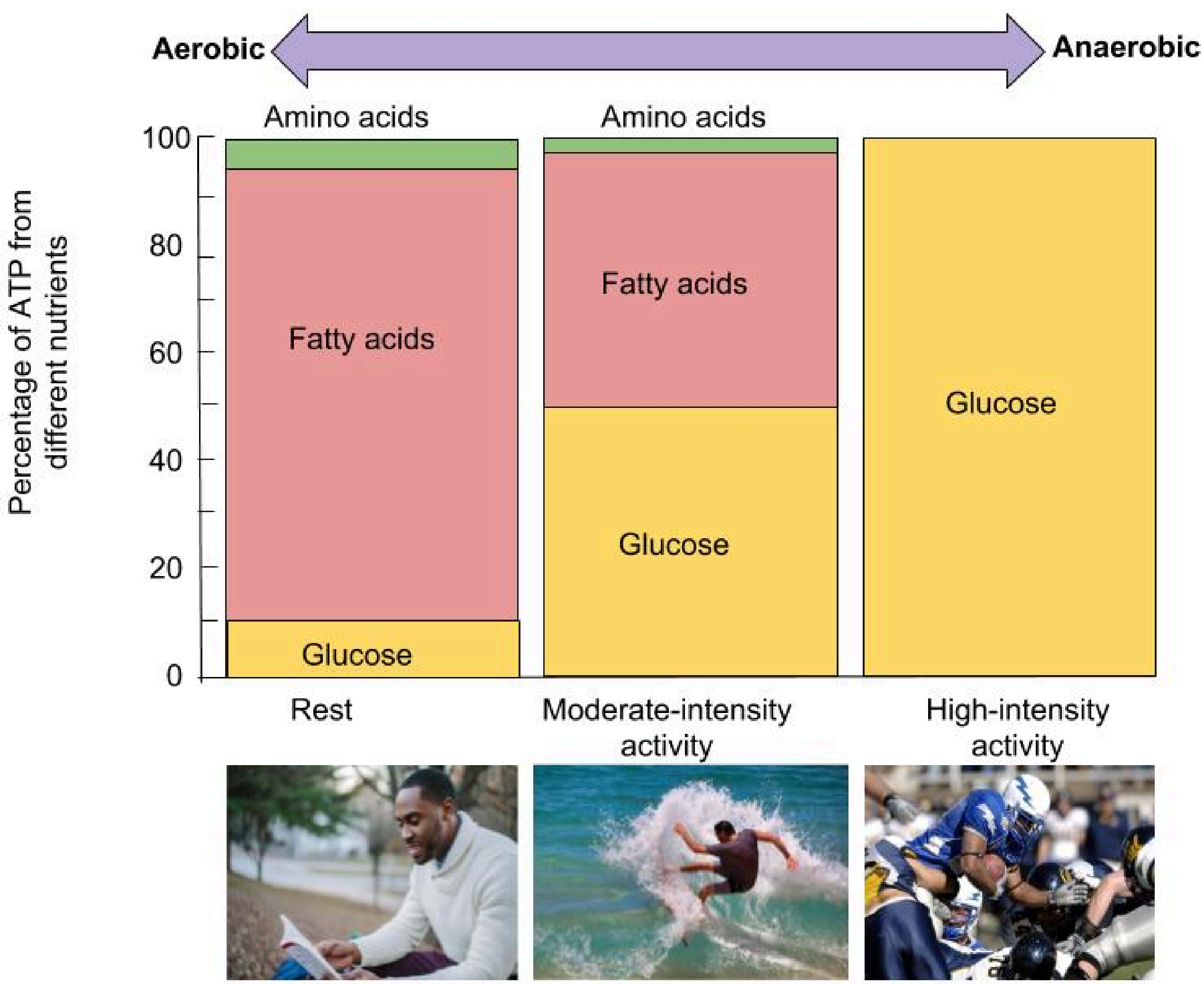

Figure 17.34 *The Effect of Exercise Intensity on Fuel Sources. Image by Allison Calabrese / CC BY 4.0*

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 from 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.

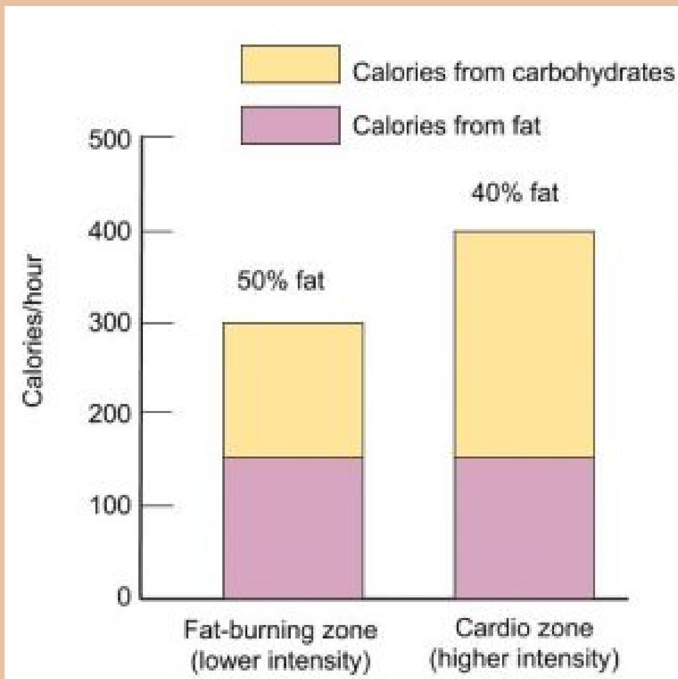

Figure 17.35 *Carbohydrate and fat usage in the fat-burning zone and the cardio zone. Image by Allison Calabrese / CC BY 4.0*

"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.

17.4 Sports Nutrition

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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 [1]

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.

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.

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 enough carbohydrates from their diet and replace their glycogen stores. Carbohydrate needs should increase about 3-10 g/kg/day depending on the type of training or competition. See Table 17.41 "Daily Needs for Carbohydrate Fuel" for carbohydrate needs for athletes depending on the intensity of the exercise.

Table 17.41 Daily Needs for Carbohydrate Fuel

Activity Level	Example of Exercise	Increased Carbohydrate Need (g/kg of athlete's body weight per 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

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, 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.

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. See Table 17.42 "Recommended Protein Intakes for Individuals" below for a better representation of protein needs depending on extent of training and dietary sources.

Table 17.42 The Recommended Protein Intakes for Individuals[2]

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

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 17.42 "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.

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 energy 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 Figure 17.41 "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 and kidney function, temperature regulation and electrolyte balance problems.

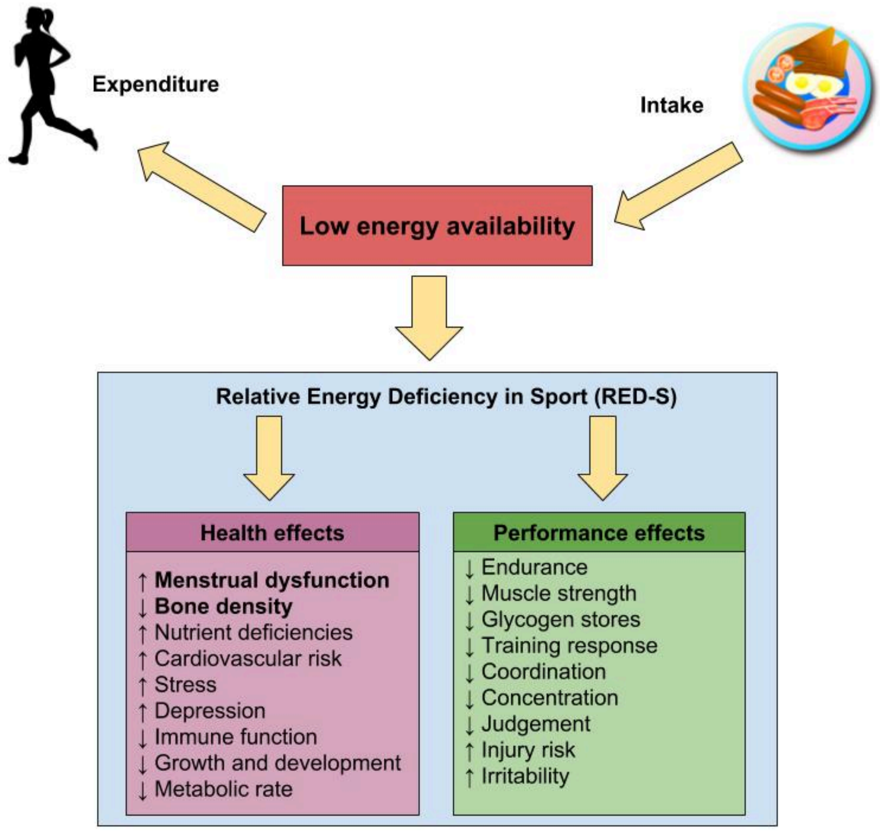

Figure 17.41 *Relative Energy Deficiency in Sport Effects. Image by Allison Calabrese / CC BY 4.0*

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 17.42 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.[3]

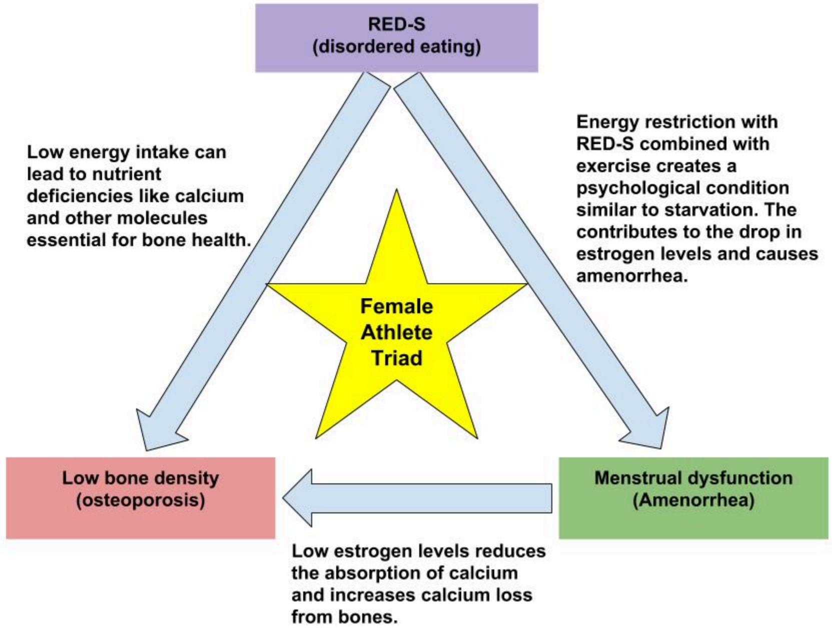

Figure 17.42 *The Female Athlete Triad. Image by Allison Calabrese / CC BY 4.0*

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.[4] See Table 17.43 “Increased Iron Need 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 17.43 Increased Iron Need in Endurance Athletes[5]

	Male	Female
Daily iron loss – Sedentary Individual	1 mg/day	1.5 mg/day
Daily iron loss – Endurance Athlete	1.8 mg/day	2.5 mg/day
Increased dietary need (assumes 10% absorption efficiency)	8 mg/day	10 mg/day

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.

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 E, and selenium that can be obtained through a **nutrient dense** diet.

Notes

1. Unless otherwise noted, information in this section is taken from: 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. Source: Dietary Reference Intakes, 2002 ACSM/ADA/Dietitians of Canada Position Statement: Nutrition & Athletic Performance, 2001. Accessed March 17, 2018.
3. The Female Athlete Triad. American College of Sports Medicine. http://www.acsm.org/public-information/articles/2016/10/07/the-female-athlete-triad. Published October 7, 2016. Accessed March 16, 2018.
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5. 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.

17.5 Water and Electrolyte Needs

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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 17.51 "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.

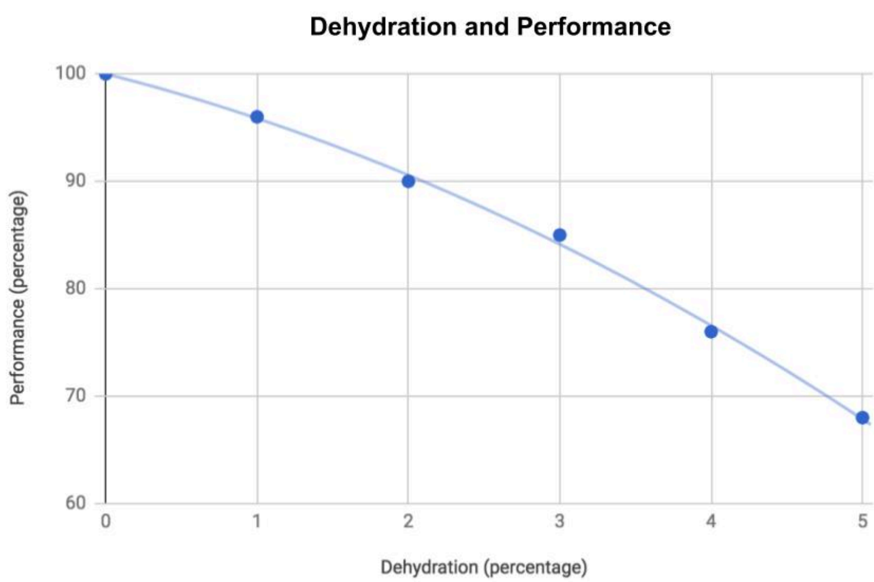

***Figure 17.51** Dehydration Effect on Exercise Performance. Image by Allison Calabrese / CC BY 4.0*

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 by 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 17.52 "The Heat Index").

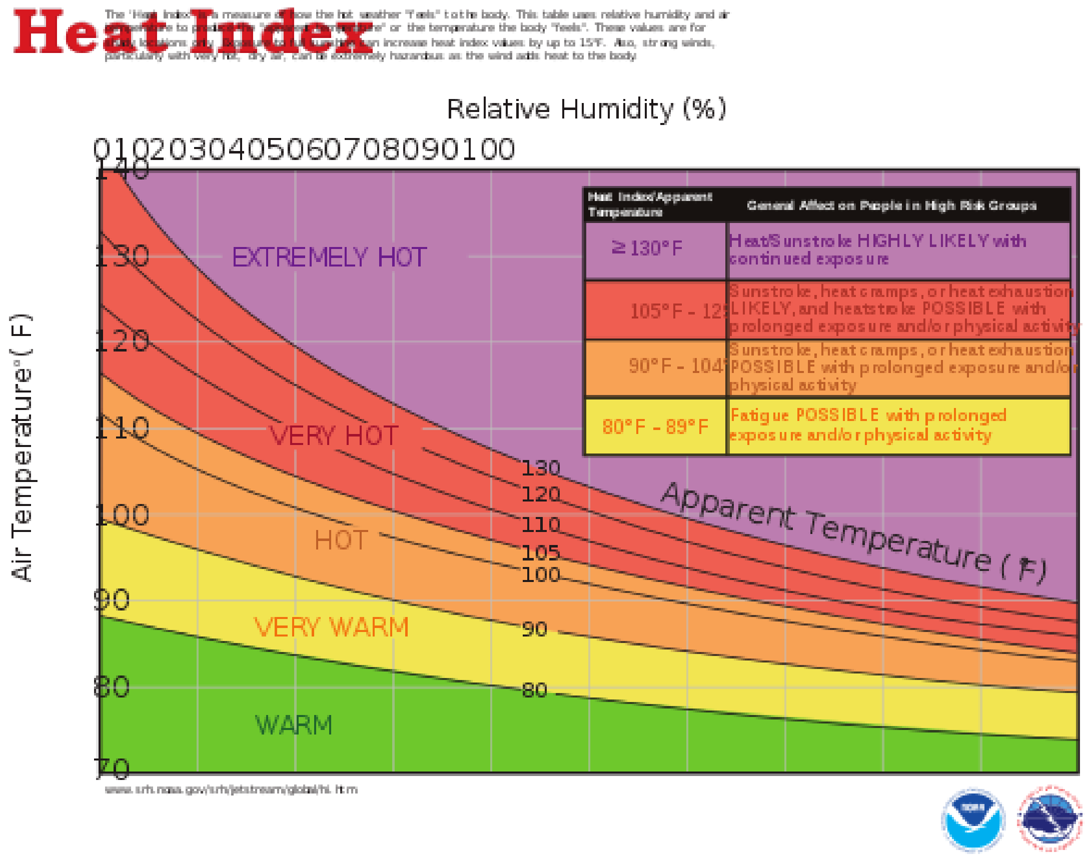

Figure 17.52 *The Heat Index. Credit: "Heat Index" by National Weather Service, Southern Region Headquarters / Public Domain*

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 and is easily replaced during the first meal after exercising. However, during long endurance exercises such as a marathon or triathlon, sodium losses are larger and must be replenished as well. Drinking water after completing an exercise will replenish water loss, only. If water is replenished without sodium after a long period of physical activity, 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 17.53 "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 13, Water and Electrolytes.

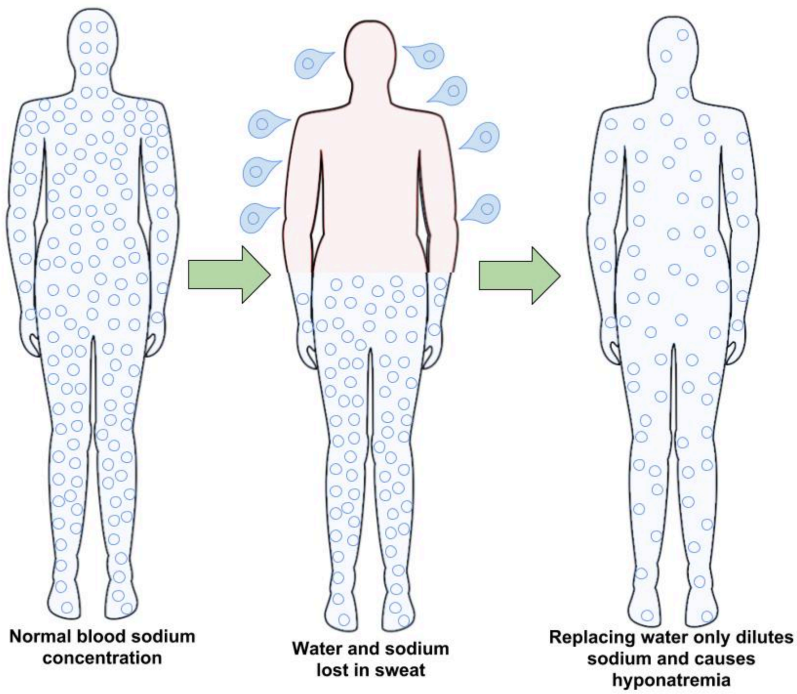

***Figure 17.53** The Effect of Exercise on Sodium Levels. Image by Allison Calabrese / CC BY 4.0*

17.6 Food Supplements and Food Replacements

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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 US Preventive Task Force also recommends a level of folate intake which can be easier to achieve with a supplement. In addition, 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, 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 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

The **Food and Drug Administration (FDA)** regulates supplements, but it treats them like food rather than pharmaceuticals. Dietary supplements must meet the FDA's Good Manufacturing Standards, but are not required to meet the standards for drugs, although some companies do so voluntarily. Also, although supplement manufacturers are allowed to say a particular ingredient may reduce the risk of a disease or disorder, or that it might specifically target certain body systems, these claims are not approved by the FDA. This is why labels that make structural and functional claims are required to carry a disclaimer saying the product is not intended "to diagnose, treat, cure, or prevent any disease." In addition, in the United States, supplements are taken off the market only after the FDA has proven that they are hazardous.[3] To revisit the topic of structural and functional claims refer back to Section 2.7 "Discovering Nutrition Facts".

Before Taking Supplements

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.

Food: The Best Medicine

Poor dietary choices and a sedentary lifestyle account for about 300–600 thousand deaths every year according to the US Department of Health and Human Services. That number is thirteen times higher than the deaths due to gun violence.[4] The typical North American diet is too high in saturated fat, sodium, and sugar, and too low in fiber in the form of whole fruits, vegetables, and whole grains to keep people healthy. With so many threats to optimal health it is vital to address those factors that are under your control, namely dietary and lifestyle choices. A diet that supplies your body with the needed energy and nutrients daily will result in efficient body functioning and in protection from disease. Making sound nutritional choices can also provide support for individuals undergoing treatment for short-term or chronic conditions. Finding a balance between nutritional needs with concerns about drug interactions can hasten recovery, improve quality of life, and minimize the side effects from treatment protocols.

Notes

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.
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CHAPTER XVIII

CHAPTER 18: FOOD SAFETY

In chapter 18, we'll be looking at various topics related to food safety; the prevention of foodborne illness. We'll discuss what different types of foodborne illness exist, what causes them, and how they can be prevented. In learning about prevention, we'll focus both on the individual and on the roles of government organizations.

Sections:

Adapted from Fialkowski Revilla, et al., *Human Nutrition*.

18.0 Introduction to Food Safety

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Image by Maarten Van de Heuvel on unsplash.com / CCO

Learning Objectives

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

- Describe the major types and causes of foodborne illness and contamination
- Describe the purpose and process of food irradiation
- Describe consumer-level techniques for avoiding foodborne illness

Foodborne Illness and Food Safety

Foodborne illness is a serious threat to health. Sometimes called "food poisoning," foodborne illness is a common public health problem that can result from exposure to a pathogen or a toxin via food or beverages. Raw foods, such as seafood, produce, and meats, can all be contaminated during harvest (or slaughter for meats), processing, packaging, or during distribution, though meat and poultry are the most common source of foodborne illness. For all kinds of food, contamination also can occur during preparation and cooking in a home kitchen or in a restaurant. For example in 2009, the Marshall Islands reported 174 cases presenting with vomiting and diarrhea. After an epidemiological investigation was completed, they identified the cause to be egg sandwiches that had been left at room temperature too long resulting in the growth of foodborne toxins in the egg sandwiches.[1]

In many developing nations, contaminated water is also a major source of foodborne illness. Many people are affected by foodborne illness each year, making food safety a very important issue. Annually, one out of six Americans becomes sick after consuming contaminated foods or beverages.[2] Foodborne illness can range from mild stomach upset to severe symptoms, or even fatalities. The problem of food contamination can not only be dangerous to your health, it can also be harmful to your wallet. Medical costs and lost wages due to salmonellosis, just one foodborne disease, are estimated at over $1 billion per year.

At-Risk Groups

No one is immune from consuming contaminated food but, whether you become seriously ill depends on the microorganism, the amount you have consumed, and your overall health. In addition, some groups have a higher risk than others for developing severe complications to foodborne disease. Who is most at risk? Young children, elderly people, and pregnant women all have a higher chance of becoming very sick after consuming contaminated food. Other high-risk groups include people with compromised immune systems due to HIV/AIDS, immunosuppressive medications (such as after an organ transplant), and long-term steroid use for asthma or arthritis. Exposure to contaminated food could also pose problems for diabetics, cancer patients, people who have liver disease, and people who have stomach problems as a result of low stomach acid or previous stomach surgery. People in all of these groups should handle food carefully, make sure that what they eat has been cooked thoroughly, and avoid taking any chances that could lead to exposure.

Notes

1. Thein CC, Trinidad RM, Pavlin B. A Large Foodborne Outbreak on a Small Pacific Island. Pacific Health Dialogue. 2010, 16(1). https://www.ncbi.nlm.nih.gov/pubmed/20968238. Accessed January 28, 2018.
2. Foodborne Illnesses and Germs. Centers for Disease Control and Prevention. https://www.cdc.gov/foodsafety/foodborne-germs.html. Updated January 23, 2018. Accessed January 28, 2017.

18.1 The Major Types of Foodborne Illness

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Foodborne illnesses are either infectious or toxic in nature. The difference depends on the agent that causes the condition. Microbes, such as bacteria, cause food infections, while toxins, such as the kind produced by molds, cause **intoxications**. Different diseases manifest in different ways, so **signs and symptoms** can vary with the source of contamination. However the illness occurs, the microbe or toxin enters the body through the gastrointestinal tract, and as a result common symptoms include diarrhea, nausea, and abdominal pain. Additional symptoms may include vomiting, dehydration, lightheadedness, and rapid heartbeat. More severe complications can include a high fever, diarrhea that lasts more than three days, prolonged vomiting, bloody stools, and signs of shock.

One of the biggest misconceptions about foodborne illness is that it is always triggered by the last meal that a person ate. However, it may take several days or more before the onset of symptoms. If you develop a foodborne illness, you should rest and drink plenty of fluids. Avoid antidiarrheal medications, because they could slow the elimination of the contaminant.

Food Infection

According to the **CDC**, more than 250 different foodborne diseases have been identified.[1] Majority of these diseases are food infections, which means they are caused from food contaminated by microorganisms, such as bacteria, by microscopic animals called parasites, or by viruses. The infection then grows inside the body and becomes the source of symptoms. Food infections can be sporadic and often are not reported to physicians. However, occasional outbreaks occur that put communities, states and provinces, or even entire nations at risk. For example, in 1994, an outbreak of the infection salmonellosis occurred in the United States due to contaminated ice cream. An estimated 224,000 people became ill. In 1988, contaminated clams resulted in an outbreak of hepatitis A in China, which affected about 300,000 people.[2]

The Reproduction of Microorganisms

Bacteria, one of the most common agents of food infection, are single-celled microorganisms that are too small to be seen with the human eye. Microbes live, die, and reproduce, and like all living creatures, they depend on certain conditions to survive and thrive. In order to reproduce within food, microorganisms require the following:

- Temperature. Between 40°F and 140°F (4-60°C), bacteria grow rapidly. This temperature range is sometimes the "danger zone" for food safety.
- Time. More than two hours in the danger zone.
- Water. High moisture content is helpful. Fresh fruits and vegetables have the highest moisture content.
- Oxygen. Most microorganisms need oxygen to grow and multiply, but a few are anaerobic and do not.
- Acidity and pH Level. Foods that have a low level of acidity (or a high pH level) provide an ideal environment, since most microorganisms grow best around pH 7.0 and not many will grow below pH 4.0 . Examples of higher pH foods include egg, meat, seafood, milk, and corn. Examples of low pH foods include citrus fruits, sauerkraut, tomatoes, and pineapples.
- Nutrient Content. Microorganisms need protein, starch, sugars, fats, and other compounds to grow. Typically high-protein foods are better for bacterial growth.

Food Intoxication

Other kinds of foodborne illness are food intoxications, which are caused by natural toxins or harmful chemicals. These and other unspecified agents are major contributors to episodes of acute gastroenteritis and other kinds of foodborne illness.[3] Like pathogens, toxins and chemicals can be introduced to food during cultivation, harvesting, processing, or distribution. Some toxins can lead to symptoms that are also common to food infection, such as abdominal cramping, while others can cause different kinds of symptoms and complications, some very severe. For example, mercury, which is sometimes found in fish, can cause neurological damage in infants and children. Exposure to cadmium can cause kidney damage, typically in elderly people.

Notes

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18.2 The Causes of Food Contamination

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Both food infections and food intoxications can create a burden on health systems, when patients require treatment and support, and on food systems, when companies must recall contaminated food or address public concerns. It all begins with the agent that causes the contamination. When a person ingests a food contaminant, it travels to the stomach and intestines. There, it can interfere with the body's functions and make you sick. In the next part, we will focus on different types of food contaminants; including **organisms** that cause infection, different types of toxins that may be found in food, and chemicals found in the environment. Let's begin with pathogens, which include bacteria and viruses. About one hundred years ago, typhoid fever, tuberculosis, and cholera were common diseases caused by food and water contaminated by pathogens. Over time, improvements in **food processing** and water treatment eliminated most of those problems in North America. Today, other bacteria and viruses have become common causes of food infection.

Causes of Foodborne Infection

Bacteria

All foods naturally contain small amounts of bacteria. However, poor handling and preparation of food, along with improper cooking or storage can multiply bacteria and cause illness. In addition, bacteria can multiply quickly when cooked food is left out at room temperature for more than a few hours. Most bacteria grow undetected because they do not change the color or texture of food or produce a bad odor. Freezing and refrigeration slow or stop the growth of bacteria, but does not destroy the bacteria completely. The microbes can reactivate when the food is taken out and thawed.

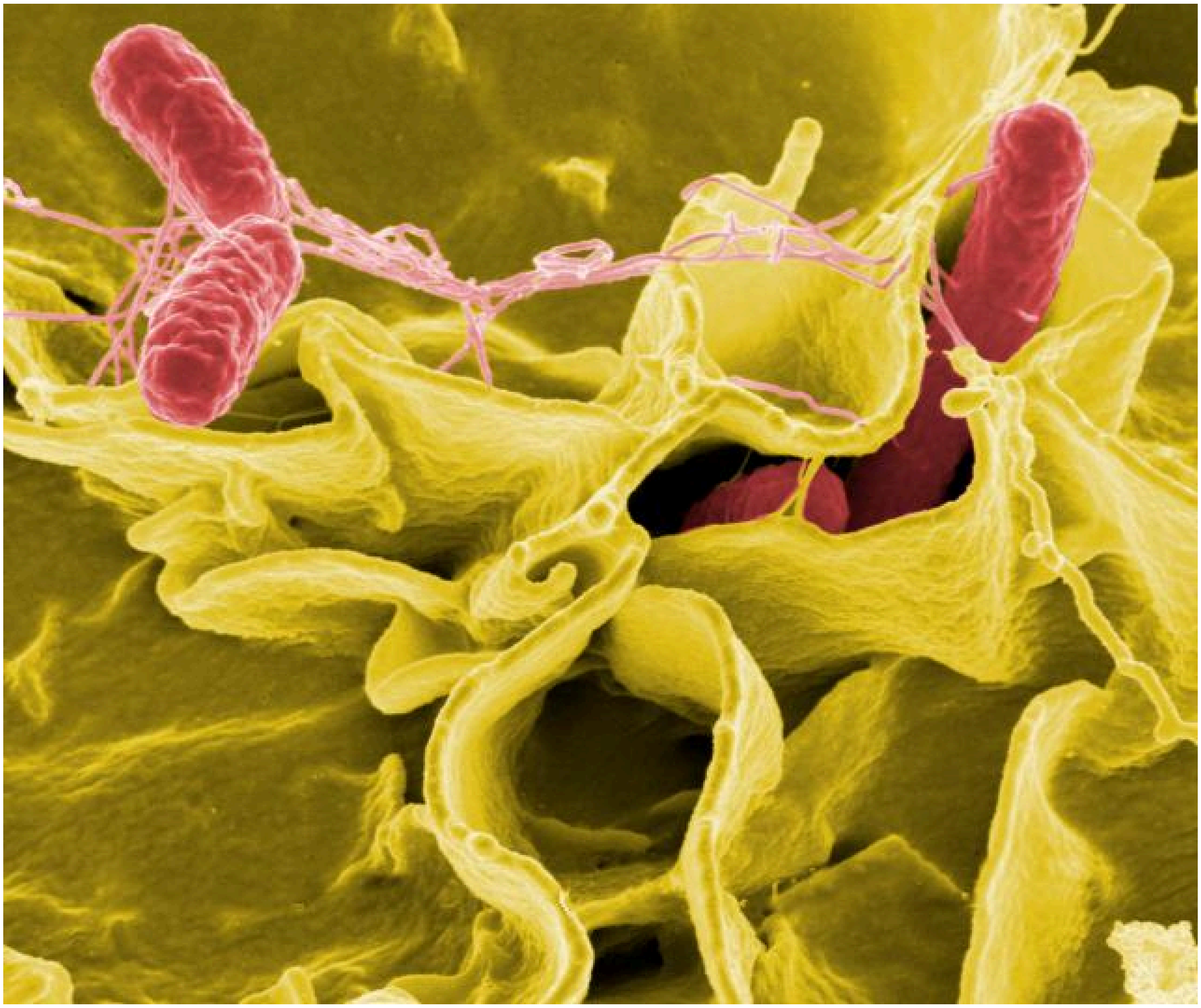

Figure 18.21 *Salmonella bacteria. Image by NIH NIAID / CC BY 2.0*

Many different kinds of bacteria can lead to food infections. One of the most common is *Salmonella*, which is found in the intestines of birds, reptiles, and mammals. *Salmonella* can spread to humans via a variety of different animal-origin foods, including meats, poultry, eggs, dairy products, and seafood. The disease it causes, salmonellosis, typically brings about fever, diarrhea, and abdominal cramps within twelve to seventy-two hours after eating. Usually, the illness lasts four to seven days, and most people recover without treatment. However, in individuals with weakened immune systems, *Salmonella* can invade the bloodstream and lead to life-threatening complications, such as a high fever and severe diarrhea.[1]

The bacterium *Listeria monocytogenes* is found in soft cheeses, unpasteurized milk, meat, and seafood. It causes a disease called listeriosis that can bring about fever, headache, nausea, and vomiting. *Listeria monocytogenes* mostly affects pregnant women, newborns, older adults, and people with cancer and compromised immune systems.

The food infection by *Escherichia coli* (*E. coli*) is found in raw or undercooked meat, raw vegetables, unpasteurized milk, minimally processed ciders and juices, and contaminated drinking water. Symptoms can occur a few days after eating, and include watery and bloody diarrhea, severe stomach cramps, and dehydration. More severe complications may include colitis, neurological symptoms, stroke, and hemolytic uremic syndrome. In young children, an *E. coli* infection can cause kidney failure and death.

The bacterium *Clostridium botulinum* causes botulism. Sources include improperly canned foods, lunch meats, and garlic. An infected person may experience symptoms within four to thirty-six hours after eating. Symptoms could include nerve dysfunction, such as double vision, inability to swallow, speech difficulty, and progressive paralysis of the respiratory system. Botulism can also be fatal.

Campylobacter jejuni causes the disease campylobacteriosis. It is the most commonly identified bacterial cause of diarrhea worldwide. Consuming undercooked chicken, or food contaminated with the juices of raw chicken, is the most frequent source of this infection. Other sources include raw meat and unpasteurized milk. Within two to five days after consumption, symptoms can begin and include diarrhea, stomach cramps, fever, and bloody stools. The duration of this disease is about seven to ten days.

The food infection shigellosis is caused by *Shigella*, of which there are several types. Sources include undercooked liquid or moist food that has been handled by an infected person. The onset of symptoms occurs one to seven days after eating, and can include stomach cramps, diarrhea, fever, and vomiting. Another common symptom is blood, pus, or mucus in stool. Once a person has had shigellosis, the individual is not likely to get infected with that specific type again for at least several years. However, they can still become infected with other types of *Shigella*.

Staphylococcus aureus (*S. aureus*) causes staphylococcal food poisoning. Food workers who carry this kind of bacteria and handle food without washing their hands can cause contamination. Other sources include meat and poultry, egg products, cream-filled pastries, tuna, potato and macaroni salad, and foods left unrefrigerated for long periods of time. Symptoms can begin thirty minutes to eight hours after eating, and include diarrhea, vomiting, nausea, stomach pain, and cramps. This food infection usually lasts one to two days.

Found in raw oysters and other kinds of seafood, *Vibrio vulnificus* belongs to the same family as the bacteria which cause cholera. This food contaminant can result in the *Vibrio* infection. Symptoms can begin anywhere from six hours to a few days after consumption, and include chills, fever, nausea, and vomiting. This disease is very dangerous and can result in fatalities, especially in people with underlying health problems.[2]

Virus

Viruses are another type of pathogen that can lead to food infections, however they are less predominant than bacteria. Viruses differ from bacteria in that they cannot grow and reproduce in foods. Instead, viruses that cause human diseases can only reproduce inside human cells (see Figure 18.22 "Viruses in the Human Body"). Hepatitis A is one of the more well-known food-contaminating viruses. Sources include raw shellfish from polluted water, and food handled by an infected person. This virus can go undetected for weeks and, on average, symptoms do not appear until about one month after exposure. At first, symptoms include malaise, loss of appetite, nausea, vomiting, and fever. Three to ten days later, additional symptoms can manifest, including **jaundice** and darkened urine. Severe cases of a hepatitis A can result in liver damage and death.

The most common form of contamination from handled foods is the norovirus, which is also known as the Norwalk-like virus, or the calicivirus. Sources include raw shellfish from polluted water, salads, sandwiches, and other ready-to-eat foods handled by an infected person. The norovirus causes gastroenteritis and within one to three days it leads to symptoms, such as nausea, vomiting, diarrhea, stomach pain, headache, and a low-grade fever.[3]

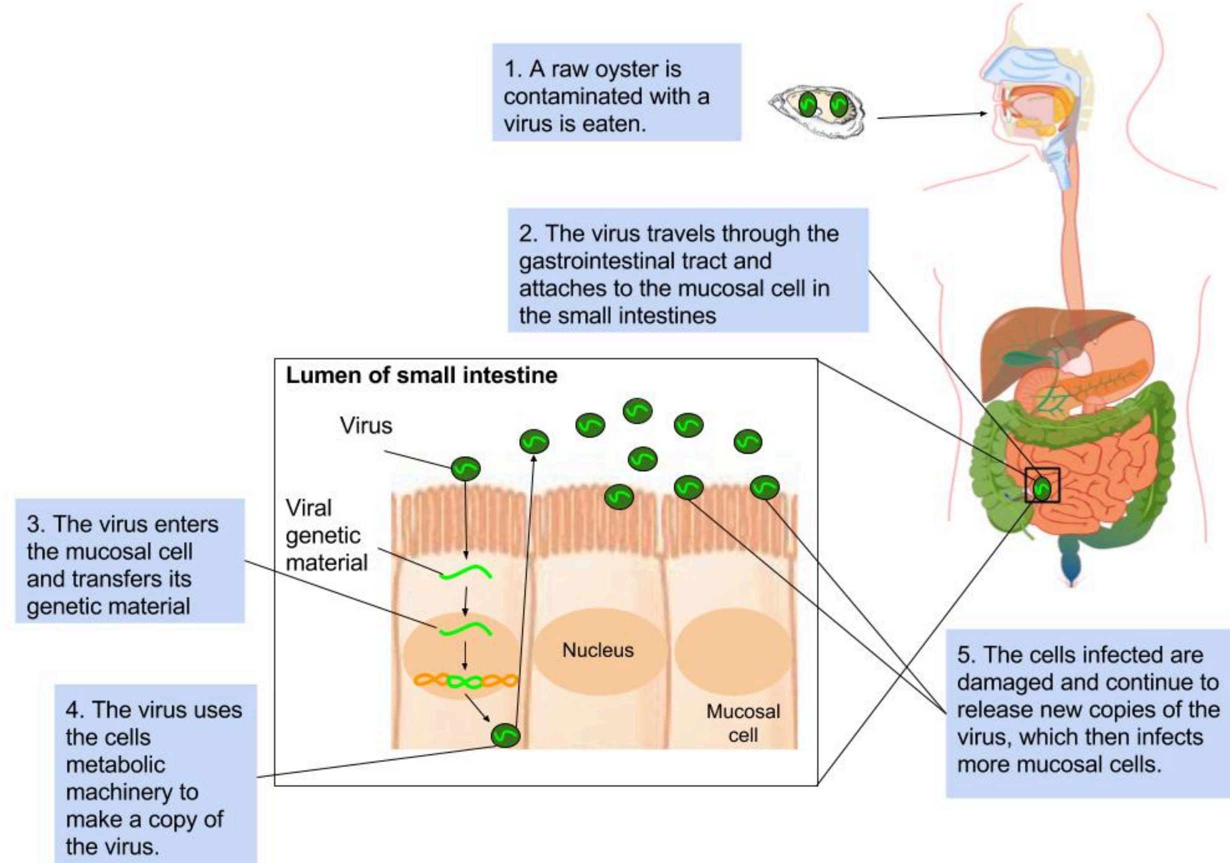

Figure 18.22 *Viruses in the Human Body. Image by Allison Calabrese / CC BY 4.0*

Parasitic Protozoa

Food-contaminating parasitic protozoa are microscopic organisms that may be spread in food and water. Several of these creatures pose major problems to food production worldwide. They include *Anisakis*, microscopic worms that invade the stomach or the intestines. Sources of this parasite include raw fish. This parasite can result in the *Anisakis* infection, with symptoms that begin within a day or less and include abdominal pain, which can be severe.

Cryptosporidium lives in the intestines of infected animals. Another common source is drinking water, when heavy rains wash animal wastes into reservoirs. One major problem with this pathogen is that it is extremely resistant to disinfection with chlorine. *Cryptosporidium* causes the disease cryptosporidiosis, with symptoms that begin one to twelve days after exposure and include watery stools, loss of appetite, vomiting, a low-grade fever, abdominal cramps, and diarrhea. For HIV/AIDS patients and others with weakened immune systems, the disease can be severe, and sometimes can lead to death.

Giardia lamblia is another parasite that is found in contaminated drinking water. In addition, it lives in the intestinal tracts of animals, and can wash into surface water and reservoirs, similar to *Cryptosporidium*. *Giardia* causes giardiasis, with symptoms that include abdominal cramping and diarrhea within one to three days. Although most people recover within one to two weeks, the disease can lead to a chronic condition, especially in people with compromised immune systems.

The parasite *Toxoplasma gondii* causes the infection toxoplasmosis, which is a leading cause of death attributed to foodborne illness in the United States. More than sixty million Americans carry *Toxoplasma gondii*, but very few have symptoms. Typically, the body's immune system keeps the parasite from causing disease. Sources include raw or undercooked meat and unwashed fruits and vegetables. Handling the feces of a cat with an acute infection can also lead to the disease.[4]

Causes of Foodborne Intoxication

Bacterial Toxins

Some bacteria produce poisonous molecules, toxins, that can linger in food even if the bacteria themselves have been killed. *Clostridium botulinum* is one of these bacteria. The botulinum toxin affects the nervous system, causing paralysis. In very small amounts this toxin is used cosmetically to paralyze muscles of the forehead (Botox treatment). If ingested in relatively larger amounts, botulinum toxin can paralyze the entire body, including the respiratory muscles, potentially causing death.

Algal Toxins

Certain algae produce toxins that become concentrated within shellfish that eat the algae. If humans then eat the poisoned shellfish, they can acquire a large enough dose of algal toxins to cause Paralytic Shellfish Poisoning. The toxins affect the nervous system, causing paralysis and potentially death. Under certain conditions, algae that produce these toxins may grow in large numbers, called an algae "bloom". Blooms of toxic algae are sometimes called "red tide," although that is a misnomer; dangerous algal blooms can occur in different colors, not just red. [5]

Mold Toxins

Mold can grow on fruits, vegetables, grains, meats, poultry, and dairy products, and typically appears as gray or green "fur."

Figure 18.23 *Moldy nectarines. Image by Roger McLassus 1951 / CC BY-SA 3.0*

Warm, humid, or damp conditions encourage mold to grow on food. Molds are microscopic fungi that live on animals and plants. No one knows how many species of fungi exist, but estimates range from ten- to three-hundred thousand. Unlike single-celled bacteria, molds are multicellular, and under a microscope look like slender mushrooms. They have stalks with spores that form at the ends. The spores give molds their color and can be transported by air, water, or insects. Spores also enable mold to reproduce. Additionally, molds have root-like threads that may grow deep into food and be difficult to see. The threads are very deep when a food shows heavy mold growth. Foods that contain mold may also have bacteria growing alongside it.

Some molds, like the kind found in blue cheese, are desirable in foods, while other molds can be dangerous. The spores of some molds can cause allergic reactions and respiratory problems. In the right conditions, a few molds produce mycotoxins, which are natural, poisonous substances that can make you sick if they are consumed. Mycotoxins are contained in and around mold threads, and in some cases, may have spread throughout the food. The Food and Agriculture Organization of the United Nations estimates that mycotoxins affect 25 percent of the world's food crops. They are found primarily in grains and nuts, but other sources include apples, celery, and other produce.

The most dangerous mycotoxins are aflatoxins, which are produced by strains of fungi called *Aspergillus* under certain temperature and humidity conditions. Contamination has occurred in peanuts, tree nuts, and corn. Aflatoxins can cause aflatoxicosis in humans, livestock, and domestic animals. Symptoms include vomiting and abdominal pain. Possible complications include liver failure, liver cancer, and even death. Many countries try to limit exposure to aflatoxins by monitoring their presence on food and feed products.[6]

Poisonous Mushrooms

Figure 18.24 *Amanita Muscaria. Image by Onder Wijsgek / CC BY 3.0*

Like molds, mushrooms are fungi and the poisonous kind produces mycotoxins that can cause food intoxication. Toxic mushrooms, also known as toadstools, can cause severe vomiting and other symptoms. However, only a few varieties are fatal. Toxic mushrooms cannot be made safe by cooking, freezing, **canning**, or processing. The only way to avoid food intoxication is to refrain from eating them. Mushroom guides can help wild gatherers distinguish between the edible and toxic kinds[7].

Environmental Contaminants

Pesticides

Pesticides are important in food production to control diseases, insects, and other pests.

They protect crops and ensure a large yield. However, synthetic pesticides can leave behind residues, particularly on produce, that can be harmful to human health. Foods that contain the highest levels of pesticide residue include conventionally-grown peaches, apples, bell peppers, celery, nectarines, strawberries, cherries, pears, spinach, lettuce, and potatoes. Foods that contain the lowest levels of pesticide residue include avocados, pineapples, bananas, mangoes, asparagus, cabbage, and broccoli.[8] In many cases, the amount of pesticide exposure is too small to pose a risk. However, harmful exposures can lead to certain health problems and complications, including cancer. Also, infants and young children are more susceptible to the hazards of pesticides than adults. In addition, using synthetic pesticides, herbicides, and fertilizers contributes to soil and water pollution and can be hazardous to farm workers.

To protect the public and their workers, many farmers now rely on alternatives to synthetic pesticide use, including crop rotation, natural pesticides, and planting non food crops nearby to lure pests away. Some consumers choose to reduce their exposure to pesticides by purchasing organic produce. Organic foods are grown or produced without synthetic pesticides or fertilizer, and all growers and processors must be certified by the **US Department of Agriculture (USDA)**. However, conventionally-grown produce should be fine for fruits and vegetables that appear on the low-residue list.

Pollutants

Pollutants are another kind of chemical contaminant that can make food harmful. Chemical runoff from factories can pollute food products and drinking water. For example, dioxins are chemical compounds created in industrial processes, such as manufacturing and bleaching pulp and paper. Fish that swim in dioxin-polluted waters can contain significant amounts of this pollutant, which causes cancer. When metals contaminate food, it can result in serious and even life-threatening health problems. A common metal contaminant is lead, which can be present in drinking water, soil, and air. Lead exposure most often affects children, who can suffer from physical and mental developmental delays as a result.

Methyl mercury occurs naturally in the environment and is also produced by human activities. Fish can absorb it, and the predatory fish that consume smaller, contaminated fish can have very high levels. This highly toxic chemical can cause mercury poisoning, which leads to developmental problems in children, as well as autoimmune effects. A condition called Minamata disease was identified in 1956 in Japan. It was named for the town of Minamata, which was the site of an environmental disaster when methyl mercury was released into the surface water near a factory. Many residents experienced neurological issues, including numbness in hands and feet, muscle weakness, a narrowing of the field of vision, damage to hearing and speech, and ataxia, which is a lack of muscle coordination.[9]

PCBs, or polychlorinated biphenyls, are man-made organic compounds that consist of carbon, hydrogen and chlorine. Due to their non-flammability, chemically stable, and high boiling points PCBs were manufactured and used commercially from 1929 until 1979 when it was banned. Like methylmercury, higher concentrations of this contaminant are found in predatory fish. Health effects include complications in physical and neurological development in children, and this compound is potentially a carcinogen. PCB contamination also can affect the immune, reproductive, nervous, and endocrine systems.[10]

Notes

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18.3 Protecting the Public Health

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Most foodborne infections go unreported and undiagnosed. However, the **CDC** estimates that about seventy-six million people in the United States become ill from foodborne pathogens or other agents every year. In North America, a number of government agencies work to educate the public about food infections and intoxications, prevent the spread of disease, and quell any major problems or outbreaks. They include the CDC, the **FDA**, and the USDA, among other organizations.

Efforts on the Governmental Level

A number of government agencies work to ensure food safety and to protect the public from foodborne illness. Food regulatory agencies work to protect the consumer and ensure the safety of our food. Food and drug regulation in the United States began in the late nineteenth century when state and local governments began to enact regulatory policies. In 1906, Congress passed the Pure Food and Drugs Act, which led to the creation of the US Food and Drug Administration (FDA). Today, a number of agencies are in charge of monitoring how food is produced, processed, and packaged.[1]

The Food and Drug Administration (FDA)

The USDA and the FDA enforce laws regarding the safety of domestic and imported food. In addition, the Federal Food, Drug, and Cosmetic Act of 1938 gives the FDA authority over food ingredients. The FDA enforces the safety of domestic and imported foods. It also monitors supplements, food labels, claims that corporations make about the benefits of products, and pharmaceutical drugs. Sometimes, the FDA must recall contaminated foods and remove them from the market to protect public health. For example, in 2011 contaminated peanut butter led to the recall of thousands of jars of a few popular brands.[2]

Recalls are almost always voluntary and often are requested by companies after a problem has been discovered. In rare cases, the FDA will request a recall. But no matter what triggers the removal of a product, the FDA's role is to oversee the strategy and assess the adequacy and effectiveness of the recall.

Many consumers have concerns about safety practices during the production and distribution of food. This is especially critical given recent outbreaks of foodborne illnesses. For example, during fall 2011 in the United States, there was an eruption of the bacteria *Listeria monocytogenes* in cantaloupe. It was one of the deadliest outbreaks in over a decade and resulted in a number of deaths and hospitalizations.[3] In January 2011, the Food Safety Modernization Act was passed to grant more authority to the FDA to improve food safety. The FDA and other agencies also address consumer-related concerns about protecting the nation's food supply in the event of a terrorist attack.

The US Department of Agriculture (USDA)

The USDA headed by the Secretary of Agriculture, develops and executes federal policy on farming and food. This agency supports farmers and ranchers, protects natural resources, promotes trade, and seeks to end hunger in the United States and abroad. The USDA also assures food safety, and in particular oversees the regulation of meat, poultry, and processed egg products. The CDC tracks outbreaks, identifies the causes of food infection and intoxication, and recommends ways to prevent foodborne illness. Other government agencies that play a role in protecting the public include the Food Safety and Inspection Service, a division of the USDA, which enforces laws regulating meat and poultry safety. The Agricultural Research Service, which is the research arm of the USDA, investigates a number of agricultural practices, including those related to animal and crop safety. The National Institute of Food and Agriculture conducts research and education programs on food safety for farmers and consumers.

The Environmental Protection Agency (EPA)

The Environmental Protection Agency (EPA) works to protect human health and the environment. Founded in 1970, the agency conducts environmental assessment, education, research, and regulation. The EPA also works to prevent pollution and protect natural resources. Two of its many regulatory practices in the area of agriculture include overseeing water quality and the use of pesticides.The EPA approves pesticides and other chemicals used in agriculture, and sets limits on how much residue can remain on food. The FDA analyzes food for surface residue and waxes. Processing methods can either reduce or concentrate pesticide residue in foods. Therefore, the Food Quality Protection Act, which was passed in 1996, requires manufacturers to show that pesticide levels are safe for children.

The Centers for Disease Control and Prevention (CDC)

The Centers for Disease Control and Prevention (CDC) are the government agency tasked with monitoring illness in the United States. They gather data from public health departments in all 50 states and monitor the data to detect new outbreaks of disease, monitor existing health concerns, and track the success of public health initiatives. The CDC also carries out research and trains public health experts who can be dispatched to control outbreaks of disease. Much of the CDC's work is focused on infectious disease, but they also track cases of foodborne illness. When a major outbreak of *Listeria* or *Salmonella* makes the news, it's because the CDC detected a sudden increase in cases. You can read more about the CDC's role in food safety at the link below:

Web Link: CDC and Food Safety

Efforts within the Food Industry

The Hazard Analysis Critical Control Points (HACCP) is a program within the food industry designed to promote food safety and prevent contamination by identifying all areas in food production and retail where contamination could occur. Companies and retailers determine the points during processing, packaging, shipping, or shelving where potential contamination may occur.. Those companies or retailers must then establish critical control points to prevent, control, or eliminate the potential for food contamination. The USDA requires the food industry to follow HACCP for meat and poultry, while the FDA requires it for seafood, low-acid canned-food, and juice. HACCP is voluntary for all other food products but its main goal is to prevent contamination at all costs.

Everyday Connection

The Seven Steps to HACCP:

1. Conduct a hazard analysis: The manufacturer must first determine any food safety hazards (ex. biological, chemicals, or physical) and identify preventative measures to control the hazards.
2. Identify the critical control points: Critical control point (CCP) is a point or procedure in food manufacturing where control can be applied to prevent or eliminate food hazards that may cause the food to be unsafe.
3. Establish critical limits: A critical limit is the maximum or minimum value that a food hazard must be controlled at a CCP to prevent, eliminate or reduce it to an acceptable level.
4. Establish monitoring requirements: The manufacture must establish procedures to monitor the control points to ensure the process is under control and not above the CCP.
5. Establish corrective actions: Corrective actions are needed when monitoring indicates a deviation from the established critical limit to ensure that no produce injurious to health has occurred as a result of the deviation.
6. Establish verification procedures: Verification ensures that the HACCP plan is adequate with CCP records, critical limits and microbial sampling and analysis.
7. Record keeping procedure: The manufacturer must maintain certain documents including its hazard analysis, HACCP plan, and records monitoring the CCP, critical limits, and the verification of handling processed deviations.

For more information on the HACCP visit https://www.fsis.usda.gov/Oa/background/keyhaccp.htm.

Notes

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18.4 Food Preservation

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The Food System

The food system is a network of farmers and related operations, including food processing, wholesale and distribution, retail, industry technology, and marketing. The milk industry, for example, includes everything from the farm that raises livestock, to the milking facility that extracts the product, to the processing company that pasteurizes milk and packages it into cartons, to the shipping company that delivers the product to stores, to the markets and groceries that stock and sell the product, to the advertising agency that touts the product to consumers. All of these components play a part in a very large system.

Two important aspects of a food system are preservation and processing. Each provides for or protects consumers in different ways. **Food preservation** includes the handling or treating of food to prevent or slow down spoilage. **Food processing** involves transforming raw ingredients into packaged food, from fresh-baked goods to frozen dinners. Although there are numerous benefits to both, preservation and processing also pose some concerns, in terms of both **nutrition** and **sustainability**.

Food Preservation

Food preservation protects consumers from harmful or toxic food by limiting the growth of bacteria within food. There are different ways to preserve food. Some are ancient methods that have been practiced for generations, such as curing, smoking, pickling, salting, fermenting, **canning**, and preserving fruit in the form of jam. Others include the use of modern techniques and technology, including drying, vacuum packing, **pasteurization**, and freezing and refrigeration. Preservation guards against foodborne illnesses, and also protects the flavor, color, moisture content, or nutritive value of food.

We'll discuss a few of the more common forms of food preservation below, but be aware that there are many others.

Low-Temperature Storage

One of the most common ways food is preserved in the era of electricity is by storing it at low temperatures, either refrigeration (below 40°F/4°C) or freezing (below 0°F/-18°C). The bacteria that cause food to spoil and the ones that can make us sick are unable to grow at these temperatures. However, the bacteria are still there and will begin growing again if the food is put back into warmer temperatures, as happens if you leave it on the counter or if the power to your refrigerator fails.

High-Temperature Treatment

Low temperatures keep bacteria from growing, but high temperatures can actually kill bacteria. This is one reason why you cook many types of food before eating it (apart from enhancing the flavor). This is also why you can boil contaminated water to make it drinkable. There are several different forms of food preservation that use high temperatures to sterilize food. We'll discuss two: canning and Pasteurization.

Canning

In canning, foods are placed into jars or cans and heated to a temperature that destroys any bacteria, often by boiling. The containers are also vacuum sealed to prevent other bacteria from entering after the container cools down. Canning is an important part of the industrial food system, and many people also practice canning at home.

Pasteurization

Pasteurization is an industrial process used to eliminate bacteria in milk or juice. This process was invented by the French chemist Louis Pasteur in 1862. Pasteurization involves exposing liquids to high temperatures for a very brief amount of time. The short exposure keeps the liquid from cooking, reducing changes to taste or texture. The time and temperature used in Pasteurization varies depending on the product, but in the US, for milk, it's around 158°F (70°C) for 15 seconds. This temperature greatly reduces the number of bacteria in milk but does not kill all of them, which is why milk in the US must remain refrigerated. Many other countries use ultra-high temperature Pasteurization for milk (140°C for 4 seconds), which kills all bacteria, meaning that unopened milk can last for months unrefrigerated.

Dehydration

Drying food is an effective method of food preservation, because bacteria need water in order to live, just like we do. This is possibly one of the earliest forms of food preservation. Sugar and salt may be used to accelerate the dehydration process, as both of these substances draw water out of bacterial cells at high concentrations. Think of a salty piece of beef jerky for an example of dehydration in action.

Fermentation

Fermentation is the process by which some types of bacteria or yeast break down carbohydrates to make ATP under anaerobic conditions. Some types of fermentation produce molecules that are toxic to bacteria. Different fermenting microbes produce different molecules through fermentation, including alcohol, carbon dioxide, and acids. The ethanol in wine, beer, and other alcoholic beverages and the carbon dioxide that causes bread to rise before baking are both products of fermentation. When fermentation is being used as food preservation, the fermentation product is usually lactic acid. The acidity (low pH) of the fermented food inhibits growth of harmful bacteria. You see this in sauerkraut, kimchi, and yogurt.

Food Irradiation: What You Need to Know

Food irradiation is a very modern form of preserving food that is not like any other. Food irradiation (the application of ionizing radiation to food) is a technology that improves the safety and extends the shelf life of foods by reducing or eliminating microorganisms and insects. Like pasteurizing milk and canning fruits and vegetables, irradiation can make food safer for the consumer. The Food and Drug Administration (FDA) is responsible for regulating the sources of radiation that are used to irradiate food. The FDA approves a source of radiation for use on foods only after it has determined that irradiating the food is safe.

Irradiation does not make foods radioactive, compromise nutritional quality, or noticeably change the taste, texture, or appearance of food. In fact, any changes made by irradiation are so minimal that it is not easy to tell if a food has been irradiated.

Why Irradiate Food?

Irradiation can serve many purposes.

- Prevention of Foodborne Illness – to effectively eliminate organisms that cause foodborne illness, such as Salmonella and E. coli.
- Preservation – to destroy or inactivate organisms that cause spoilage and decomposition and extend the shelf life of foods.
- Control of Insects – to destroy insects in or on tropical fruits imported into the United States. Irradiation also decreases the need for other pest-control practices that may harm the fruit.
- Delay of Sprouting and Ripening – to inhibit sprouting (e.g., potatoes) and delay ripening of fruit to increase longevity.
- Sterilization – irradiation can be used to sterilize foods, which can then be stored for years without refrigeration. Sterilized foods are useful in hospitals for patients with severely impaired immune systems, such as patients with AIDS or undergoing chemotherapy. Foods that are sterilized by irradiation are exposed to substantially higher levels of treatment than those approved for general use.

How Is Food Irradiated?

There are three sources of radiation approved for use on foods.

- Gamma rays are emitted from radioactive forms of the element cobalt (Cobalt 60) or of the element cesium (Cesium 137). Gamma radiation is used routinely to sterilize medical, dental, and household products and is also used for the radiation treatment of cancer.
- X-rays are produced by reflecting a high-energy stream of electrons off a target substance (usually one of the heavy metals) into food. X-rays are also widely used in medicine and industry to produce images of internal structures.
- Electron beam (or e-beam) is similar to X-rays and is a stream of high-energy electrons propelled from an electron accelerator into food.

Is Irradiated Food Safe to Eat?

The FDA has evaluated the safety of irradiated food for more than 30 years and has found the process to be safe. The World Health Organization (WHO), the **Centers for Disease Control and Prevention (CDC)** and the U.S. Department of Agriculture (USDA) have also endorsed the safety of irradiated food.

The FDA has approved a variety of foods for irradiation in the United States including:

- Beef and Pork
- Crustaceans (e.g., lobster, shrimp, and crab)
- Fresh Fruits and Vegetables
- Lettuce and Spinach
- Poultry
- Seeds for Sprouting (e.g., for alfalfa sprouts)
- Shell Eggs
- Shellfish – Molluscan (e.g., oysters, clams, mussels, and scallops)
- Spices and Seasonings

How Will I Know if My Food Has Been Irradiated?

The FDA requires that irradiated foods bear the international symbol for irradiation. Look for the Radura symbol along with the statement "Treated with radiation" or "Treated by irradiation" on the food label. Bulk foods, such as fruits and vegetables, are required to be individually labeled or to have a label next to the sale container. The FDA does not require that individual ingredients in multi-ingredient foods (e.g., spices) be labeled. It is important to remember that irradiation is not a replacement for proper food handling practices by producers, processors, and consumers. Irradiated foods need to be stored, handled, and cooked in the same way as non-irradiated foods, because they could still become contaminated with disease-causing organisms after irradiation if the rules of basic food safety are not followed.[1]

Notes

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18.5 Food Processing

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Food processing includes the methods and techniques used to transform raw ingredients into packaged food. Workers in this industry use harvested crops or slaughtered and butchered livestock to create products that are marketed to the public. There are different ways in which food can be processed, from a one-off product, such as a wedding cake, to a mass-produced product, such as a line of cupcakes packaged and sold in stores.

The Pros and Cons of Food Processing

Image by Dean Hochman / CC BY 2.0

Food processing has a number of important benefits, such as creating products that have a much longer shelf life than raw foods. Also, food processing protects the health of the consumer and allows for easier shipment and the marketing of foods by corporations. However, there are certain drawbacks. Food processing can reduce the nutritional content of raw ingredients. For example, **canning** involves the use of heat, which destroys the vitamin C in canned fruit. Also, certain **food additives** that are included during processing, such as high fructose corn syrup, can affect the health of a consumer. However, the level of added sugar can make a major difference. Small amounts of added sugar and other sweeteners, about 6 to 9 teaspoons a day or less, are not considered harmful.[1]

Food Additives

If you examine the label for a processed food product, it is not unusual to see a long list of added materials. These natural or synthetic substances are food additives and there are more than three hundred used during food processing today. The most popular additives are benzoates, nitrites, sulfites, and sorbates, which prevent molds and yeast from growing on food.[2] Food additives are introduced in the processing stage for a variety of reasons. Some control acidity and alkalinity, while others enhance the color or flavor of food. Some additives stabilize food and keep it from breaking down, while others add body or texture. The table below lists some common food additives and their uses:

Table 18.51 Food Additives[3]

Additive	Reason for Adding
Beta-carotene	Adds artificial coloring to food
Caffeine	Acts as a stimulant
Citric acid	Increases tartness to prevent food from becoming rancid
Dextrin	Thickens gravies, sauces, and baking mixes
Gelatin	Stabilizes, thickens, or texturizes food
Modified food starch	Keeps ingredients from separating and prevents lumps
MSG	Enhances flavor in a variety of foods
Pectin	Gives candies and jams a gel-like texture
Polysorbates	Blends oil and water and keep them from separating
Soy lecithin	Emulsifies and stabilizes chocolate, margarine, and other items
Sulfites	Prevent discoloration in dried fruits
Xanthan gum	Thickens, emulsifies, and stabilizes dairy products and dressings

The Pros and Cons of Food Additives

The FDA works to protect the public from potentially dangerous additives. Passed in 1958, the Food Additives Amendment states that a manufacturer is responsible for demonstrating the safety of an additive before it can be approved. The Delaney Clause that was added to this legislation prohibits the approval of any additive found to cause cancer in animals or humans. However, most additives are considered to be "generally recognized as safe," a status that is determined by the FDA and referred to as GRAS.

Food additives are typically included in the processing stage to improve the quality and consistency of a product. Many additives also make items more "shelf stable," meaning they will last a lot longer on store shelves and can generate more profit for store owners. Additives can also help to prevent spoilage that results from changes in temperature, damage during distribution, and other adverse conditions. In addition, food additives can protect consumers from exposure to rancid products and foodborne illnesses.

Food additives aren't always beneficial, however. Some substances have been associated with certain diseases if consumed in large amounts. For example, the FDA estimates that sulfites can cause allergic reactions in 1 percent of the general population and in 5 percent of asthmatics. Similarly, the additive monosodium glutamate, which is commonly known as MSG, may cause headaches, nausea, weakness, difficulty breathing, rapid heartbeat, and chest pain in some individuals.[4]

Food Enrichment and Fortification[5]

Many foods are enriched or fortified to boost their nutritional value. Enrichment involves adding **nutrients** to restore those that were lost during processing. For example, iron and certain B vitamins are added to white flour to replace the nutrients that are removed in the process of milling wheat. Fortification is slightly different than enrichment and involves adding new nutrients to enhance a food's nutritive value. For example, folic acid is typically added to cereals and grain products, while calcium is added to some orange juice.

Certain enrichment and fortification processes have been instrumental in protecting public health. For example, adding iodine to salt has virtually eliminated iodine deficiencies, which protects against thyroid problems. Adding folic acid to wheat helps increase intake for pregnant women, which decreases the risk of **neural tube** defects in their children. Also, **vegans** or other people who do not consume many dairy products are able to drink orange juice or soy milk that has been fortified with calcium to meet the daily recommendations. However, there is some concern that foods of little nutritive value will be fortified in an effort to improve their allure, such as soft drinks with added vitamins.

Notes

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18.6 The Effect of New Technologies

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As mentioned earlier, new technology has had a tremendous effect on the food we eat and the customs and culture related to food consumption. For example, microwaves are used to reduce cooking time or to heat up leftover food. Refrigerators and freezers allow produce to travel great distances and last longer. On the extreme end of making food last longer, there is special food for astronauts that is appropriate for consumption in space. It is safe to store, easy to prepare in the low-gravity environment of a spacecraft, and contains balanced nutrition to promote the health of people working in space. In the military, soldiers consume Meals Ready-to-Eat (MREs), which contain an entire meal in a single pouch.

Consumer Info About Food From Genetically Engineered Plants

FDA regulates the safety of food for humans and animals, including foods produced from genetically engineered (GE) plants. Foods from GE plants must meet the same food safety requirements as foods derived from traditionally bred plants. Read more at Consumer Info About Food From Genetically Engineered Plants.[1]

Genetically Modified Foods

Genetically modified foods (also known as GM or GMO foods), are plants or animals that have undergone some form of genetic engineering. In the United States, much of the soybean, corn, and canola crop is genetically modified. The process involves the alteration of an organism's DNA, which allows farmers to cultivate plants with desirable characteristics.[2] For example, scientists could extract a gene that produces a chemical with antifreeze properties from a fish that lives in an arctic region (such as a flounder).

They could then splice that gene into a completely different species, such as a tomato, to make it resistant to frost, which would enable farms to grow that crop year-round.[3]

Certain modifications can be beneficial in resisting pests or pesticides, improving the ripening process, increasing the nutritional content of food, or providing resistance to common viruses. Although genetic engineering has improved productivity for farmers, it has also stirred up debate about consumer safety and environmental protection. Possible side effects related to the consumption of GM foods include an increase in allergenicity, or tendencies to provoke allergic reactions. There is also some concern related to the possible transfer of the **genes** used to create genetically engineered foods from plants to people. This could influence human health if antibiotic-resistant genes are transferred to the consumer. Therefore, the World Health Organization (WHO) and other groups have encouraged the use of genetic engineering without antibiotic-resistance genes. Genetically modified plants may adversely affect the environment as well and could lead to the contamination of non-genetically engineered organisms.[4]

Genetically modified foods fall under the purview of the EPA, the USDA, and the FDA. Each agency has different responsibilities and concerns in the regulation of GM crops. The EPA ensures that pesticides used for GM plants are safe for the environment. The USDA makes sure genetically engineered seeds are safe for cultivation prior to planting. The FDA determines if foods made from GM plants are safe to eat. Although these agencies act independently, they work closely together and many products are reviewed by all three.[5]

Notes

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18.7 Efforts on the Consumer Level: What You Can Do

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Consumers can also take steps to prevent foodborne illness and protect their health. Although you can often detect when mold is present, you can't see, smell, or taste bacteria or other agents of foodborne disease. Therefore, it is crucial to take measures to protect yourself from disease. The four most important steps for handling, preparing, and serving food are[1]:

- **Clean.** Wash hands thoroughly. Clean surfaces often and wash utensils after each use. Wash fruits and vegetables (even if you plan to peel them).
- **Separate.** Don't cross-contaminate food during preparation and storage. Use separate cutting boards for produce and for meat, poultry, seafood, and eggs. Store food products separately in the refrigerator.
- **Cook.** Heat food to proper temperatures. Use a food thermometer to check the temperature of food while it is cooking. Keep food hot after it has been cooked.
- **Chill.** Refrigerate any leftovers within two hours. Never thaw or marinate food on the counter.

Know when to keep food and when to throw it out. It can be helpful to check the website http://www.stilltasty.com, which explains how long refrigerated food remains fresh.

Buying Food

It is best to buy your food from reputable grocers with clean, sanitary facilities, that keep products at appropriate temperatures. Consumers should examine food carefully before they purchase it. It is important to look at food in glass jars, check the stems on fresh produce, and avoid bruised fruit. Do not buy canned goods with dents or bulges, which are at risk for contamination with *Clostridium botulinum*. Fresh meat and poultry are usually free from mold, but cured and cooked meats should be examined carefully. Also, avoid torn, crushed, or open food packages, and do not buy food with frost or ice crystals, which indicates that the product has been stored for a long time, or thawed and refrozen. It is also a good idea to keep meat, poultry, seafood, and eggs separate from other items in your shopping cart as you move through the grocery store.

Storing Food

Refrigerate perishable foods quickly; they should not be left out for more than two hours. The refrigerator should be kept at 40°F (or 4°C) or colder, and checked periodically with a thermometer. Store eggs in a carton on a shelf in the refrigerator, and not on the refrigerator door where the temperature is warmest. Wrap meat packages tightly and store them at the bottom of the refrigerator, so juices won't leak out onto other foods. Raw meat, poultry, and seafood should be kept in a refrigerator for only two days. Otherwise, they should be stored in the freezer, which should be kept at 0°F (or −18°C). Store potatoes and onions in a cool, dark place, but not under a sink because leakage from pipes could contaminate them. Empty cans of perishable foods or beverages that have been opened into containers, and promptly place them in a refrigerator. Also, be sure to consume leftovers within three to five days, so mold does not have a chance to grow.

Preparing Food

Wash hands thoroughly with warm, soapy water for at least twenty seconds before preparing food and every time after handling raw foods. Washing hands is important for many reasons. One is to prevent cross-contamination between foods. Also, some pathogens can be passed from person to person, so hand washing can help to prevent this. Fresh fruits and vegetables should also be rinsed thoroughly under running water to clean off pesticide residue[2].

This is particularly important for produce that contains a high level of residue, such as apples, pears, spinach, and potatoes. Washing also removes most dirt and bacteria from the surface of produce.

Other tips to keep foods safe during preparation include defrosting meat, poultry, and seafood in the refrigerator, microwave, or in a water-tight plastic bag submerged in cold water. Never defrost at room temperature because that is an ideal temperature for bacteria to grow. Also, marinate foods in the refrigerator and discard leftover marinade after use because it contains raw juices. Always use clean cutting boards, which should be washed with soap and warm water by hand or in a dishwasher after each use. Another way to sanitize cutting boards is to rinse them with a solution of 5 milliliters (1 teaspoon) chlorine bleach to about 1 liter (1 quart) of water. If possible, use separate cutting boards for fresh produce and for raw meat. Also, wash the top before opening canned foods to prevent dirt from coming into contact with food.

Cooking Food

Cooked food is safe to eat only after it has been heated to an internal temperature that is high enough to kill bacteria. You cannot judge the state of "cooked" by color and texture alone. Instead, use a food thermometer to be sure. The appropriate minimum cooking temperature varies depending on the type of food. Seafood should be cooked to an internal temperature of 145°F, beef, lamb, and pork to 160°F, ground chicken and turkey to 165°F, poultry breasts to 165°F, and whole poultry and thighs to 180°F. When microwaving, rotate the dish and stir contents several times to ensure even cooking.

Serving Food

After food has been cooked, the possibility of bacterial growth increases as the temperature drops. So, food should be kept above the safe temperature of 140°F, using a heat source such as a chafing dish, warming tray, or slow cooker. Cold foods should be kept at 40°F or lower. When serving food, keep it covered to block exposure to any mold spores hanging in the air. Use plastic wrap to cover foods that you want to remain moist, such as fresh fruits, vegetables, and salads. After a meal, do not keep leftovers at room temperature for more than two hours. They should be refrigerated as promptly as possible. It is also helpful to date leftovers, so they can be used within a safe time, which is generally three to five days when stored in a refrigerator.

Notes

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CHAPTER XIX

CHAPTER 19: NUTRITION AND SOCIETY

In this final chapter, we'll discuss several different topics related to the intersection of food and society. From sustainable practices, through historical and cultural influences on food choice, to economic concerns and food security.

Sections:

- 19.1 Sustainability
- 19.2 Historical Perspectives on Food
- 19.3 Comparing Diets
- 19.4 The Politics of Food
- 19.5 Food Costs and Inflation
- 19.6 Food Security
- 19.7 Nutrition and Your Health
- 19.8 Diets around the World
- 19.9 Start Your Sustainable Future Today

Adapted from Jellum, et al. *Principles of Nutrition.* Acknowledgements therein:

- Adapted from: Zimmerman and Snow. "An Introduction to Nutrition" v. 1.0. Accessed on February 22, 2018. https://2012books.lardbucket.org/books/an-introduction-to-nutrition/

Section 19.3 adapted from Fialkowski Revilla, et al., *Human Nutrition.*

19.1 Sustainability

Sustainability is a word that's often talked about in the realm of food and **nutrition**. The term relates to the goal of achieving a world that meets the needs of its present inhabitants while preserving resources for future generations. As awareness about sustainability has increased among the media and the public, both agricultural producers and consumers have made more of an effort to consider how the choices they make today will impact the planet tomorrow.

Figure 19.11 *Raising free-range chickens that feed out in the open is one example of a sustainable agricultural practice. ©Thinkstock*

However, defining sustainability can be difficult because the term means different things to different groups. For most, sustainable agriculture can best be described as an umbrella term that encompasses food production and consumption practices that do not harm the environment, that do support agricultural communities, and that are healthy for the consumer.[1] From factory farms to smaller-scale ranches and granges, sustainable farming practices are being implemented more and more as the long-term viability of the current production system has been called into question.

Yet, the concept of sustainability is not new to agricultural science, practice, or even policy. It has evolved throughout modern history as a way to achieve self-reliance. It is also a vehicle for maintaining rural communities and supporting the concept of conservation and protection of the land.[2] In 1990, the US federal government defined sustainable agriculture in a piece of legislation known as the **Farm Bill**. The practice was described as an integrated system of plant and animal production that satisfies human needs for food, along with fiber for fabric and other uses. The Farm Bill further defines sustainable agriculture as a practice that enhances environmental quality and also the natural resource base upon which the agricultural economy depends. Sustainable agriculture also makes the most efficient use of nonrenewable resources, sustains the economic viability of farm operations, and supports the quality of life for farmers and society as a whole.[3]

In other words, the practice of sustainable agriculture strives to eschew conventional farming methods, including the cultivation of single crops and row crops continuously over many seasons, the dependency on agribusiness, and the rearing of livestock in concentrated, confined systems.[3] Instead, sustainability includes a focus on biodiversity among both crops and livestock; conservation and preservation to replenish the soil, air, and water; animal welfare; and fair treatment and wages for farm workers.[4] Sustainable agriculture also encourages the health of consumers by rejecting extensive use of pesticides and fertilizers and promoting the consumption of organic, locally produced food. Although many farmers and food companies work to implement these practices, some use the idea of sustainability to attract consumers without completely committing to the concept. "Greenwashing" is a derisive term (similar to "whitewashing") for a corporation or industry falsely utilizing a pro-environmental image or message to expand its market base.

Sustainability depends not only on agricultural producers, but also on consumers. The average person can do a number of things to consume a more sustainable diet, from eating less meat to purchasing fruits and vegetables grown on nearby farms. For example, produce sold in the Midwest typically travels an average of more than fifteen hundred miles from farm to supermarket. However, increasing the consumption of more locally-grown produce by 10 percent would save thousands of gallons in fossil fuel each year.[5]

Some consumers are choosing to make smarter nutritional choices, eat healthier foods, and enjoy fresh, locally grown products. They read the labels on products in their local stores, make more home-cooked meals using whole-food ingredients, and pay attention to the decisions that legislators and other officials make regarding food production and consumption. Will you be one of them? How you can adjust your dietary selections to benefit not only your body and mind but also to help sustain the planet for future generations?

Video Link: Green Careers: Sustainable Agriculture

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19.2 Historical Perspectives on Food

Throughout history, our relationship with food has been influenced by changing practices and perspectives. From the invention of agriculture to the birth of refrigeration, technological advances have also affected what we eat and how we feel about our food. Therefore, it can be helpful to examine theories and customs related to diet and nutrition across different civilizations and time periods.

Civilizations and Time Periods

Diet and cuisine have undergone enormous changes from ancient times to today. The basic diet of the ancient era consisted of cereals, legumes, oil, and wine. These staples were supplemented by vegetables and meat or fish, along with other items, such as honey and salt. During the middle ages, poor people consumed meager diets that consisted of small game supplemented with either barley, oat, or rye, while the wealthy had regular access to meat and fish, along with wheat.[1] During the Industrial Revolution, diets became more varied, partly because of the development of refrigeration and other forms of **food preservation**. In the contemporary era, many people have access to a wide variety of food that is grown locally or shipped from far-off places.

Figure 19.21 *Flatbread made from barley or wheat was a staple in the traditional diet during the ancient era. ©Thinkstock*

Hunters and Gatherers

Human beings lived as hunters and gatherers until the invention of agriculture. Following a nomadic lifestyle, early people hunted, fished, and gathered fruit and wild berries, depending on their location and the availability of wild plants and wild game. To aid their constant quest for food, humans developed weapons and tools, including spears, nets, traps, fishing tackle, and the bow and arrow.[1]

The Beginning of Agriculture

About ten thousand years ago, people began to cultivate crops and domesticate livestock in Mesopotamia, an area of the world that is known today as the Middle East. Agriculture flourished in this region due to the fertile floodplain between the Euphrates and Tigris Rivers, and early crops included wheat, barley, and dates. The development of agriculture not only enriched the diet of these early people, it also led to the birth of civilization as farmers began to settle into sizable, stable communities.[2]

One of the most fertile regions of the ancient world was located along the Nile River Valley in ancient Egypt. The rich soil yielded several harvests per year. Common crops were barley, wheat, lentils, peas, and cabbage, along with grapes, which were used to make wine. Even poor Egyptians ate a reasonably healthy diet that included fish, vegetables, and fruit. However, meat was primarily a privilege of the rich. Popular seasonings of this era included salt, pepper, cumin, coriander, sesame, fennel, and dill.[3]

Meals Determined Social Status

In ancient Rome, differences in social standing affected the diet. For people of all socioeconomic classes, breakfast and lunch were typically light meals that were often consumed in taverns and cafes. However, dinners were eaten at home and were taken much more seriously. Wealthy senators and landowners ate meals with multiple courses, including appetizers, entrees, and desserts. Rich Romans also held extravagant dinner parties, where guests dined on exotic foods, such as roasted ostrich or pheasant. In contrast, people of the lower classes ate mostly bread and cereals.[4] The average person ate out of clay dishes, while wealthy people used bronze, gold, or silver.

Social status determined the kinds of food that people consumed in many other parts of the world as well. In ancient China, emperors used their wealth and power to hire the best chefs and acquire delicacies, such as honey, to sweeten food. Dishes of the ancient era included steamed Mandarin fish, rice and wheat noodles, and fried prawns. Imperial cuisine also included improved versions of dishes that were consumed by the common people, such as soups and cereals.[5]

The Medieval Era

The eating habits of most people during the Medieval Era depended mainly on location and financial status. In the feudal system of Europe, the majority of the population could not afford to flavor their food with extravagant spices or sugar. In addition, transporting food was either outrageously expensive or out of the question due to the inability to preserve food for a long period of time. As a result, the common diet consisted of either wheat, meat, or fish, depending on location. The typical diet of the lower classes was based on cereals and grains, porridge, and gruel. These staples were supplemented with seasonal fruits, vegetables, and herbs. Wine, beer, and cider were also common, and were often safer to drink than the un-sanitized, untreated water.

The Crusades

During the Medieval Era, soldiers from Europe waged war over religion in the Middle East in military campaigns that came to be known as the Crusades. Upon their return, the crusaders brought back new foods and spices, exposing Europeans of the middle ages to unusual flavors. Cooking with exotic spices, such as black pepper, saffron, and ginger, became associated with wealth because they were expensive and had to be imported.

Food Preservation in the Past

During the Medieval and Renaissance eras, most meals consisted of locally grown crops because it was extremely difficult to transport food over long distances. This was mostly due to an inability to preserve food for long periods. At that time, food preservation consisted mostly of drying, salting, and smoking. Pickling, which is also known as brining or corning, was another common practice and involved the use of **fermentation** to preserve food.

The Modern Era

The modern era began in North America and Europe with the dawn of the Industrial Age. Before that period, people predominantly lived in agrarian communities. Farming played an important role in the development of the United States and Canada. Almost all areas of the country had agrarian economies dictated by the harvesting seasons. In the 1800s, society began to change as new machines made it easier to cultivate crops, and to package, ship, and store food. The invention of the seed drill, the steel plow, and the reaper helped to speed up planting and harvesting. Also, food could be transported more economically as a result of developments in rail and refrigeration. These and other changes ushered in the modern era and affected the production and consumption of food.

Food Preservation in Modern Times

Technological innovations during the 1800s and 1900s also changed the way we cultivate, prepare, and think about food. The invention and refinement of the refrigerator and freezer made it possible for people to store food for much longer periods. This, in turn, allowed for the transportation of food over greater distances. For example, oranges grown in Florida would still be fresh when they arrived in Seattle.

Prior to refrigeration, people relied on a number of different methods to store and preserve food, such as pickling. Other preservation techniques included using sugar or honey, **canning**, and preparing a confit, which is one of the oldest ways to preserve food and involves salting meat and cooking it in its own fat. To store foods for long periods, people used iceboxes or kept vegetables, such as potatoes, onions, and winter squash, in cellars during the winter months.

The Great Depression

During the Great Depression of the 1930s, the United States faced incredible food shortages and many people went hungry. This was partly because extreme droughts turned parts of the Midwest into a Dust Bowl, where farmers struggled to raise crops. Millions of Americans were unemployed or underemployed and were forced to wait in long breadlines for free food. This was also a period of incredible reforms, as the government worked to provide for and protect the people. Some important changes included subsidies and support for suffering farmers.

World War II

Food shortages also occurred during World War II in the 1940s. At that time, people voluntarily made due with less to ensure that soldiers training and fighting overseas had the supplies they needed. To focus on saving at home, government programs included rationing food (particularly meat, butter, and sugar), while the media encouraged families to plant their own fruits and vegetables in “victory” (backyard) gardens.

Contemporary Life

Today, agriculture remains a large part of the economy in many developing nations. In fact, nearly 50 percent of the world’s labor is employed in agriculture.[2] In the United States however, less than 2 percent of Americans produce food for the rest of the population.[6] Also, most farms are no longer small-scale or family-owned. Large-scale agribusiness is typical for both crop cultivation and livestock rearing, including concentrated animal feeding operations. Conventional farming practices can include abuses to animals and the land. Therefore, more and more consumers have begun to seek out organic and locally grown foods from smaller- scale farms that are less harmful to the environment.

Other changes also affect food production and consumption in the modern era. The invention of the microwave in the 1950s spurred the growth of frozen foods and TV dinners. Appliances such as blenders and food processors, toasters, coffee and espresso machines, deep fryers, and indoor grills have all contributed to the convenience of food preparation and the kinds of meals that people enjoy cooking and eating.

Diet Trends over Time

Today, consumers can choose from a huge variety of dietary choices that were not available in the past. For example, strawberries can be purchased in New York City in wintertime, because they are quickly and easily transported from places where the crop is in season, such as California, Mexico, or South America. In the western world, especially in North America, food products are also relatively cheap. As a result, there is much less disparity between the diets of the lower and upper classes than in the past. It would not be unusual to find the same kind of meat or poultry served for dinner in a wealthy neighborhood as in a poorer community.

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19.3 Comparing Diets

UNIVERSITY OF HAWAIʻI AT MĀNOA FOOD SCIENCE AND HUMAN NUTRITION PROGRAM

Diet Trends and Health

In the past, health was regarded merely as the absence of illness. However, a growing understanding of the complexity and potential of the human condition has prompted a new way of thinking about health. Today, we focus on the idea of wellness, which involves a great deal more than just not being sick. Wellness is a state of optimal well-being that enables an individual to maximize their potential. This concept includes a host of dimensions—physical, mental, emotional, social, environmental, and spiritual—which affect one's quality of life.[1] Striving for wellness begins with an examination of dietary choices.

Dietary Food Trends

Hundreds of years ago, when food was less accessible and daily life required much more physical activity, people worried less about **obesity** and more about simply getting enough to eat. In today's industrialized nations, conveniences have solved some problems and introduced new ones, including the hand-in-hand obesity and diabetes epidemics. Fad diets gained popularity as more North Americans struggled with excess pounds. However, new evidence-based approaches that emphasize more holistic measures are on the rise. These new dietary trends encourage those seeking to lose weight to eat healthy, whole foods first, while adopting a more active lifestyle. These sound practices put dietary choices in the context of wellness and a healthier approach to life.

Functional Foods

Many people seek out foods that provide the greatest health benefits. This trend is giving rise to the idea of **functional foods**, which not only help meet basic nutritional needs but also are reported to fight illness and aging. According to the **Academy of Nutrition and Dietetics** (AND), formerly known as the The American Dietetic Association, functional foods may reduce the risk of disease or promote optimal health. The AND recognizes four types of functional foods. They are: conventional foods, **modified foods**, medical foods, and special dietary use foods.[2]

The first group, conventional foods, represents the simplest form of functional foods. They are whole foods that have not been modified. Examples include whole fruits and vegetables (which are abundant in **phytochemicals** and antioxidants), yogurt and kefir (which contain natural **probiotic** bacteria that can help maintain digestive system health), and moderate amounts of dark chocolate, made with 70% or more cacao (which contains antioxidants).

Modified foods have been fortified, enriched, or enhanced with additional **nutrients** or bioactive compounds. Foods are modified using biotechnology to improve their nutritional value and health attributes. Examples of modified foods include calcium-fortified orange juice, breads enriched with B vitamins, iodized salt, cereals fortified with **vitamins** and **minerals**, margarine enhanced with plant **sterols**, and energy drinks that have been enriched with herbs (ginseng or guarana) or **amino acids** (taurine). It is important to consider that the health claims of some modified foods may be debatable, or entirely fraudulent. Check with a health professional regarding the effects of modified foods on your health.

Medical foods are designed for enteric administration under the guidance of a medical professional. (During enteric administration, food is treated so that it goes through the stomach undigested. Instead, the food is broken down in the intestines only.) Medical foods are created to meet very specific nutritional requirements. Examples of medical foods include liquid formulas for people with kidney disease, liver disease, diabetes, or other health issues. Medical food is also given to comatose patients through a gastronomy tube because they cannot eat by mouth.

Special dietary use foods do not have to be administered under a doctor's care and can be found in a variety of stores. Similar to medical foods, they address special dietary needs and meet the nutritional requirements of certain health conditions. For example, a bottled oral supplement administered under medical supervision is a medical food, but it becomes a special dietary use food when it is sold to retail customers. Examples of special dietary use foods include gluten-free foods, lactose-free dairy products, and formulas and shakes that promote weight loss.

Popular Diets

The concept of functional foods represents initiatives aimed at addressing health problems. Certain diet plans take this concept one step further, by striving to prevent or treat specific conditions. For example, it is widely understood that people with diabetes need to follow a particular diet. Although some of these diet plans may be nutritionally sound, use caution because some diets may be fads or be so extreme that they actually cause health problems.

Before experimenting with a diet, discuss your plans with your doctor or a registered dietitian. Throughout this section, we will discuss some of the more popular diets. Some fall under the category of fad diets, while others are backed by scientific evidence. Those that fall into the latter category provide a good foundation to build a solid regimen for optimal health.

The DASH Diet

We first introduced the DASH diet in chapter 13. We'll revisit it briefly here. The Dietary Approaches to Stop **Hypertension**, or DASH diet, focuses on reducing sodium intake to either 2,300 milligrams per day (as recommended by the **Dietary Guidelines for Americans**) or 1,500 milligrams per day for certain populations. The DASH diet is an evidence-based eating plan that can help reduce high blood pressure. This plan may also decrease the risk of heart attack, stroke, diabetes, **osteoporosis**, and certain cancers.[3]

DASH tips to lower sodium include:

- Using spices instead of salt to add flavor
- Reading sodium content on processed or canned food labels, and choosing low-sodium options

- Removing some sodium from canned foods (such as beans) by rinsing the product before consumption
- Avoiding salt when cooking

DASH dieters are recommended to consume a variety of whole grains and high-fiber fruits and vegetables, and moderate amounts of low-fat dairy products, **lean meats**, and heart-healthy fish. In addition, DASH limits the use of saturated fats to less than 7 percent of total **calories**, and limits the consumption of sweets and alcohol. The DASH diet also calls for consuming less added sugar and drinking fewer sugar-sweetened drinks. It replaces red meat with fish and legumes and calls for increased calcium, magnesium, potassium, and fiber. Also, even though some people on the DASH diet may find it lowers their HDL (good) cholesterol along with their LDL (bad) cholesterol, it still has a positive cumulative effect on heart health.[4]

The Gluten-Free Diet

The gluten-free diet helps people whose bodies cannot tolerate **gluten**, a protein found in wheat, barley, and rye. One of the most important ways to treat this condition is to avoid the problematic foods, which is not easy. Although following a gluten-free diet is challenging, it is prescribed for patients with gluten intolerance and celiac disease, an autoimmune disorder with a genetic link. People who have celiac disease cannot consume gluten products without damaging their intestinal lining. Eating a gluten-free diet means finding replacements for bread, cereal, pasta, and more. It also means emphasizing fresh fruits, vegetables, and other foods without gluten. However, it is important to note that the gluten-free trend has become something of a fad even for those without a gluten intolerance. Celiac disease is a relatively rare condition found in only 1 percent of the population. Therefore, a gluten-free diet should be followed only with a physician's recommendation.

Low-Carb Diets

Low-carb diets, which include the Atkins Diet and the South Beach Diet, focus on limiting carbohydrates—such as grains, fruit, and starchy vegetables—to promote weight loss. The theory behind the low-carb diet is that **insulin** prevents the breakdown of fat by allowing sugar in the form of blood glucose to be used for energy. Proponents of this approach believe that because limiting carbs generally lowers insulin levels, it would then cause the body to burn stored fat instead. They believe this method not only brings about weight loss, but also reduces the risk factors for a number of conditions. However, some studies have shown that people who followed certain low-carb diet plans for two years lost an average of nearly 9 pounds, which is similar to the amount of weight lost on higher carbohydrate diets.[5]

The benefits of this kind of diet include an emphasis on whole, unprocessed foods and a de-emphasis of refined carbohydrates, such as white flour, white bread, and white sugar. However, there are a number of downsides. Typically, the first two weeks allow for only 20 grams of carbs per day, which can be dangerously low. In addition, dieters using the low-carb approach tend to consume twice as many saturated fats as people on a diet high in healthy carbohydrates. Low-carb diets are also associated with a higher energy intake, and the notion that "calories don't count," which is prevalent in this kind of diet, is not supported by scientific evidence.[6]

The Macrobiotic Diet

The macrobiotic diet is part of a health and wellness regimen based in Eastern philosophy. It combines certain tenets of Zen Buddhism with a vegetarian diet and supports a balance of the oppositional forces of yin and yang. Foods are paired based on their so-called yin or yang characteristics. Yin foods are thought to be sweet, cold, and passive, while yang foods are considered to be salty, hot, and aggressive.

Whole grains make up about 50 percent of the calories consumed and are believed to have the best balance of yin and yang. Raw and cooked vegetables comprise about 30 percent of the diet and include kale, cabbage, collards, bok choy, and broccoli on a daily basis, along with mushrooms and celery a few times a week. Bean or vegetable-based soups and broths can make up 5 to 10 percent of daily caloric intake. Additionally, the diet allows small amounts of fish and seafood several times a week, along with a few servings of nuts. The macrobiotic diet prohibits certain foods, such as chocolate, tropical fruits, and animal products, because they are believed to fall on the far end of the yin-yang spectrum, which would make it difficult to achieve a Zen-like balance.

The macrobiotic diet focuses on foods that are low in saturated fats and high in fiber, which can help to lower the risk of cardiovascular disease. Proponents of this diet also believe that it may protect against cancer. However, many nutritionists and healthcare providers express concerns, particularly if the diet is followed strictly. Extreme macrobiotic eating can be low in protein, low in calories, and pose a risk for starvation. In addition, the diet is also very low in essential vitamins and minerals.[7]

The Mediterranean Diet

The traditional Mediterranean diet incorporates many elements of the dietary choices of people living in Greece and southern Italy. The Mediterranean diet focuses on small portions of nutritionally-sound food. This diet features food from plant sources, including vegetables, fruits, whole grains, beans, nuts, seeds, breads and potatoes, and olive oil. It also limits the consumption of processed foods and recommends eating locally grown foods rich in **micronutrients** and antioxidants. Other aspects of this eating plan include consuming fish and poultry at least twice per week, eating red meat only a few times per month, having up to seven eggs per week, and drinking red wine in moderation. Unlike most diets, the Mediterranean diet does not cut fat consumption across the board. Instead, it incorporates low-fat cheese and dairy products, and it substitutes olive oil, canola oil, and other healthy oils for butter and margarine.

More than fifty years of nutritional and **epidemiological** research has shown that people who follow the Mediterranean diet have some of the lowest rates of chronic disease and the highest rates of longevity among the populations of the world. Studies have shown that the Mediterranean diet also helps to decrease excess body weight, blood pressure, blood fats, and blood sugar and insulin levels significantly.[8]

Tools for Change

For six years, researchers from the University of Bordeaux in France followed the dietary habits of more than seven thousand individuals age sixty-five and over. Participants who described greater consumption of extra-virgin olive oil reportedly lowered their risk of suffering a stroke by 41 percent. The study controlled for stroke risk factors, such as smoking, alcohol intake, high blood pressure, and a sedentary lifestyle. To increase the amount of olive oil in your diet, try spreading olive oil instead of butter on your toast, making your own salad dressing using olive oil, vinegar or lemon juice, and herbs, cooking with olive oil exclusively, or simply adding a dose of it to your favorite meal.[9]

The Raw Food Diet

The raw food diet is followed by those who avoid cooking as much as possible in order to take advantage of the full nutrient content of foods. The principle behind raw foodism is that plant foods in their natural state are the most wholesome for the body. The raw food diet is not a weight-loss plan, it is a lifestyle choice. People who practice raw foodism eat only uncooked and unprocessed foods, emphasizing whole fruits and vegetables. Staples of the raw food diet include whole grains, beans, dried fruits, seeds and nuts, seaweed, sprouts, and unprocessed produce. As a result, food preparation mostly involves peeling, chopping, blending, straining, and dehydrating fruits and vegetables.

The positive aspects of this eating method include consuming foods that are high in fiber and nutrients, and low in calories and saturated fat. However, the raw food diet offers little in the way of protein, dairy, or fats, which can cause deficiencies of the vitamins A, D, E, and K. In addition, not all foods are healthier uncooked, such as spinach and tomatoes. Also, cooking eliminates potentially harmful microorganisms that can cause foodborne illnesses. Therefore, people who primarily eat raw foods should thoroughly clean all fruit and vegetables before eating them. Poultry and other meats should always be cooked before eating.[10]

Vegetarian and Vegan Diets

Vegetarian and **vegan** diets have been followed for thousands of years for different reasons, including as part of a spiritual practice, to show respect for living things, for health reasons, or because of environmental concerns. For many people, being a vegetarian is a logical outgrowth of "thinking green." A meat-based food system requires more energy, land, and water resources than a plant-based food system. This may suggest that the plant-based diet is more sustainable than the average meat-based diet in the U.S. By avoiding animal flesh, vegetarians hope to look after their own health and that of the planet at the same time. Broadly speaking, vegetarians eat beans, grains, and fruits and vegetables, and do not eat red meat, poultry, seafood, or any other animal flesh. Some vegetarians, known as lacto vegetarians, will eat dairy products. Others, known as lacto-ovo vegetarians, will eat dairy products and eggs. A vegan diet is the most restrictive vegetarian diet—vegans do not eat dairy, eggs, or other animal products, and some do not eat honey.

Vegetarian diets have a number of benefits. Well-balanced eating plans can lower the risk of a number of chronic conditions, including **heart disease**, diabetes, and obesity. They also help to promote **sustainable agriculture**. However, if a vegetarian does not vary his or her food choices, the diet may be insufficient in calcium, iron, omega-3 fatty acids, zinc, and vitamin B_{12}. Also, if people who follow these diets do not plan out their meals, they may gravitate toward foods high in fats.

Table 19.31 The Pros and Cons of Seven Popular Diets

Diet	Pros	Cons
DASH Diet	• Recommended by the National Heart, Lung, and Blood Institute, the American Heart Association, and many physicians • Helps to lower blood pressure and cholesterol • Reduces risk of heart disease and stroke • Reduces risk of certain cancers • Reduces diabetes risk	• There are very few negative factors associated with the DASH diet • Risk for hyponatremia
Gluten-Free Diet	• Reduces the symptoms of gluten intolerance, such as chronic diarrhea, cramping, constipation, and bloating • Promotes healing of the small intestines for people with celiac disease, preventing malnutrition • May be beneficial for other autoimmune diseases, such as Parkinson's disease, rheumatoid arthritis, and multiple sclerosis	• Risk of folate, iron, thiamin, riboflavin, niacin, and vitamin B6 deficiencies • Special gluten-free products can be hard to find and expensive • Requires constant vigilance and careful food label reading, since gluten is found in many products
Low-Carb Diet	• Restricts refined carbohydrates, such as white flour and white sugar • May temporarily improve blood sugar or blood cholesterol levels	• Not entirely evidence-based • Results in higher fat and protein consumption • Does not meet the RDA for carbohydrates to provide glucose to the brain
Macrobiotic Diet	• Low in saturated fats and high in fiber • Emphasizes whole foods and de-emphasizes processed foods • Rich in phytoestrogens, which may reduce the risk of estrogen-related cancers	• Not entirely evidence-based • Lacks certain vitamins and minerals; supplements are often required • Can result in a very low caloric intake • Lack of energy may result from inadequate protein

Diet	Pros	Cons
Mediterranean Diet	• A reduced risk of cardiovascular disease and mortality • A lower risk of cancer • De-emphasizes processed foods and emphasizes whole foods and healthy fats • Lower sodium intake, due to fewer processed foods • Emphasis on monosaturated fats leads to lower cholesterol • Highlighting fruits and vegetables raises consumption of antioxidants	• Does not specify daily serving amounts • Potential for high fat and high calorie intake as nuts and oils are calorie-dense foods • Drinking one to two glasses of wine per day may not be healthy for those with certain conditions
Raw Food Diet	• Emphasizes whole foods • Focuses on nutritionally-rich foods	• Not entirely evidence-based • Very restrictive and limits protein and healthy fat intake • Could encourage the development of foodborne illness • Extremely difficult to follow • High in fiber which can cause essential nutrient deficiencies
Vegetarianism and Veganism	• May reduce some chronic diseases such as cancer, heart disease, and Type 2 diabetes • May help with weight reduction and weight maintenance	• Guidelines regarding fat and nutrient consumption must be followed • Higher risk for nutrient deficiencies such as protein, iron, zinc, omega-3, vitamin B12 • Consumption of a high fiber diet interferes with mineral and nutrient bioavailability • Vegetarian and vegan protein sources are lower quality with majority missing at least one essential amino acids

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19.4 The Politics of Food

Some people have begun to view their choices regarding diet and nutrition in light of their political views. More and more, consumers weigh their thoughts on the environment and the world, while making decisions about what to purchase in the grocery store. For example, many people choose to eat free-range chickens due to concerns about animal welfare. Others worry about the higher cost of organically produced food or find that those products are not available in their communities. As a result, feelings about food have become a political mine field.

Food Politics

The production and sale of food is an extremely big business and touches people in all industries and walks of life. Food is not only crucial for day-to-day survival, but also strongly affects overall health and well-being, as well as the economy and culture of a region or a country. So, it is no wonder that more and more producers and consumers alike are speaking out about food to ensure that their interests are protected. Food politics can influence many stakeholders and interests, but always involve the production, regulation, inspection, distribution, and/or retail of food.

Stakeholders

Stakeholders in food politics include large and small farmers, along with large and small food companies. Other important stakeholders include restaurants and other food-service providers, food distributors, grocery stores and other retail outlets, consumers, and trade associations.

Anti-hunger advocates, nutrition advocates, and food-industry lobbyists also have important roles to play. Nongovernmental organizations, such as the American Cancer Society and the WHO, also work to promote good health and nutrition. Each group has its own perspective and its own agenda in disputes related to food.

Disputes

Food politics can be influenced by ethical, cultural, medical, and environmental disputes over agricultural methods and regulatory policies. They are also greatly influenced by manufacturing processes, marketing practices, and the pursuit of the highest possible profit margin by food manufacturers and distributers. Common disputes and controversies include the genetic modification of plants, the potential dangers of **food additives**, chemical run-off from large- scale farms, and the reliance on factory-farming practices, such as the use of pesticides in crop cultivation and antibiotics in livestock feed. Additional issues and concerns include the use of sugar, salt, and other potentially unhealthy ingredients, the promotion of fast food and junk food to children, and sanitary standards related to livestock.

The Role of Government

Federal and state policy plays a major role in the politics of food production and distribution. As previously discussed, government agencies regulate the proper processing and preparation of foods, as well as overseeing shipping and storage. They pay particular attention to concerns related to public health. As a result, the enforcement of regulations has been strongly influenced by public concern over food-related events, such as outbreaks of foodborne illnesses.

Food Production, Distribution, and Safety

Many consumers have concerns about safety practices during the production and distribution of food. This is especially critical given recent outbreaks of food-borne illnesses. For example, during fall 2011 in the United States, there was an eruption of the bacteria *Listeria monocytogenes* in cantaloupe. It was one of the deadliest outbreaks in over a decade and resulted in a number of deaths and hospitalizations.[1] In January 2011, the Food Safety Modernization Act was passed to grant more authority to the **FDA** to improve food safety. The FDA and other agencies also address consumer-related concerns about protecting the nation's food supply in the event of a terrorist attack.

Addressing Hunger

Government agencies also play an important role in addressing hunger via federal food-assistance programs. The agencies provide debit cards (formerly distributed in the form of food vouchers or food stamps) to consumers to help them purchase food and they also provide other forms of aid to low-income adults and families who face hunger and nutritional deficits. This topic will be discussed in greater detail later in this chapter.

The Dual Role of the USDA

The **USDA** has a dual role in the advancement of American agribusiness and the promotion of health and nutrition among the public. This can create conflicts of interest, and some question whether the USDA values the interests of the agriculture and food industries over consumer health.

However, there is no question that the USDA makes a great deal of effort to educate the public about diet and nutrition. Working with the US Department of Health and Human Services, the agency codeveloped the *Dietary Guidelines for Americans* to inform consumers about the ways their dietary habits affect their health. The USDA also implements all federal nutrition programs.

The Farm Bill

The Farm Bill (introduced in 1990) is a massive piece of legislation that determines the farm and food policy of the federal government. It addresses policy related to federal food programs and other responsibilities of the USDA. The Farm Bill also covers a wide range of agricultural programs and provisions, including farm subsidies and rural development.

And, it influences international trade, commodity prices, environmental preservation, and food safety.

The massive Farm Bill is updated and renewed every five years. Over the decades, it has expanded to incorporate new issues, such as conservation and bioenergy. The Farm Bill passed in 2008, known as the Food, Conservation, and Energy Act, included new policy on horticulture and livestock provisions. The 2008 bill also differed from previous legislation in terms of the large number and scope of proposals that were raised.[2]

Agricultural Subsidies

The Farm Bill can directly and indirectly have wide-ranging effects. For example, the bill dictates subsidies and other forms of agricultural funding or support. Farmers rely on this kind of support to offset varying crop yields and unfavorable weather conditions. The agricultural industry also depends on the federal government to provide some form of price control to guard against flooding the market and dragging down prices. As an example, major changes in the policy of agricultural subsidies were implemented in the 1970s to increase farm incomes and produce cheaper food. As a result of these policies and subsidies, much more corn was grown, giving rise to high fructose corn syrup as a primary sweetener in a number of products today, since corn syrup is cheaper to produce. It is also sweeter than cane sugar, which encouraged its widespread use.

Historically, Congress has pursued farm support programs to ensure that the US population has continued access to abundant and affordable food. However, some leaders worry about the effectiveness of government programs as well as the cost to taxpayers and consumers. Others question if continued farm support is even needed and wonder if it remains compatible with current economic objectives, domestic policy, trade policy, and regulatory restrictions.[2] For example, federal dairy policies can raise the price of milk and other dairy products, which can detrimentally affect school lunch and food stamp programs. Regarding all of these issues, Congress must heed the demands of its constituents. In the end, it is inevitable that consumers' growing interest in food issues will affect not only the choices they make in the grocery store, but also the decisions they make in the voting booth.

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19.5 Food Costs and Inflation

Statistics show that Americans spend more than $1.5 trillion on food each year at supermarkets, in restaurants, and from other food providers.[1] According to the USDA, a thrifty family of four spends about $540-$620 per month on groceries.[2] A number of factors affect the rising cost of food. They include agricultural production, processing and manufacturing, wholesale distribution, retail distribution, and consumption.

Around the world, commodity prices rose sharply in 2010 as crop production shortfalls led to reduced supplies and a higher volatility in agricultural markets. Other factors that played a role in increasing food prices include a population boom that has drastically increased demand, droughts and other natural disasters that have crippled farmers, and trade policies and practices that are unfair to developing nations.

Rising agricultural commodity prices have led to concerns about food insecurity and hunger. In an agricultural outlook report for 2010–2020, the Secretary-General of the Organization for Economic Co-operation and Development states, "While higher prices are generally good news for farmers, the effect on the poor in developing countries who spend a high proportion of their income on food can be devastating. That is why we are calling on governments to improve information and transparency of both physical and financial markets, encourage investments that increase productivity in developing countries, remove production and trade distorting policies, and assist the vulnerable to better manage risk and uncertainty."[3]

Who Bears the Cost?

The cost of our food is influenced by the policies and practices of farms, food and beverage companies, food wholesalers, food retailers, and food service companies. These costs include the energy required to produce and distribute food products from farm field to supermarket to table. Rising prices also reflect the marketing and advertising of food. All of these factors affect all participants in a food system, but some participants are more affected than others. A 2011 report by the Economic Research Service of the USDA shows the division of the consumer food dollar among various aspects of the American food system. A far greater amount of the money you spend to buy a product goes toward the marketing components than toward the actual farmer.[4]

The Consumer Price Index

The Consumer Price Index (CPI) measures changes in the price level paid for goods and services. This economic indicator is based on the expenditures of the residents of urban areas, including working professionals, the self-employed, the poor, the unemployed, and retired workers, as well as urban wage earners and clerical workers. The CPI has subsidies for many different types of products, including food and beverages. It is a closely-watched statistic that is used in a variety of ways, including measuring inflation and regulating prices.

Implications around the World

Food prices and inflation disproportionately affect people at lower income levels. For the poorest people of the world, increasing prices can raise levels of hunger and starvation. In many developing countries where the cost for staple crops steadily rises, consumers have faced shortages or even the fear of shortages, which can result in hoarding and rioting. This happened in 2007 and 2008 during rice shortages in India and other parts of Asia. Rioters burned hundreds of food ration stores in the Indian region West Bengal. In the West African nation Burkina Faso, food rioters looted stores and burned government buildings as a result of rising prices for food and other necessities.[5] In some poor countries, protests also have been fueled by concerns over corruption, because officials earned fortunes from oil and minerals, while locals struggled to put food on their tables. Bringing down prices would quell protests, but could take a decade or more to accomplish.

The End of the Era of Cheap Food

Concerns about food shortages and rising prices reflect the end of the era of cheap food.

Following World War II, grain prices fell steadily around the world for decades. As farms grew in scale, factory-farm practices, such as the use of synthetic and mined fertilizers and pesticides, increased. Agribusinesses also invested in massive planting and harvesting machines. These practices pushed crop yields up and crop prices down. Food became so inexpensive that we entered what came to be called the "era of cheap food."

However, by 2008, economic experts had declared that the era of cheap food was over. The rapid growth in farm output had slowed to the point that it failed to keep pace with population increases and rising affluence in once-developing nations. Consumption of four staples—wheat, rice, corn, and soybeans—outstripped production and resulted in dramatic stockpile decreases.

The consequence of this imbalance has been huge spikes felt moderately in the West and to a much greater degree in the developing world. As a result, hunger has worsened for tens of millions of poor people around the world.[6]

Two major trends played a part in this shift. First, prosperity in India and China led to increased food consumption in general, but more specifically to increased meat consumption. Increased meat consumption has led to an increased demand for livestock feed, which has contributed to an overall rise in prices. The second trend relates to biofuels, which are made from a wide variety of crops (such as corn and palm nuts), which increasingly are used to make fuel instead of to feed people.

The world population in 2010 was 6.9 billion.[7] It is projected to grow to 9.4 billion by 2050.[8] The rate of increase is particularly high in the developing world, and the increased population, along with poverty and political instability, are helping to foster long-term food insecurity. In the coming decades, farmers will need to greatly increase their output to meet the rising demand, while adapting to any future trends.[9]

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19.6 Food Security

Physiologically, hunger relates to appetite and is the body's response to a need for nourishment. Through stomach discomfort or intestinal rumbling, the body alerts the brain that it requires food. This uneasy sensation is easily addressed with a snack or a full meal. However, the term "hunger" also relates to a weakened condition that is a consequence of a prolonged lack of food. People who suffer from this form of hunger typically experience malnourishment, along with poor growth and development.

Hunger

Adequate food intake that meets nutritional requirements is essential to achieve a healthy, productive lifestyle. However, millions of people in North America, not to mention globally, go hungry and are malnourished each year due to a recurring and involuntary lack of food. The economic crisis of 2008 caused a dramatic increase in hunger across the United States.[1]

Key Hunger Statistics

In 2010, 925 million people around the world were classified as hungry. Although this was a decrease from a historic high of more than one billion people from the previous year, it is still an unbearable number. Every night, millions and millions of people go to sleep hungry due to a lack of the money or resources needed to acquire an adequate amount of food. This graph shows the division of hungry people around the globe.

Key Hunger Terms

A number of terms are used to categorize and classify hunger. Two key terms, food security and food insecurity, focus on status and affect hunger statistics. Another term, **malnutrition**, refers to the deficiencies that a hungry person experiences.

Food Security

Most American households are considered to be food secure, which means they have adequate access to food and consume enough nutrients to achieve a healthy lifestyle. However, a minority of US households will experience food insecurity at certain points during the year, which means their access to food is limited due to a lack of money or other resources. This graphic shows the percentage of food-secure and food-insecure households in the United States during the year 2010.

Food Insecurity

Food insecurity is defined as not having adequate access to food that meets nutritional needs. According to the USDA, about 48.8 million people live in food-insecure households and have reported multiple indications of food access problems. About sixteen million of those have "very low food security," which means one or more people in the household were hungry at some point over the course of a year due to the inability to afford enough food. The difference between low and very low food security is that members of low insecurity households have reported problems of food access, but have reported only a few instances of reduced food intake, if any. African American and Hispanic households experience food insecurity at much higher rates than the national average.[2]

Households with limited resources employ a variety of methods to increase their access to adequate food. Some families purchase junk food and fast food—cheaper options that are also very unhealthy. Other families who struggle with food security supplement the groceries they purchase by participating in government assistance programs. They may also obtain food from emergency providers, such as food banks and soup kitchens in their communities.

Malnutrition

A person living in a food-insecure household may suffer from malnutrition, which results from a failure to meet nutrient requirements. This can occur as a result of consuming too little food or not enough key nutrients. There are two basic types of malnutrition. The first is **macronutrient** deficiency and relates to the lack of adequate protein, which is required for cell growth, maintenance, and repair. The second type of malnutrition is micronutrient deficiency and relates to inadequate vitamin and mineral intake.[3] Even people who are overweight or obese can suffer from this kind of malnutrition if they eat foods that do not meet all of their nutritional needs.

At-Risk Groups

Worldwide, three main groups are most at risk of hunger: the rural poor in developing nations who also lack access to electricity and safe drinking water, the urban poor who live in expanding cities and lack the means to buy food, and victims of earthquakes, hurricanes, and other natural and man-made catastrophes.[4] In the United States, there are additional subgroups that are at risk and are more likely than others to face hunger and malnutrition. They include low-income families and the working poor, who are employed but have incomes below the federal poverty level.

Senior citizens are also a major at-risk group. Many elderly people are frail and isolated, which affects their ability to meet their dietary requirements. In addition, many also have low incomes, limited resources, and difficulty purchasing or preparing food due to health issues or poor mobility. As a result, more than six million senior citizens in the United States face the threat of hunger.[5]

The Homeless

One of the groups that struggles with hunger are the millions of homeless people across North America. According to a recent study by the US Conference of Mayors, the majority of reporting cities saw an increase in the number of homeless families.[6] Hunger and homelessness often go hand-in-hand as homeless families and adults turn to soup kitchens or food pantries or resort to begging for food.

Children

Rising hunger rates in the United States particularly affect children. Nearly one out of four children, or 21.6 percent of all American children, lives in a food-insecure household and spends at least part of the year hungry.[4] Hunger delays their growth and development and affects their educational progress because it is more difficult for hungry or malnourished students to concentrate in school. In addition, children who are undernourished are more susceptible to contracting diseases, such as measles and pneumonia.[3]

Video Link: Going Hungry in America

Government Programs

The federal government has established a number of programs that work to alleviate hunger and ensure that many low-income families receive the nutrition they require to live a healthy life. A number of programs were strengthened by the passage of the Healthy, Hunger-Free Kids Act of 2010. This legislation authorized funding and set the policy for several key core programs that provide a safety net for food-insecure children across the United States.

The Federal Poverty Level

The federal poverty level (FPL) is used to determine eligibility for food-assistance programs. This monetary figure is the minimum amount that a family would need to acquire shelter, food, clothing, and other necessities. It is calculated based on family size and is adjusted for annual inflation. Although many people who fall below the FPL are unemployed, the working poor can qualify for food programs and other forms of public assistance if their income is less than a certain percentage of the federal poverty level, along with other qualifications.

USDA Food Assistance Programs

Government food and nutrition assistance programs that are organized and operated by the USDA work to increase food security. They provide low-income households with access to food, the tools for consuming a healthy diet, and education about nutrition. The USDA monitors the extent and severity of food insecurity via an annual survey. This contributes to the efficiency of food assistance programs as well as the effectiveness of private charities and other initiatives aimed at reducing food insecurity.[2]

The Supplemental Nutrition Assistance Program

Formerly known as the Food Stamp Program, the Supplemental Nutrition Assistance Program (SNAP) provides monthly benefits for low-income households to purchase approved food items at authorized stores. Clients qualify for the program based on available household income, assets, and certain basic expenses. In an average month, SNAP provides benefits to more than forty million people in the United States.[2]

The program provides Electronic Benefit Transfers (EBT) which work similarly to a debit card. Clients receive a card with a certain allocation of money for each month that can be used only for food. In 2010, the average benefit was about $134 per person, per month and total federal expenditures for the program were $68.2 billion.[2]

The Special, Supplemental Program for Women, Infants, and Children

The Special, Supplemental Program for Women, Infants and Children (WIC) provides food packages to pregnant and breastfeeding women, as well as to infants and children up to age five, to promote adequate intake for healthy growth and development. Most state WIC programs provide vouchers that participants use to acquire supplemental packages at authorized stores. In 2018, WIC served approximately 9.2 million participants per month[7] at an average monthly cost of about forty-two dollars per person.[8]

The National School Lunch Program

The **National School Lunch Program (NSLP)** and School Breakfast Program (SBP) ensure that children in elementary and middle schools receive at least one healthy meal each school day, or two if both the NSLP and SBP are provided. According to the USDA, these programs operate in over 101,000 public and nonprofit private schools and residential child-care institutions.[9]

In 2016, 30.4 million children participated in the National School Lunch Program[10] and approximately 14.5 million children participated in the School Breakfast Program[11].

Other Food-Assistance Programs for Children

Other government programs provide meals for children after school hours and during summer breaks. The Child and Adult Care Food Program (CACFP) offers meals and snacks at child-care centers, daycare homes, and after-school programs. Through CACFP, more than 3.2 million children and 112,000 adults receive nutritious meals and snacks each day.[12] The Summer Food Service Program provides meals to children during summer break. Sponsors include day camps and other recreation programs where at least half of the attendees live in households with incomes below the federal poverty level.[13] These and other programs help to fill in the gaps during the typical day of a food-insecure child.

The Head Start Program

Head Start is a health and development program for children aged three to five, from low- income families. The philosophy behind the organization is that early intervention can help address the educational, social, and nutritional deficiencies that children from lower-income families often experience. Launched in 1965, it is one of the longestrunning, poverty-related programs in the United States. Today, Head Start programs include education, meals, snacks, and access to other social services and health guidance.[14]

Other Forms of Assistance

Other forms of assistance include locally-operated charitable organizations, such as food banks and food pantries, which acquire food from local manufacturers, retailers, farmers, and community members to give to low-income families. Neighborhood soup kitchens provide meals to the homeless and other people in need. These and other organizations are run by nonprofit groups, as well as religious institutions, to provide an additional safety net for those in need of food.

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19.7 Nutrition and Your Health

The adage, "you are what you eat," seems to be more true today than ever. In recent years, consumers have become more conscientious about the decisions they make in the supermarket. Organically grown food is the fastest growing segment of the food industry. Also, farmers' markets and chains that are health-food-oriented are thriving in many parts of North America. Shoppers have begun to pay more attention to the effect of food on their health and well-being. That includes not only the kinds of foods that they purchase, but also the manner in which meals are cooked and consumed. The preparation of food can greatly affect its nutritional value. Also, studies have shown that eating at a table with family members or friends can promote both health and happiness.

Family Meals

In the past, families routinely sat down together to eat dinner. But in recent decades, that comfortable tradition has fallen by the wayside. In 1900, two percent of meals were eaten outside of the home. By 2010, that figure had risen to 50 percent.[1] Today, family members often go their own way at mealtimes and when they do sit down together, about three times a week, the meal often lasts less than twenty minutes and is spent eating a microwaved meal in front of a television.

Figure 19.71 *Home-cooked meals provide parents an opportunity to teach their children about nutrition. ©Thinkstock*

However, recent studies have shown that home-cooked, family meals really matter. Family meals usually lead to the consumption of healthy food packed with nutrition, rather than an intake of **empty calories**. Other benefits include strengthening familial bonds, improving family communication, and helping young children learn table manners. Increased frequency of family meals has also been associated with certain developmental assets, such as support, boundaries and expectations, commitment to learning, positive values, and social competency.[2]

Home-prepared meals provide an opportunity for more balanced and better-portioned meals with fewer **calories**, sodium, and less saturated fat. When families prepare food together, parents or caregivers can also use the time to teach children about the ways their dietary selections can affect their health.

The Adolescent Diet

Teenagers' dietary choices are influenced by their family's economic status, the availability of food inside and outside the home, and established traditions. Studies have found links between the prevalence of family meals during adolescence and the establishment of healthy dietary behaviors by young adulthood. Yet, many of today's teenagers make food selections on their own, which often means eating junk food or fast food on the go.

However, adolescents who regularly consume family meals or have done so in the past are more likely to eat breakfast and to eat more fruits and vegetables. Research has shown that adolescents who have regular meals with their parents are 42 percent less likely to drink alcohol, 50 percent less likely to smoke cigarettes, and 66 percent less likely to use marijuana. Regular family dinners also help protect teens from **bulimia**, **anorexia**, and diet pills. In addition, the frequency of family meals was inversely related to lower academic scores and incidents of depression or suicide.[1]

Sustainable Eating

As discussed at the beginning of this chapter, sustainable agricultural practices provide healthy, nutritious food for the consumers of today, while preserving natural resources for the consumers of tomorrow. **Sustainability** not only has economic and environmental benefits, but also personal benefits, including reduced exposure to pesticides, antibiotics, and growth hormones. Sustainable eaters do all of the following:

- **Consume less processed food.** People who eat sustainably focus on whole foods that are high in nutritive value, rather than heavily processed foods with lots of additives.
- **Eat more home-cooked meals.** Sustainable eaters go out to restaurants less often, and when they do, they dine at establishments that provide dishes made from whole-food ingredients.
- **Consume a plant-based diet.** Research has shown that a plant-based diet, focused on whole grains, vegetables, fruits, and legumes, greatly reduces the risk of heart disease.
- **Buy organic food products.** Organically produced foods have been cultivated or raised without synthetic pesticides, antibiotics, or genetic engineering. Certified

organic foods can be identified by the USDA's stamp.
- **Buy locally grown foods.** Buying locally benefits the environment by reducing the fossil fuels needed to transport food from faraway places. Also, farmers keep eighty to ninety cents for every dollar spent at a farmer's market.

Disease Prevention and Management

Eating fresh, healthy foods not only stimulates your taste buds, but also can improve your quality of life and help you to live longer. As discussed, food fuels your body and helps you to maintain a healthy weight. Nutrition also contributes to longevity and plays an important role in preventing a number of diseases and disorders, from obesity to cardiovascular disease. Some dietary changes can also help to manage certain chronic conditions, including high blood pressure and diabetes. A doctor or a nutritionist can provide guidance to determine the dietary changes needed to ensure and maintain your health.

Heart Health

According to the WHO, cardiovascular disease is the leading cause of death on the planet.[3] However, a healthy diet can go a long way toward preventing a number of conditions that contribute to cardiovascular malfunction, including high levels of blood cholesterol and narrowed arteries. As discussed in this text, it is extremely helpful to reduce the intake of trans- fat, saturated fat, and sodium. This can considerably lower the risk of cardiovascular disease, or manage further incidents and artery blockages in current heart patients. It is also beneficial to eat a diet high in fiber and to include more omega-3 fatty acids, such as the kind found in mackerel, salmon, and other oily fish.

High Blood Pressure

Blood pressure is the force of blood pumping through the arteries. When pressure levels become too high, it results in a condition known as hypertension, which is asymptomatic but can lead to a number of other problems, including heart attacks, heart failure, kidney failure, and strokes. For people with high blood pressure, it can be beneficial to follow the same recommendations as those for heart patients. First of all, it is crucial to reduce the intake of sodium to prevent pressure levels from continuing to rise. It can also be helpful to increase potassium intake. However, patients should check with a doctor or **dietitian** first, especially if there are kidney disease concerns.

Diabetes

The rising rates of diabetes have triggered a health crisis in the United States and around the world. In diabetics, the levels of blood glucose, or blood sugar, are too high because of the body's inability to produce insulin or to use it effectively. There are two types of this disease. Although the causes of Type 1 diabetes are not completely understood, it is known that obesity and genetics are major factors for Type 2.

Nutrition plays a role in lowering the risk of Type 2 diabetes or managing either form of the disease. However, it is a myth that there is one diabetes diet that every patient should follow. Instead, diabetics should keep track of the foods they consume that contain **carbohydrates** to manage and control blood-glucose levels. Also, a dietitian can help patients create a specific meal plan that fits their preferences, lifestyle, and health goals.

Kidney Disease

Chronic kidney failure is the gradual loss of kidney function and can cause dangerous levels of fluid and waste to build up in the body. Nutrition is very important in managing end-stage renal disease, and a patient with this condition should discuss a meal plan with a dietitian and physician. Certain macro- and micronutrients will need to be monitored closely, including protein, potassium, sodium, and phosphorus. Kidney patients must also keep track of their caloric intake and dietitians may recommend consuming more **fast-releasing carbohydrates** and low-saturated fats to boost the number of calories consumed each day.

Cancer

Certain cancers are linked to being overweight or obese. Additionally, some foods are related to either an increased or decreased risk for certain cancers. Foods linked to decreased cancer risk include whole grains, high-fiber foods, fruits, and vegetables. Foods linked to increased cancer risk include processed meats and excess alcohol.

Digestive Disorders

Digestive disorders can include constipation, heartburn or gastroesophageal reflux disease, **inflammatory bowel disease**, including Crohn's and **ulcerative colitis**, and **irritable bowel syndrome**. These disorders should be addressed with a physician. However, for many of them, diet can play an important role in prevention and management. For example, getting enough fiber and fluids in your diet and being active can help to alleviate constipation.

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19.8 Diets around the World

In the past, people's culture and location determined the foods they ate and the manner in which they prepared their meals. For example, in the Middle East, wheat was a staple grain and was used to make flatbread and porridge, while halfway around the world in Mesoamerica, maize was the staple crop and was used to make tortillas and tamales. Today, most people have access to a wide variety of food and can prepare them any way they choose. However, customs and traditions still strongly influence diet and cuisine in most areas of the world.

Comparing Diets

There are a multitude of diets across the globe, in all regions and cultures. Each is influenced by the traditions of the past, along with the produce and livestock available. Local tastes, agricultural economics, and incomes still have a profound effect on what many people eat around the world. In this section, you will read a few examples of cuisines in different countries and regions, demonstrating differences in preferences. We will also compare common dietary choices in each region for a key meal—breakfast.

North America

The people of the United States and Canada consume a wide variety of food. Throughout both countries, people enjoy eating all kinds of cuisine from barbecue, pizza, peanut butter sandwiches, and pie to sushi, tacos, chow Mein, and roti (an Indian flatbread). This is partly due to the influence of immigration. As people immigrated to North America, they brought their dietary differences with them. In the 1800s, for example, Italian immigrants continued to cook spaghetti, pesto, and other cultural dishes after arriving in the United States. Today, Italian cuisine is enjoyed by many Americans from all backgrounds.

The variety of North American cuisine has also been impacted by regional variations. For example, fried chicken, cornbread, and sweet tea are popular in the southern states, while clam chowder, lobster rolls, and apple cider are enjoyed in New England. Also, as more people seek to support sustainable agriculture, locally grown crops and whole-food cooking practices often factor into what Americans eat and how they eat it.

Breakfast in North America

Meals can vary widely from one region of the world to another. Therefore, it can be interesting and informative to compare the choices made for a particular meal around the globe.

Throughout this section, we will explore the kinds of foods that people consume as they begin their day. Breakfast is a vital meal in any part of the world because it breaks the long overnight fast. An adequate breakfast also provides fuel for the first part of the day and helps improve concentration and energy levels.

Let's begin with breakfast in North America. On weekdays, North Americans often eat breakfast in a hurry or on the go. Therefore, many people choose breakfast foods that are quick and easy to prepare or can be eaten during the trip to school or the office. As a result, breakfast cereals with milk are extremely popular, and also oatmeal, toast, or bagels. However, on the weekends, some people spend a longer time enjoying a hearty breakfast or going out for brunch. Typical choices emphasize hot foods and include egg dishes, such as omelets and scrambled or fried eggs, along with pancakes, waffles, french toast, bacon or sausage, and orange juice, coffee, or tea to drink.

Central and South America

Both Central America and South America feature cuisines with rich Latin flavors. In addition, rice and corn are staples in both and form the basis for many dishes. Both regions are also affected by the mixture of influences from the native populations and the cultural traditions brought by Spanish and Portuguese immigrants during the 1600s and beyond.

South America has a diverse population, which is reflected in dietary choices across the continent. The northwestern region boasts some of the most exotic food in Latin America. In northeastern South America, many dishes feature a contrast of sweet and salty tastes, including raisins, prunes, capers, and olives. Also, rice grown in the area and seafood off the coast are key ingredients in South American-style paella. The north central part of the continent reflects a Spanish influence. Many of the dominant spices—cumin, oregano, cinnamon, and anise—came from Spain, along with orange and lime juices, wine, and olive oil. The south is cattle country and the locals enjoy grass-fed beef cooked in the form of asados, which are large cuts roasted in a campfire. Another popular meat dish is parrilladas, which are thick steaks grilled over oak.[1]

From Mexico in the North to Panama in the South, Central American cuisine features some of the world's favorite foods, including rice, beans, corn, peppers, and tropical fruits. This area combines a variety of culinary traditions derived from the native Maya and Aztec populations, arrivals from Spain, and African and Latin-influenced neighbors along the Caribbean. In this region of the world, tamales are common. Spicy seasonings, including hot chili peppers, are also very popular.

Typical Southern and Central American Foods

Typical foods in South and Central America include quinoa, which is a grain-like crop that is cultivated for its edible seeds. Quinoa has a high protein and fiber content, is gluten-free, and is particularly tasty cooked in pilafs. Another popular grain product is the tortilla, which is a flatbread made from wheat or corn. Tortillas are used to make a number of dishes, including burritos, enchiladas, and tacos. Fruits and vegetables that are common in Mexico, Central America, and South America include corn, avocados, yucca, peppers, potatoes, mangoes, and papayas. Rice, beans, and a soft cheese known as queso fresco are common to the cuisine in this area of the world as well.

Figure 19.81 *Tamales, which are popular in Mexico and parts of Central and South America, are made from a shell called a masa that is stuffed with meat or vegetables and steamed or boiled in a wrapper of dried corn leaves. The wrapping is discarded prior to eating. ©Thinkstock*

Breakfast in Central America

In this region, the first meal of the day commonly includes huevos rancheros (fried eggs served over a tortilla and topped with tomato sauce). Other popular breakfast dishes include pan dulce (a sweetened bread), along with fried plantains, and a spicy sausage called chorizo. The typical beverage is coffee, which is available in many forms, including café con leche (which is sweetened with lots of milk) and café de olla (with cinnamon and brown sugar). Hot chocolate is also popular and tends to be thick, rich, and flavored with spices such as cinnamon or achiote. In the Yucatan region, huevos motulenos are prepared by spreading refried beans onto fresh tortillas with fried eggs, peas, chopped ham, and cheese.

Europe

European cuisine is extremely diverse. The diet in Great Britain is different from what people typically consume in Germany, for example. However, across the continent, meat dishes are prominent, along with an emphasis on sauces. Potatoes, wheat, and dairy products are also staples of the European diet.

The nations along the Mediterranean Sea are particularly renowned for their flavorful food. This part of the world boasts a number of famous dishes associated with their countries of origin. They include Italy's pasta, France's coq au vin, and Spain's paella.

Italy

Although Italy is a relatively small nation, the difference in cuisine from one region to another can be great. For example, the people of northern Italy tend to rely on dairy products such as butter, cream, and cheeses made from cow's milk, because the land is flatter and better suited to raising cattle. In southern Italy, there is greater reliance on olive oil than butter, and cheeses are more likely to be made from sheep's milk.[2] However, there are a number of common ingredients and dishes across the country. Italian cuisine includes a variety of pasta, such as spaghetti, linguine, penne, and ravioli. Other well-known dishes are pizza, risotto, and polenta. Italians are also known for cooking with certain spices, including garlic, oregano, and basil.

France

For centuries, the French have been famous for their rich, extravagant cuisine. Butter, olive oil, pork fat, goose fat, and duck fat are all key ingredients. Common French dishes include quiche, fondue, baguettes, and also creams and tarts. Frites, or French fries, are cut in different shapes and fried in different fats, depending on the region. Fresh-baked bread is also found across the nation from the skinny baguettes of Paris to the sourdough breads in other parts of the country.

Every region of France seems to have its version of coq au vin (braised chicken most often cooked with garlic, mushrooms, and pork fat in wine). For instance, in the northeast, the dish is prepared a la biere (in beer). In Normandy in the northwest, coq au vin is cooked au cidre (in apple cider).[3]

Spain

One of the most popular Spanish dishes is paella, a gumbo of rice, seafood, green vegetables, beans, and various meats. The ingredients can vary wildly from one region to another, but rice is always the staple of the dish. Spain is also renowned for its tapas, which are appetizers or snacks. In restaurants that specialize in preparing and serving tapas, diners often order a number of different dishes from a lengthy menu and combine them to make a full meal.

Cooks in Spain rely on a variety of olive oils known for their flavors, ranging from smooth and subtle to fruity and robust. Spanish cuisine combines Roman, North African, and New World flavors. Key ingredients include rice, paprika, saffron, chorizo, and citrus fruits.[4]

Video Link: The Mediterranean Diet

Breakfast in Europe

In some countries, such as France, Italy, and Belgium, coffee and bread are common breakfast foods. However, the people of Great Britain and Ireland tend to enjoy a bigger breakfast with oatmeal or cold cereal, along with meats like bacon and sausage, plus eggs and toast. Tea is also popular in this area, not only for breakfast, but throughout the day. The continental-style breakfast is most commonly associated with France and includes fresh-baked croissants, toast, or a rich French pastry called brioche, along with a hot cup of tea, coffee, or café au lait.

Africa

The continent of Africa is home to many different countries and cultural groups. This diversity is reflected in the cuisine and dietary choices of the African people. Traditionally, various African cuisines combine locally grown cereals and grains, with fruits and vegetables. In some regions, dairy products dominate, while in others meat and poultry form the basis of many dishes.

Ethiopia

Ethiopia, located along the Horn of Africa, is one of the few African countries never colonized by a foreign nation prior to the modern era. So, outside influences on the culture were limited. Religious influences from Jewish, Islamic, and Catholic traditions played a larger role on the shaping of Ethiopian cuisine, because of the need to adhere to different dietary restrictions. For example, approximately half of Ethiopians are Muslim and must abstain from eating pork or using spices and nuts to flavor dishes. Ethiopia is also known for dishes that use local herbs and spices, including fenugreek, cumin, cardamom, coriander, saffron, and mustard. Many dishes also reflect a history of vegetarian cooking since meat was not always readily available.[5]

In addition, Ethiopians use their hands to eat. First, diners tear off pieces of injera, a spongy, tangy flatbread made from teff flour. Then, they use the pieces as utensils to scoop up vegetables, legumes, and meats from a communal plate.[6] Teff is a grass that grows in the highlands of Ethiopia and is a staple of the diet.

Central and West Africa

Stretching from mountains in the north to the Congo River, Central Africa primarily features traditional cuisine. Meals are focused on certain staples, including cassava, which is a mashed root vegetable, and also plantains, peanuts, and chili peppers. In West Africa, which includes the Sahara Desert and Atlantic coast, the cuisine features dishes made from tomatoes, onions, chili peppers, and palm nut oil. Popular dishes in both regions include stews and porridges, such as ground nut stew made from peanuts, and also fufu, a paste made from cassava or maize.

Breakfast in Africa

African breakfast choices are strongly influenced by the colonial heritage of a region. The people of West Africa typically enjoy the French continental-style breakfast. However, in the eastern and southern parts of the continent, the traditional English breakfast is more common. In North Africa, breakfast is likely to include tea or coffee, with breads made from sorghum or millet. In East and West Africa, a common breakfast dish is uji, a thick porridge made from cassava, millet, rice, or corn. Kitoza is a delicacy made from dried strips of beef that are eaten with porridge in Madagascar. In Algeria, French bread, jam, and coffee is a typical breakfast.

The people of Cameroon eat beignets, which is a doughnut eaten with beans or dipped in a sticky, sugary liquid called bouilli.

Asia

Asia is a massive continent that encompasses the countries of the Middle East, parts of Russia, and the island nations of the southeast. Due to this diversity, Asian cuisine can be broken down into several regional styles, including South Asia, which is represented for our purposes here by India, and East Asia which is represented for our purposes by China, Korea, and Japan. Even with this variety, the Asian nations have some dietary choices in common. For example, rice is a staple used in many dishes across the continent.

India

In India, there is much variety between the different provinces. The nation's many kinds of regional cuisines can date back thousands of years and are influenced by geography, food availability, economics, and local customs. However, vegetarian diets are common across the nation for religious reasons, among others. As a result, Indian dishes are often based on rice, lentils, and vegetables, rather than meat or poultry. Indian cooking also features spicy seasonings, including curries, mustard oil, cumin, chili pepper, garlic, ginger, and garam masala, which is a blend of several spices.[7] India is also known for its breads, including the flatbreads roti and chapati. Dishes that are popular not only in India but around the world include samosa, a potato-stuffed pastry; shahi paneer, a creamy curry dish made out of soft cheese and tomato sauce; and chana masala, chickpeas in curry sauce.[8]

China

China has the world's most sizable population. As a result, there are many different culinary traditions across this vast country, which is usually divided into eight distinct cuisine regions. For example, Cantonese cuisine, which is also known as Guangdong, features light, mellow dishes that are often made with sauces, including sweet-and-sour sauce and oyster sauce.

Cantonese-style cuisine has been popularized in Chinese restaurants around the world. Another cuisine is known as Zhejiang, which is often shortened to Zhe, and originates from a province in southern China. It features dishes made from seafood, freshwater fish, and bamboo shoots.[9]

Key ingredients that are used in several, but not all, of the different regions include rice, tofu, ginger, and garlic. Tea is also a popular choice in most parts of the country.

Chinese use chopsticks as utensils. These small tapered sticks can be made from a variety of materials, including wood, plastic, bamboo, metal, bone, and ivory. Both chopsticks are held in one hand, between the thumb and fingers, and are used to pick up food.

Korea

Korean cuisine is primarily centered on rice, vegetables, and meat. Commonly-used ingredients include sesame oil, soy sauce, bean paste, garlic, ginger, and red pepper. Most meals feature a number of side dishes, along with a bowl of steam-cooked, short grain rice. Kimchi, a fermented cabbage dish, is the most common side dish served in Korea and is consumed at almost every meal. Another signature dish, bibimbap, is a bowl of white rice topped with sautéed vegetables and chili pepper paste and can include egg or sliced meat. Bulgogi consists of marinated, barbecued beef.[10]

Japan

As in other parts of Asia, rice is a staple in Japan, along with seafood, which is plentiful on this island nation. Other commonly-used ingredients include noodles, teriyaki sauce, dried seaweed, mushrooms and other vegetables, meat, and miso, which is soybean paste. Some favorite foods include the raw fish dishes sashimi and sushi, which are not only popular in Japan, but are also around the world. Typical beverages include green tea and also sake, which is a wine made of fermented rice.[11]

The traditional table setting in Japan includes placing a bowl of rice on the left and a bowl of miso soup on the right side. Behind the rice and the soup are three flat plates which hold the accompanying side dishes. Similar to China, chopsticks are used in Japan and are generally placed at the front of the table setting. At school or work, many Japanese people eat out of a bento lunch box, which is a single-portion takeout or home-cooked meal. Bento boxes typically include rice, fish or meat, and cooked or pickled vegetables.

The Middle East

Middle Eastern cuisine encompasses a number of different cooking styles from Asian countries along the Mediterranean, as well as from North African nations, such as Egypt and Libya. In this part of the world, lamb is the most commonly consumed meat and is prepared in a number of ways, including as a shish kebab, in a stew, or spit-roasted. However, kosher beef, kosher poultry, and fish are eaten as well. Other staples include the fruits and vegetables that grow in the hills of many Middle Eastern countries, such as dates, olives, figs, apricots, cucumber, cabbage, potatoes, and eggplant. Common grains include couscous, millet, rice, and bulghur.

Popular dishes include Syrian baba ganoush, which is pureed eggplant, and kibbeh, or lamb with bulghur wheat, from Lebanon.[12] A flatbread called pita served with hummus, or pureed chickpeas, is another popular dish in this region of the world.

Most people who reside in the Arab countries of the Middle East are Muslim, which can affect their diet. Many Muslims do not consume alcohol or pork. They also observe certain diet- related religious traditions, such as a daytime fast during the month of Ramadan. Other residents of the Middle East include Jews and Christians, and their traditions also affect what foods they eat and how they prepare it. For example, many Jews in Israel keep kosher and follow a set of dietary laws that impact food choices, storage, and preparation.

Breakfast in Asia

To continue the comparison of breakfast around the world, let's examine the first meal of the day in many parts of Asia. In India, the first meal of the day commonly includes eggs scrambled with spices, potatoes, and onions, as well as fresh fruit and yogurt. Breakfast in China often consists of rice complemented by vegetables, meat, or fish. In Korea, a traditional breakfast would include soup made of either beef ribs or pork intestines, a selection of bread and pastries, rice, and kimchi, which is believed to promote intestinal health. Breakfast in Japan does not greatly differ from any other meal. It typically consists of a bowl of steamed white rice, a small piece of fish, a bowl of miso soup with tofu, vegetables, green tea, and occasionally pickled plums called umeboshi. Hot bowls of noodles in broth topped with pork slices, scallions, and bamboo shoots are also common.

Congee is a common breakfast food across Asia. This dish is a porridge made of rice that is consumed in a number of Asian countries, including Vietnam, Thailand, Burma, and Bangladesh. Congee can be prepared both savory and sweet and contain a variety of ingredients, usually meats, vegetables, and herbs. It can be eaten alone or served as a side dish.

The Diversity of Palates and Habits

Around the globe, people enjoy different foods and different flavors. In some cultures, the main dishes are meat-based, while others focus on plant-based meals. You can also find different staples in different regions of the world, including rice, potatoes, pasta, corn, beans, root vegetables, and many kinds of grains. Different flavors are also popular on different parts of the planet, from sweet to salty to sour to spicy.

Figure 19.82 *In the different regions of China, congee is prepared with various types of rice, which results in different consistencies. ©Thinkstock*

Food Availability

People tend to eat what grows or lives nearby. For example, people in coastal areas tend to consume more seafood, while those in inland areas tend to structure their diet around locally- grown crops, such as potatoes or wheat. In many developing countries, a large part of the diet is composed of cereal grains, starchy roots, and legumes. However, a number of common staples are consumed worldwide, including rice, corn, wheat, potatoes, cassava, and beans.

Income and Consumption

In addition to regional dissimilarities in diets, income also plays a major role in what foods people eat and how they prepare them. The average global calorie consumption has increased to record levels in recent years. This is a consequence of rising incomes, which have allowed consumers in many regions to expand both the variety and the quantity of food they eat.

Among developing countries, the daily intake of calories per person rose by nearly 25 percent from the early 1970s to the mid-1990s.[13] People in the western world were able to increase their consumption of meat and poultry, fruits and vegetables, and fats and oils. However, those gains were minimal in the poorest countries, where many continue to struggle with hunger and a limited diet.[14]

Different Ways of Eating

People from different parts of the world consume their food in different ways and what is common in one country may be considered impolite in another. For example, in some areas people eat with their fingers, while in others using a fork is much more acceptable. In some regions of the world, people slurp their soup, while in others they quietly sip it. In some places, diners eat off of individual plates, while in others people sit at a table with a large communal plate from which everyone eats.

No matter where you travel, you will find that food production, purchase, and preparation affect all facets of life, from health and economics to religion and culture. Therefore, it is vital for people from all walks of life to consider the choices they make regarding food, and how those decisions affect not only their bodies, but also their world. Alice Waters, an influential chef and founder of the nonprofit program Edible Schoolyard, as well as an advocate for sustainable production and consumption, has said, "Remember food is precious. Good food can only come from good ingredients. Its proper price includes the cost of preserving the environment and paying fairly for the labor of the people who produce it. Food should never be taken for granted.[15]

Video Link: Alice Waters: Edible Education

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19.9 Start Your Sustainable Future Today

As we near the end of our journey in the world of health and nutrition, let's address how to adjust your lifestyle today to ensure better health and wellness tomorrow. Adopting sustainable practices can go a long way toward helping you achieve optimal health, while also helping to protect the health of our planet. Remember, that sustainability involves meeting present nutritional needs while preserving resources for the future. It includes agricultural practices and processes, along with the choices that consumers make when they shop for their food. Ideally, sustainable practices include methods that are healthy, conserve the environment, protect livestock, respect food industry workers, provide fair wages to farmers, and support farming communities. When a practice or a process is sustainable, it can be maintained for decades, or even centuries, to come.

Living a Sustainable Lifestyle

There are a number of steps you can take to live a more sustainable lifestyle. Utilizing an environmentally-friendly approach to good nutrition is a great way to remain and stay healthy. As an initial step, you might try to buy more whole foods rather than processed foods. You might also drink more water, rather than sodas and juices with added sugar. It is also a good idea to drink from a reusable water bottle to avoid adding more plastic to your local landfill, not to mention saving the fuel it takes to ship bottles of water. Here are some other suggestions to live a more sustainable lifestyle:

Learn more about food. Learn about your local food system, what is native to the area, what is imported or shipped in, how food moves from farms to processors to retail in your area, and what practices are used. Read labels to see where food comes from and what the growing and processing practices are. You might also try taking a cooking class to learn more about food in general.

Eat a plant-based diet. A plant-based diet is not necessarily vegetarian or vegan; it simply emphasizes whole grains, fruits, vegetables, and legumes over meat and poultry.

Plant-based foods are good sources of carbohydrates, protein, fat, vitamins, and minerals. They also help to decrease your risk for cancer and other chronic conditions.

Support local farmers. Purchase more locally grown food to promote sustainability. This could involve going to a farmer's market or a nearby farm. Locally grown food requires less fossil fuel because it does not have to travel great distances. Locally grown food also puts money back into your community and helps farmers in your area. Shopping at a farmer's market or a local farm may also provide an opportunity to talk to the farmer who grew the food to learn more about what you put on your plate.

Join a community garden. You can't get more local than food that is grown in your own backyard. Consider growing your own food, or trying a community garden if you do not have the space at your home. Produce from a local garden will not only be fresher, it will often taste better. In addition, it will provide an opportunity to get to know like-minded individuals in your community.

Help spread the word. Talk to friends and family members about food, nutrition, and living a sustainable lifestyle. Also, pay attention to food and nutrition policy at the federal, state, and local levels. Take a look at what foods are available in your community. Are there supermarkets or corner stores? What is available in the university dining hall? If healthy options are lacking, can you talk to someone to bring about changes?

Changing Your Behavior

Living a sustainable lifestyle and achieving optimal health is not easy. Taking steps to exercise more, eat healthier foods, and work harder to avoid food contamination may involve making major changes in your life. However, change is a process, and researchers have long studied the various stages of that process, as well as what helps or hinders it. While creating and implementing change is not easy, the more conscious you are of the process, and the more you prepare, the greater the chances are for success. Learning about the different stages of behavioral change can help you take a proactive approach to living a sustainable lifestyle.

Appendix A: Metric System Basics

LUMEN LEARNING

Learning Outcomes

- Describe the general relationship between the U.S. customary units and metric units of length, weight/mass, and volume
- Define the metric prefixes and use them to perform basic conversions among metric units
- Solve application problems using metric units
- State the freezing and boiling points of water on the Celsius and Fahrenheit temperature scales.
- Convert from one temperature scale to the other, using conversion formulas

What Is Metric?[1]

The metric system uses units such as **meter**, **liter**, and **gram** to measure length, liquid volume, and mass, just as the U.S. customary system uses feet, quarts, and ounces to measure these.

In addition to the difference in the basic units, the metric system is based on 10s, and different measures for length include kilometer, meter, decimeter, centimeter, and millimeter. Notice that the word "meter" is part of all of these units.

The metric system also applies the idea that units within the system get larger or smaller by a power of 10. This means that a meter is 100 times larger than a centimeter, and a kilogram is 1,000 times heavier than a gram. You will explore this idea a bit later. For now, notice how this idea of "getting bigger or smaller by 10" is very different than the relationship between units in the U.S. customary system, where 3 feet equals 1 yard, and 16 ounces equals 1 pound.

Length, Mass, and Volume

The table below shows the basic units of the metric system. Note that the names of all metric units follow from these three base units.

Table A.1 Metric base units for length, mass, and volume, plus other commonly used units

Length	Mass	Volume
base units		
meter	gram	liter
other units you may see		
kilometer	kilogram	dekaliter
centimeter	centigram	centiliter
millimeter	milligram	milliliter

In the metric system, the basic unit of length is the meter. A meter is slightly larger than a yardstick, or just over three feet.

The basic metric unit of mass is the gram. A regular-sized paperclip has a mass of about 1 gram.

Among scientists, one gram is defined as the mass of water that would fill a 1-centimeter cube. You may notice that the word "mass" is used here instead of "weight". In the sciences and technical fields, a distinction is made between weight and mass. Weight is a measure of the pull of gravity on an object. For this reason, an object's weight would be different if it was weighed on Earth or on the moon because of the difference in the gravitational forces. However, the object's mass would remain the same in both places because mass measures the amount of substance in an object. As long as you are planning on only measuring objects on Earth, you can use mass/weight fairly interchangeably, but it is worth noting that there is a difference!

Finally, the basic metric unit of volume is the liter. A liter is slightly larger than a quart.

The handle of a shovel is about 1 meter.

A paperclip weighs about 1 gram.

A medium-sized container of milk is about 1 liter.

Though it is rarely necessary to convert between the customary and metric systems, sometimes it helps to have a mental image of how large or small some units are. The table below shows the relationship between some common units in both systems.

Table A.2 Comparing metric measurements to non-metric measurements

	Common Measurements in Customary and Metric Systems
Length	1 centimeter is a little less than half an inch.
	1.6 kilometers is about 1 mile.
	1 meter is about 3 inches longer than 1 yard.
Mass	1 kilogram is a little more than 2 pounds.
	28 grams is about the same as 1 ounce.
Volume	1 liter is a little more than 1 quart.
	4 liters is a little more than 1 gallon.

Prefixes in the Metric System

The metric system is a base 10 system. This means that each successive unit is 10 times larger than the previous one.

The names of metric units are formed by adding a prefix to the basic unit of measurement. To tell how large or small a unit is, you look at the **prefix**. To tell whether the unit is measuring length, mass, or volume, you look at the base.

Table A.3 Prefixes in the metric system

Prefixes in the Metric System						
kilo-	*hecto-*	*deka-*	**meter** **gram** **liter**	*deci-*	*centi-*	*milli-*
1,000 times **larger** than base unit	100 times **larger** than base unit	10 times **larger** than base unit	**base units**	10 times **smaller** than base unit	100 times **smaller** than base unit	1,000 times **smaller** than base unit

Using this table as a reference, you can see the following:

- A kilogram is 1,000 times larger than one gram (so 1 kilogram = 1,000 grams).
- A centimeter is 100 times smaller than one meter (so 1 meter = 100 centimeters).
- A dekaliter is 10 times larger than one liter (so 1 dekaliter = 10 liters).

Here is a similar table that just shows the metric units of measurement for mass, along with their size relative to 1 gram (the base unit). The common abbreviations for these metric units have been included as well.

Table A.4 Measuring Mass in the Metric System

Measuring Mass in the Metric System						
kilogram (kg)	hectogram (hg)	dekagram (dag)	gram (g)	decigram (dg)	centigram (cg)	milligram (mg)
1,000 grams	100 grams	10 grams	gram	0.1 gram	0.01 gram	0.001 gram

Since the prefixes remain constant through the metric system, you could create similar charts for length and volume. The prefixes have the same meanings whether they are attached to the units of length (meter), mass (gram), or volume (liter).

Metric System in Nutrition

There are several places where you'll see the metric system as you're learning about **nutrition**.

Calories and kilocalories

Calories are the base unit used to measure the amount energy found in food, just as gram is the base unit for measuring mass or meter is the base unit for measuring length. In the US, we just use the term "calorie". But what we call a "calorie" is really a kilocalorie, which you now know means 1000 calories. This is why you'll see "kcal" on **nutrition facts labels** from Canada. A kilocalorie is also sometimes referred to as a Calorie, with a capital C. One (small) calorie is the amount of energy needed to raise one gram of water by one degree Celsius. A kilocalorie is the amount of energy needed to raise one kilogram (1,000 grams) of water by one degree Celsius.

Grams, milligrams, and micrograms

You'll also see the metric system used when discussing the amount of **nutrients** our body needs. When learning about the **macronutrients** (carbohydrates, lipids, and protein), you'll see the recommended intake reported in grams. Now you know that "gram" is the metric base unit for measuring mass. When learning about the **micronutrients**, you'll see recommended intakes reported in milligrams and even micrograms. Looking at the table above, you can see that a "milligram" is 0.001 gram, or one one-thousandth (1/1000) of a gram. A "microgram" is one one-thousandth of a milligram, making it one one-millionth of a gram (1/1,000,000). Another way to put this is to say that it takes one thousand milligrams to make up a gram, and one million micrograms to make up a gram.

Converting Units Up and Down the Metric Scale

Converting between metric units of measure requires knowledge of the metric prefixes and an understanding of the decimal system, that's about it.

For instance, you can figure out how many centigrams are in one dekagram by using the table above. One dekagram is larger than one centigram, so you expect that one dekagram will equal many centigrams.

In the table, each unit is 10 times larger than the one to its immediate right. This means that 1 dekagram = 10 grams; 10 grams = 100 decigrams; and 100 decigrams = 1,000 centigrams. So, 1 dekagram = 1,000 centigrams.

Once you begin to understand the metric system, you can use a shortcut to convert among different metric units. The size of metric units increases tenfold as you go up the metric scale. The decimal system works the same way: a tenth is 10 times larger than a hundredth; a hundredth is 10 times larger than a thousandth, etc. By applying what you know about decimals to the metric system, converting among units is as simple as moving decimal points.

Here is the first problem from above: How many milligrams are in one decigram? You can recreate the order of the metric units as shown below:

$$kg \quad hg \quad dag \quad g \quad d\underbrace{g \quad c}_{1}\underbrace{g \quad m}_{2}g$$

This question asks you to start with 1 decigram and convert that to milligrams. As shown above, milligrams is two places to the right of decigrams. You can just move the decimal point two places to the right to convert decigrams to milligrams: $1\ dg = 1\underbrace{\ 0\ }_{1}\underbrace{\ 0\ }_{2}.\ mg$.

The same method works when you are converting from a smaller to a larger unit, as in the problem: Convert 1 centimeter to kilometers.

$$k\underbrace{m \quad h}_{5}\underbrace{m \quad da}_{4}\underbrace{m \quad }_{3}\underbrace{m \quad d}_{2}\underbrace{m \quad c}_{1}m \quad mm$$

Note that instead of moving to the right, you are now moving to the left, so the decimal point must do the same:

$$1\ cm = 0.\underbrace{\ 0\ }_{5}\underbrace{\ 0\ }_{4}\underbrace{\ 0\ }_{3}\underbrace{\ 0\ }_{2}\underbrace{\ 1\ }_{1}km.$$

Factor Label Method

There is yet another method that you can use to convert metric measurements, the **factor label method**. You used this method when you were converting measurement units within the U.S. customary system.

The factor label method works the same in the metric system; it relies on the use of unit fractions and the cancelling of intermediate units. The table below shows some of the **unit equivalents** and **unit fractions** for length in the metric system. (You should notice that all of the unit fractions contain a factor of 10. Remember that the metric system is based on the notion that each unit is 10 times larger than the one that came before it.)

Also, notice that two new prefixes have been added here: mega- (which is very big) and micro- (which is very small).

Table A.5 Metric Conversion Factors

Unit Equivalents	Conversion Factors	
1 meter = 1,000,000 micrometers	$\frac{1\ m}{1,000,000\ \mu m}$	$\frac{1,000,000\ \mu m}{1\ m}$
1 meter = 1,000 millimeters	$\frac{1\ m}{1,000\ mm}$	$\frac{1,000\ mm}{1\ m}$
1 meter = 100 centimeters	$\frac{1\ m}{100\ cm}$	$\frac{100\ cm}{1\ m}$
1 meter = 10 decimeters	$\frac{1\ m}{10\ dm}$	$\frac{10\ dm}{1\ m}$
1 dekameter = 10 meters	$\frac{1\ dam}{10\ m}$	$\frac{10\ m}{1\ dam}$
1 hectometer = 100 meters	$\frac{1\ hm}{100\ m}$	$\frac{100\ m}{1\ hm}$
1 kilometer = 1,000 meters	$\frac{1\ km}{1,000\ m}$	$\frac{1,000\ m}{1\ km}$
1 megameter = 1,000,000 meters	$\frac{1\ Mm}{1,000,000\ m}$	$\frac{1,000,000\ m}{1\ Mm}$

When applying the factor label method in the metric system, be sure to check that you are not skipping over any intermediate units of measurement!

Notes

1. Appendix A is adapted from: https://courses.lumenlearning.com/waymakermath4libarts/chapter/the-metric-system/.

Appendix B: Math for Nutrition

SURYA TEWARI

Nutrition Math help

This handout covers how to do basic math calculations for **nutrition**.

How to calculate the calories

1 Calorie= 1 kilocalorie

Example – calculating total calories from a doughnut and the number of calories from the three energy macronutrients found in a doughnut.

Doughnuts have 11g of fat, 21g for carbs and 2 grams for protein.

How to convert grams of macronutrient to calories:

1g of fat = 9 calories
1g of protein or carbohydrate = 4 calories

Calories from fat in doughnut	11x 9 = 99 calories
Calories from carbohydrates in doughnut	21 x 4= 84 calories
Calories from protein in doughnut	2x 4 = 8 calories
Total calories of a doughnut =	99+84+8 = 191 calories

Note that you can calculate grams from calories e.g. 8 calories/ 4 calories per gram = 2 grams of protein. .

Percent calories from each macronutrient

We will use the information given for a single doughnut above

% of fat in doughnut (99/191) x 100 = 51.8%

% of carbs in doughnut (84/191) x 100 = 44%

% of protein in doughnut (8/191) x 100 = 4.2%

If you know the % of a nutrient and the total calories you can calculate calories from nutrient and then grams e.g. a doughnut has 191 calories and 44 % of the calories are from fat and 4.2 % from protein. What percent of the doughnut it fat and how many calories does it represent?

100 – 44- 4.2 = 51.8% of the calories in a doughnut come from fat.

191 x (51.8/100) = 99 calories – you can then convert calories to grams.

Other resources

How to count calories

YouTube video on counting calories in food

Appendix C: Chemistry for Nutrition

LISA BARTEE AND JACK BROOK

Living things are highly organized and structured, following a hierarchy that can be examined on a scale from small to large. The examination of the smallest parts involves a knowledge of chemistry. We discussed the levels of organization of living things in the last chapter. In this chapter, we will learn some basic chemistry that is important in order to understand how molecules in **cells** function.[1]

ATOMS

An **atom** is the smallest component of an element that retains all of the chemical properties of that element. For example, one hydrogen atom has all of the properties of the element hydrogen, such as it exists as a gas at room temperature, and it bonds with oxygen to create a water molecule. Hydrogen atoms cannot be broken down into anything smaller while still retaining the properties of hydrogen. If a hydrogen atom were broken down into subatomic particles, it would no longer have the properties of hydrogen.

All atoms contain **protons, electrons,** and **neutrons** (Figure C.1). The only exception is hydrogen (H), which is made of one proton and one electron. A proton is a positively charged particle that resides in the nucleus (the core of the atom) of an atom. An electron is a negatively charged particle that travels in the space around the nucleus. In other words, it resides outside of the nucleus. Neutrons, like protons, reside in the nucleus of an atom. The positive (protons) and negative (electrons) charges balance each other in a neutral atom, which has a net zero charge.

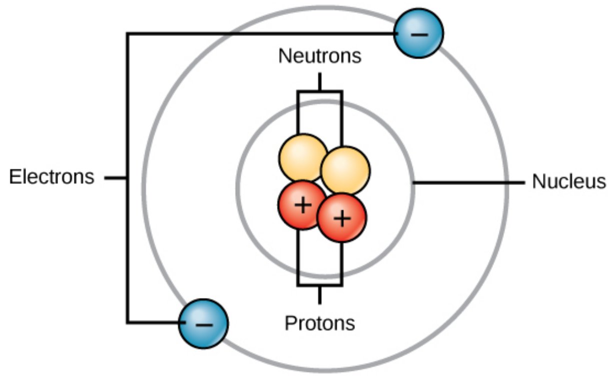

Figure C.1 *Atoms are made up of protons and neutrons located within the nucleus, and electrons surrounding the nucleus.*

At the most basic level, all **organisms** are made of a combination of atoms. They contain atoms that combine together to form molecules. In multicellular organisms, such as animals, molecules can interact to form cells that combine to form tissues, which make up **organs**. These combinations continue until entire multicellular organisms are formed.

Each **element** has its own unique properties. An element is a substance whose atoms all have the same number of protons. Different elements have different melting and boiling points, and are in different states (liquid, solid, or gas) at room temperature. They also combine in different ways. Some form specific types of bonds, whereas others do not. How they combine is based on the number of electrons present. Because of these characteristics, the elements are arranged into the periodic table of elements, a chart of the elements that includes the atomic number and relative atomic mass of each element. The periodic table also provides key information about the properties of elements (Figure C.2) —often indicated by color-coding. The arrangement of the table also shows how the electrons in each element are organized and provides important details about how atoms will react with each other to form molecules.

Isotopes are different forms of the same element that have the same number of protons, but a different number of neutrons. Some elements, such as carbon, potassium, and uranium, have naturally occurring isotopes. Carbon-12, the most common isotope of carbon, contains six protons and six neutrons. Carbon-14 contains six protons and eight neutrons. These two alternate forms of carbon are isotopes. Some isotopes are very stable. Other isotopes are unstable and will lose protons, other subatomic particles, or energy to form more stable elements. These unstable isotopes are called radioactive isotopes or radioisotopes.

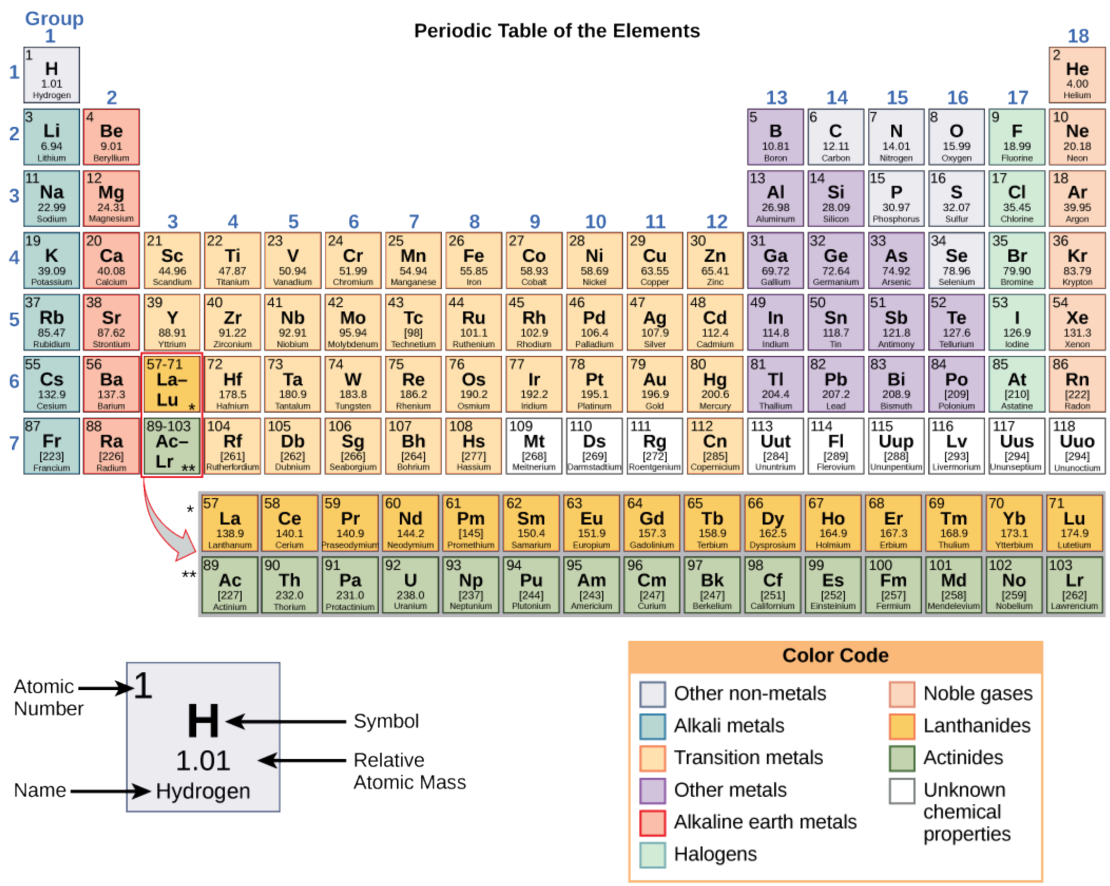

Figure C.2 *Arranged in columns and rows based on the characteristics of the elements, the periodic table provides key information about the elements and how they might interact with each other to form molecules. Most periodic tables provide a key or legend to the information they contain.*

CHEMICAL BONDS

Atoms can form several types of chemical bonds. These bonds are interactions between two atoms that hold the atoms together. It is important to understand the various types of bonds because they help determine how different molecules function within an organism. There are four types of bonds or interactions: covalent, ionic, hydrogen bonds, and van der Waals interactions.

Covalent Bonds

Another type of strong chemical bond between two or more atoms is a **covalent bond**. These bonds form when an electron is shared between two elements. Covalent bonds are the strongest and most common form of chemical bond in living organisms.

The hydrogen and oxygen atoms that combine to form water molecules are bound together by strong covalent bonds. The electron from the hydrogen atom shares its time between the hydrogen atom and the oxygen atom. In order for the oxygen atom to be stable, two electrons from two hydrogen atoms are needed, hence the subscript "2" in H_2O. H_2O means that there are 2 hydrogen atoms bonded to 1 oxygen atom (the 1 is implied below the O in the chemical formula). This sharing makes both the hydrogen and oxygen atoms more chemically stable.

There are two types of covalent bonds: polar and nonpolar (Figure C.3). **Nonpolar covalent bonds** form between two atoms that share the electrons equally so there is no overall charge on the molecule. For example, an oxygen atom can bond with another oxygen atom. This association is **nonpolar** because the electrons will be equally shared between each oxygen atom. Another example of a nonpolar covalent bond is found in the methane (CH_4) molecule. The carbon atom shares electrons with four hydrogen atoms. The carbon and hydrogen atoms all share the electrons equally, creating four nonpolar covalent bonds (Figure C.3).

In a **polar covalent bond**, the electrons shared by the atoms spend more time closer to one atom than to the other. Because of the unequal distribution of electrons between the atoms, a slightly positive ($\delta+$) or slightly negative ($\delta-$) charge develops. The covalent bonds between hydrogen and oxygen atoms in water are polar covalent bonds. The shared electrons spend more time near the oxygen than they spend near the hydrogen. This means that the oxygen has a small negative charge while the hydrogens have a small positive charge.

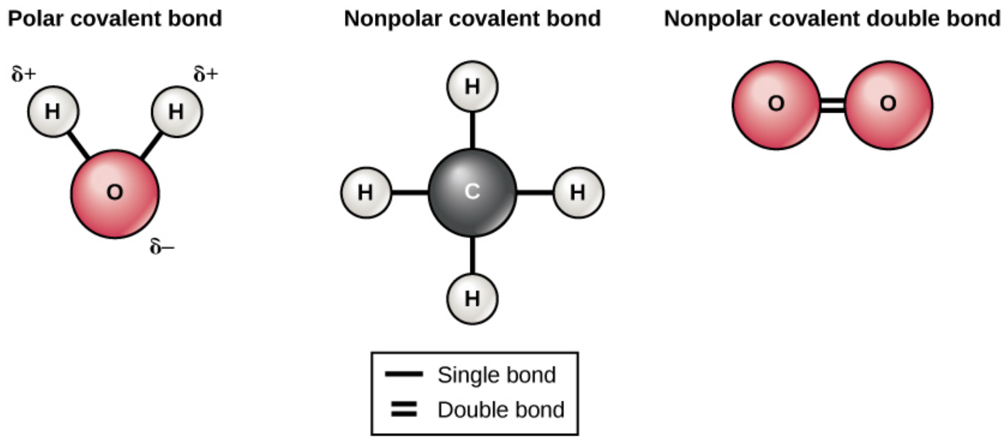

Figure C.3 *The water molecule (left) depicts a polar bond with a slightly positive charge on the hydrogen atoms and a slightly negative charge on the oxygen. Examples of nonpolar bonds include methane (middle) and oxygen (right).*

Ionic Bonds

Atoms normally have an equal number of protons (positive charge) and electrons (negative charge). This means that atoms are normally uncharged because the number of positively charged particles equals the number of negatively charged particles. When an atom does not contain equal numbers of protons and electrons, it will have a net charge. An atom with a net charge is called an **ion.** Positive ions are formed by losing electrons. Negative ions are formed by gaining electrons. Atoms can lose and donate electrons in order to become more stable.

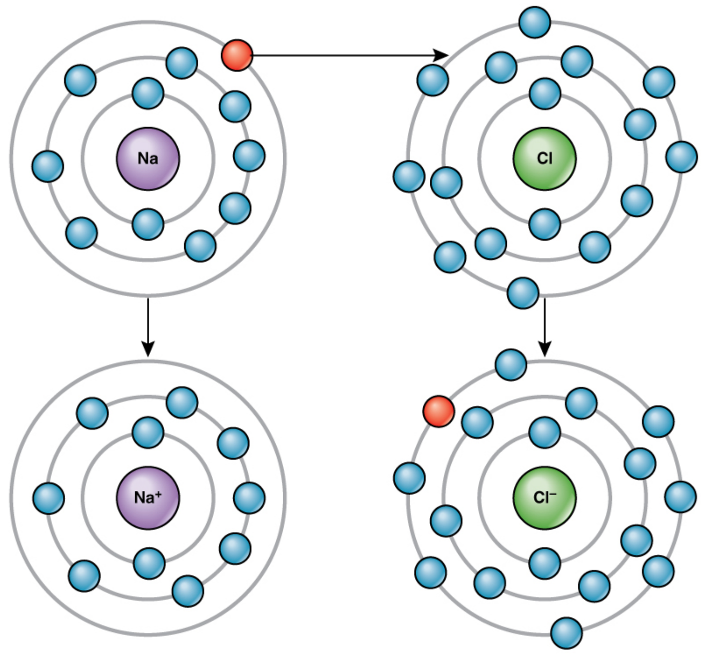

Figure C.4 *If sodium (Na) gives an electron to chlorine (Cl), the sodium atom becomes positively charged (Na+) and the chlorine atom becomes negatively charged (Cl–).*

When an element donates an electron from its outer shell, as in the sodium atom example above, a positive ion is formed (Figure C.5). The element accepting the electron is now negatively charged. Because positive and negative charges attract, these ions stay together and form an **ionic bond**, or a bond between ions. The elements bond together with the electron from one element staying predominantly with the other element. When Na and Cl combine to produce NaCl, an electron from a sodium atom goes to stay with the other seven electrons in the chlorine atom, forming a positively charged sodium ion and a negatively charged chlorine ion. The sodium and chloride ions attract each other.

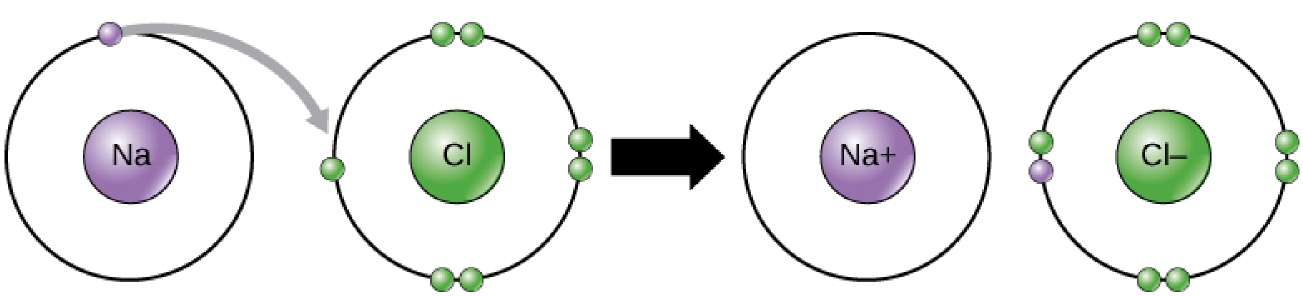

Figure C.5 *The formation of the ionic compound NaCl.*

Video link: Chemical Bonding – Ionic vs. Covalent Bonds

Hydrogen Bonds

Ionic and covalent bonds are strong bonds that require considerable energy to break. However, not all bonds between elements are ionic or covalent bonds. Weaker bonds can also form. These are attractions that occur between positive and negative charges that do not require much energy to break. Two weak bonds that occur frequently are hydrogen bonds and van der Waals interactions. These bonds give rise to the unique properties of water and the unique structures of DNA and proteins.

When polar covalent bonds containing a hydrogen atom form, the hydrogen atom in that bond has a slightly positive charge. This is because the shared electron is pulled more strongly toward the other element and away from the hydrogen nucleus. Because the hydrogen atom is slightly positive (δ+), it will be attracted to neighboring negative partial charges (δ–). When this happens, a weak interaction occurs between the δ+ charge of the hydrogen atom of one molecule and the δ– charge of the other molecule. This interaction is called a hydrogen bond. This type of bond is common; for example, the liquid nature of water is caused by the hydrogen bonds between water molecules (Figure C.6). Hydrogen bonds give water the unique properties that sustain life. If it were not for hydrogen bonding, water would be a gas rather than a liquid at room temperature.

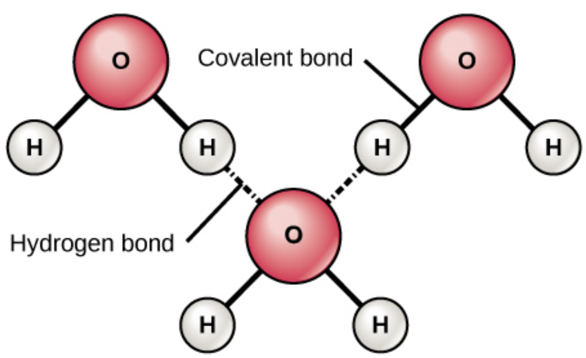

Figure C.6 *Hydrogen bonds form between slightly positive (δ+) and slightly negative (δ–) charges of polar covalent molecules, such as water.*

Hydrogen bonds can form between different molecules and they do not always have to include a water molecule. Hydrogen atoms in polar bonds within any molecule can form bonds with other adjacent molecules. For example, hydrogen bonds hold together two long strands of DNA to give the DNA molecule its characteristic double-stranded structure. Hydrogen bonds are also responsible for some of the three-dimensional structure of proteins.

Video link: Polar Bonds and Hydrogen Bonds

van der Waals Interactions

Like hydrogen bonds, van der Waals interactions are weak attractions or interactions between molecules. They occur between polar, covalently bound, atoms in different molecules. Some of these weak attractions are caused by temporary partial charges formed when electrons move around a nucleus. These weak interactions between molecules are important in biological systems.

WATER

Figure C.7 *Water: without it, life wouldn't exist. Photo credit ronymichaud; CC0 license; https://pixabay.com/en/users/ronymichaud-647623/*

Do you ever wonder why scientists spend time looking for water on other planets? It is because water is essential to life; even minute traces of it on another planet can indicate that life could or did exist on that planet. Water is one of the more abundant molecules in living cells and the one most critical to life as we know it. Approximately 60–70 percent of your body is made up of water. Without it, life simply would not exist.

Water Is Polar

The hydrogen and oxygen atoms within water molecules form **polar covalent bonds**. The shared electrons spend more time associated with the oxygen atom than they do with hydrogen atoms. There is no overall charge to a water molecule, but there is a slight positive charge on each hydrogen atom and a slight negative charge on the oxygen atom. Because of these charges, the slightly positive hydrogen atoms repel each other and form the unique shape. Each water molecule attracts other water molecules because of the positive and negative charges in the different parts of the molecule.

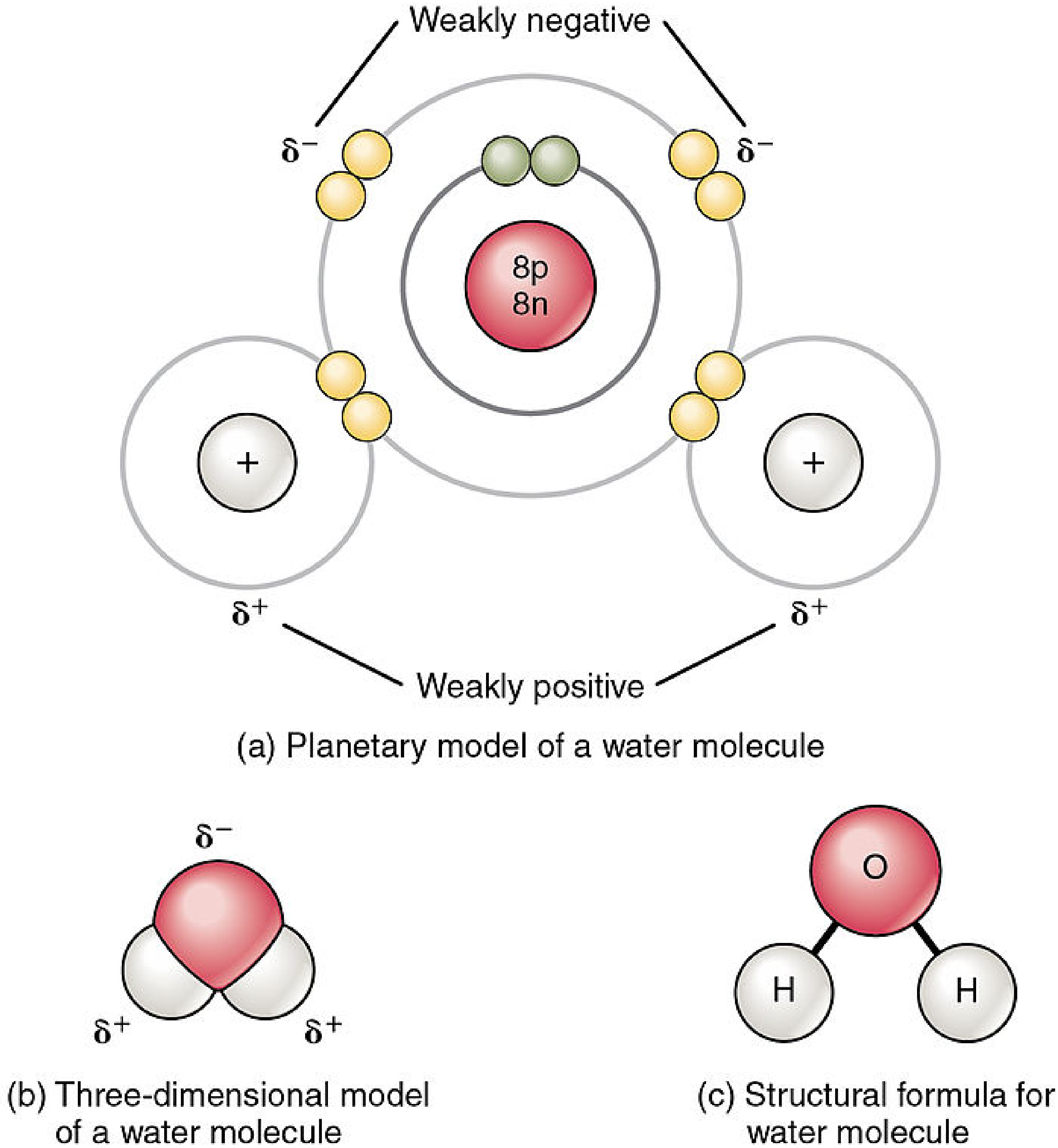

Figure C.8 *The electrons in the covalent bond connecting the two hydrogens to the atom of oxygen in a water molecule spend more time on the oxygen atom. This gives the oxygen atom a slightly negative charge (since electrons are negatively charged). Credit: Anatomy & Physiology, Connexions Web site. http://cnx.org/content/col11496/1.6/, Jun 19, 2013.*

Water also attracts other polar molecules (such as sugars), forming hydrogen bonds.

When a substance readily forms hydrogen bonds with water, it can dissolve in water and is referred to as **hydrophilic** ("water-loving"). Hydrogen bonds are not readily formed with nonpolar substances like oils and fats (Figure C.9). These nonpolar compounds are **hydrophobic** ("water-fearing") and will not dissolve in water.

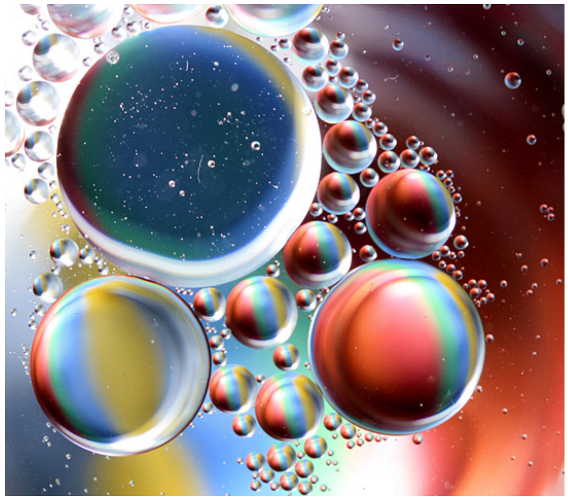

Figure C.9 *As this macroscopic image of oil and water show, oil is a nonpolar compound and, hence, will not dissolve in water. Oil and water do not mix. (credit: Gautam Dogra)*

Water Stabilizes Temperature

The hydrogen bonds in water allow it to absorb and release heat energy more slowly than many other substances. Temperature is a measure of the motion (kinetic energy) of molecules. As the motion increases, energy is higher and thus temperature is higher. Water absorbs a great deal of energy before its temperature rises. Increased energy disrupts the hydrogen bonds between water molecules. Because these bonds can be created and disrupted rapidly, water absorbs an increase in energy and temperature changes only minimally. This means that water moderates temperature changes within organisms and in their environments. As energy input continues, the balance between hydrogen-bond formation and destruction swings toward the destruction side. More bonds are broken than are formed. This process results in the release of individual water molecules at the surface of the liquid (such as a body of water, the leaves of a plant, or the skin of an organism) in a process called evaporation. Evaporation of sweat, which is

90 percent water, allows for cooling of an organism, because breaking hydrogen bonds requires an input of energy and takes heat away from the body.

Conversely, as molecular motion decreases and temperatures drop, less energy is present to break the hydrogen bonds between water molecules. These bonds remain intact and begin to form a rigid, lattice-like structure (e.g., ice) (Figure C.10a). When frozen, ice is less dense than liquid water (the molecules are farther apart). This means that ice floats on the surface of a body of water (Figure C.10b). In lakes, ponds, and oceans, ice will form on the surface of the water, creating an insulating barrier to protect the animal and plant life beneath from freezing in the water. If this did not happen, plants and animals living in water would freeze in a block of ice and could not move freely, making life in cold temperatures difficult or impossible.

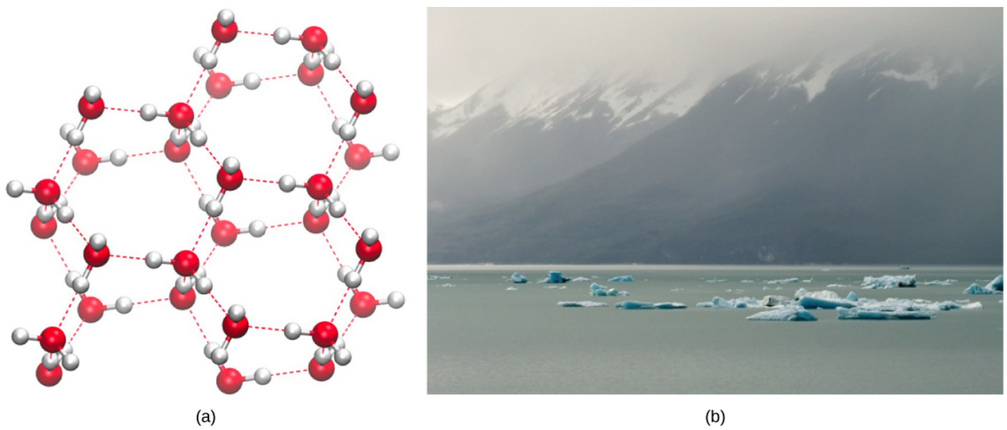

Figure C.10 *(a) The lattice structure of ice makes it less dense than the freely flowing molecules of liquid water. Ice's lower density enables it to (b) float on water. (credit a: modification of work by Jane Whitney; credit b: modification of work by Carlos Ponte)*

Water Is an Excellent Solvent

Because water is polar, with slight positive and negative charges, ionic compounds and polar molecules can readily dissolve in it. Water is, therefore, what is referred to as a solvent—a substance capable of dissolving another substance. The charged particles will form hydrogen bonds with a surrounding layer of water molecules. This is referred to as a sphere of hydration and serves to keep the particles separated or dispersed in the water. In the case of table salt (NaCl) mixed in water (Figure C.11, the sodium and chloride ions separate, or dissociate, in the water, and spheres of hydration are formed around the ions. A positively charged sodium ion is surrounded by the partially negative charges of oxygen atoms in water molecules. A negatively charged chloride ion is surrounded by the partially positive charges of hydrogen atoms in water molecules. These spheres of hydration are also referred to as hydration shells. The polarity of the water molecule makes it an effective solvent and is important in its many roles in living systems.

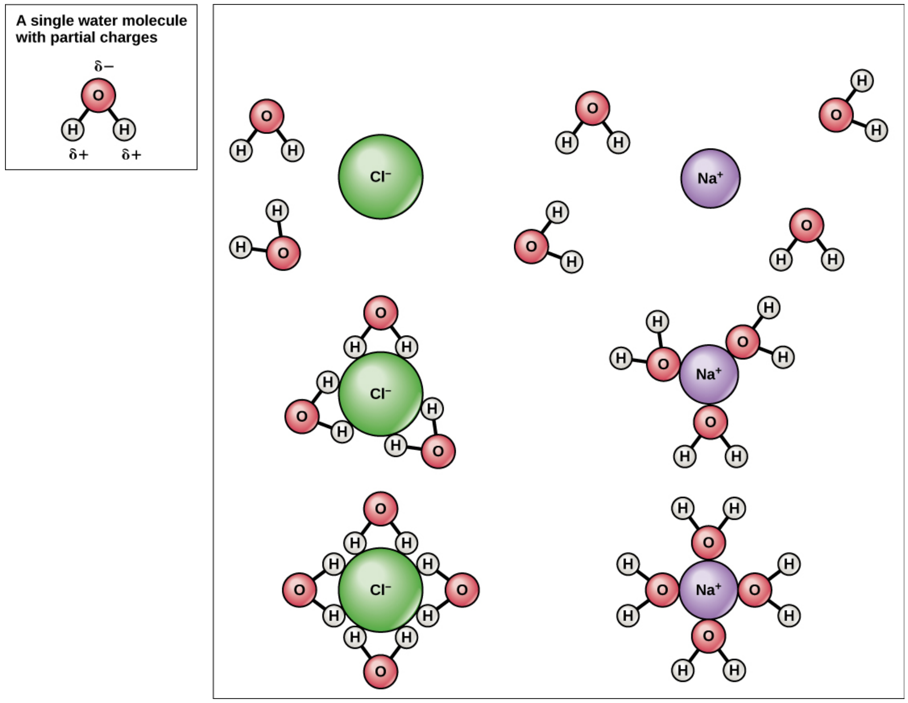

Figure C.11 *When table salt (NaCl) is mixed in water, spheres of hydration form around the ions.*

Water Is Cohesive

Have you ever filled up a glass of water to the very top and then slowly added a few more drops? Before it overflows, the water actually forms a dome-like shape above the rim of the glass. This water can stay above the glass because of the property of cohesion. In cohesion, water molecules are attracted to each other (because of hydrogen bonding), keeping the molecules together at the liquid-air (gas) interface, although there is no more room in the glass. Cohesion gives rise to surface tension, the capacity of a substance to withstand rupture when placed under tension or stress. When you drop a small scrap of paper onto a droplet of water, the paper floats on top of the water droplet, although the object is denser (heavier) than the water. This occurs because of the surface tension that is created by the water molecules. Cohesion and surface tension keep the water molecules intact and the item floating on the top. It is even possible to "float" a steel needle on top of a glass of water if you place it gently, without breaking the surface tension (Figure C.12).

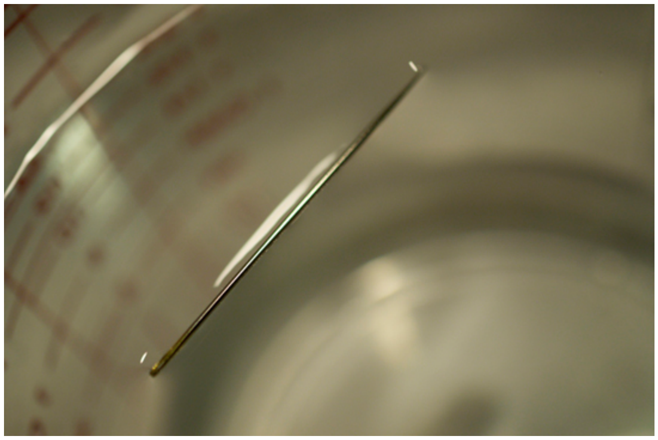

Figure C.12 *The weight of a needle on top of water pulls the surface tension downward; at the same time, the surface tension of the water is pulling it up, suspending the needle on the surface of the water and keeping it from sinking. Notice the indentation in the water around the needle. (credit: Cory Zanker)*

These cohesive forces are also related to the water's property of adhesion, or the attraction between water molecules and other molecules. This is observed when water "climbs" up a straw placed in a glass of water. You will notice that the water appears to be higher on the sides of the straw than in the middle. This is because the water molecules are attracted to the straw and therefore adhere to it.

Cohesive and adhesive forces are important for sustaining life. For example, because of these forces, water can flow up from the roots to the tops of plants to feed the plant.

BUFFERS, pH, ACIDS, and BASES

The **pH** of a solution is a measure of its **acidity** or **alkalinity.** You may have used litmus paper or purple cabbage juice, which can both be used as a pH indicator – they change different colors in the presence of an acid or a base. You might have used a pH indicator to make sure the water in an outdoor swimming pool is properly treated. In both cases, this pH test measures the amount of hydrogen ions (H^+) that exists in a given solution. High concentrations of hydrogen ions yield a low pH, whereas low levels of hydrogen ions result in a high pH. The overall concentration of hydrogen ions is inversely related to its pH and can be measured on the pH scale (Figure C.13). Therefore, the more hydrogen ions present, the lower the pH; conversely, the fewer hydrogen ions, the higher the pH.

The pH scale ranges from 0 to 14. A change of one unit on the pH scale represents a change in the concentration of hydrogen ions by a factor of 10, a change in two units represents a change in the concentration of hydrogen ions by a factor of 100. Thus, small changes in pH represent large changes in the concentrations of hydrogen ions. Pure water is **neutral.** It is neither acidic nor basic, and has a pH of 7.0. Anything below 7.0 (ranging from 0.0 to 6.9) is **acidic,** and anything above 7.0 (from 7.1 to 14.0) is **alkaline (basic).** The blood in your veins is slightly alkaline (pH = 7.4). The environment in your stomach is highly acidic (pH = 1 to 2). Orange juice is mildly acidic (pH = approximately 3.5), whereas baking soda is basic (pH = 9.0).

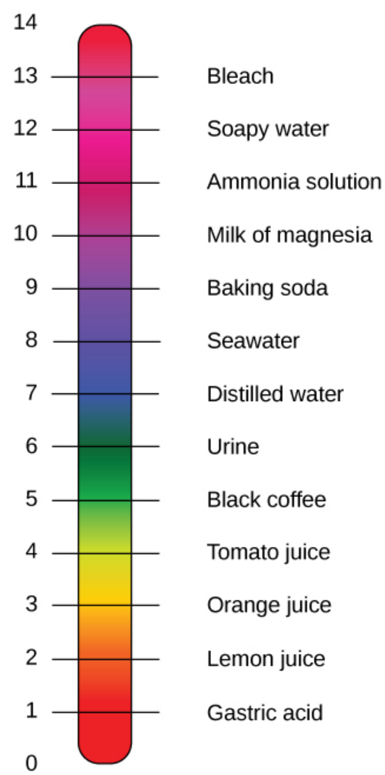

Figure C.13 *The pH scale measures the amount of hydrogen ions (H+) in a substance. (credit: modification of work by Edward Stevens)*

Acids are substances that provide hydrogen ions (H^+) and lower pH, whereas bases provide hydroxide ions (OH^-) and raise pH. The stronger the acid, the more readily it donates H^+. For example, hydrochloric acid and lemon juice are very acidic and readily give up H^+ when added to water. Conversely, bases are those substances that readily donate OH^-. The OH^- ions combine with H^+ to produce water, which raises a substance's pH. Sodium hydroxide and many household cleaners are very alkaline and give up OH^- rapidly when placed in water, thereby raising the pH.

Most cells in our bodies operate within a very narrow window of the pH scale, typically ranging only from 7.2 to 7.6. If the pH of the body is outside of this range, the respiratory system malfunctions, as do other organs in the body. Cells no longer function properly, and proteins will break down. Deviation outside of the pH range can induce coma or even cause death.

So how is it that we can ingest or inhale acidic or basic substances and not die? Buffers are the key. **Buffers** readily absorb excess H^+ or OH^-, keeping the pH of the body carefully maintained in the aforementioned narrow range (they help maintain homeostasis). Carbon dioxide is part of a prominent buffer system in the human body; it keeps the pH within the proper range. This buffer system involves carbonic acid (H_2CO_3) and bicarbonate (HCO_3^-) anion. If too much H^+ enters the body, bicarbonate will combine with the H^+ to create carbonic acid and limit the decrease in pH. Likewise, if too much OH^- is introduced into the system, carbonic acid will rapidly dissociate into bicarbonate and H^+ ions. The H^+ ions can combine with the OH^- ions, limiting the increase in pH. While carbonic acid is an important product in this reaction, its presence is fleeting because the carbonic acid is released from the body as carbon dioxide gas each time we breathe. Without this buffer system, the pH in our bodies would fluctuate too much and we would fail to survive.

ABSOLUTELY NECESSARY CHEMISTRY SUMMARY

Matter

- Matter is anything that occupies space and has mass.
- Matter is made up of atoms of different elements.
- All of the 92 elements that occur naturally have unique qualities that allow them to combine in various ways to create compounds or molecules.

- Atoms consist of protons, neutrons, and electrons.
- Atoms are the smallest units of an element that retain all of the properties of that element.

Chemical Bonds

- Electrons can be donated or shared between atoms to create bonds.
- Ionic bonds form between a positively and a negatively charged atom. They are fairly strong bonds.
- Covalent bonds form when atoms share one or more electrons. They are very strong bonds.
- Hydrogen bonds form between partially charged atoms. They are weak bonds.
- van der Waals interactions form between polar, covalently bound atoms. They are weak attractions that are often temporary.

Water

- is POLAR, allowing for the formation of hydrogen bonds,
- is an excellent SOLVENT: because water is polar, it allows ions and other polar molecules to dissolve.
- STABILIZES TEMPERATURE: the hydrogen bonds between water molecules give water the ability to hold heat better than many other substances. As the temperature rises, the hydrogen bonds between water continually break and reform, allowing for the overall temperature to remain stable, although increased energy is added to the system.
- is COHESIVE: hydrogen bonds allow for the property of surface tension.

pH, Acids, Bases, and Buffers

- The pH of a solution is a measure of the concentration of hydrogen ions in the solution. The pH scale ranges from 0 to 14.

    - A solution with an equal number of hydrogen ions and hydroxide ions is neutral and has a pH of 7.
    - A solution with a high number of hydrogen ions is acidic and has a low pH value (below 7).
    - A solution with a high number of hydroxide ions is basic and has a high pH value (above 7).
- Buffers are solutions that moderate pH changes when an acid or base is added to the buffer system. Buffers are important in biological systems because of their ability to maintain constant pH conditions.

Notes

1. Appendix B is adapted from Bartee, Lisa. *MHCC Biology 112: Biology for Health Professions*. Mt. Hood Community College. https://mhccbiology112.pressbooks.com/. This textbook is based on the OpenStax *Concepts of Biology* textbook.

Appendix D: Alternative Sweeteners

Sugar substitutes and alternative sweeteners were discussed in chapter 5. This appendix gives additional chemical and health-related information about a variety of sweeteners.

Sugar Alcohols (Polyols, Sugar Replacers)

Sugar(s) can provide a lot of **calories** and contribute to tooth decay. Thus there are many other compounds that are used as alternatives to sugar that have been developed or discovered. We will first consider **sugar alcohols** and then the alternative sweeteners in subsequent sections.

Below you can see the molecular structure of three common sugar alcohols: **xylitol**, **sorbitol**, and **mannitol**.

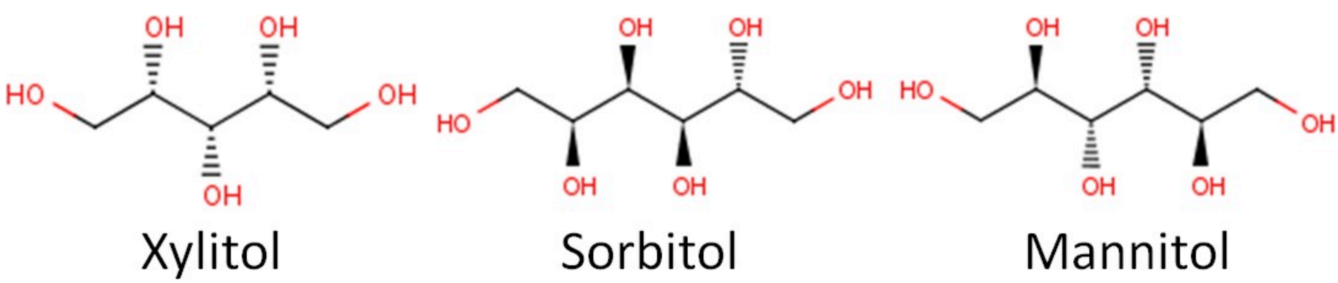

Figure D.1 *Structure of three commonly used sugar alcohols: xylitol, sorbitol, and mannitol. Alcohol subgroups are (OH), and you can see many of them in these structures. Source 1 Source 2 Source 3*

Sugar alcohols are also known as "sugar replacers", because some in the public might get confused by the name sugar alcohol. Some might think a sugar alcohol is a sweet alcoholic beverage. Another name for them is nutritive sweeteners, which indicates that they do provide calories. Sugar alcohols are nearly as sweet as sucrose but only provide approximately half the calories as shown below. The name **polyols** also seems to be increasingly used to describe these compounds.

Table D.1 Relative sweetness of monosaccharides, disaccharides, and sugar alcohols[12]

Sweetener	Relative Sweetness	Energy (kcal/g)
Lactose	0.2	4*
Maltose	0.4	4
Glucose	0.7	4
Sucrose	1.0	4
Fructose	1.2-1.8	4
Erythritol	0.7	0.4
Isomalt	0.5	2.0
Lactitol	0.4	2.0
*Differs based on a person's lactase activity		

Sugars are fermented by bacteria on the surfaces of teeth. This results in a decreased pH (higher acidity) that leads to tooth decay and, potentially, cavity formation (a process officially known as **dental caries**). The major advantage of sugar alcohols over sugars is that sugar alcohols are not fermented by bacteria on the tooth surface. There is a nice picture of this process in the link below as well as a video explaining the process of tooth decay.

Web Link: Sugar and Dental Caries

Video Link: Tooth Decay (1:06)

Alternative Sweeteners

Alternative sweeteners are simply alternatives to sucrose and other mono- and disaccharides that provide sweetness. Many have been developed to provide zero-calorie or low calorie sweetening for foods and drinks.

Because many of these provide little to no calories, these sweeteners are also referred to as non-nutritive sweeteners (**FDA** is using high-intensity sweeteners to describe these products[3]). Aspartame does provide calories, but because it is far sweeter than sugar, the small amount used does not contribute meaningful calories to a person's diet. Until the FDA allowed the use of the term **stevia**, this collection of sweeteners was commonly referred to as **artificial sweeteners**, because they were synthetically or artificially produced. However, with stevia, the descriptor artificial can no longer be used to describe these sweeteners. More recently, Luo Han Guo (monk fruit) extracts have also been allowed to be used as another high-intensity sweetener that is not synthesized or artificially produced. The table in the link below summarizes the characteristics of the FDA approved high-intensity sweeteners.

Web Link: FDA High-Intensity Sweeteners

Saccharin

Saccharin is the oldest of the artificial sweeteners. Saccharin was linked to bladder cancer in rats in the late 70's, but subsequent research did not establish the link in humans. While saccharin might not present as a significant health hazard, you do not want to use it in cooking or baking because it develops a bitter taste.[4]

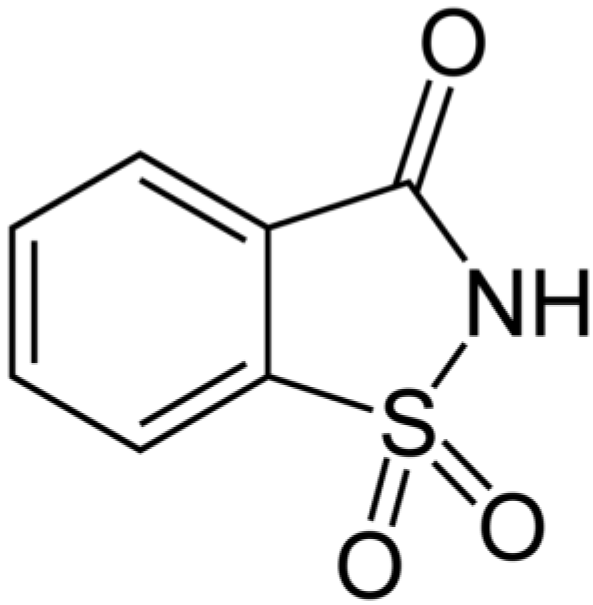

Figure D.2 *Structure of saccharin. Image source*

Cyclamate

Cyclamate (sodium cyclamate) is a artificial sweetener that was discovered in 1937. It was banned by the FDA in 1969, primarily due to its questionable safety. Cyclamate is about 30 times sweeter than sucrose, and is often used in combination with other artificial sweeteners. Cyclamate is approved for use in over 80 countries, including those in the European Union and Canada.

Aspartame

Aspartame is made up of 2 **amino acids** (**phenylalanine** and aspartate) and a methyl (CH_3) group. Aspartame is marketed under the product name NutraSweet ®. The compound is broken down during digestion into the individual amino acids. This is why it provides 4 kcal/g, just like protein.[5]

Because it can be broken down to phenylalanine, products that contain aspartame contain the following message: “Phenylketonurics: Contains phenylalanine.” When heated, aspartame breaks down and loses its sweet flavor.[6]

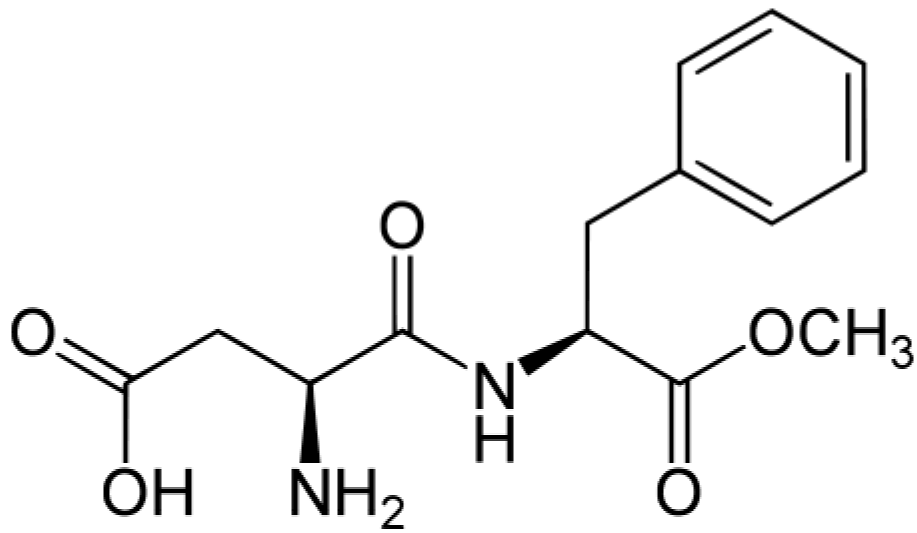

Figure D.3 *Structure of aspartame. Image source*

Neotame

Neotame is like aspartame version 2.0. Neotame is structurally identical to aspartame except that it contains an additional side group (bottom of figure below, which is flipped backwards to make it easier to compare their structures). While this looks like a minor difference, it has profound effects on the properties of neotame. Neotame is much sweeter than aspartame and is heat-stable. It can still be broken down to phenylalanine, but such small amounts are used that it is not a concern for those with PKU.[78]

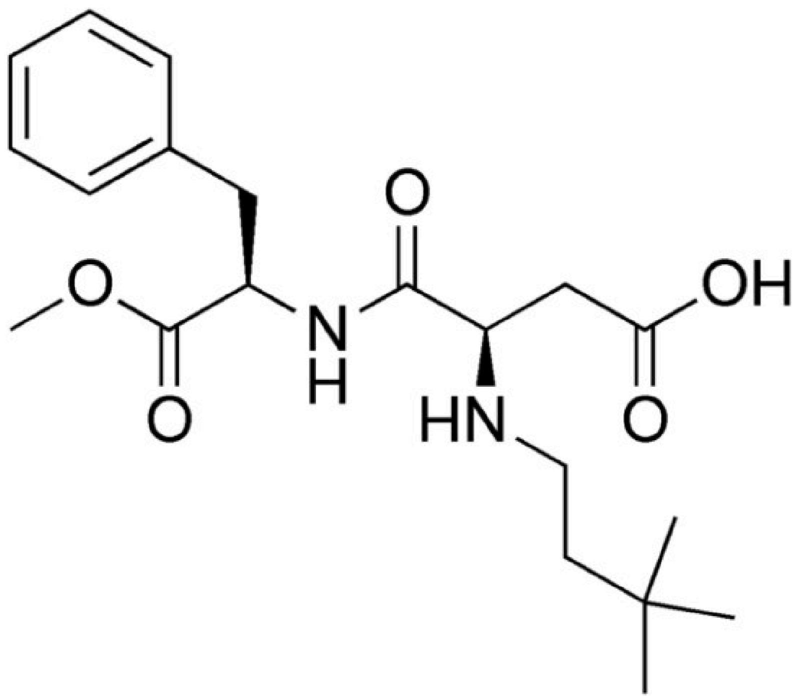

Figure D.4 *Structure of neotame. Image source*

Advantame

The newest, sweetest alternative sweetener approved by the FDA in 2014 is **advantame**. It is heat-stable and does not have a trade name yet.[9] Notice it also has a similar structure to aspartame and neotame. Like Neotame, it can be broken down to phenylalanine, but such small amounts are used that it is not a concern for those with PKU. However, it has a much higher acceptable daily intake than Neotame[10], meaning there is less concern about adverse effects from consuming too much.

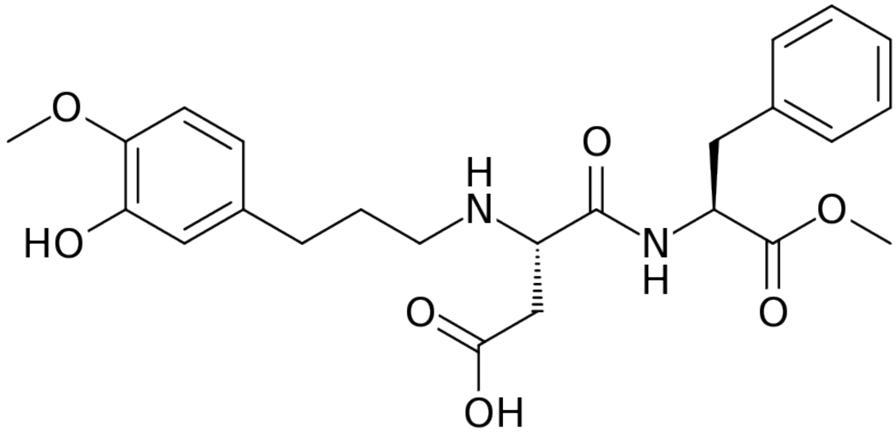

Figure D.5 *Structure of advantame. Image Source*

Acesulfame-Potassium (K)

Acesulfame-potassium (K) is not digested or absorbed, therefore it provides no energy or potassium to the body.[11] It is a heat-stable alternative sweetener.

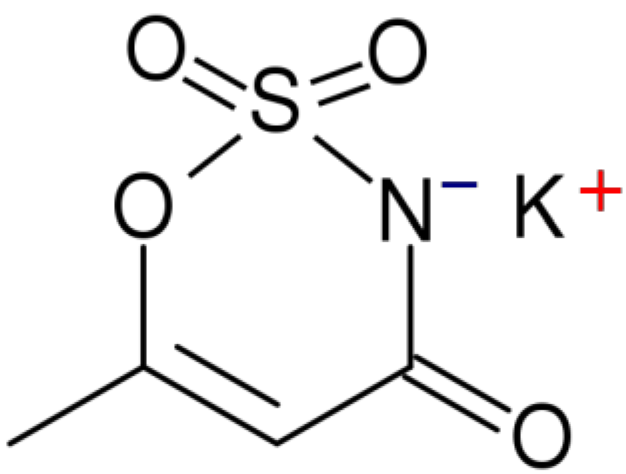

Figure D.6 *Structure of acesulfame-potassium* (K). *Image source*

Sucralose

Sucralose is structurally identical to sucrose except that three of the alcohol groups (OH) are replaced by chlorine molecules (Cl). This small change causes sucralose to not be digested and as such is excreted in feces.[12][13] It is a heat-stable alternative sweetener.

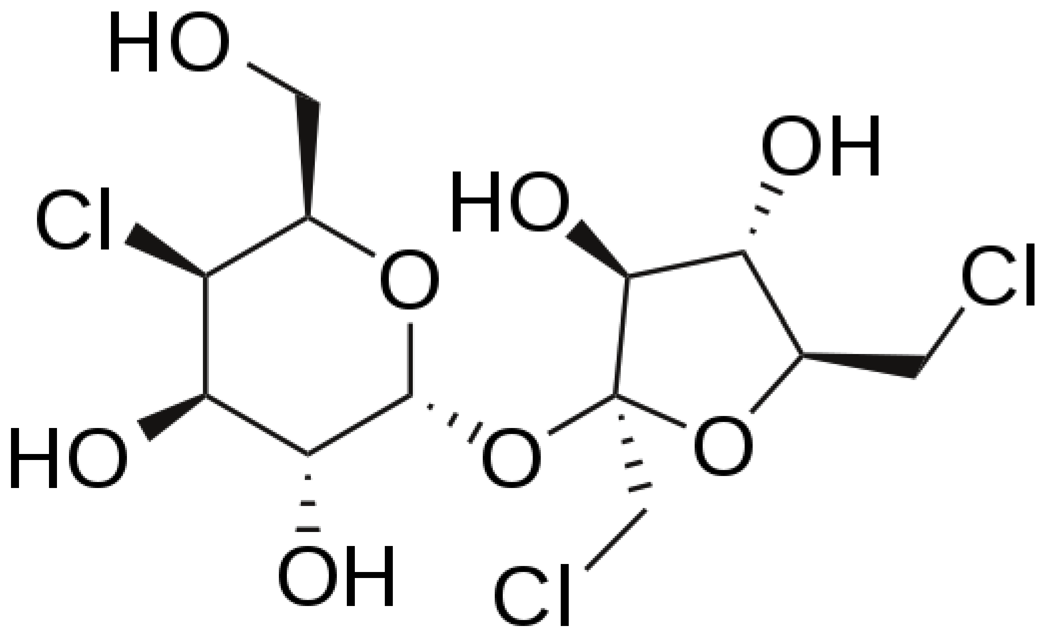

***Figure D.7** Structure of sucralose. Image source*

Stevia

Stevia is a heat-stable alternative sweetener derived from a South American shrub, with the leaves being the sweet part. The components responsible for this sweet taste are a group of compounds known as **steviol glycosides**. The structure of steviol is shown in Figure D.8.

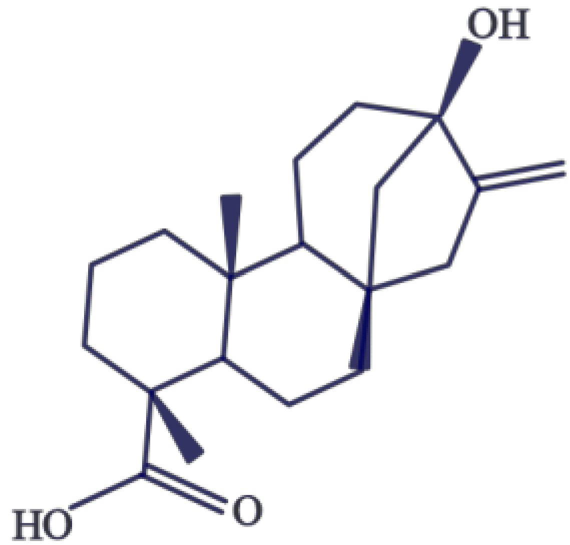

Figure D.8 *Structure of steviol. Image source*

The term glycoside means that there are sugar molecules bonded to steviol. The two predominant steviol glycosides are stevioside and rebaudioside A. Stevia sweeteners have been marketed as natural alternative sweeteners, something that has been stopped by lawsuits as described in the following link.

Web Link: What is natural and who decides?

Luo Han Guo (Monkfruit) Extracts

Luo Han Guo (aka *Siraitia grosvenrii* Swingle, monk fruit) extracts are a newer, natural heat-stable alternative sweetener option derived from a native Chinese fruit. These extracts are sweet because of the mogrosides that they contain.[14] The structure of a mogroside is shown below.

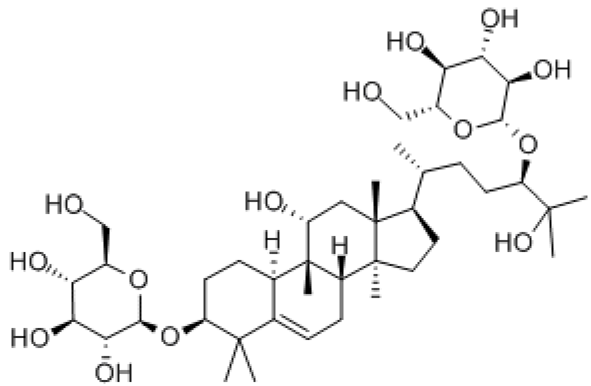

Figure D.9 *Structure of a mogroside. Image source*

Notes

1. Wardlaw GM, Hampl J. (2006) *Perspectives in Nutrition.* New York, NY: McGraw-Hill.
2. Whitney E, Rolfes SR. (2008) *Understanding Nutrition.* Belmont, CA: Thomson Wadsworth.
3. http://www.fda.gov/food/ingredientspackaginglabeling/foodadditivesingredients/ucm397725.htm
4. Byrd-Bredbenner C, Moe G, Beshgetoor D, Berning J. (2009) *Wardlaw's Perspectives in Nutrition.* New York, NY: McGraw-Hill.
5. Byrd-Bredbenner. et al. (2009)
6. Whitney, Rolfes. (2008)
7. Whitney, Rolfes. (2008)
8. Byrd-Bredbenner, et al. (2009)
9. http://www.fda.gov/food/ingredientspackaginglabeling/foodadditivesingredients/ucm397725.htm
10. Byrd-Bredbenner, et al. (2009)
11. Whitney, Rolfes. (2008)
12. Whitney, Rolfes. (2008)
13. Byrd-Bredbenner, et al. (2009)
14. http://www.fda.gov/food/ingredientspackaginglabeling/foodadditivesingredients/ucm397725.htm

Appendix E: Careers in Nutrition

UNIVERSITY OF HAWAIʻI AT MĀNOA FOOD SCIENCE AND HUMAN NUTRITION PROGRAM

If you are considering a career in **nutrition**, it is important to understand the opportunities that may be available to you. Both dietitians and nutritionists provide nutrition-related services to people in the private and public sectors. A dietitian is a healthcare professional who has registered credentials and can provide nutritional care in the areas of health and wellness for both individuals and groups. A nutritionist is an unregistered professional who may have the credentials of a dietitian, or may have acquired the knowledge via other avenues. People in both professions work to apply nutritional science, using evidence-based best practices, to help people nourish their bodies and improve their lives.[1]

Becoming a registered dietitian requires a Bachelor's or Master's degree in dietetics, including courses in biology, chemistry, biochemistry, microbiology, anatomy and physiology, nutrition, and food-service management. Other suggested courses include economics, business, statistics, computer science, psychology, and sociology. In addition, people who pursue this path must complete a dietetic internship and pass a national exam. Also, some states have licensure that requires additional forms and documentation. To become a registered dietetic technician you must complete a dietetic technician program that involves supervised practice. Forty-seven states have licensure requirements for registered dietitians and nutritionists. A few remaining states do not have laws that regulate this profession.[2] Go to https://www.cdrnet.org/certifications to learn more.

Working in Nutrition

Dietitians and nutritionists plan food and nutrition programs, promote healthy eating habits, and recommend dietary modifications. For example, a dietitian might teach a patient with **hypertension** how to follow the DASH diet and reduce their sodium intake. Nutrition-related careers can be extremely varied. Some individuals work in the government, while others are solely in the private sector. Some jobs in nutrition focus on working with athletes, while others provide guidance to patients with long-term, life-threatening diseases. But no matter the circumstance or the clientele, working in the field of diet and nutrition focuses on helping people improve their dietary habits by translating nutritional science into food choices.

In the public sector, careers in nutrition span from government work to community outreach. Nutritionists and dietitians who work for the government may become involved with federal food programs, federal agencies, communication campaigns, or creating and analyzing public policy. On the local level, clinical careers include working in hospitals and nursing-care facilities. This requires creating meal plans and providing nutritional guidance to help patients restore their health or manage chronic conditions. Clinical dietitians also confer with doctors and other health-care professionals to coordinate dietary recommendations with medical needs. Nutrition jobs in the community often involve working in public health clinics, cooperative extension offices, and HMOs to prevent disease and promote the health of the local community. Nutrition jobs in the nonprofit world involve anti-hunger organizations, public health organizations, and activist groups.

Nutritionists and dietitians can also find work in the private sector. Increased public awareness of food, diet, and nutrition has led to employment opportunities in advertising, marketing, and food manufacturing. Dietitians working in these areas analyze foods, prepare marketing materials, or report on issues such as the impact of vitamins and herbal supplements. Consultant careers can include working in wellness programs, supermarkets, physicians' offices, gyms, and weight-loss clinics. Consultants in private practice perform nutrition screenings for clients and use their findings to provide guidance on diet-related issues, such as weight reduction. Nutrition careers in the corporate world include designing wellness strategies and nutrition components for companies, working as representatives for food or supplement companies, designing marketing and educational campaigns, and becoming lobbyists. Others in the private sector work in food-service management at health-care facilities or at company and school cafeterias. Sustainable agricultural practices are also providing interesting private sector careers on farms and in food systems. There are employment opportunities in farm management, marketing and sales, compliance, finance, and land surveying and appraisal.

Working Toward Tomorrow

Whether you pursue nutrition as a career or simply work to improve your own dietary choices, what you have learned in this course can provide a solid foundation for the future. Remember, your ability to wake up, to think clearly, communicate, hope, dream, go to school, gain knowledge, and earn a living are totally dependent upon one factor—your health. Good health allows you to function normally and work hard to pursue your goals. Yet, achieving optimal health cannot be underestimated. It is a complex process, involving multiple dimensions of wellness, along with your physical or medical reality. The knowledge you have now acquired is also key. However, it is not enough to pass this nutrition class with good grades. Nutrition knowledge must be applied to make a difference in your life, throughout your life.

Throughout this textbook, we have focused on the different aspects of nutritional science, which helps to optimize health and prevent disease. Scientific evidence provides the basis for dietary guidelines and recommendations. In addition, researchers in the field of nutrition work to advance our knowledge of food production and distribution. Nutritional science also examines the ill effects of **malnutrition** and food insecurity. The findings that are uncovered today will influence not only what we eat, but how we grow it, distribute it, prepare it, and even enjoy it tomorrow.

Notes

1. Appendix C is adapted from Fialkowski Revilla, et al. *Human Nutrition.*
2. Dietitians and Nutritionists. Bureau of Labor Statistics. Occupational Outlook Handbook, 2010-11 Edition. https://www.bls.gov/ooh/healthcare/dietitians-and-nutritionists.htm. Updated April 13, 2018. Accessed April 15, 2018.

Glossary

Absorption

Absorption is the process of getting nutrients from the digestive tract into the blood or lymph.

Academy of Nutrition and Dietetics (AND)

AND is the largest organization of nutrition professionals worldwide and dietitians registered with the AND are committed to helping Americans eat well and live healthier lives. Source: https://www.eatright.org/

Acceptable Macronutrient Distribution Range (AMDR)

Acceptable Macronutrient Distribution Range (AMDR) is the calculated range of how much energy from carbohydrates, fats, and protein is recommended for a healthy diet.

Accessory organs

Accessory organs (salivary glands, liver, gallbladder, pancreas) do not come directly in contact with food or digestive contents, but still play a crucial role in the digestive process.

Acid–base balance

Acid–base balance refers to the balance between input (intake and production) and output (elimination) of hydrogen ion.
Source - https://www.sciencedirect.com/topics/medicine-and-dentistry/acid-base-balance

Activated vitamin D3

see calcitriol

Active site

The location within the enzyme where the substrate binds is called the enzyme's active site.

Active transport

Active transport requires energy to move against the concentration gradient (low to high concentration).

Adenosine Triphosphate (ATP)

Adenosine Triphosphate (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.

Adequate

Adequate refers to a diet that provides sufficient amounts of each essential nutrient, as well as fiber and calories.

Adequate Intake

Adequate Intake are created for nutrients when there is insufficient consistent scientific evidence to set an EAR for the entire population.

Adulthood

Adulthood is the period from adolescence to the end of life and begins at age nineteen.

Aerobic capacity

Aerobic capacity, or VO2 is the most common standard for evaluating cardiorespiratory endurance. VO2 max is your maximal oxygen uptake, and the VO2 max test measures the amount of oxygen (in relation to body weight) that you can use per minute. This value of oxygen consumption is referred to as VO2 max, 'V' meaning volume, and 'max' meaning the maximum amount of oxygen (O2) an individual is capable of utilizing.

Aerobic exercise

Aerobic exercise is continuous exercise (lasting more than 2 minutes) that can range from low to high levels of intensity.

Aerobic respiration

Aerobic respiration refers to the process by which cells make adenosine triphosphate (ATP) in the presence of oxygen. This is the reason why we breathe oxygen in from the air. Aerobic respiration involves glycolysis, the citric acid cycle, and the electron transport chain / chemiosmosis.

Albumin

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.

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.

Allergy

An allergy occurs when a protein in food triggers an immune response, which results in the release of antibodies, histamine, and other defenders that attack foreign bodies. Possible symptoms include itchy skin, hives, abdominal pain, vomiting, diarrhea, and nausea.

Allergy warnings

Food manufacturers are required by the FDA to list on their packages if the product contains any of the eight most common ingredients that cause food allergies. These eight common allergens are as follows: milk, eggs, peanuts, tree nuts, fish, shellfish, soy, and wheat.

Alpha-Lipoic acid

Alpha-Lipoic acid: reacts with reactive oxygen species such as superoxide radicals, hydroxyl radicals, hypochlorous acid, peroxyl radicals, and singlet oxygen. It also protects membranes by interacting with vitamin C, which may in turn recycle vitamin E.

Amenorrhea

Amenorrhea refers to the absence of a menstrual cycle.

Amino acids

Amino acids are the building blocks of proteins, simple subunits composed of carbon, oxygen, hydrogen, and nitrogen.

Anabolism

Anabolism refers to anabolic metabolic pathways. Anabolic pathways use energy to build polymers from smaller molecules.

Anaerobic cellular respiration

Anaerobic cellular respiration is a way that many types of bacteria produce adenosine triphosphate (ATP) in the absence of oxygen. During anaerobic cellular respiration, bacterial cells use the same three basic stages: glycolysis, the citric acid cycle, and the electron transport chain / chemiosmosis, but another molecule is used in place of oxygen gas. Human cells cannot do anaerobic respiration; in the absence of oxygen, human cells use lactic acid fermentation to make ATP.

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.

Anaphylaxis

Anaphylaxis is a life-threatening reaction (from a severe allergy) that results in difficulty breathing, swelling in the mouth and throat, decreased blood pressure, shock, or even death.

Anemia

Anemia is when a person's ability to carry oxygen throughout the body is lowered, due to a lack of red blood cells and/or hemoglobin.

Angiotensin

Angiotensin is a hormone that regulates blood pressure. When blood pressure is low, angiotensin targets three different organs (the adrenal glands, the hypothalamus, and the muscle tissue surrounding the arteries) to increase blood volume and raise blood pressure.

Anorexia nervosa

Anorexia nervosa is a potentially fatal condition characterized by undereating and excessive weight loss. People with this disorder are preoccupied with dieting, calories, and food intake to an unhealthy degree. Anorexics have a poor body image, which leads to anxiety, avoidance of food, a rigid exercise regimen, fasting, and a denial of hunger. The condition predominantly affects females.

Anthropometry

Anthropometry- measurements taken to assess growth and body composition to determine nutritional health: length, height, weight, head circumference, mid-arm circumference, skin-fold thickness, head/chest ratio, and hip/waist ratio.

Antibody

An antibody is a protein produced by the body's immune system when it detects harmful substances, called antigens. Examples of antigens include microorganisms (bacteria, fungi, parasites, and viruses) and chemicals.
Source - https://medlineplus.gov/ency/article/002223.htm

Antigen

An antigen is a substance that activates the immune response, causing production of antibodies.

Antioxidants

Antioxidants combat free radicals, ROS, and oxidative stress. They donate an electron from itself to a free radical, in order to regenerate a stable compound e.g. vitamins A, C and E.

Appetite

Appetite refers to when you want to eat food. This is different from hunger.

Apple-shaped

Apple-shaped bodies are people who carry more weight around the waist.

Ariboflavinosis

Riboflavin deficiency 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.

Arterial plaque

Arterial plaque is a fatty deposit that accumulates on the arterial wall.

Artificial sweeteners

Artificial sweeteners are zero calorie or low-calorie replacements for sugar that have been manufactured. They are not nutrients and have no nutritious value.

Atherosclerosis

Atherosclerosis is a condition that occurs when too much plaque builds up in your arteries, causing them to narrow.

Atrophic gastritis

Digestive secretions decline later in life as well, which can lead to atrophic gastritis (inflammation of the lining of the stomach).

B1

Thiamin - vitamin B1

B5

Pantothenic acid

B6

Vitamin B6 (Pyridoxine)

B7

Biotin (Vitamin B7)

Balanced Diet

A balanced diet results when you do not consume one nutrient at the expense of another, but rather get appropriate amounts of all nutrients.

Barrett's esophagus

Barrett's esophagus occurs when the linings of the esophagus transform to tissue types that are more consistent with the linings of the stomach or intestine.

Basal metabolic rate (BMR)

The basal metabolic rate (BMR) is the amount of energy required by the body to conduct its basic functions over a certain time period.

Basal metabolism

Basal metabolism refers to the calories you burn while at rest. See basal metabolic rate.

Beriberi

Thiamin deficiency, also known as beriberi, can cause symptoms of fatigue, confusion, movement impairment, pain in the lower extremities, swelling, and heart failure.

Bile

Bile is produced in the liver and takes part in fat digestion. Bile acts as an emulsifier, or detergent. It, along with phospholipids, breaks the large triglyceride droplets into smaller triglyceride droplets that increase the surface area accessible for digestive enzymes.

Binge-eating disorder

People who suffer from binge-eating disorder experience regular episodes of eating an extremely large amount of food in a short period of time. Binge eating is a compulsive behavior, and people who suffer from it typically feel it is beyond their control. This behavior often causes feelings of shame and embarrassment, and leads to obesity, high blood pressure, high cholesterol levels, Type 2 diabetes, and other health problems. Both males and females suffer from binge-eating disorder.

Bioavailability

The term bioavailability refers to the proportion or fraction of a nutrient, consumed in the diet, that is absorbed and utilized by the body.
Source - https://journals.sagepub.com/doi/pdf/10.1177/15648265110321S104

Biochemical Assessments

Also known as laboratory methods of assessment. Biochemical assessments include measuring a nutrient or its metabolite in the blood, feces, urine or other tissues that have a relationship with the nutrient

Biotin (B7)

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.

Biotinidase

A specific enzyme, biotinidase, is required to release biotin from protein so that it can be absorbed in the gut.

Blood pressure

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.

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 muscle and smaller proportion of fat than an unfit individual of the same weight.

Body Mass Index (BMI)

BMI is a person's weight in kilograms divided by the square of height in meters. A high BMI can indicate high body fatness.
Source - https://www.cdc.gov/obesity/adult/defining.html

Bone mineral density (BMD)

A bone mineral density (BMD) test measures how much calcium and other types of minerals are in an area of your bone.
https://medlineplus.gov/ency/article/007197.htm

Bulimia nervosa

Bulimia nervosa is characterized by alternating cycles of overeating and undereating. People who suffer from it partake in binge eating, followed by compensatory behavior, such as self-induced vomiting, laxative use, and compulsive exercise. As with anorexia, most people with this condition are female.

Calcitriol

The activated form of vitamin D. (Vitamin D3).

Calcium

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.

Calorie

A Calorie is a unit of food energy. 1 kilocalorie = 1 Calorie = 1000 calories

Cancer

Cancer is a term used for diseases in which abnormal cells divide without control. Cancer cells can spread to other parts of the body through the blood and lymph systems. There are more than 100 kinds of cancer.

Canning

In canning, foods are placed into jars or cans and heated to a temperature that destroys any bacteria, often by boiling. The containers are also vacuum sealed to prevent other bacteria from entering after the container cools down.

Carbohydrates

Carbohydrates are a macronutrient composed of carbon, hydrogen, and oxygen in a 1:2:1 ratio and are soluble in water.

Cardio zone

The cardio zone occurs when high intensity aerobic activity keeps the heart rate between about 70 to 85% of your maximum heart rate.

Cardiorespiratory endurance

Cardiorespiratory endurance is the ability to perform large-muscle, whole-body exercise at moderate to high intensities for extended periods of time.
https://www.ncbi.nlm.nih.gov/books/NBK241309/

Carotenoids

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.

Catabolism

Catabolism refers to catabolic metabolic pathways. Catabolic pathways break down polymers into their monomers, releasing energy

Catalase

Antioxidant enzyme that converts hydrogen peroxide to water, using iron as a cofactor.

Celiac disease

Celiac disease is a condition in which people cannot consume the protein gluten because it causes their body to generate an autoimmune response (immune cells attack the body's own cells) that causes damage to the villi in the intestine.

Cells

Cells are the most basic building units of life. All living things are composed of cells.

Cellular respiration

Glucose and other molecules from food are broken down to release energy in a complex series of chemical reactions that together are called cellular respiration.

Centers for Disease Control and Prevention (CDC)

The Centers for Disease Control and Prevention (CDC) are the government agency tasked with monitoring illness in the United States. They gather data from public health departments in all 50 states and monitor the data to detect new outbreaks of disease, monitor existing health concerns, and track the success of public health initiatives. The CDC also carries out research and trains public health experts who can be dispatched to control outbreaks of disease. Much of the CDC's work is focused on infectious disease, but they also track cases of foodborne illness.https://www.cdc.gov/

Chemical Digestion

Chemical Digestion: Enzymatic breakdown of food

Chemiosmosis

This flow of hydrogen ions across the membrane through ATP synthase is called chemiosmosis.

Child and Adult Care Food Program (CACFP)

The Child and Adult Care Food Program (CACFP) offers meals and snacks at child-care centers, daycare homes, and after-school programs.

Childhood

Childhood, takes place from ages four to eight.

Chloride

Chloride is the primary negatively-charged ion in extracellular fluid. Chloride aids in fluid balance mainly because it follows sodium in order to maintain charge neutrality. It also have many other functions.

Cholecystectomy

cholecystectomy is surgery to remove the gallbladder.

Cholecystokinin (CCK)

Cholecystokinin (CCK) stimulates the secretion of digestive enzymes, also stimulates the contraction of the gallbladder causing the secretion of stored bile into the duodenum.

Cholesterol

Cholesterol is a fat-like substance in the body. High levels in the blood can lead to heart disease and stroke.

Chylomicrons

Chylomicrons are lipoproteins formed by the merging of a protein carrier, triglycerides, cholesterol, and phospholipids.

Cis fatty acid

When the hydrogen atoms are bonded to the same side of the carbon chain, it is called a cis fatty acid.

Citric acid cycle

Citric acid cycle is a series of reactions also known as the tricarboxylic acid (TCA) cycle or the Krebs cycle. The citric acid cycle is the final common pathway for the oxidation of fuel molecules—amino acids, fatty acids, and carbohydrates. Most fuel molecules enter the cycle as acetyl coenzyme.
Source - https://www.ncbi.nlm.nih.gov/books/NBK21163/

Clinical assessment

Clinical signs and symptoms that might indicate potential specific nutrient deficiency, attention are given to organs such as skin, eyes, tongue, ears, mouth, hair, nails, and gums.

Cobalamin

Cobalamin is vitamin B12

Coenzymes

Small organic molecules that are required for enzyme activation. (Organic cofactors)

Cofactors

Cofactors can be either organic or inorganic molecules that are required by enzymes to function.

Colic

Colic is a common problem during infancy, characterized by crankiness and crying jags.

Collagen

Collagen is the most abundant protein in the body. Collagen is a strong, fibrous protein made up of mostly glycine and proline.

Colostrum

Colostrum is produced immediately after birth, prior to the start of milk production, and lasts for several days after the arrival of the baby. It is thicker than breast milk, and is yellowish or creamy in color. Colostrum is packed with concentrated nutrition for newborns. This special milk is high in fat-soluble vitamins, minerals, and immunoglobulins (antibodies) that pass from the mother to the baby. Immunoglobulins provide passive immunity for the newborn and protect the baby from bacterial and viral diseases.

Complementary protein

Incomplete protein foods are called complementary foods because when consumed in tandem they contain all nine essential amino acids at adequate levels.

Complete protein

Foods that contain all nine essential amino acids are called complete protein sources, or high-quality protein sources.

Concentration gradient

Concentration gradient is a result of an unequal distribution of solutes within a solution.

Consumer Price Index (CPI)

The Consumer Price Index (CPI) measures changes in the price level paid for goods and services. This economic indicator is based on the expenditures of the residents of urban areas, including working professionals, the self-employed, the poor, the unemployed, and retired workers, as well as urban wage earners and clerical workers.

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.

Coronary artery disease

Coronary artery disease is a type of heart disease that occurs when a substance called plaque builds up in the arteries that supply blood to the heart.

Cretinism

A condition that can be caused by iodine deficiency during fetal development or infancy. Lack of thyroid hormone during brain development can lead to severe physical and neurological impairment.

Crohn's disease

Crohn's disease can occur anywhere throughout the GI tract, but most commonly occurs in the last part of the ileum. Crohn's disease may also involve all layers of the intestine.

Cystic fibrosis (CF)

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.

Daily Value (DV)

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.

Defecation

Defecation: Elimination of solid, indigestible waste.

Dehydration

Dehydration refers to water loss from the body without adequate replacement. Physiologically, dehydration decreases blood volume. 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.

Denaturation

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.

Dietary Approaches to Stop Hypertension (DASH)

Dietary Approaches to Stop Hypertension (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.

Dietary fiber

Dietary fibers are polysaccharides that are highly branched and cross-linked. 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.

Dietary folate equivalents (DFE)

Dietary folate equivalents (DFE) to reflect the fact that folic acid is more bioavailable and easily absorbed than folate found in food.

Dietary Reference Intakes (DRI)

"Dietary Reference Intakes" (DRI) is an umbrella term for four reference values: Estimated Average Requirements (EAR), Recommended Dietary Allowances (RDA), Adequate Intakes (AI), and Tolerable Upper Intake Levels (UL).

Dietitians

Dietitians are nutrition professionals who integrate their knowledge of nutritional science into helping people achieve a healthy diet and develop good dietary habits. 1.1.

Digestion

The process of breaking down food into its component parts is called digestion. Both chemical and mechanical break down occur in the digestive tract.

Disaccharides

Disaccharides are made up of two monosaccharides and are commonly found in fruits and vegetables, including sugar beets and sugar cane, and as lactose in dairy products.

Discretionary Calories

When following a balanced, healthful diet with many nutrient-dense foods, you may consume enough of your daily nutrients before you reach your daily calorie limit. The remaining calories are discretionary (to be used according to your best judgment).

Disease

Disease is defined as any abnormal condition affecting the health of an organism, and is characterized by specific signs and symptoms.

Diverticula

Diverticula (plural, diverticulum singular), or out- pouches, are formed at weak points in the large intestine, primarily in the lowest section of the sigmoid colon.

Diverticulitis

Diverticulitis occurs when one or a few diverticula in the wall of your colon become inflamed.
Source - https://www.niddk.nih.gov/health-information/digestive-diseases/diverticulosis-diverticulitis

Duodenum

Duodenum is the first part of the small intestine.

Dyslipidemia

Dyslipidemia is the condition of having high levels of cholesterol and lipids in the blood, and/or low levels of high-density lipoprotein (HDL). Dyslipidemia can lead to cardiovascular disease and other medical concerns.

Dysphagia

Some older adults have difficulty getting adequate nutrition because of the disorder dysphagia, which impairs the ability to swallow. Any damage to the parts of the brain that control swallowing can result in dysphagia, therefore stroke is a common cause. Dysphagia is also associated with advanced dementia because of overall brain function impairment.

Eating disorders

Eating disorders involve extreme behavior related to food and exercise.

Eicosanoids

Eicosanoids are powerful hormones that control many important body functions, such as the central nervous system and the immune system.

Electrolytes

Electrolytes are substances that, when dissolved in water, dissociate into charged ions.

Electron transport chain

The energy carrier molecules produced during glycolysis and the citric acid cycle are used to power the electron transport chain and chemiosmosis (together known as oxidative phosphorylation). The end result of this is the majority of ATP produced during aerobic.

Empty calories

When a food provides primarily calories, and little else of value to our health, we say that food has "empty calories."

Emulsifiers

Emulsifiers can keep oil and water mixed. Emulsions are mixtures of two liquids that do not mix.

Energy

Energy is the ability to do work or to create some kind of change.

Energy balance

Energy balance is achieved when intake of energy is equal to energy expended. See positive and negative energy balance as well.

Enrichment

Enrichment is applicable when the natural contents of some micronutrients normally available in the food are intentionally increased.
Source - https://www.sciencedirect.com/topics/food-science/food-enrichment

Enterocytes

Enterocytes are the cells that line the villi of the small intestine and absorb nutrients. (also known as enteric cells or brush border cells).

Environmental Protection Agency (EPA)

The Environmental Protection Agency (EPA) works to protect human health and the environment. Founded in 1970, the agency conducts environmental assessment, education, research, and regulation. The EPA also works to prevent pollution and protect natural resources. Two of its many regulatory practices in the area of agriculture include overseeing water quality and the use of pesticides.The EPA approves pesticides and other chemicals used in agriculture, and sets limits on how much residue can remain on food. The FDA analyzes food for surface residue and waxes

Enzymes

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.

Epidemiological studies

The CDC defines epidemiological studies as scientific investigations that define frequency, distribution, and patterns of health events in a population. These studies describe the occurrence and patterns of health events over time.

Epigenetics

Epigenetics is the study of how your behaviors and environment can cause changes that affect the way your genes work. (https://www.cdc.gov/genomics/disease/epigenetics.htm)

Ergocalciferol

Inactive form of vitamin D, must be converted to calcitriol to function. (Also called Vitamin D2.)

Essential amino acids

Essential amino acids are amino acid we must consume as the body cannot synthesize them either at all or in sufficient amounts. There are nine forms and they must be consumed.

Essential fatty acids

There are some fatty acids that the body cannot synthesize and these are called essential fatty acids. Essential fatty acids must be obtained from food. They fall into two categories—omega-3 and omega-6.

Essential nutrients

Essential nutrients - Essential nutrients are substances we must consume to stay healthy. 1.2

Estimated Average Requirements (EAR)

Estimated Average Requirements (EAR) 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.

Estimated Energy Requirement (EER)

Estimated Energy Requirement (EER) is the estimated number of calories needed to maintain caloric balance.

Estimated Energy Requirement (EER)

EER is a standardized mathematical prediction of a person's daily energy needs in kilocalories per day required to maintain weight.

Extracellular water

The extracellular water compartment into interstitial fluid (in the spaces between cells), blood plasma, and other bodily fluids such as the cerebrospinal fluid which surrounds and protects the brain and spinal cord.

Extrusion reflex.

If parents try to feed an infant who is too young or is not ready, their tongue will push the food out, which is called an extrusion reflex.

Facilitated diffusion

Facilitated diffusion is the type of passive transport is similar to diffusion in that it also moves with the concentration gradient (higher concentration to lower concentration). While it requires no energy, it does require a carrier protein to transport the solute across.

Failure-to-thrive (FTT)

Insufficient weight or height gain during infancy may indicate a condition known as failure-to-thrive (FTT), which is characterized by poor growth. FTT can happen at any age, but in infancy, it typically occurs after six months.

Farm Bill

The Farm Bill (introduced in 1990) is a massive piece of legislation that determines the farm and food policy of the federal government. It addresses policy related to federal food programs and other responsibilities of the USDA. The Farm Bill also covers a wide range of agricultural programs and provisions, including farm subsidies and rural development. And, it influences international trade, commodity prices, environmental preservation, and food safety.

Fast-releasing carbohydrates

Fast-releasing carbohydrates, often called simple sugars, are quickly broken down to provide energy. (see slow-releasing carbohydrates)

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. About 50% of the calories burned in this zone come from fat.

Fat-soluble

Fat-soluble molecules are molecules that dissolve in oils and other lipids, not in water. Fat-soluble nutrients are found in foods containing fat and are absorbed first into the lymphatic system and then moved to the blood system. Excess fat-soluble vitamins are stored in fatty tissue or the liver.

Female athlete triad

The “female athlete triad” is a combination of three conditions characterized by amenorrhea, disrupted eating patterns, and osteoporosis.

Fermentation

Fermentation is the process by which some types of bacteria or yeast break down carbohydrates to make ATP in the absence of oxygen. Some types of fermentation produce molecules that are toxic to bacteria. Different fermenting microbes produce different molecules through fermentation, including alcohol, carbon dioxide, and acids. The ethanol in wine, beer, and other alcoholic beverages and the carbon dioxide that causes bread to rise before baking are both products of fermentation. When fermentation is being used as food preservation, the fermentation product is usually lactic acid.

Fetal alcohol syndrome

Consumption of alcoholic beverages results in a range of abnormalities that fall under the umbrella of fetal alcohol spectrum disorders. They include learning and attention deficits, heart defects, and abnormal facial features

Fetus

From the ninth week after conception until birth, a developing human baby is called a fetus.

Flexibility

Flexibility is the range of motion available to your joints.

Fluid balance

Fluid balance refers to maintaining the distribution of water in the body.

Fluoride

Fluoride is known mostly as the mineral that combats tooth decay. It assists in tooth and bone development and maintenance.

Fluorosis

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

Folate

Folate is a required coenzyme for the synthesis of the amino acid methionine, and for making RNA and DNA.

Food additives

Food additives are substances added to food to maintain or improve its safety, freshness, taste, texture, or appearance. https://www.who.int/news-room/fact-sheets/detail/food-additives

Food and drug administration (FDA)

The Federal Food, Drug, and Cosmetic Act of 1938 gives the FDA authority over food ingredients. The FDA enforces the safety of domestic and imported foods. It also monitors supplements, food labels, claims that corporations make about the benefits of products, and pharmaceutical drugs. Sometimes, the FDA must recall contaminated foods and remove them from the market to protect public health.

Food infections

Food infections are from microbes in food.

Food intolerance

A food intolerance is an unpleasant digestive tract response to certain foods that does not involve an immune reaction. Lactose intolerance is the most common example.

Food intoxications

Food intoxications are caused by natural toxins or harmful chemicals. These and other unspecified agents are major contributors to episodes of acute gastroenteritis and other kinds of foodborne illness. Like pathogens, toxins and chemicals can be introduced to food during cultivation, harvesting, processing, or distribution.

Food irradiation

Food irradiation (the application of ionizing radiation to food) is a technology that improves the safety and extends the shelf life of foods by reducing or eliminating microorganisms and insects.

Food jag

Toddlers may go on a food jag and eat one or two preferred foods—and nothing else.

Food poisoning

See foodborne illness

Food preservation

Food preservation includes the handling or treating of food to prevent or slow down spoilage.

Food processing

Food processing involves transforming raw ingredients into packaged food, from fresh-baked goods to frozen dinners.

Foodborne diseases

See Foodborne illness (food poisoning)

Foodborne illness (food poisoning)

Foodborne illness (food poisoning) is a common public health problem that can result from exposure to a disease-causing microbe or a toxin via food or beverages.

Fortification

Fortification is adding new nutrients to enhance a food's nutritive value. For example, folic acid is typically added to cereals and grain products, while calcium is added to some orange juice.

Free Radical

Free Radical – a molecule with an unpaired electron in its outer orbital. Free radicals are highly reactive because they actively seek an electron to stabilize (pair with) the unpaired electron within the molecule. This makes free radicals very strong oxidants.

Functional fiber

Functional fibers have been added to foods and have been shown to provide health benefits to humans.

Functional foods

Functional foods are generally understood to be a food, or a food ingredient, that may provide a health benefit beyond the traditional nutrients (macro and micronutrients) it contains. Functional foods are often a rich source of a phytochemicals or zoochemicals, or contain more of a certain nutrient than a normal food.

Gallbladder

The gallbladder is a GI tract accessory organ that stores bile.

Gallstones

Gallstones are formed when bile hardens in the gallbladder.

Gastric pits

Gastric pits are indentations in the stomach's surface that contain hormone- and enzyme-producing cells of the stomach.

Gastritis

see -atrophic gastritis

Gastroesophageal reflux disease (GERD)

The leaking of the very acidic gastric contents results in a burning sensation commonly referred to as "heartburn." If this occurs more than twice per week and is severe, the person may have gastroesophageal reflux disease (GERD).

Gastrointestinal (GI or digestive) tract

The gastrointestinal (GI or digestive) tract, the passageway through which our food travels, is a "tube within a tube."

Genes

Genes are responsible for your many traits as an individual and are defined as the sequences of DNA that code for all the proteins in your body.

Genetically modified organisms

Genetically modified organisms (also known as GM or GMO foods), are plants or animals that have undergone some form of genetic engineering.

Genome

The complete set of genes in an organism's DNA.

Gestational diabetes

Gestational diabetes is an abnormal glucose tolerance during pregnancy. The body becomes resistant to the hormone insulin, which enables cells to transport glucose from the blood.

Gestational hypertension

Gestational hypertension is a condition of high blood pressure during the second half of pregnancy. Also referred to as pregnancy-induced hypertension.

Glucagon

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.

Glucogenic

Glucogenic amino acids , and can be converted to either pyruvate or a citric acid cycle intermediate.

Gluconeogenesis

Gluconeogenesis is the synthesis of glucose from non-carbohydrate sources.

Glucose

Glucose, the most abundant carbohydrate in the human body, is a monosaccharide, has six carbon atoms, twelve hydrogen atoms, and six oxygen atoms.

Glutathione peroxidase (GPX)

Glutathione peroxidase (GPX): is a selenoenzyme that converts hydrogen peroxide to water. It can also convert other reactive oxygen species (ROSs) to water.

Gluten

Gluten is a protein that is bound to starch in the endosperm of grains such as: wheat, barley, rye and triticale.

Glycemic index (GI)

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).

Glycemic load

The Glycemic load is calculated by multiply the glycemic index by the amount to carbohydrates in the food and dividing the answer by 100.

Glycogenesis

Glycogenesis occurs when there is a lot of ATP present, the extra glucose is converted into glycogen for storage.

Glycogenolysis

The break down of glycogen to glucose is called glycogenolysis.

Glycolysis

Glycolysis is a step in cellular respiration when a 6-carbon glucose is broken in half and a small amount of energy is transferred to ATP and other energy carrier molecules.

Gout

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.

Greenwashing

"Greenwashing" is a derisive term (similar to "whitewashing") for a corporation or industry falsely utilizing a pro-environmental image or message to expand its market base.

Hazard Analysis Critical Control Points (HACCP)

The Hazard Analysis Critical Control Points (HACCP) is a program within the food industry designed to promote food safety and prevent contamination by identifying all areas in food production and retail where contamination could occur.

Head Start

Head Start is a health and development program for children aged three to five, from low- income families. The philosophy behind the organization is that early intervention can help address the educational, social, and nutritional deficiencies that children from lower-income families often experience.

Health

Health as "a state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity

Health claim

A health claim is a statement that links a particular food with a reduced risk of developing disease and must be evaluated by the FDA prior to use.

Heart disease

"heart disease" refers to several types of heart conditions. The most common type is coronary artery disease, which can cause a heart attack. Other kinds of heart disease may involve the valves in the heart, or the heart may not pump well and cause heart failure.

Heat cramps

Heat cramps are involuntary muscle spasms that usually involve the muscle being exercised, which causes by an imbalance of electrolytes, usually sodium.

Heat exhaustion

Heat exhaustion occurs when dehydration decreases blood volume to a degree that cooling the body is no longer possible. Symptoms include heavy sweating, rapid breathing, and disorientation.

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.

Helicobacter pylori (H. pylori)

Helicobacter pylori (H. pylori) is a spiral-shaped bacterium that penetrates the stomach lining , making the tissue more susceptible to the damaging effects of acid, leading to the development of sores and ulcers.

Hemochromatosis

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.

Hemoglobin

Hemoglobin is the oxygen-carrying protein within red blood cells.

Hemorrhoids

Hemorrhoids are swollen or inflamed veins of the anus or lower rectum.

High-fructose corn syrup (HFCS)

High-fructose corn syrup (HFCS) is a sweetener made from corn syrup that has been processed to contain nearly equal amounts of the simple sugars fructose and glucose (42% fructose or 55% fructose). HFCS is often used as a replacement for sucrose (table sugar) in processed foods, due to its increased sweetness and ease of use in industrial recipes.

High-quality protein

A protein is considered high-quality, by nutritional standards, if it contains all the essential amino acids in the proportions needed by the human body.

Hitting the wall

Prolonged muscle use (such as exercise for longer than a few hours) can deplete the glycogen energy reserves and is characterized by fatigue and a decrease in exercise performance. This is often referred to as "hitting the wall".

Hormone

A hormone is a compound that is produced in one tissue, released into circulation, then has an effect on a different organ.

Hunger

Hunger is a physical sensation of feeling empty that is communicated to the brain by both mechanical and chemical signals from the periphery. Contrast with appetite.

Hydrogenation

Hydrogenation is the addition of hydrogen to a molecule. This is typically done with oils to make them more saturated, which makes them more solid and stable at room temperature.

Hypercalcemia

Hypercalcemia is an abnormally high level of calcium in the blood.

Hyperemesis gravidarum

Hyperemesis gravidarum is a severe form of pregnancy-associated nausea. It is marked by prolonged vomiting, which can result in dehydration and require hospitalization.

Hyperglycemia

Hyperglycemia is when blood glucose levels are higher than normal. Hyperglycemia is usually associated with diabetes, but it can occur in response to medications or other health conditions.

Hyperkalemia

Hyperkalemia is abnormally high levels of potassium in the blood. 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.

Hypertension

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.

Hypoglycemia

Hypoglycemia is when blood glucose levels are lower than normal. Hypoglycemia can lead to feelings of tiredness, anxiety, or irritability, and if not treated, can progress to seizures and lack of consciousness, as the brain is unable to function without glucose as an energy source.

Hypokalemia

Hypokalemia is insufficient potassium levels in the body. 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.

Hyponatremia

Hyponatremia is abnormally low blood sodium levels. The symptoms of hyponatremia, include nausea, muscle cramps, confusion, dizziness, and in severe cases, coma and death.

Hypothalamus

The hypothalamus is a region of the brain that controls many different unconscious activities, including appetite and body temperature.

Hypothyroidism

Hypothyroidism occurs when insufficient amounts of thyroid hormone are produced. Signs and symptoms including fatigue, sensitivity to cold, constipation, weight gain, depression, dry skin, and paleness.

Incomplete protein sources

Foods that contain some of the essential amino acids, but not all, are called incomplete protein sources.

Infancy

Infancy is the earliest part of childhood. It is the period from birth through age one.

Inflammatory bowel disease (IBD)

Inflammatory bowel disease (IBD) refers to a number of inflammatory conditions in the intestine. The two most common are Crohn's disease and ulcerative colitis.

Ingestion

Taking food into the mouth.

Insensible water loss

Insensible water loss is the loss of water from our bodies of which we are unaware.

Insulin

Insulin is a hormone released from the pancreas that brings blood glucose levels down. 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.

Interventional clinical trial studies

Interventional clinical trial studies are scientific investigations in which participants receive a specific treatment (or intervention). Participants receiving the intervention are compared to a control group that receives no intervention or a placebo.

Intoxication

See food intoxication.

Iodine

Iodine is a micronutrient that is used to make thyroid hormone. Thyroid hormones regulate protein synthesis, metabolism and enzymatic activity. They are also required for proper skeletal and central nervous system development in fetuses and infants.

Irritable bowel syndrome (IBS)

Irritable bowel syndrome (IBS) is characterized by muscle spasms in the colon that result in abdominal pain, bloating, constipation, and/or diarrhea.

Jaundice

Jaundice is a yellowing of the skin and whites of the eyes caused by liver failure. Bilirubin is a substance created by the breakdown of red blood cells and is removed by the liver. If the liver cannot remove bilirubin, bilirubin accumulates in the skin, giving the yellow tone of jaundice. Jaundice can also occur in newborns when a newborn's liver does not efficiently remove bilirubin from the blood.

Ketogenic amino acids

Ketogenic amino acids can only be converted to acetyl-CoA or acetoacetyl-CoA, which cannot be used for gluconeogenesis.

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.

Kinetic energy

Kinetic energy is energy in motion.

Kwashiorkor

Kwashiorkor occurs when a person has limited energy intake and a diet that is lacking protein.

Lactase

Lactase is a digestive enzyme that breaks the bond between glucose and galactose within the disaccharide lactose.

Lactation

Lactation is the synthesis and secretion of breast milk.

Lacto-ovo vegetarian

Lacto-ovo vegetarians eat only plant products, eggs, and dairy.

Lean meat

Lean foods contain fewer than a set amount of grams of fat for that particular cut of meat.

Leptin

Leptin is a hormone produced by fat which suppresses appetite by communicating to the satiety center in the hypothalamus that the body is in positive energy balance.

Light (Lite)

Light or lite refer to foods that contain 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

Lingual lipase

Lingual lipase is a lipid-digesting enzyme in the mouth. It has a small role in digestion in adults, but may be important for infants to help break down triglycerides in breast milk.

Lipid

Lipids are a family of macronutrient molecules composed of carbon, hydrogen, and oxygen, but unlike carbohydrates, they are insoluble in water.

Lipogenesis

Lipogenesis is the synthesis of fatty acids, beginning with acetyl-CoA.

Lipolysis

Lipolysis is the cleavage of triglycerides to glycerol and fatty acids.

Listeriosis

A foodborne illness caused by the bacteria *Listeria monocytogenes* can cause spontaneous abortion and fetal or newborn meningitis. Symptoms include headaches, muscle aches, nausea, vomiting, and fever. If the infection spreads to the nervous system, it can result in a stiff neck, convulsions, or a feeling of disorientation.

Lysozyme

Lysozyme helps break down bacteria cell walls to prevent a possible infection.

Macrobiotic diet

The macrobiotic diet is part of a health and wellness regimen based in Eastern philosophy. It combines certain tenets of Zen Buddhism with a vegetarian diet and supports a balance of the oppositional forces of yin and yang. Foods are paired based on their so-called yin or yang characteristics. Yin foods are thought to be sweet, cold, and passive, while yang foods are considered to be salty, hot, and aggressive.

Macronutrients

Nutrients that are needed in large amounts and can be processed by the body into cellular energy - protein, fats and carbohydrates.

Magnesium

Essential mineral that serves as an essential cofactor for many enzymes. Magnesium also has a role in bone structure.

Major minerals (Macrominerals)

Major minerals (sometimes called macrominerals) are 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.

Malnutrition

Malnutrition refers to one not receiving proper nutrition and does not distinguish between the consequences of too many nutrients or the lack of nutrients, both of which impair overall health.

Maltase

Maltase is a digestive enzyme that breaks the bond between the two glucose units of maltose.

Manganese

Manganese (a micronutrient) is a cofactor for enzymes that are required for carbohydrate and cholesterol metabolism, bone formation, and the synthesis of urea.

Marasmic kwashiorkor

Marasmic kwashiorkor is when kwashiorkor and marasmus coexist as a combined syndrome.

Marasmus

Marasmus is a form of severe malnutrition that occurs when a person is getting insufficient energy and protein.

Mature milk

Mature milk is the final fluid that a new lactating parent produces. In most individuals, it begins to secrete at the end of the second week after childbirth. There are two types of mature milk that appear during a feeding. Foremilk occurs at the beginning and includes water, vitamins, and protein. Hind-milk occurs after the initial release of milk and contains higher levels of fat, which is necessary for weight gain.

Meaningful antioxidant

An antioxidant is considered meaningful when it has these two characteristics: 1) Found in appreciable amounts in a location where there are free radicals/ROS that need to be quenched, 2) It is not redundant with another antioxidant that is already providing that function.

Mechanical digestion

Mechanical digestion involves physically breaking food down into smaller pieces, usually through muscle contractions, such as occurs during chewing or in the stomach.

Medical foods

Medical foods are designed for administration directly into the stomach under the guidance of a medical professional (enteric administration). Medical foods are created to meet very specific nutritional requirements for patients with health issues such as kidney or liver disease, or comatose patients.

Mediterranean diet

The Mediterranean diet focuses on small portions of nutritionally-sound food. This diet features food from plant sources, including vegetables, fruits, whole grains, beans, nuts, seeds, breads and potatoes, and olive oil. It also limits the consumption of processed foods and recommends eating locally grown foods rich in micronutrients and antioxidants. Other aspects of this eating plan include consuming fish and poultry at least twice per week, eating red meat only a few times per month, having up to seven eggs per week, and drinking red wine in moderation.

Megaloblastic anemia

Megaloblastic anemia is characterized by very large, abnormal red blood cells. This is usually due to a lack of due to a lack of folate or vitamin B12.

Menopause

Menopause is the ending of menstruation due to lower levels of estrogen and progesterone that occur with age. A person is considered to have reached menopause when they have not menstruated in 12 months. Menopause typically occurs in the late forties or early fifties and may include a number of symptoms, such as hot flashes, mood swings, and weight gain.

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.

Metabolic pathway

A metabolic pathway is a series of chemical reactions that takes a starting molecule and modifies it, step-by-step, through a series of metabolic intermediates, eventually yielding a final product.

Metabolism

Together, all of the chemical reactions that take place inside cells, including those that consume or generate energy, are referred to as the cell's metabolism.

Micelles

Micelles are droplets with a fatty acid (hydrophobic) core and a water-soluble (hydrophilic) exterior. Bile salts in the digestive tract envelop fatty acids and monoglycerides to form micelles.

Micronutrients

Micronutrients are nutrients required by the body in lesser amounts, but are still essential for carrying out bodily functions. Minerals and vitamins are micronutrients.

Microvilli

Microvilli are microscopic cell extensions that increase the surface area of a cell. They do not move. An example is the brush border membrane on intestinal cells.

Middle age

Middle age is the period of adulthood that stretches from age thirty-one to fifty.

Minerals

Minerals are solid inorganic substances that form crystals and are classified depending on how much of them we need. Trace minerals such as zinc, iron, or iodine are only required in a few milligrams or less per day. Major minerals such as calcium, sodium, and potassium are required in hundreds of milligrams per day.

Moderate physical activity

Moderate physical activities are those where "you can talk while you do them, but can't sing."

Moderation

Moderation in nutrition means not eating to the extremes, neither too much nor too little.

Modifiable risk factors

Modifiable risk factors are those we can control, such as exercise, diet, sun exposure, smoking, and alcohol use.

Modified foods

Modified foods have been fortified, enriched, or enhanced with additional nutrients or bioactive compounds to improve their nutritional value and health attributes. Examples include calcium-fortified orange juice, iodized salt, and cereals fortified with vitamins and minerals.

Monosaccharides

Monosaccharides are the simplest of all sugars and are the building blocks of all carbohydrates. The monosaccharides are glucose, fructose, and galactose.

Monounsaturated fatty acid

Any fatty acid that has only one double bond is a monounsaturated fatty acid.

Morning sickness

Nausea and vomiting associated with pregnancy, typically in the first trimester. Although referred to as "morning sickness," the nausea and vomiting can occur all day long.

Myoglobin

Myoglobin is a protein found in the muscle tissues that enhances the amount of available oxygen for muscle contraction.

MyPlate

US federal government multimedia tool that aims to help Americans choose healthier foods from the five food groups (grains, vegetables, fruits, dairy, and proteins). Myplate.gov

National School Lunch Program (NSLP)

The National School Lunch Program (NSLP) and School Breakfast Program (SBP) ensure that children in elementary and middle schools receive at least one healthy meal each school day, or two if both the NSLP and SBP are provided.

Negative energy balance

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.

Neural tube

The neural tube is a hollow tube in vertebrate embryos that gives rise to the brain and spinal cord.

Niacin

Niacin (vitamin B3) is a component of the coenzymes NADH and NADPH, which are involved in the catabolism and/or anabolism of carbohydrates, lipids, and proteins. Niacin can be synthesized by humans from the amino acid tryptophan in an anabolic process requiring enzymes dependent on riboflavin, vitamin B6, and iron. Niacin is made from tryptophan only after tryptophan has met all of its other needs in the body.

Non-Exercise Activity Thermogenesis (NEAT)

NEAT stands for Non-Exercise Activity Thermogenesis. Even at rest we can burn calories, but we can increase the number of calories burnt by doing minor movements.

Non-nutrients

Substances in food that serve no nutritional purpose. They may be harmful or beneficial.

Nonessential amino acids

Nonessential amino acids are amino acids the body can make from other molecules. There are 11.

Nonmodifiable risk factors

Risk factors we cannot control - age, sex, body size, family history, medical conditions and medications.

Nonsteroidal anti-inflammatory medications (NSAIDs)

NSAIDs are medications used for the treatment of arthritis and other painful inflammatory conditions in the body. Aspirin, ibuprofen (Advil, Motrin), naproxen (Aleve, Naprosyn), and etodolac (Lodine) are a few examples of this class of medications.

Nutrient dense

Nutrient dense refers to food that contain many nutrients relative to the amount of calories provided.

Nutrients

Nutrients are substances the body needs to stay healthy.

Nutrigenomics

Nutrigenomics, also called nutritional genetics, aims to identify what nutrients to eat to “turn on” healthy genes and “turn off” genes that cause disease.

Nutrition

Nutrition is the sum of all processes involved in how organisms obtain nutrients, metabolize them, and use them to support all of life's processes.

Nutrition Facts Panel

FDA regulated food label that gives consumers information on the nutrition content, serving size, and number of servings in packaged food.

Nutritional science

Nutritional science is the investigation of how an organism is nourished, and incorporates the study of how nourishment affects personal health, population health, and planetary health.

Obesity

Obesity is the condition of having excess accumulation of body fat. It is associated with health problems such as type 2 diabetes, heart disease, and hypertension.

Obesogenic

An obesogenic environment is an environment that promotes increased food intake, non-healthful foods, and physical inactivity.

Older adolescence

Older adolescence is defined as between ages fourteen and eighteen.

Oligosaccharides

Oligosaccharides are carbohydrate molecules of middling size, made of 3-10 monosaccharides joined together.

Organ systems

Organ systems consist of two or more organs that work together to support a specific physiological function.

Organelles

Organelles are distinct structures within cells that carry out specific functions.

Organic

Organic is a federally regulated term that refers to foods that contain 95% organic ingredients.

Organism

An organism is the complete living system capable of conducting all of life's biological processes.

Organs

Organs are a group of tissues arranged in a specific manner to support a common physiological function.

Osmoreceptors

Osmoreceptors are specialized protein receptors on cells of the hypothalamus that detect sodium concentration in the blood.

Osmoregulation

Osmoregulation is the control of fluid balance and composition in the body.

Osmosis

Osmosis is the net movement of water through a selectively permeable membrane from a solution where there is a low solute concentration to a solution with a higher solute concentration.

Osteomalacia

In adults, vitamin D deficiency causes a disease called osteomalacia, which is characterized by low bone mineral density (BMD). Osteomalacia has the same symptoms and consequences as osteoporosis and often coexists with osteoporosis.

Osteoporosis

Osteoporosis is a condition where the bones become fragile due to loss of bone density.

Overnutrition

Overnutrition is the consumption of more food than needed, which can result in obesity.

Oxidant

An oxidant is a molecule that takes electrons away from other molecules, causing oxidation.

Oxidative phosphorylation

The electron transport chain and the production of ATP through chemiosmosis are collectively called oxidative phosphorylation.

Oxidative stress

Oxidative stress refers to an imbalance between the production of reactive oxygen species (ROS) orfree radicals and the body's ability to quench them. In other words, oxidative stress is what your cells experience when you're making more free radicals than your cells can handle.

Oxidized

A compound is oxidized when it loses at least one electron.

Pancreatic amylase

Pancreatic amylase is an enzyme made in the pancreas and released into the small intestine that breaks down starch into shorter and shorter carbohydrate chains.

Pantothenic acid

Pantothenic acid (vitamin B5) forms coenzyme A, which is the main carrier of carbon molecules in a cell and essential for bringing carbon atoms into the citric acid cycle.

Parathyroid hormone (PTH)

Parathyroid hormone is a hormone released from the parathyroid gland that plays a key role in regulating blood calcium concentration. When blood calcium levels are low, PTH is secreted to increase blood calcium levels by releasing calcium from bone, acting on the kidneys to decrease calcium loss in urine, and activating vitamin D to increase calcium absorption from food.

Partially hydrogenated oils

Partially hydrogenated oils are made when hydrogen is added to vegetable oil (through the process of hydrogenation) to increase the shelf-life and flavor stability of foods.

Passive transport

Passive transport is the transport of molecules across the cell membrane without the use of ATP.

Pasteurization

Pasteurization is an industrial process that eliminates bacteria in milk or juice by exposing droplets to high temperatures for a very brief amount of time.

Peak bone mass density (BMD)

Peak bone mass density is the highest bone mass density an individual reaches in their lifetime, typically reached in early adulthood.

Pear-shaped bodies

"Pear-shaped" bodies refer to people who carry more weight around the hips.

Pellagra

Niacin deficiency is commonly known as pellagra. Symptoms include fatigue, decreased appetite, and indigestion and are commonly followed by the four D's: diarrhea, dermatitis, dementia, and sometimes death.

Pepsin

Pepsin is a digestive enzyme in the stomach that breaks down the proteins in food into individual peptides (shorter chains of amino acids).

Peptic ulcers

Peptic ulcers are painful sores in the gastrointestinal tract caused by breakdown of the lining of the digestive tract.

Peptide bonds

Peptide bonds are bonds formed between the carboxylic acid group of one amino acid and the amino group of another.

Peroxiredoxin

Peroxiredoxin is an antioxidant enzyme that participates directly in eliminating hydrogen peroxide (H2O2) and neutralizing other reactive oxygen species (ROS).

Phenylketonuria (PKU)

Individuals with phenylketonuria (PKU) have a mutation in the enzyme that converts the amino acid phenylalanine to the amino acid tyrosine. If their condition is not managed, they can accumulate high levels of phenylalanine which can cause brain damage.

Phospholipids

Phospholipids are molecules with two fatty acids and a phosphate group attached to a glycerol backbone. The fatty acids give a phospholipid a hydrophobic "tail" and the phosphate group gives the phospholipid a hydrophilic "head".

Phosphorus

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.

Photosynthesis

Photosynthesis is the process by which plants use energy from sunlight to convert carbon dioxide gas (CO2) from the atmosphere into sugar molecules, like glucose.

Phytochemicals

Phytochemicals are compounds in plants (phyto) that are believed to provide health benefits beyond the traditional nutrients.

Pica

Pica is a medical disorder in which a person willingly consuming foods with little or no nutritive value, such as dirt, clay, and laundry starch.

Polysaccharides

Polysaccharides are polymers consisting of chains of monosaccharide or disaccharide units joined together. Starches and fibers are the two main groups of polysaccharides.

Polyunsaturated fatty acid

A polyunsaturated fatty acid is a fatty acid with two or more double bonds or two or more points of unsaturation.

Positive energy balance

A positive energy balance refers to a person taking in more kilocalories than expending.

Potassium

Potassium is the most abundant positively charged ion inside of cells. Nerve impulse involves not only sodium, but also potassium. 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.

Potential energy

Potential energy is stored energy, or energy waiting to happen.

Prebiotic

A prebiotic is a non-digestible food component that selectively stimulates the growth of beneficial intestinal bacteria.

Prediabetes

Prediabetes is a serious health condition where blood sugar levels are higher than normal, but not high enough yet to be diagnosed as diabetes. Prediabetes increases your risk for type 2 diabetes, heart disease, and stroke.

Preeclampsia

Preeclampsia (sometimes referred to as toxemia) is a serious complication of pregnancy marked by elevated blood pressure, swelling, and protein in the urine.

Pregnancy

Pregnancy is the development of a zygote into an embryo and then into a fetus in preparation for childbirth.

Primary protein structure

Primary protein structure is the sequence of amino acids in a protein.

Probiotic

A probiotic is a live microorganism that is consumed, and colonizes in the body

Propulsion

Propulsion is the movement of food through the gastrointestinal tract.

Protein Digestibility Corrected Amino Acid Score (PDCAAS)

The PDCAAS is a method adopted by the US Food and Drug Administration (FDA) 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 (amino acid score x digestibility).

Protein turnover

All cells in the body continually break down proteins and build new ones, a process referred to as protein turnover.

Proteins

Proteins are macronutrient molecules composed of one or more chains of amino acids, joined by peptide bonds.

Puberty

Puberty is the beginning of adolescence, typically ages nine to thirteen.

Qualified health claims

Qualified health claims have supportive evidence which is not as definitive as with (non-qualified) health claims.

Quaternary protein structure

The fourth (quaternary) level of protein structure is achieved when two or more amino acid chains combine to make one larger functional protein.

Randomized clinical interventional trial

A randomized clinical interventional trial is a study in which 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.

Reactive Oxygen Species (ROS)

Reactive Oxygen Species (ROS) are oxygen-containing free radicals. ROS contribute to oxidative stress within cells.

Recommended Dietary Allowances (RDA)

The RDA value of a nutrient is the amount calculated to meet the average daily needs of 97-98% of the healthy target population.

Redox reaction

"Redox reactions" refers to paired oxidation and reduction reactions together.

Reduced

A compound is reduced when it gains at least one electron.

Relative energy deficiency in sport (RED-S)

A syndrome that occurs when the energy intake for athletes does not meet the high energy demands required by exercise.

Respiration

See cellular respiration.

Retinoids

The retinoids are a family of compounds that are structurally and functionally similar to vitamin A.

Retinol

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")

Riboflavin

Riboflavin (vitamin B2) 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 B6 and folate, are dependent on the actions of flavoproteins.

Ribonucleic acid (RNA)

Ribonucleic acid (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. RNA is the "messenger" molecule in protein translation; it carries the instructions from DNA into the cytoplasm of the cell.

Rickets

Insufficient vitamin D during childhood causes rickets, a disorder characterized by soft, weak, deformed bones that are exceptionally susceptible to fracture.

Salivary amylase

Salivary amylase is an enzyme in saliva that breaks down starch into shorter carbohydrate chains.

Salivary glands

Salivary glands are glands located in and around the mouth that release saliva, mucus, and three enzymes: salivary amylase, lingual lipase, and lysozyme.

Salt substitutes

A salt substitute is a seasoning that may be used in place of table salt. Salt substitutes may still contain sodium, just in lesser amounts than table salt.

Salt-sensitive

Salt-sensitive means that a person's blood pressure increases with increased salt intake and decreases with decreased salt intake.

Satiety

Satiety is the sensation of fullness that signals you to stop eating.

Saturated fatty acids

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.

School Breakfast Program (SBP)

See The National School Lunch Program (NSLP)

Scientific method

The scientific method is an organized process of inquiry used in forensic science, nutritional science, and every other science.

Secondary protein structure

Secondary protein structure occurs when hydrogen bonding of the peptide backbone causes the amino acid chain to fold in a repeating pattern of a helix or a sheet.

Segmentation

Segmentation refers to contractions of the small intestine that mix chyme with pancreatic juices and bile.

Selenium

Selenium is a mineral that acts as an antioxidant and as a cofactor of enzymes that release active thyroid hormone in cells. Low levels of selenium can cause symptoms similar to iodine deficiency.

Senior

The senior stage of life is considered to be from age fifty-one until the end of life.

Sensible water loss

Sensible water loss is loss of water from our body that we are consciously aware of.

Set point

The body's set point is considered to be the weight or amount of body fat that the brain will try to maintain. Losing weight to below the set point will trigger an increase in energy intake. Gaining weight to above the set point will trigger an increase in energy expenditure.

Signs and symptoms

Signs refer to readily observed identifying characteristics of a disease such as swelling, weight loss, or fever. Symptoms are the subjective features of a disease recognized by a patient and/or their doctor.

Simple diffusion

Simple diffusion is the movement of solutes from an area of higher concentration to an area of lower concentration (with the concentration gradient) without the help of a protein.

Slow-releasing carbohydrates

Slow-releasing carbohydrates are long chains of simple sugars that can be branched or unbranched and slowly release sugar into the body.

Socioeconomic status

Socioeconomic status is a measurement made up of three variables: income, occupation, and education. Socioeconomic status affects nutrition by influencing what foods you can afford and consequently, food choice and food quality.

Sodium

The mineral sodium is vital for maintaining fluid balance, nerve impulse transmission, nutrient absorption in the small intestine, nutrient reabsorption in the kidney, and many other essential functions.

SoFAS

Solid fats and sugars

Solutes

Solutes are substances dissolved in a fluid (the solvent).

Special dietary use foods

Special dietary use foods do not have to be administered under a doctor's care and can be found in a variety of stores. Similar to medical foods, they address special dietary needs and meet the nutritional requirements of certain health conditions. For example, a bottled oral supplement administered under medical supervision is a medical food, but it becomes a special dietary use food when it is sold to retail customers.

Special, Supplemental Program for Women, Infants and Children (WIC)

The Special, Supplemental Program for Women, Infants and Children (WIC) provides food packages to pregnant and breastfeeding women, as well as to infants and children up to age five, to promote adequate intake for healthy growth and development. Most state WIC programs provide vouchers that participants use to acquire supplemental packages at authorized stores.

Sphincter

Sphincters are muscular openings that separate one compartment of the digestive tract from the next.

Spina bifida

Spina bifida is a neural-tube defect that occurs when the spine does not completely enclose the spinal cord.

Sports anemia

A form of anemia found in athletes. Blood volume expands to increase oxygen delivery to the muscles. In sports anemia, 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.

Sterols

Sterols are complex molecules related to cholesterol that contain interlinking rings of carbon atoms, with side chains of carbon, hydrogen, and oxygen attached.

Structure/function claims

Structure/function claims are marketing claims on food or supplement labels that are not supported by scientific evidence. Such claims must not mention cure or treatment of a specific disease and must include a disclaimer that the claim has not been evaluated by the FDA.

Substrate

The chemical reactants to which an enzyme binds are called the enzyme's substrates.

Sucrase

Sucrase is a digestive enzyme that breaks sucrose into glucose and fructose molecules.

Sugar alcohols

Sugar alcohols (such as sorbitol, xylitol, and glycerol) are industrially synthesized derivatives of monosaccharides. Sugar alcohols are often used in place of table sugar to sweeten foods as they are incompletely digested and absorbed, and therefore less caloric.

Superoxide dismutase (SOD)

Superoxide dismutase (SOD) is a family of antioxidant enzymes that use copper, zinc, or manganese as cofactors. SOD converts superoxide to hydrogen peroxide and oxygen.

Supplemental Nutrition Assistance Program (SNAP)

The Supplemental Nutrition Assistance Program (SNAP) provides monthly benefits for low-income households to purchase approved food items at authorized stores. Clients qualify for the program based on available household income, assets, and certain basic expenses.

Sustainability

Sustainability refers to the goal of achieving a world that meets the needs of its present inhabitants while preserving resources for future generations.

Sustainable agriculture

Sustainable agriculture is an umbrella term that encompasses food production and consumption practices that do not harm the environment, that do support agricultural communities, and that are healthy for the consumer.

Sweating

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.

Tertiary protein structure

Tertiary protein structure is the three-dimensional shape of a single amino acid chain. As the different side chains of amino acids chemically interact, they either repel or attract each other, resulting in the folded structure.

Thermic effect of food

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".

Thiamin (vitamin B1)

Thiamin (vitamin B1) acts as a coenzyme for enzymes that break down glucose for energy production. 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, RNA, and DNA.

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. Thirst is an osmoregulatory mechanism to increase water input.

Thirst center

The "thirst center" is the region of the brain responsible for the sensation of thirst. It is contained within the hypothalamus, a portion of the brain that lies just above the brainstem.

Tissues

Tissues are groups of cells that share a common structure and function and work together.

Toddler

Toddler is considered to be two to three years of age.

Tolerable Upper Intake Levels (UL)

ULs indicate the highest level of continuous intake of a particular nutrient that may be taken without causing health problems.

Total energy expenditure (TEE)

The sum of caloric expenditure in a day is referred to as total energy expenditure (TEE).

Toxemia

See preeclampsia

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.

Trans fatty acid

In a trans fatty acid, the hydrogen atoms are attached on opposite sides of the carbon chain.

Transcription

The first stage in protein synthesis, transcription is the copying of the genetic information in DNA into a single-stranded molecule of RNA.

Transitional milk

The second stage of milk production, transitional milk begins to be produced two to four days after birth and lasts for approximately two weeks. Transitional milk includes high levels of fat, lactose, and water-soluble vitamins. It also contains more calories than colostrum.

Translation

The second stage in protein synthesis. Translation occurs when messenger RNA attaches to a ribosome, which adds amino acids to the growing protein chain in a very specific order, determined by the sequence of the RNA.

Triglycerides

Triglycerides are the main form of lipid found in the body and in the diet. A triglyceride molecule consists of a glycerol backbone attached to three fatty acids.

Ulcerative colitis

Ulcerative colitis is an inflammatory bowel disease characterized by ulcers, or sores, in the lining of the colon and/or rectum.

Undernutrition

Undernutrition is characterized by a lack of nutrients and insufficient energy supply. Compare to overnutrition.

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.

US Department of Agriculture (USDA)

The USDA develops and executes federal policy on farming and food. This agency supports farmers and ranchers, protects natural resources, promotes trade, and seeks to end hunger in the United States and abroad. The USDA also oversees the regulation of meat, poultry, and processed egg products.

US Dietary Guidelines

The US Dietary Guidelines for Americans are a set of evidence-based recommendations designed to help healthy people meet their nutritional needs and prevent disease.

Vegan

A vegan diet eliminates all animal products.

Vigorous activities

Vigorous activities are considered to be those where you can only say a few words without stopping to catch your breath.

Villi

Villi (singular: villus) are finger-shaped projections from the inner wall of the small intestine.

Vitamin A

Vitamin A is the name of a group of fat-soluble retinoids, including retinol, retinal, and retinyl esters. Vitamin A is involved in immune function, vision, reproduction, and cellular communication.

Vitamin B complex

The B vitamins in the vitamin B complex include thiamine, riboflavin, niacin (nicotinic acid), niacinamide (nicotinamide), the vitamin B6 group (including pyridoxine, pyridoxal, pyridoxamine), biotin, pantothenic acid, folic acid, and vitamin B12. They are needed to support energy metabolism and growth.

Vitamin B12

Vitamin B12 is an essential part of coenzymes necessary for fat and protein catabolism, and for hemoglobin synthesis. An enzyme requiring vitamin B12 is needed by a folate-dependent enzyme to synthesize DNA. Thus, a deficiency in vitamin B12 has similar consequences to health as folate deficiency.

Vitamin B6

Vitamin B6 is a coenzyme involved in amino acid synthesis and breakdown, glycogenolysis, and synthesis of neurotransmitters. Vitamin B6 is also a required coenzyme for the synthesis of hemoglobin, and so a deficiency in vitamin B6 can cause anemia.

Vitamin C

Vitamin C, also called ascorbic acid, is a highly effective antioxidant. It is also required for some signaling molecules in the brain, hormones, and amino acids, and for the synthesis of collagen protein.

Vitamin D

Vitamin D (also referred to as calciferol) is a fat-soluble vitamin that is naturally present in a few foods, added to others, and available as a dietary supplement. It is also produced endogenously when ultraviolet (UV) rays from sunlight strike the skin and trigger vitamin D synthesis. Vitamin D is essential for calcium absorption from food.

Vitamin E

Vitamin E occurs in eight chemical forms, of which alpha-tocopherol appears to be the only form that meets human requirements. Alpha-tocopherol and vitamin E's other constituents are primarily responsible for protecting cell membranes against lipid destruction caused by free radicals, therefore making it an antioxidant.

Vitamin K

Vitamin K refers to a group of fat-soluble vitamins that are similar in chemical structure. Vitamin K is critical for blood clotting. It is also important for bone health.

Vitamins

Vitamins are organic compounds that must be taken in from the diet.

VO2

See aerobic capacity

Water intoxication

Water intoxication occurs when more water is taken in than is needed or than can be excreted. Excessive water intake can dilute the levels of critical electrolytes in the blood, and can be fatal.

Water-soluble

Water-soluble molecules are molecules that dissolve in water, not in oils. Water-soluble nutrients are absorbed directly into the bloodstream. Excess water-soluble vitamins are removed in the urine.

Wernicke-Korsakoff syndrome

A form of thiamin deficiency, Wernicke-Korsakoff syndrome can include symptoms 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.

WIC

see Special Supplemental Nutrition Program for Women, Infants, and Children (WIC)

Xerophthalmia

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.

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.

Zoochemical

Zoochemicals are the animal equivalent of phytochemicals in plants. They are compounds in animals that are believed to provide health benefits beyond the traditional nutrients that food contains.

Zygote

At conception, a sperm cell fertilizes an egg cell, creating a zygote.