AN INTRODUCTION TO HUMAN NUTRITION



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An Introduction to Human Nutrition

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Preface

Preface

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CHAPTER OVERVIEW

1: What is Good Nutrition?

1.1: Introduction

1.2: Nutrition in Health, Disease and Wellness

1.3: Essential Nutrients

1.4: Nutrition Research and Advice

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1.1: Introduction



Learning Objectives

1. For each category of the “Dimensions of Wellness,” give an example of how food and nutrition intake is impacted.
2. Compare the terms nutrition, nutrient, essential nutrient, and diet.
3. Identify the six classes of nutrients by size (how measured) and state the energy content (if applicable).
4. Compare and give examples of the terms macronutrient and micronutrient in human nutrition.
5. Distinguish between nutritional research and advice.
6. Locate and interpret credible sources of nutrition information.
7. Evaluate the validity of nutritional claims made in advertisements.

To understand good nutrition, it is important to understand why we eat the foods we eat and what is in them. In this chapter, you will learn how the dimensions of wellness affect food choices, and you will learn what is in the foods we eat. Another important aspect of this class is interpreting nutrition information. Nutrition is a science, but it can be a field that is filled with claims. For example, you may see headlines that say coffee is good for you, whereas other sources suggest you should limit your coffee intake. How can you interpret this conflicting information? This chapter will help you distinguish between nutritional research and advice so you can evaluate claims in the field of nutrition.

Cover art: "Top view vegetables, herbs and spices around a white plate. Healthy eating concept(opens in new window)" by wuestenigel(opens in new window) is licensed under CC BY 2.0.

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1.2: Nutrition in Health, Disease and Wellness

Nutrition: From Science to the Refrigerator

Nutrition



Figure 1.2.1: Nutritious foods at a grocery store.[1]

The word nutrition first appeared in 1551 and comes from the Latin word *nutrire*, meaning “to nourish.” Today, we define **nutritional science** as 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. Registered Dietitians are nutrition professionals who integrate their knowledge of nutritional science into helping people achieve healthy food habits. The Academy of Nutrition and Dietetics (AND) is the largest organization of nutrition professionals worldwide. To learn more from the AND’s nutritional advice, visit EatRight.Org (opens in new window).

Nutrition is a science, but its impact reaches far beyond the lab or research article. 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. What we eat impacts our health. Our goal is to figure out what to eat (including nutrients) to achieve and maintain good health. We have a lot of work to do. Mark Menjivar’s portrait exhibition, “You Are What You Eat,” provides snapshots of the insides of the refrigerators of American mechanics, doctors, school teachers, hunters, short-order cooks, college students, vegans, and more. Menjivar hopes these images will invoke new thoughts about “how we care for our bodies. How we care for others. And how we care for the land,” principles that we will discuss throughout this book.

You Are What You Eat

Mark Menjivar has traveled around the United States taking photographs of the contents of refrigerators of different kinds of people. Please see Mark Menjivar's portrait gallery. As you look at these images, think about how the contents of your refrigerator impact your own health, the health of your family and friends, and the health of this planet.

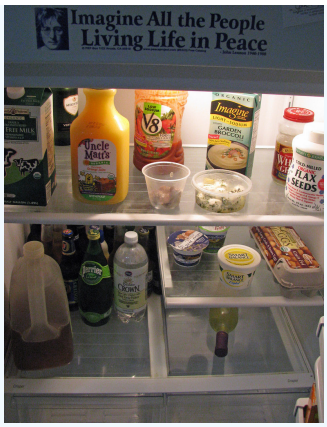


Figure 1.2.2: Current contents of a refrigerator.[2]

Nutrition in Health, Disease and Wellness

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." This definition was adopted into the WHO constitution in 1948 and has not been amended since. **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 disease characteristics 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). Mental illnesses, originally thought to affect only mental and social well-being, can also impact a person's physical status, finances, and job.

This expanded concept, known as **wellness**, goes beyond WHO's original idea of health and definition of disease. Wellness has been defined as "functioning optimally within your current environment."[3] This idea of living to one's full potential is commonly framed as the "dimensions of wellness." Looking at our daily choices of what we eat from each dimension supports why making these choices can be so complicated! In this book, we will consider eight Dimensions of Wellness (Figure 1.2.3) and their impact on making healthy food choices.

The Eight Dimensions of Wellness

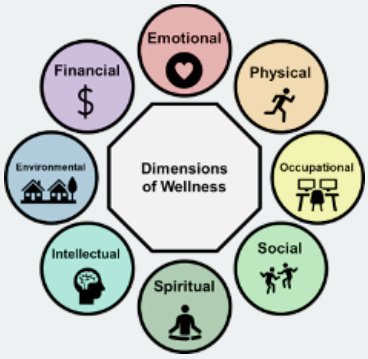


Figure 1.2.3: Dimensions of Wellness.[4] Each dimension has an impact on our daily food choices.

Overview of the Dimensions of Wellness

Dimension of Wellness	How the dimension impacts healthy food choices
Physical	Structure and function of the body
Emotional	Feelings you experience and coping strategies used
Social	Family, friends, and others you interact with during the day
Environmental	Your physical surroundings/location
Occupational	Daily demands related to where, when, or why you work
Intellectual	Ability to receive, process, and use accurate information
Spiritual	Values, as well as religious or cultural principles that drive choices

Table 1.2.1: Dimensions of Wellness.[5]

Application of the Dimensions of Wellness: College Student

Let's take a college student as an example: The student is carrying extra weight (physical) that they gained over the summer while working multiple jobs (occupational) to save up for tuition (financial). The student is feeling self-conscious about their weight (emotional) and is stressed out about the upcoming school year (emotional). The students' roommates are always ordering out (social, financial, physical), and it is hard to say no to that! The refrigerator is filled with restaurant to-go containers and soda bottles. Long work hours (occupational) limit the ability to do any outside fitness activities (physical) because it is not safe to be outside alone at night (environmental). Social media has been confusing on what to eat (intellectual), although the student values their body and deep down knows what better food choices should look like (spiritual). The student wants to start the new school year healthier, but you can see how complicated this could be when you consider all eight dimensions of wellness! Can you think of any shifts this student could make in their current habits?

Nutrition Guidelines to Support Public Health

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

Historically, the Dietary Guidelines for Americans are based on current scientific evidence and medical knowledge for all life stages, genders, and various racial and ethnic backgrounds. Its intended use is to help individuals and families make healthy food choices, guide public policy for federal nutrition programs, and provide background for consistent nutrition education communication to consumers. "The purpose of the *Dietary Guidelines for Americans* is to provide advice on what to eat and drink to build a healthy diet that can promote healthy growth and development, help prevent diet-related chronic disease, and meet nutrient needs."[6]

Although the Dietary Guidelines for Americans were not widely distributed until the 1980s, their release followed many historical events that demonstrated the importance of diet to health. 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 a nation ill-housed, ill-clad, ill-nourished. The test of our progress is not whether we add more to the abundance of those who have much; it is whether we provide enough for those who have too little."[7]

In the latter part of the twentieth century, nutrition scientists, public health organizations, and the American public recognized that eating too much of certain foods was 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. It is estimated that 76.4% of Americans have one or more chronic conditions.[8]

Let's look at obesity as an example. Data from the National Health and Nutrition Examination Survey (NHANES) reported that 40.3% of adults have a weight that qualifies as obese.[9] The Centers for Disease Control and Prevention (CDC) reported child and obesity prevalence of 19.7%.[10] This level of obesity comes with an economic cost. It has been reported that the annual medical cost of obesity in the US was $173 billion.[10] Medical costs for obese adults were $1,800 higher than medical costs for people with healthy weight. This annual cost exceeds $200 billion if the overweight population is included in the statistics.[11] The goal of nutrition guidelines is to use evidence-based advice for preventing chronic conditions like obesity to support public health and reduce the burden of these conditions.

From the time of Atwater until the onset of the Great Depression, nutrition scientists had discovered many of the vitamins and minerals that are essential for the functioning of the human body. Their work and the acknowledgment by President FDR of the nutritional inadequacy of the American diet evoked a united response between scientists and government, leading to the enrichment of flour (adding vitamins and minerals), the development of free or reduced-cost school lunch programs, and advancements in nutrition education in this country. In this course, we will look at the impact of inadequate and excessive diets on our society, along with strategies to assess evidence-based nutrition research so we can translate nutrition research to choose a food pattern that supports our health.

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1.3: Essential Nutrients

Diet versus Food and Nutrients

There are many popular diets, most often associated with weight loss and popularized in social media. Many of these so-called diets are not based on scientific research and could come with health risks, as well as a big cost to your bank account! In this book, we will use the term **diet** to represent a pattern of eating. There are medically based diets to manage chronic conditions that are based on evidence-based research. Some food patterns, such as the Mediterranean Diet, are based on decades of research on populations and their positive health outcomes. Your personal diet is defined as the foods you choose to eat, impacted by each dimension of wellness discussed earlier in this chapter. Keep these ideas in mind as we discuss how diet relates to food and nutrients.

Diet: A Pattern of Eating



Figure 1.3.1: The Ketogenic Diet Menu.[1] Each diet represents a pattern of eating, and diets need to be based on research and personal needs.

What is in Food?

The diet of most people contains a variety of foods: fruit, dairy, beans, meats, nuts, seeds, leafy green vegetables, as well as fats, oils, and sweets. The foods we eat contain nutrients. **Nutrients** are substances required by the body to perform its basic functions. Nutrients must be obtained from diet because the human body does not synthesize them or does not synthesize them in large enough amounts for human health. Nutrients are used for many body functions, such as growing, moving your muscles, repairing tissues, and much more! In summary, an **essential nutrient** is a nutrient you must have, a nutrient your body cannot make in adequate amounts, and, therefore, a nutrient you must eat or drink in adequate amounts.

Six classes of essential nutrients are required for the body to function and maintain overall health: carbohydrates, lipids (fats), proteins, water, vitamins, and minerals. Other substances in food appear to be very important for human health, such as colorful plant pigments, whereas others may be harmful to human health, such as preservatives, colorings, flavorings, and pesticide residues.

Essential Nutrients

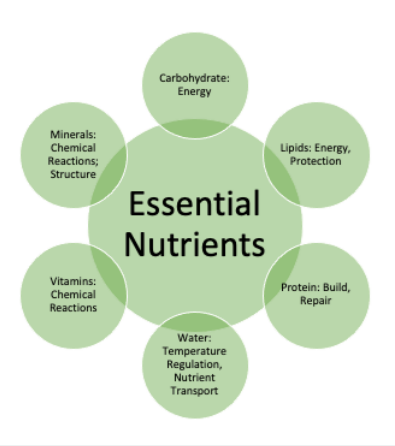


Figure 1.3.2: The six classes of nutrients.[2]

Macronutrients

Nutrients that are needed in large amounts are called **macronutrients**. There are three major classes of macronutrients: carbohydrates, lipids (fats), and proteins. All three of these nutrients are needed in relatively large amounts, *and* they contain Calories that can be "burned" in your body to create energy for your body cells. The energy from these 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** (note that Calorie with a capital C indicates kcalories, the term used in science research). The next time you are eating a packaged food, look on the "Nutrition Facts" panel to find out how many Calories you are getting when you eat one serving of that food. Water is also a macronutrient because you require a large amount of it, but unlike the other macronutrients, it does not yield Calories. One other possible component of the diet that can provide Calories is alcohol, though it is generally not considered to be a nutrient.

Macronutrients

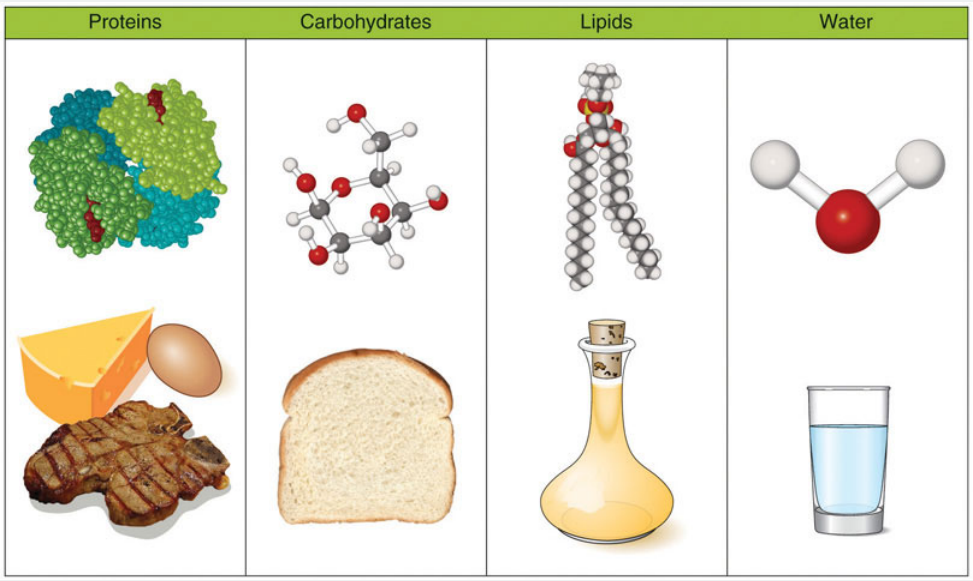


Figure 1.3.3: The macronutrients: carbohydrates, lipids, protein, and water.[3]

Carbohydrates

When you eat a food that contains carbohydrates, like bread or broccoli, for example, you receive approximately 4 Calories for every gram of carbohydrate you eat. Carbohydrates are molecules composed of carbon, hydrogen, and oxygen. The major whole food sources of carbohydrates are grains, milk, fruits, and starchy vegetables such as potatoes and corn. Non-starchy vegetables, such as spinach and green beans, also contain carbohydrates, but in lesser quantities. Many processed foods contain carbohydrates, providing a Calorie source without many vitamins or minerals.

Carbohydrates are broadly classified into two forms based on their chemical structure: fast-releasing carbohydrates, often called "simple sugars," and slow-releasing carbohydrates, often called "complex carbohydrates." Fast-releasing carbohydrates consist of one or two basic sugar units. They are sometimes called "simple sugars" because their chemical structure is fairly simple, with only one or two sugar units. If the carbohydrate has one sugar unit, we call it a **monosaccharide**. Mono means one, and saccharide means sugar. Examples of monosaccharides include glucose (the sugar that is in your blood); fructose (a sugar commonly found in fruit); and galactose (a sugar that is found as part of milk sugar). If the carbohydrate has two sugar units, we call it a **disaccharide**. Di means two, and saccharide means sugar. Examples of disaccharides include: sucrose (table sugar); lactose (milk sugar) and maltose (sugar in grains). **Sucrose** is made of a glucose linked together with a fructose. **Lactose** is made of a glucose linked together with galactose. **Maltose** is made of two glucose molecules bonded together. To digest a disaccharide, your body has to break the two sugars apart. We will talk more about this when we discuss lactose intolerance in a later chapter.

Slow-releasing carbohydrates are long chains of simple sugars (**polysaccharides**) that can be branched or unbranched. Some polysaccharides that you have probably heard of are starch and fiber. During digestion, the body does its best to break down all slow-releasing carbohydrates like starch into 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 fully broken down in the human body and passes through the digestive tract undigested unless the bacteria that live in the large intestine break it down for us. Therefore, starch is considered a Calorie source, but fiber is not considered a Calorie source.

In addition to providing energy and serving as building blocks for bigger macromolecules, carbohydrates are essential for the proper functioning of the nervous system, heart, and kidneys. As mentioned, glucose can be stored in the body for future use. In humans, the storage molecule of carbohydrates is called glycogen, and in plants, it is known as **starch**. Glycogen and starch are 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 predominately found in butter, oils, meats, dairy products, nuts, seeds, and many processed foods. The three main types of lipids are fats in the form of triglycerides (triacylglycerols), phospholipids, and sterols. The main job of fat is to store energy. Fats provide more energy per gram than carbohydrates (nine Calories per gram of fat versus four Calories per gram of carbohydrate). Cholesterol, another form of lipid, does not provide Calories. In addition to energy storage, lipids serve as cell membranes, surround and protect organs, aid in temperature regulation, and regulate many other bodily functions.

Proteins

Proteins are molecules composed of chains of subunits called **amino acids**. Amino acids are composed of carbon, oxygen, hydrogen, and nitrogen. The food sources of proteins are meats, dairy products, seafood, and various plant-based foods, including beans and nuts. The word protein comes from a Greek word meaning “of primary importance,” which is an apt description of these macronutrients; they are also known colloquially as the “workhorses” of life. Proteins provide four Calories 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 100,000 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 hydrogen atoms and one oxygen atom per molecule of water. Water does not provide any Calories. More than 60 percent of your total body weight is water. Without it, nothing could be transported in or out of the body, chemical reactions would not occur, organs would not be cushioned, and body temperature would fluctuate widely. On average, an adult consumes just over two liters of water daily from food and drink. 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, a topic we will explore in a later chapter.

Alcohol (not a nutrient)

Drinks containing alcohol are a source of Calories even though they are generally not considered nutrients. Alcohol comprises carbon, hydrogen, and oxygen and provides approximately 7 Calories for every gram consumed. In addition to alcohol, many of these drinks contain carbohydrates as well.

Micronutrients

Micronutrients are nutrients the body requires 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. (Tables 1.3.1 and 1.3.2 provide a complete list and their major functions). In contrast to macronutrients (carbohydrates, fats, and proteins), micronutrients do not contain Calories. This is often confusing because most people have heard how tired a person will feel if they are low in a micronutrient such as iron. The tiredness can be explained by the fact that micronutrients assist in the process of making energy by being part of enzymes (i.e., coenzymes). Enzymes catalyze chemical reactions in the body and are involved in many 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 molybdenum, selenium, zinc, iron, and iodine, are only required in a few milligrams or less; and **macrominerals**, such as calcium, magnesium, potassium, sodium, and phosphorus, are required in hundreds of milligrams. Many minerals are critical for enzyme function; others are used to maintain fluid balance, build bone tissue, synthesize hormones, transmit nerve impulses, contract and relax muscles, and protect against harmful free radicals.

Table 1.3.1: : Minerals and Their Major Functions

Minerals	Major Functions
Macrominerals	
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	
Iron	Carries oxygen, assists in energy production
Zinc	Protein and DNA production, wound healing, growth, immune system function
Iodine	Thyroid hormone production, growth, metabolism
Selenium	Antioxidant
Copper	Coenzyme, iron metabolism
Manganese	Coenzyme
Fluoride	Bone and teeth health maintenance, tooth decay prevention

Minerals	Major Functions
Chromium	Assists insulin in glucose metabolism
Molybdenum	Coenzyme

Vitamins

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

Table 1.3.2: Vitamins and Their Major Functions

Vitamins	Major Functions
Water Soluble Vitamins	
B_1 (thiamine)	Coenzyme, energy metabolism assistance
B_2 (riboflavin)	Coenzyme, energy metabolism assistance
B_3 (niacin)	Coenzyme, energy metabolism assistance
B_5 (pantothenic acid)	Coenzyme, energy metabolism assistance
B_6 (pyroxidine)	Coenzyme, amino acid synthesis assistance
B_7 Biotin	Coenzyme
B_9 Folate	Coenzyme, essential for growth
B_{12} (cobalamin)	Coenzyme, red blood cell synthesis
C	Collagen synthesis, antioxidant
Fat Soluble Vitamins	
A	Vision, reproduction, immune system function
D	Bone and teeth health maintenance, immune system function
E	Antioxidant, cell membrane protection
K	Bone and teeth health maintenance, blood clotting

Vitamin deficiencies can cause severe health problems. For example, a deficiency in niacin causes a disease called pellagra, which was common in the early twentieth century. The common signs and symptoms of pellagra are known as the "4Ds—diarrhea, dermatitis, dementia, and death." Until scientists found out that better diets relieved the signs and symptoms of pellagra, many people with the disease ended up in insane asylums awaiting death (Video 1.3.1). Other vitamins were also found to prevent certain disorders and diseases such as scurvy (vitamin C), night blindness (vitamin A), and rickets (vitamin D).

The Discovery of Pellagra



Video 1.3.1: This video provides a brief history of Dr. Joseph Goldberger's discovery that pellagra was a diet-related disease.[4]

Food Quality: Nutrient Density compared with Calorie Density

One way to think about the quality of your food is to consider how many nutrients you receive from a serving of that food compared to the number of Calories you receive from one serving of the food. For example, a candy bar gives you quite a few Calories but not very many of the essential nutrients. We would say that the candy bar has Calorie density but low Nutrient density. An apple on the other hand, has quite a few essential nutrients but not very many Calories. We would say that the apple has high nutrient density but low Calorie density. **Nutrient density** can be defined as a measure of nutrients relative to the amount of Calories they provide. A nutrient-dense food may also be referred to as a nutrient-rich food. Nutrient-dense foods are the opposite of "empty-calorie" foods, such as carbonated sugary soft drinks, which provide many calories and very little, if any, other nutrients.

What's in the Foods You Eat?

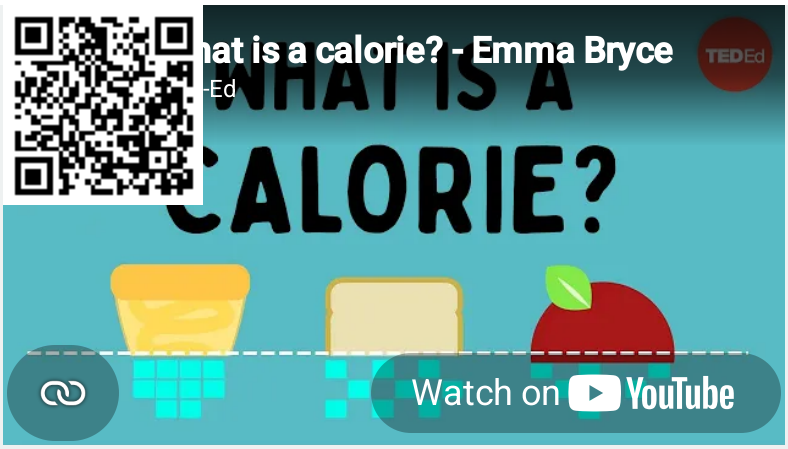
Curious to know if your favorite foods contain essential nutrients? Visit the USDA's search tool "What's In the Foods You Eat?" (opens in new window)

Food Energy

Although this is only Chapter 1, you have already seen the words "Calories" and "Energy" used several times. In everyday life, you have probably heard people talk about how many Calories they burned on the treadmill or how many Calories are listed on a bag of chips. Calories are a measure of energy. It takes quite a lot of Calories (energy) to keep us alive. Even if a person is in a coma, they still burn approximately 1000 Calories of energy for their heart to beat, their blood to circulate, their lungs to breathe, and similar life-sustaining actions. We burn even more Calories when we exercise. The carbohydrates, fats, and proteins we eat and drink provide Calories for us (and alcohol as well if we choose to consume it). Sometimes people refer to these nutrients as "energy-yielding." As you read above, carbohydrates provide 4 Calories for every gram we consume; proteins provide 4 Calories for every gram we consume; fats provide 9 Calories for every gram we consume, and alcohol provides 7 Calories of energy for every gram we consume. Vitamins, minerals, and water do not provide any Calories, even though they are still essential nutrients.

Please watch the following Ted-Ed video, "What is a Calorie?" It will describe in more detail what a Calorie is and why you may want to know how many Calories you are consuming compared with how many you are burning each day.

Calories



Video 1.3.2: What is a calorie?[5]

Food: A Better Source of Nutrients

It is better to get all your micronutrients from the foods you eat than from supplements. Supplements contain only what is listed on the label, but foods contain many more macronutrients, micronutrients, and other chemicals, such as antioxidants, that benefit health. Vitamins, multivitamins, and supplements are a $20 billion industry in this country, and more than 50 percent of Americans purchase and use them daily. According to the *British Medical Journal*, randomized clinical trials "have largely shown no benefit of vitamin, mineral, and fish oil supplements on the risk of major non-communicable diseases in people without clinical nutritional deficiency."[6] Of course, there are exceptions in favor of supplementation, such as those on restrictive diets due to medical conditions.

Attributions

- Zimmerman, "An Introduction to Nutrition (Zimmerman)(opens in new window)," CC BY-NC-SA 3.0(opens in new window). *The original material was reorganized and updated. New figures were added. New references were added.*

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1.4: Nutrition Research and Advice

Scientific Research to Determine the Health Effects of Food and Nutrients

In the same way that 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**.

Below is an illustration of the scientific method at work—in this case, to prove that iodine is a nutrient.[1-2] In 1811, French chemist Bernard Courtois was isolating saltpeter to produce gunpowder to be used by Napoleon's army. To achieve 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 reveals some of the process leading to the conclusion that iodine is a nutrient.

- **Observation.** Eating seaweed is a cure for goiter, a gross enlargement of the thyroid gland in the neck.
- **Hypothesis.** In 1813, Swiss physician Jean-Francois Coindet hypothesized that the seaweed contained iodine, and 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 Adolphe Chatin proposed that the low iodine content in food and water of certain areas far away from the ocean was the primary cause of goiter and renounced the theory that goiter resulted from 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% of goitrous children were cured.
- **Hypothesis.** In 1918, Swiss doctor Bayard proposed iodizing salt as a good way to treat areas in which goiter was endemic.
- **Experimental test.** Iodized salt was transported by mules to a small village at the base of the Matterhorn where more than 75 percent of schoolchildren were goitrous. It was given to families to use for six months.
- **Results.** The iodized salt was beneficial in treating goiter in this remote population.
- **Experimental test.** Physician David Marine conducted the first experiment of treating goiter with iodized salt in America in Akron, Ohio.
- **Results.** This study conducted on over 4,000 schoolchildren 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 goiterism. 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.



Figure 1.4.1: Iodized salt is a primary iodine source for Americans.[3]

Evidence-Based Approach to Nutrition

It was 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. An evidence-based approach to nutrition includes:[4-5]

- Defining the problem or uncertainty (e.g., the rate of colon cancer is higher in people who eat red meat)
- Formulating it as a question (e.g., Does eating red meat contribute to colon cancer risk?)
- Setting criteria for quality evidence
- Evaluating the body of evidence
- Summarizing the body of evidence and making decisions
- Specifying the strength of the supporting evidence required to make decisions
- Disseminating the findings

The Food and Nutrition Board 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 entire procedure for setting the DRI is documented and made available to the public. 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.

For a list of reliable sources that advocate good nutrition to promote health and prevent disease using evidence-based science, see Table 1.4.1. In subsequent sections, 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.

Table 1.4.1: Reliable Web Resources for Nutrition and Health

Organization
Governmental
US Department of Agriculture (opens in new window)
USDA Center for Nutrition Policy and Promotion (opens in new window)
US Department of Health and Human Services (opens in new window)
Centers for Disease Control and Prevention (opens in new window)
Food and Drug Administration (opens in new window)
Healthy People (opens in new window)
Office of Disease Prevention and Health Promotion (opens in new window)

Organization
Health Canada (opens in new window)
International
World Health Organization (opens in new window)
Food and Agricultural Organization of the United Nations (opens in new window)
Nongovernmental
Harvard School of Public Health (opens in new window)
Mayo Clinic (opens in new window)
Linus Pauling Institute (opens in new window)
American Society for Nutrition (opens in new window)
American Medical Association (opens in new window)
American Diabetes Association (opens in new window)
The Academy of Nutrition and Dietetics (opens in new window)
Dietitians of Canada (opens in new window)

Types of Scientific Studies

Many types of scientific studies can provide supporting evidence for a particular hypothesis. These include epidemiological studies, interventional clinical trials, and randomized clinical interventional trials.

Epidemiological studies are observational studies that look for health patterns and are often the front-line studies for public health. The CDC defines epidemiological studies as scientific investigations that define the 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.[6]

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. Scientists regard epidemiological studies as a starting place for ideas about what types of lifestyle choices MAY contribute to a disease. They can show a correlation between two things happening but not whether one factor CAUSED the other. My favorite example of this is a thought experiment where a make-believe scientist observes (through epidemiological studies) that grey hair often goes along with Alzheimer's Disease. Wouldn't it be silly for that scientist to predict that grey hair CAUSES Alzheimer's Disease? Could that scientist easily test that silly prediction? Suppose that scientist dyed gray the hair of a group of people to see if the color gray truly increased their risk of Alzheimer's disease. The whole thing is silly, but I think you get the point. Epidemiological studies may give us ideas but those ideas need clinical trials to determine what the patterns mean.

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*.[7] 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. The attributes of high-quality clinical interventional trial studies are:

- those that include a control group, which does not receive the intervention, to which you can compare the people who receive the intervention being tested;
- those in which the subjects are 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;
- those studies that include a sufficient number of participants.

What are **confounding variables**? These are factors other than the one being tested that could influence the study's results. For instance, in the study we just considered, if one group of adults did less physical activity than the other, then it could be the amount of physical activity rather than the diet being tested that caused the differences in blood pressures among the groups.

The limitations of these types of scientific studies are that they are difficult to carry on for long periods, are costly, and require that participants remain compliant with the intervention. Furthermore, it is unethical to study certain interventions. (An example of an unethical intervention would be to advise one group of pregnant mothers to drink alcohol to determine the effects of alcohol intake on pregnancy outcome because we know that alcohol consumption during pregnancy damages the developing fetus.)

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 randomly assigned 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 that provide supporting evidence for a hypothesis include laboratory **studies conducted on animals or cells**. An advantage of this type of study is that it typically does not cost as much as human studies and requires less time to conduct. Other advantages are that researchers have more control over the environment, and the amount of confounding variables can be significantly reduced. Moreover, animal and cell studies provide a way to study relationships at the molecular level. They 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 is 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.

Evaluating Nutrition Research

Evaluating nutrition research for **bias** and **conflicts of interest** requires a critical approach that goes beyond simply reading the conclusions. Industry funding and financial relationships can subtly influence study design, data interpretation, and reporting, often favoring outcomes that benefit sponsors. Researchers may selectively report positive results or frame findings in ways that appear more favorable than they truly are. For example, a systematic review of individual studies on the health impacts of sugar-sweetened beverages in the early 2000’s found that industry-related studies were dramatically more likely to reach weak conclusions regarding adverse health effects of these beverages. In that same time period, independent studies on sugar-sweetened beverages were almost 10 times more likely to reach a strong conclusion suggesting adverse health effects of consumption of sugar-sweetened beverages.[8] Publication bias also plays a role, as journals tend to prioritize studies with significant or positive outcomes, which can distort the overall evidence base. These factors make it essential to question whether the research is truly independent and whether the methodology supports unbiased conclusions.

To detect potential bias, start by reviewing disclosure statements for funding sources and author affiliations, as these can reveal conflicts of interest. Do the authors have funding or connections to food industries or organizations? Next, assess the study design. Pay attention to the choice of control groups, sample size, and statistical methods, which are important to avoid bias in the experiment and data analysis. Additionally, consulting systematic reviews and meta-analyses can provide a broader perspective, highlighting patterns of bias across multiple studies. Transparency measures, such as open data and independent replication, further strengthen confidence in findings. By applying these strategies, credible nutrition research can be distinguished from studies influenced by external interests.

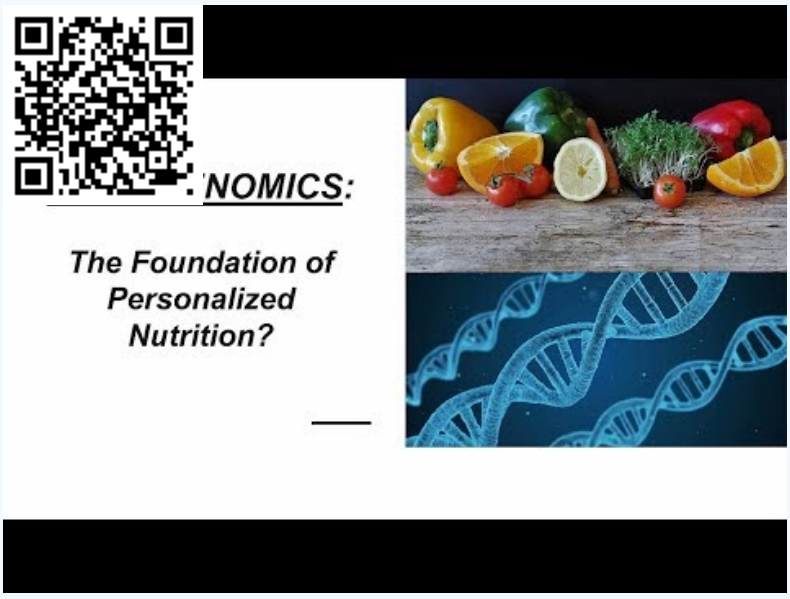
Evolving Science

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 funding. Indeed, just as an air quality study paid for by a tobacco company diminishes its value in readers' minds, so does one on red meat performed at a laboratory funded by a national beef association.

Science can also be contentious, even among experts who 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. It also instigates public health policymakers 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. Beware of Social Media claims that they have found a cure or new way to treat a health condition that is based on personal experience rather than evidence-based science research!

Nutrition Research: Nutrigenomics

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 makes 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. Check out this video on nutritional genomics.[9]



Video 1.4.1: Nutritigenomics: The Foundation of Personalized Nutrition? Penn State University[9]

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 (Figure 1.4.2). 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.



Figure 1.4.2: Smart refrigerator.[10] Technology like smart refrigerators can change the way we track nutrition and health.

Credible Nutrition Professionals

Finding credible nutrition information can begin with evidence-based resources, as noted earlier in this chapter (Table 1.4.1). Some professions serve to translate the science into practical use for the consumer. In addition to a college degree, supervised practice (internship), and national board exam, credentialed nutrition professionals must complete continuing education coursework to ensure they practice under the most current science-based evidence. Professional credentials and licenses are in place to protect the public from harm. Many professionals, such as personal trainers and teachers, are encouraged to promote healthy eating habits but should take caution to not exceed their scope of practice by avoiding medical or prescriptive nutrition principles. In many states, to practice in the area of nutrition specific to medical nutrition therapy and prescriptive nutrition, you need the Registered Dietitian credential and a state license. A weekend seminar may provide a "certificate," but this is not equivalent to a "credential." Also note that there are many research scientists, such as those associated with science departments and major universities and healthcare institutions, who are also experts in the field of nutrition and are considered credible nutrition sources. Below are two examples of credible credentialed nutrition professionals:

Registered Dietitian-Nutritionist

"RDs are food and nutrition experts who have met the Commission on Dietetic Registration's (CDR) criteria to earn the RD credential. RDs work in a wide variety of employment settings, including health care, business and industry, community/public health, education, research, government agencies, and private practice." Earning this credential includes:

1. Completion of a minimum of a graduate degree by a university accredited by a USDE recognized accrediting agency (**or foreign equivalent** (opens in new window)).
2. Completion of an Accreditation Council for Education in Nutrition and Dietetics (ACEND) accredited **Didactic Program in Dietetics (DPD)** (opens in new window).
3. Completion of an ACEND accredited **Dietetic Internship (DI** (opens in new window)**)** or ACEND **Coordinated Program (CP)**(opens in new window). There are additional options for graduate and doctoral degreed applicants through ACEND.
4. Obtain state license in states in which it is required.[11]

Diplomate, The American Clinical Board of Nutrition

The "DACBN certification program is to enact change on the traditional health care industry in the United States by certifying advanced, doctoral-level professionals who are focused on providing a nutritional model of preventative health care in a variety of professional settings."[12] In addition to an earned doctorate and working as a healthcare professional, candidates for this credential must complete 300 clock hours of professional practice in the area of nutrition, write a paper that is submitted to a research journal, pass a credentialing exam, and complete continuing education hours.

Attributions

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CHAPTER OVERVIEW

2: Tools for Healthy Eating

2.1: Introduction
2.2: Keys to Healthy Eating
2.3: Dietary Reference Intakes (DRI)
2.4: Dietary Guidelines and Recommendations
2.5: Food Labels
2.6: Evidence-based Eating Patterns

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2.1: Introduction



Learning Objectives

1. Relate the information provided by DRI values, dietary guidelines, and food labels to the criteria that contribute to a healthy diet (adequate, balance, Calorie control, moderation, variety).
2. Compare and contrast the purpose of the DRI, EAR, RDA, AI, UL and AMDR in planning healthy meals.
3. Use nutrient food labels to support selection of healthy foods.
4. Describe the role of the FDA and the USDA in regulating nutrient labels and claims.
5. Define requirements for foods to be labelled organic.

In this chapter, you will learn about the tools and guidelines for achieving a healthy diet. There are several dietary reference intake values that can be used to plan and assess the nutrient intake for a person given their age, weight, gender and activity level. The intake values help define dietary guidelines and recommendations to improve health for individual needs. Finally, you will learn about food labels and nutrient fact panels to help you select healthy foods.

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2.2: Keys to Healthy Eating

Key Factors in a Healthy Food Plan

Achieving a healthy diet is a matter of balancing the quality and quantity of food that is eaten. There are five key factors involved:

- 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.
- **Moderation** means not eating to the extremes, neither too much nor too little.
- **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.
- **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 different food groups (vegetables, legumes, fruits, grains, protein foods, and dairy).

Adequacy

An adequate diet is one that favors nutrient-dense foods. **Nutrient-dense foods** are defined as foods that contain many essential nutrients per calorie. Nutrient-dense or "nutrient-rich" foods are the opposite of "empty-calorie" foods, such as sugary carbonated beverages, which are also called "nutrient-poor." Nutrient-dense foods include fruits and vegetables, whole grains lean meats, poultry, fish, legumes, nuts and seeds and no-sugar added dairy products.

Does your diet contain nutrient-dense foods? Table 2.2.1 provides ideas for improving nutrient density.

Table 2.2.1: The Smart Choice: Nutrient-Dense Food Alternatives

Instead of…	Replace with…
Sweetened yogurt	Plain yogurt with fresh fruit
Sweetened milk (chocolate, strawberry)	Traditional unsweetened milk
Sugar-sweetened soft drinks	Seltzer mixed with 100% fruit juice
Sweetened cereals	Whole grain 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
Bacon or Sausage	Lean ham or Canadian Bacon
Recipes that call for sugar	Experiment with reducing the amount of sugar and adding spices (cinnamon, nutmeg, and vanilla)

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 to get the necessary amounts of calcium and iron from your diet, a proper balance between food choices is critical. Another example is that although sodium is a vital nutrient, in overabundance, it can contribute to high blood pressure, congestive heart failure and chronic kidney disease. Remember, nutrients 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. Condiments that may contribute added sodium, sugar or fat should be considered within your calorie goals. But as part of an otherwise healthful diet and consumed only on an occasional basis, these foods should not have too much of an impact on overall health. It's important to remember that eating is, in part, about enjoyment and indulging with a spirit of moderation. This fits within a healthy food plan.

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. To lose weight, you need to ensure that more Calories are burned than consumed. Likewise, to gain weight, Calories must be eaten in excess of what is expended daily.

Variety

Variety involves eating different foods from all the food groups. Eating a varied diet helps to ensure that you receive all the nutrients necessary. 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!

Table 2.2.2:Ideas for Eating a Variety of Healthy Choices

Grain	Vegetable	Fruit	Dairy	Protein
Whole-grain products: oats, brown rice, quinoa, barley, buckwheat, millet, sorghum, bulgur, kasha, farrow, wheat berries, corn, rye berries, amaranth, spelt, teff	**Dark green:** broccoli, kale, spinach, collards, romaine lettuce, turnip greens	Apples, apricots, bananas, cherries, oranges, grapefruit, kiwi, mangoes, lemons, limes peaches, pears, papaya, pineapple, plums, prunes	**All fluid milk** (fat-free, low-fat, reduced-fat, whole milk, lactose-free), fortified dairy alternatives (almond milk, soy milk); **yogurt** (unsweeted)	**Meats:** beef, pork, lamb
	Red and orange: Acorn squash, butternut squash, carrots, pumpkin, red peppers, sweet potatoes	**Berries:** strawberries, blueberries, raspberries	**Hard natural cheeses:** Swiss, cheddar, mozzarella, parmesan	**Poultry:** chicken, turkey, goose, duck
	Other vegetables: Asparagus, avocado, bean sprouts, beets, Brussels sprouts, cabbage, cauliflower, celery, eggplant, green beans, green peppers, mushrooms, okra, onions, parsnips	**Melons:** cantaloupe, honey dew, watermelon	**Soft cheeses:** ricotta, cottage	**Eggs**
	Beans and peas: Black beans, black-eyed peas, chickpeas, kidney beans, lentils, navy beans, pinto beans, soybeans, split peas, white beans			**Beans and peas:** (see vegetable column)

Grain	Vegetable	Fruit	Dairy	Protein
	Starchy: Potatoes, Cassava, green bananas, green peas, green lima beans, plantains, taro, water chestnuts			**Nuts and seeds:** almonds, cashews, hazelnuts, peanuts, pecans, pistachios, walnuts, pumpkin seeds, sesame seeds, hemp seeds, chia seeds, flax seeds, sunflower seeds
				Seafood: catfish, cod, flounder, haddock, halibut, herring, mackerel, pollock, porgy, salmon, sea bass, snapper, swordfish, trout, tuna
				Shellfish: crab, shrimp, scallops, mussels, lobster

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.



Figure 2.2.1: Widening your food palate will increase your intake of vital nutrients. "Breakfast!(opens in new window)"[1] by amytrippmyers is licensed under CC BY 2.0.

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2.3: Dietary Reference Intakes (DRI)

Dietary Reference Intakes (DRI) are the general numerical recommendation levels for specific nutrients. This DRI system is used in both the United States and Canada.

Dietary Reference Intakes: A Brief Overview

The most recent recommendations from the Food and Nutrition Board of the National Academies of Sciences, Engineering, and Medicine are the **Dietary Reference Intakes** (DRI).[1] The DRI includes 4 sets of standards:

- **Estimated Average Requirements (EARs)**: expected to satisfy the needs of 50% of the people in that age group based on a review of the scientific literature.
- **Recommended Dietary Allowances (RDA)**: average daily level of intake sufficient to meet the nutrient requirements of nearly all (97%-98%) healthy people.
- **Adequate Intakes (AI)**: established when evidence is insufficient to develop an RDA and is set at a level assumed to ensure nutritional adequacy.
- **Tolerable Upper Intake Levels (UL)**: maximum daily intake unlikely to cause adverse health effects.

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.

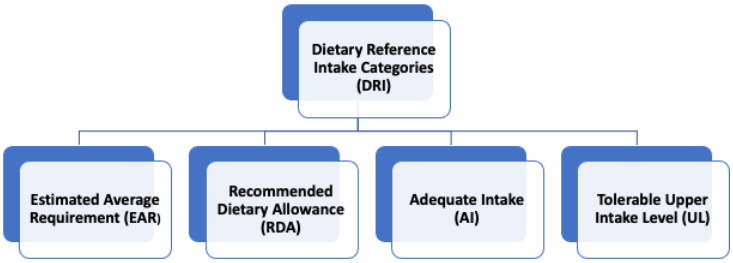


Figure 2.3.1: Dietary Reference Intake Categories (Source: Jan Dowell)

DRIs are mainly used by healthcare professionals and policymakers to determine nutritional recommendations for special groups of people who may need help reaching nutritional goals. This includes planning for people who are participating in programs such as the National School Lunch Program and the Special Supplemental Food Program for Women, Infants, and Children (WIC). The DRI is not appropriate for people who are ill or malnourished, even if they were healthy previously. DRIs are used on food labels to help consumers compare the nutrient content of products while shopping and are used in many popular nutrition tracking apps. One disadvantage of the DRIs for consumers is that it may be difficult to translate all the numbers into actual foods while planning meals and snacks.

Determining Dietary Reference Intakes

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

1. **Estimated Average Requirements.** 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% of people in their target group within a given life stage and for a particular gender. 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.
2. **Recommended Dietary 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%) of the target healthy population. It is important to note that RDAs are not the same thing as individual nutritional requirements. The actual nutrient needs of a given individual will be different than the RDA. However,

since we know that 97 to 98% of the population's needs are met by the RDA, we can assume that if a person is consuming the RDA of a given nutrient, they are most likely meeting their nutritional need for that nutrient. The important thing to remember is that the RDA is meant as a *recommendation*, and meeting the RDA means it is very likely that you are meeting your actual *requirement* for that nutrient. Also note that it is a "dietary" allowance, not a "daily" allowance. Most nutrients can be met over time, not a 24-hour period.

3. **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 of 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.
4. **Tolerable Upper Intake Levels.** The UL was established to help distinguish healthy 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.

Recommendation or Requirement? There is a distinct difference between a requirement and a recommendation. For instance, the DRI for vitamin D is a *recommended* 15 mcg (600 international units) each day. However, 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 your blood level results.

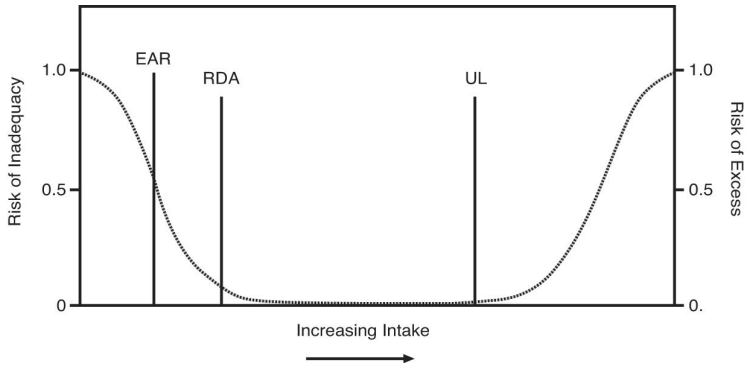


Figure 2.3.2: DRI Graph.(opens in new window) This graph illustrates the risks of nutrient inadequacy and nutrient excess as we move from a low intake of a nutrient to a high intake. Starting on the left side of the graph, you can see that when you have a very low intake of a nutrient, your risk of nutrient deficiency is high. As your nutrient intake increases, the chances that you will be deficient in that nutrient decrease. The point at which 50% of the population meets their nutrient need is the EAR, and the point at which 97 to 98% of the population meets their needs is the RDA. The UL is the highest level at which you can consume a nutrient without it being too much—as nutrient intake increases beyond the UL, the risk of health problems resulting from that nutrient increases. Source: Institute of Medicine. © 2012 National Academy of Sciences.

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 2.3.1: 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

Nutrient	Value (percentage of Calories)

Source: Adapted from Dietary Reference Intakes (DRIs): Acceptable Macronutrient Distribution Ranges.[2]

Tips for Using the Dietary Reference Intakes

You can use the DRIs to help assess and plan your nutrient intake if you like to crunch numbers and are familiar with what foods provide the various nutrients. Keep in mind when evaluating your intake that the values established have been devised with an ample safety margin and should be used only as general guidance for nutrient intakes. Also, the values are meant to assess and plan average intake over time, meaning you don't need to meet these recommendations every single day—meeting them on average over several days is sufficient. Check out the online DRI calculator at DRI Calculator.[3]

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2.4: Dietary Guidelines and Recommendations

For many years, the US government has been encouraging Americans to develop healthful dietary habits. The *Dietary Guidelines for Americans (DGA)* have been the cornerstone of federal nutrition policy and education in the United States since their first release in 1980. These guidelines are helpful for interpreting DRI values and nutrition research to make personal choices for a healthy diet.

2.4.1 Establishing the Dietary Guidelines for Americans

The formal development of U.S. dietary guidance began in the 1970s, when rising concerns about chronic disease prompted Congress to request nutrition guidance for the public. A major milestone was the publication of the Dietary Goals for the United States in 1977, which laid the groundwork for what would become the Dietary Guidelines.[1]

Beginning in 1980, the U.S. Department of Agriculture (USDA) and the Department of Health and Human Services (HHS) jointly published the first Dietary Guidelines for Americans, fulfilling a federal mandate to provide regular updates based on the latest scientific evidence. The Guidelines have continued to be updated every five years since.

The process of establishing the DGA is a structured process driven by scientific studies, systematic reviews of data, and public input. Every five years, USDA and HHS appoint experts in nutrition, medicine, and public health to form the Dietary Guidelines Advisory Committee (DGAC). The DGAC independently reviews scientific evidence, considers public comments, and submits a report of their findings to the USDA and HHS. Next, the USDA and HHA use the scientific report, federal initiatives, and an additional review of scientific studies, if needed, to develop and release the DGA. Once the DGA are published, they provide guidance for federal nutrition programs, policymakers and health professionals, nutrition education programs, and consumers. In addition, the Nutrition Monitoring and Related Research Act of 1990 mandates that every federal agency must promote and apply the Dietary Guidelines when conducting any food, nutrition, or health program.[2]



Figure 2.4.1: 4.1 Process of establishing the Dietary Guidelines for Americans (E. Shanle)

2.4.2 Changes in Dietary Guidelines for Americans

The first edition of the DGA introduced foundation advice on eating a variety of foods with adequate starch and fiber. The original 11-page guidelines published in 1980 recommended Americans focused on seven guidelines (Figure 2.4.2). The guidelines recommended eating a variety of foods, maintaining a healthy weight, eating adequate fiber and starches, and avoiding too much fat, saturated fat, cholesterol, sugar, and sodium, and maintaining moderate alcohol consumption for those that drink alcohol.[3] These recommendations continued to be the focus of subsequent versions of the guidelines, with expanded guidance on amounts and scientific evidence to support the guidelines.

In 1995, the DGA included the Food Guide Pyramid to provide guidance on the recommended number of daily servings from each of the five major food groups, with breads, cereals, rice, and pasta serving as the foundation of the pyramid.[4] The seven guiding principles established in 1980 continued to be a focus, but more specific guidance on physical activity was provided for maintaining a healthy weight.

In 2000, the 43-page DGA included 10 guidelines: aim for a healthy weight, be physically active each day, let the pyramid guide your food choices, choose a variety of grains and whole grains, choose a variety of fruits and vegetables, keep food safe to eat, limit saturated fats and cholesterol, moderate sugar intake, choose less sodium, and drink in moderation if you drink alcohol.[5]

In 2005, the DGA expanded to a 60-page document that was written for policy makers, educators, and healthcare providers instead of the general public.[6] The DGAC took a different approach from previous advisory committees by systematically reviewing scientific evidence centered around specific questions related to dietary guidance. Using an evidence-based analysis, the DGAC provided specific recommendations about food and nutrient intake without exceeding recommended calorie needs.[7]

The next version of the DGA released in 2010 provided a new framework that focused more on dietary patterns than specific nutrients and provided guidance for all individuals over the age of 2, including those at risk for chronic diseases. The 2010 DGA emphasized a healthy eating pattern that included nutrient-dense foods, whole grains, and more fruits and vegetables than previous versions of the guidelines. MyPlate replaced the pyramid graphic with a simple plate-and-cup visual designed to illustrate the recommended proportions of the five food groups—fruits, vegetables, grains, protein, and dairy—thereby helping consumers understand and apply principles of variety, balance, and portion control at mealtimes (Figure 2.4.2).[8] The 2015 DGA continued to use MyPlate as a visual framework, with new recommended limits on the amounts of added sugars and saturated fats.[9] In 2020, the DGA included 130 pages of guidance focused on eating nutrient-dense foods while remaining within recommended calorie limits, similar to previous versions. However, the 2020 DGA included recommendations for infants under the age of 2 for the first time.[10]

In 2025, a major shift in the DGA occurred. After the DGAC submitted the scientific report, a second review committee conducted an independent review of scientific studies related to dietary information. The second review committee published *The Scientific Foundation For the Dietary Guidelines for Americans* and rejected more than half of the recommendations of the DGAC.[11] Unlike the previous versions of the DGA, the 2025 DGA was 9 pages of recommendations designed for the general public. The visual framework for the 2025 DGA also changed significantly (Figure 2.4.2). Some recommendations remained the same, including an emphasis on eating the right amount of food, eating fruits and vegetables at every meal, incorporating healthy fats, and focusing on whole grains. However, the 2025 DGA provided new emphasis on prioritizing protein at every meal, consuming whole-fat dairy, and limiting highly processed foods, added sugars, refined grains, and alcohol.[12]

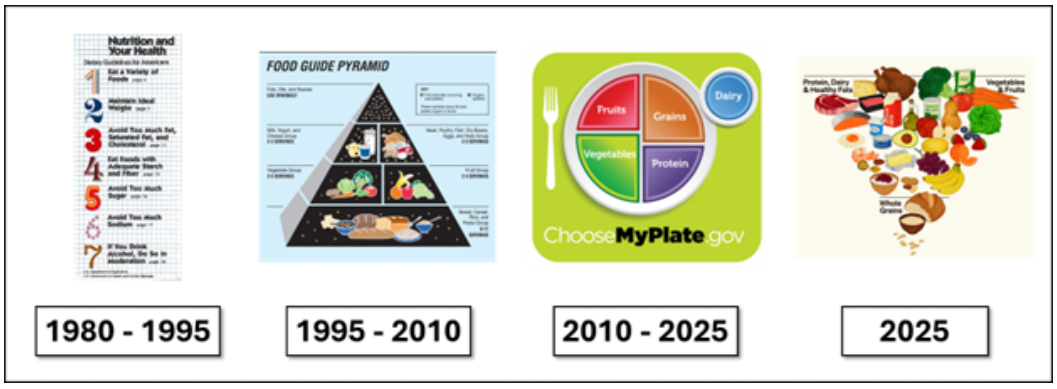


Figure 2.4.2: Changes in the Dietary Guidelines for Americans. Images from USDA Dietary Guidelines.[3, 4, 8, 12] (E. Shanle)

2.4.3 Key Recommendations in the Dietary Guidelines for Americans

Each version of the DGA provides recommendations based on scientific evidence, federal initiatives, and public health needs. Since 1980, rates of chronic conditions like obesity, diabetes, and heart disease have continued to increase in America. Several key recommendations are present in nearly all versions of the DGA to help Americans eat healthier with the goal of reducing the burden of these conditions:

- Eat a variety of foods.
- Choose nutrient-dense foods, including a variety of fruits and vegetables.
- Eat within recommended calorie limits.
- Limit saturated fats and choose foods with healthy fats.
- Limit added sugar intake.
- Choose whole grain foods.
- Limit alcohol intake if you drink alcohol.

2.4.4 Debating the Dietary Guidelines for Americans

The Dietary Guidelines for Americans have changed significantly between 1980 and today. Each version of the guidelines has faced criticism and debate. For example, the 2005 DGA recommended three servings of lowfat dairy per day. Some critics argued that this recommendation did not support a healthy diet for most Americans, particularly given the need to manage calorie intake

to maintain a healthy weight. In addition, many Americans are lactoseintolerant, and this guidance did not account for their needs.[13] The newest version of the guidelines published in 2025 also faces criticism due to the rejection of several DGAC recommendations. The 2025 DGAC recommends significantly more protein than previous guidelines and an emphasis on whole-fat dairy products, which is a concern if individuals should stay within recommended calorie limits.[14] However, the 2025 DGA recommends reducing highly processed foods, which is the first time the DGA provides such guidance. You will learn more about the DGA and the science supporting the recommendations in subsequent chapters so you can establish your personal healthy eating habits.

Attributions

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2.5: Food Labels

The Labels on Your Food

Understanding how to use DRIs in planning your nutrient intake can make you better equipped to select the right foods the next time you go to the supermarket. Food labels are designed to help consumers select foods for a healthy eating pattern.

The Nutrition Labeling and Education Act, passed in 1990 and updated in 2021, requires all packaged foods sold in the United States 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. Nutrients in the category of **mandatory inclusion** are total Calories, total fat, saturated fat, trans fat, cholesterol, total carbohydrates, dietary fiber, total sugars, added sugars, Vitamin D, calcium, iron, and potassium. Nutrients in the **optional inclusion** category are Calories from saturated fats, polyunsaturated fat, monounsaturated fat, soluble fiber, insoluble fiber, sugar alcohol, and other essential vitamins and minerals.[1]

Other types of information are required by law to appear somewhere on the consumer packaging. They include[2]

- 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
- Nutrient information on serving size and daily values

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 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 8 servings, if not more.

Interactive Link: The Food Label and You

The FDA has prepared an Interactive Food Label packed with helpful information.[3]

Reading the Nutrition Facts Panel on a Food Label

1. The first part of the Nutrition Facts panel provides information on serving size and the number of servings in the container. For example, a label on a box of crackers might tell you that twenty crackers equal one serving and that the whole box contains 10 servings. All other values listed after that are based on this one serving.
2. On the panel, the serving size is followed by the number of **Calories** for one serving. If you eat more than one serving, multiply or divide as needed.
3. Certain **nutrients** on the nutrition facts panel are mandatory and based on current scientific research on their connections to health and wellness. Manufacturers have the option to add additional nutrients, such as a cereal company that wants to provide more details on the types of fiber the cereal supplies.
4. Percent Daily Value" on the far right-hand side of the nutrition facts panel helps you determine if the food is a low or high source of a particular nutrient. The percentage of **Daily Value (percent DV)** represents the proportion of the total daily recommended amount you will get from one serving of the food on a 2000-Calorie diet. 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 fiber, vitamins, or minerals, look for a high-percent DV. Using this label, one serving is considered a high source of calcium (25% of the DV), but also a high source of sodium (37%). For example, in the food label in Figure 2.5.1, the percent DV of calcium for one serving of lasagna is 25%, which means that one serving of lasagna provides 25% of the daily recommended calcium intake. Because the DV for calcium is 1300 milligrams, the food producer determined the *percent* DV for calcium by dividing the calcium content in milligrams in each serving by 1300 milligrams and multiplying it by 100 to get it into percentage format. Be thankful they did all the math for you! Whether you consume 2,000 Calories daily or not, you can still use the percent DV as a general target.

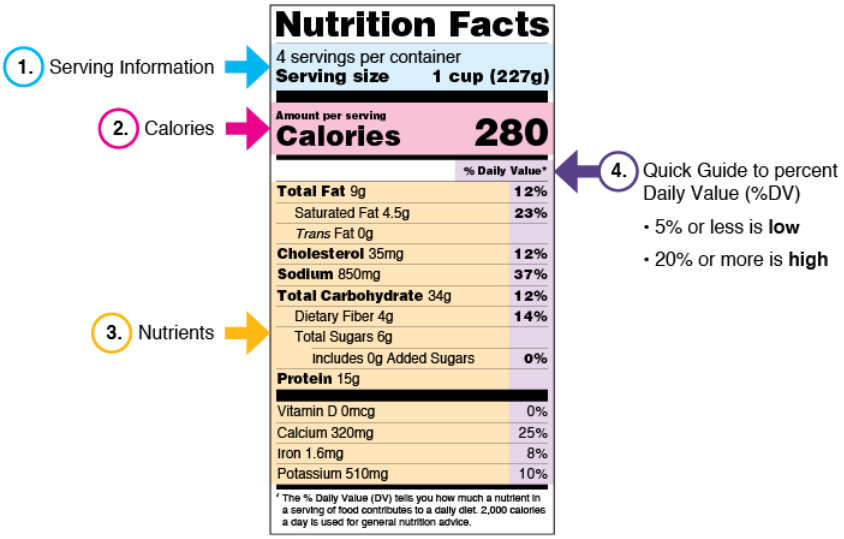


Figure 2.5.1: Sample label for lasagna.[4]

Nutrient 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, and **low sodium** indicates fewer than 140 milligrams of sodium per serving. The FDA does not have a definition for low sugar, although a **sugar-free** food can have up to 0.5 grams of sugar per serving.[5] A food claimed as **lean** means there are fewer than a set amount of grams of fat for that particular cut of meat. A food that claims to be a **high source** of a nutrient contains more than 20% of the nutrient's daily value per serving. A **good source** claim on a label means a serving of that food contains 10 to 19% of the nutrient's daily value. If a food promotes a claim of **light or lite**, it is defined as containing one-third fewer Calories or 50% less fat. If more than half the Calories come from fat, then the fat content must be reduced by 50% or more.[6]

Health Claims on Labels

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 they appear on packaging. All health claims must be substantiated by scientific evidence to be approved and put on a food label. To avoid 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. Here is an example of a health claim related to sodium. First, the food serving must be low in sodium, defined as <140 mg per serving, and the allowed health claim would be stated as "Diets low in sodium may reduce the risk of high blood pressure, a disease associated with many factors." The following statements are additional examples of approved health claims in the United States, and each claim on a label is allowed only if the food meets specific requirements:[6]

- Diets rich in whole grain foods and other plant foods and low in total fat, saturated fat, and cholesterol may reduce the risk of heart disease and some cancers.
- Diets rich in whole grain foods and other plant foods, and low in total fat, saturated fat, and cholesterol may help reduce the risk of heart disease.
- Diets containing foods that are a good source of potassium and that are low in sodium may reduce the risk of high blood pressure and stroke.
- Drinking fluoridated water may reduce the risk of dental caries or tooth decay.
- Diets low in saturated fat and cholesterol, and as low as possible in trans fat, may reduce the risk of heart disease.
- Replacing saturated fat with similar amounts of unsaturated fats may reduce the risk of heart disease. To achieve this benefit, total daily calories should not increase.

Structure/Function Claims on Labels

Some companies claim that certain foods and nutrients have health benefits 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 a diagnosis, cure, treatment, or disease prevention, and there must be a disclaimer that the FDA has not evaluated the claim.[7]

Trending Label Claims on Food Labels

As a science, the field of nutrition is constantly growing and updating with research. Here are examples of the status of some popular health claims on labels.

The claim that a food is **healthy** requires that it must be low-fat, low in saturated fat and cholesterol, contain less than 480 milligrams sodium, and provide at least 10% of the daily value for vitamins A, C, calcium, iron, protein, or fiber.[8]

The claim of **natural** means "nothing artificial or synthetic (including all color additives regardless of source) has been included in, or has been added to, a food that would not normally be expected to be in that food."[9] The FDA did not include requirements related to pesticides or processing methods or any nutrition or health benefits in the natural claim definition.

Currently, the FDA has no legal definition for **functional food** as most foods serve a function such as carbohydrate providing energy, although it does monitor the marketing claims on food labels. However, the phrase functional food is often used to describe a food's value beyond basic nutrition, such as promoting the benefits of the plant pigments in fruits and vegetables. The Academy of Nutrition and Dietetics defines functional foods as "Foods defined as whole foods along with fortified, enriched, or enhanced foods that have a potentially beneficial effect on health when consumed as part of a varied diet on a regular basis at effective levels."[10]

Foods can be labeled **gluten-free** if they do NOT contain "an ingredient that is any type of wheat, rye, barley, or crossbreeds of these grains, an ingredient derived from these grains and that has not been processed to remove gluten, or an ingredient derived from these grains that has been processed to remove gluten, if it results in the food containing 20 or more ppm gluten."[11]

USDA guidance includes multiple levels of **organic** labeling. To qualify for the organic label certification, a food must be "produced according to the USDA organic standards," and the production "methods [must] integrate cultural, biological and mechanical practices that foster cycling of resources, promote ecological balance and conserve biodiversity. Synthetic fertilizers, sewage sludge, irradiation and genetic engineering may not be used."[12] Refer to Figure 2.5.2 for more details.

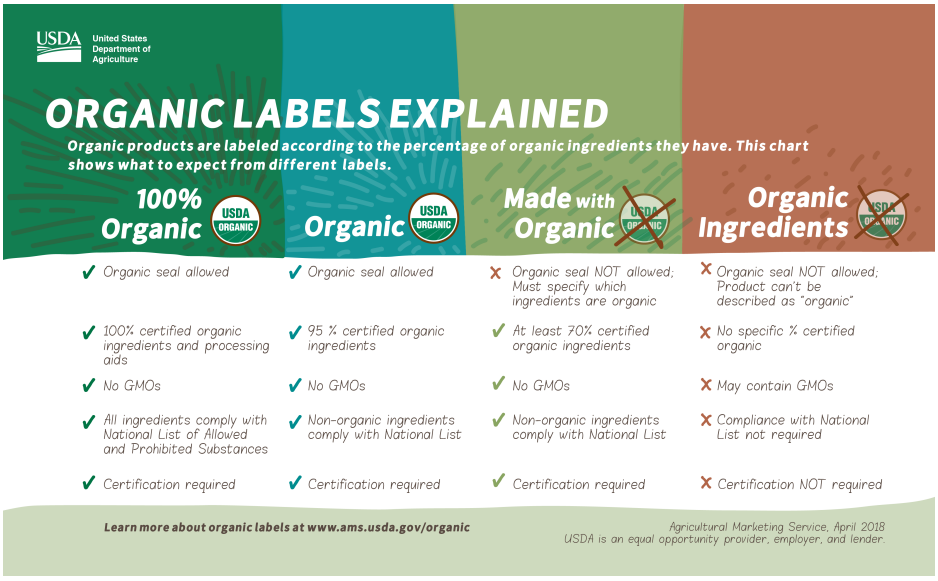


Figure 2.5.2: Organic Labels Explained[13]. USDA. Accessed July 28, 2023.

Allergy Warnings on Labels

The FDA requires food manufacturers to list on their packages whether the product contains any of the **9 most common ingredients** that cause food allergies. These 9 common allergens are as follows: milk, eggs, peanuts, tree nuts, fish, shellfish, soy, sesame, and wheat. 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. More information on food allergies is available in an upcoming chapter.

Dates on Labels

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FDA U.S. FOOD & DRUG ADMINISTRATION

Confused about what the date labels on food packages mean?

BEST IF USED BY

Here's what you should know:



You'll see a date on the label of most packaged foods.

- Labels often include phrases like "**Use by**" or "**Best if used by,**" but may only have a date. Other than infant formula, date labels are not required by federal law on packaged foods.
- Manufacturers often apply a date to inform consumers and retailers when the food will be at its best quality. Food packages may also have a date to indicate when the food was produced or packed.

SELL BY



Avoid wasting food

- Don't just rely on the date label that appears on a package. Look at and smell the food for signs of spoilage to know if it is ok to eat. Toss it if the color, consistency, or texture has changed.
- If the label recommends eating the food within a certain number of days after opening the package, eat it before that window closes.

USE BY



Extending shelf life

- Freezing is a good option for extending the shelf life of many packaged foods. Use the USDA's FoodKeeper App for information on



Figure 2.5.3 Dates on Labels[14]

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2.6: Evidence-based Eating Patterns

Decades of nutrition research suggests that eating a variety of nutrient-dense foods rich in fruits, vegetables, and whole grains promotes health. Two evidence-based eating patterns have emerged as ways to reduce the risks of chronic diseases like cardiovascular disease, diabetes, and obesity. This section provides an overview of these food plans to emphasize that scientific research supports such meal plans.

Mediterranean Diet

Beginning in the 1960s, a researcher named Ancel Keys studied the diets of seven countries (the US, Japan, Netherlands, Italy, Greece, Yugoslavia, and Finland) and found some interesting connections to risk factors for cardiovascular disease. The Mediterranean Diet, based on research more specific to countries surrounding the Mediterranean Sea, emerged from this original series of studies. The cuisines and risk factors of these countries share some similarities, which have interested researchers in any connections. These countries include Greece, Italy, Spain, France, Turkey, Syria, Morocco and Egypt. Over the decades, related research has identified benefits of the Mediterranean Diet, including reduced risk of cardiovascular (heart) disease and certain types of cancers, improved gut health, and benefits for diseases related to inflammation, cognition, and obesity.[2] For example, a randomized controlled trial of over 7,000 participants found that following the Mediterranean diet significantly lowered blood pressure, which is a factor in cardiovascular disease.[3]

The Mediterranean diet is not so much a "diet" as a healthy eating pattern within a healthy lifestyle. The Mediterranean diet emphasizes plant-based foods such as vegetables, fruits, and whole grains. More fish and beans are encouraged, with less meat, dairy, and poultry. Healthy fats, such as nuts, seeds, olives, extra virgin olive oil, and avocados, are suggested rather than highly processed oils and animal fats, including butter and bacon grease. It is not just one food or nutrient that may provide health benefits.



Figure 2.6.1: Mediterranean plate.[1] The Mediterranean diet is a healthy eating pattern emphasizes plant-based foods and healthy fats.

DASH Diet: The Dietary Approaches to Stop Hypertension

The DASH Diet originated from research by the National Institutes of Health in the 1990s. Since then, additional research has confirmed not only its association with improved blood pressure but also improvements in other heart conditions (heart failure, LDL-cholesterol), diabetes, certain cancers, and obesity. A meta-analysis of 54 randomized control trials investigating the health effects of the DASH diet found that individuals who followed the DASH diet had lower body weight, body mass index, blood pressure, and triglycerides when compared to control groups.[4] This food pattern emphasizes the intake of fruit, vegetables, whole grains, nuts and legumes, and lower-fat dairy and suggests less red and processed meat, sugar-sweetened beverages, and sodium. An excellent source of DASH Diet recipes can be found at National Heart, Blood, and Lung Institute.[5]

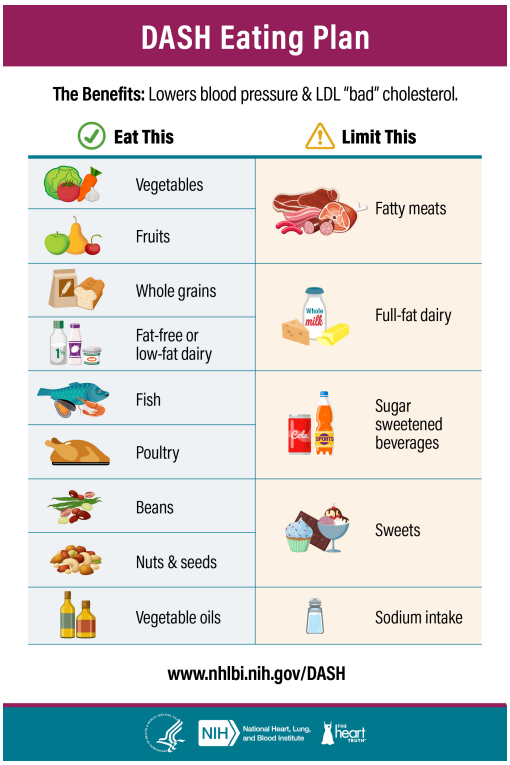


Figure 2.6.2: The DASH Eating Plan.[5] The DASH eating plan is a healthy eating pattern that reduces blood pressure and LDL cholesterol.

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CHAPTER OVERVIEW

3: Nutrition in Communities

3.1: Introduction
3.2: Modern Food Systems
3.3: Food Security
3.4: Food Sustainability
3.5: Global Perspectives
3.6: Nutrition in Action

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3.1: Introduction



Learning Objectives

1. Summarize components of modern food systems.
2. Identify agencies and regulations that ensure food security.
3. Explain the benefits, risks, and regulations of food additives.
4. Describe the scientific principles behind genetically modified foods.
5. Provide examples of how each dimension of wellness can impact food insecurity.
6. Differentiate between food security and food sustainability.
7. Describe global water-related challenges and solutions.
8. Compare and contrast food insecurity and malnutrition in developed and developing countries.
9. Propose strategies for improving food security and sustainability.

In the first two chapters, we considered nutrition as a set of personal choices that impact the individual making those choices. We have started to see that each individual may have different health needs for good nutrition. The study of nutrition goes beyond distinguishing healthy foods from unhealthy foods and identifying the essential nutrients in our food. Although this is important for individuals to make healthy choices, many other factors impact accessibility to healthy foods. If people cannot access healthy foods, they can't make healthy food choices. In this chapter, you will learn how nutrition affects communities —groups of individuals with a shared characteristic.

Over 330 million people live in America, and just over 8 billion on the entire Earth. What should we consider when thinking about nutrition in communities and the world? In this chapter, you will learn about modern food systems that produce the world's food, the agencies and regulations that ensure food safety. When considering these regulations, you will also learn about food additives and genetically modified foods. Two important aspects of nutrition in communities is food security, or having access to healthy food options; and food sustainability, or the ability to continue producing food for future generations. Finally, you will be able to consider how these concepts differ between developing and developed countries.

Cover Art: "[274] 'Field preparation' by Kayhan Guc; Category: Sustainable food (© Kayhan Guc, Sustainably Yours /EEA)" by European Environment Agency (EEA) is licensed under CC BY 2.0.

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3.2: Modern Food Systems

Modern Food Systems

How does the food in our grocery stores get from the farm to the shelf? Many steps are involved for each food product, and the food industry includes a complex collective of businesses that touches on everything from crop cultivation to manufacturing and processing, from marketing and advertising to distribution and shipment to food regulation. In the United States, each step of the process is regulated by agencies that aim to ensure the health and safety of consumers.

A **food system** comprises the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation, consumption, and disposal of food, and the outcomes of these activities, including not only nutritional and food security but also socioeconomic and environmental outcomes.[1] The milk industry, for example, includes everything from the farmers that raise 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 elements and activities play a part in a very large system that is regulated by several agencies in the United States. The short video below shows some of the parts that make up the dairy food system in the United States.

How Milk Gets from Farm to Fridge



Video 3.2.1: How Milk Gets From Farm to Fridge - A short video on the food system for milk.[2] Source: [Dairy MAX]. (2014, June 27). *How Milk Gets From Farm to Fridge* [Video]. YouTube. https://www.youtube.com/watch?v=0XSoTEcD_vQ&t=4s

Agencies that Regulate Modern Food Systems

To ensure food safety for consumers, modern food systems are required to follow regulations or rules enforced by different agencies. Each country has its own regulations for producing, packaging, and handling foods. Food regulatory agencies across the world work to protect the consumer and ensure the safety of our food. In the United States, food and drug regulations began in the late nineteenth century when state and local governments started to enact regulatory policies. In 1906, Congress passed the Pure Food and Drugs Act and the Meat Inspection Act in response to the use of poisonous preservatives and dyes in foods and unsanitary conditions in food processing plants. This act has been updated since 1906 but marked the beginning of the current US Food and Drug Administration (FDA).[3]

Today, food regulation in the United States is divided among different agencies that include the FDA, the US Department of Agriculture (USDA), and the US Environmental Protection Agency (EPA). It can be confusing to know which agency monitors and manages which regulatory practice. For example, the FDA oversees the safety of eggs when they're in the shells, whereas the USDA is in charge of the eggs once they are out of their shells. Globally, the Food and Agriculture Organization of the United Nations (FAO) specializes in fighting world hunger by conducting research and creating recommendations to improve global food systems for generations to come.

The Food and Drug Administration

Today, the FDA is responsible for regulating the safety of medical devices, drugs, foods, and cosmetics. Watch the video below to see what the FDA regulates and enforces.

What Does the FDA Do?



Video 3.2.2: A short video on the role of the U.S. Food and Drug Administration.[4] Source: [U.S. Food and Drug Administration]. (2022, October 31). *What Does the FDA Do?* [Video]. YouTube. https://www.youtube.com/watch?v=1D8mOu6SyX4

With respect to food, the FDA enforces the safety of foods grown in the United States (domestic foods) and foods that are imported from other countries through its Center for Food Safety and Applied Nutrition. This part of the FDA is responsible for providing guidance for safely producing and handling foods, overseeing recalls of unsafe foods or supplements, inspecting farms and food production facilities to ensure safe food production, and conducting research and analyzing scientific information about food claims and food safety.[5]

The US Department of Agriculture

Headed by the Secretary of Agriculture, 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. USDA's Food Safety and Inspection Service (FSIS) ensures that the nation's meat, poultry, and processed egg supply is wholesome, safe, and properly labeled. The agency is responsible for the inspection of domestic products, imports, and exports; conducting risk assessments; and educating the public about the importance of food safety.[6]

The USDA is also responsible for providing a safety net for millions of Americans who are food insecure and for developing and promoting dietary guidance based on scientific evidence. The USDA works to increase food security and reduce hunger by providing children and low-income people access to food, a healthful diet, and nutrition education in a way that supports American agriculture and inspires public confidence. The USDA provides critical nutrition assistance through Food and Nutrition Service (FNS) programs that include child nutrition programs, the Supplemental Nutrition Assistance Program (SNAP), and emergency food assistance, among many other programs. The Center for Nutrition Policy and Promotion (CNPP) is responsible for developing and promoting dietary guidance that links the best evidence-based scientific research to the nutrition needs of Americans.[7]

The Environmental Protection Agency

A third federal government agency, the Environmental Protection Agency (EPA), also plays a role in the regulation of food. The EPA works to protect human health and the environment. Founded in 1970, the agency conducts environmental assessment, education, research, and regulation to prevent pollution and protect natural resources. Under the Food Quality Protection Act (FQPA), the EPA must ensure that all pesticides used on food in the United States meet FQPA's stringent safety standard. FQPA requires an explicit determination that a pesticide's use on food is safe for children.[8]

Food and Pesticides in the United States



Figure 3.2.1: Agricultural field application.[9] Source: "Tractor Fertilize Field Pesticide And Insecticide" by aqua.mech is licensed under CC BY 2.0.

How do the USDA, FDA, and EPA work together? The regulation of pesticides in our foods is a good example of how these agencies play different roles in keeping our foods safe. The USDA measures residue levels for hundreds of pesticides and their metabolites in fruits, vegetables, grains, meat, and dairy products from across the country and food imported from other countries. The results are published in annual pesticide residue reports, which include statistics on the number of pesticide residues detected, the number of residues exceeding the tolerance established by EPA, and the number of residues detected for which no tolerance has been established. The FDA also collects data on pesticide residues in cooked food that may be a source of chemicals in human diets.[8]

Regulating Modern Food Systems: Food Preservation and Processing

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. This often involves the addition of food additives that are designed to improve the shelf-life, flavor, or look of foods. Although preservation and processing have numerous benefits, some concerns persist regarding the safety, nutrition, and sustainability of these aspects of modern food systems.

Food Preservation

Food preservation protects consumers from **food spoilage**, which leads to harmful or toxic food. Food spoils when it decomposes, becomes rancid, or becomes contaminated with microorganisms like bacteria or molds. Preservation guards against food-borne illnesses and protects the flavor, color, moisture content, or nutritive value of food. Food preservation also reduces food waste and loss, which can increase the efficiency of food systems and improve sustainability and food security.[10]

There are different ways to prevent food from spoiling. Some are ancient methods that have been practiced for generations, such as boiling, curing, smoking, pickling, salting, fermenting, or canning. For many preserved foods, like jams, for example, several food preservation processes are used together. These methods work by killing the organisms that can spoil food and creating an environment around the food that does not allow contamination or decomposition. Other preservation approaches include the use of modern techniques and technology, including drying, vacuum packing, pasteurization, and freezing and refrigeration.

Another method of preservation is **irradiation**. This process involves treating food with ionizing radiation to kill the bacteria and parasites that cause toxicity and disease. Similar technology is used to sterilize surgical instruments to avoid infection. Foods currently approved for irradiation by the FDA include flour, fruits and vegetables, juices, herbs, spices, eggs, and meat and poultry. The FDA has evaluated the safety of irradiated food for more than 30 years and has found the process safe. The World Health Organization (WHO), the Centers for Disease Control and Prevention (CDC), and the US Department of Agriculture (USDA) have also endorsed the safety of irradiated food.[11]

Most forms of preservation can affect the quality and nutritional content of food, but some processes affect nutrients more than others. For example, freezing only slightly affects the nutritional content and often preserves the flavor and appearance of foods. Curing and smoking can introduce carcinogens or cancer-causing chemicals.[12] Salting greatly increases the sodium or salt content in foods. Food additives, discussed further below, can also introduce new chemicals to foods that may cause additional health concerns.

Food Processing

Food processing includes the methods and techniques used to transform raw ingredients into packaged food. According to the USDA, a processed food is any food that has been changed from its original state through washing, cleaning, milling, cutting, chopping, heating, pasteurizing, blanching, cooking, canning, freezing, drying, dehydrating, mixing, or packaging. Based on this definition, nearly everything you find in the grocery store is considered a processed food. In 2009, the FAO introduced the NOVA system for classifying processed foods[13] (Table 3.2.1. Although this system is the most widely used globally, the USDA does not follow this classification system to classify processed foods.

Table 3.2.1. The NOVA Classification of Processed Foods[13]

Table displays the four categories of processed foods.

Category	Description
Group 1: Unprocessed or Minimally Processed Foods	Unprocessed foods are the edible parts of plants and animals that have not been altered. Minimally processed foods have slightly altered primarily for preservation. Examples include fresh or frozen fruits and vegetables, whole grains, nuts, and milk.
Group 2: Processed Culinary Ingredients	Food ingredients derived from Group 1 that are further processed by pressing, grinding, or refining. These foods are often used as ingredients to cook Group 1 foods. Examples include olive oil, flour, or honey.
Group 3: Processed Foods	Food products made Group 1 or 2 foods by adding sugar, salt, fat, or non-alcoholic fermentation. These include fresh-made breads, some cheeses, canned fruits or vegetables, or canned fish.
Group 4: Ultra-Processed Foods	Food products that have been made through industrial processes and include the addition of chemical additives beyond sugar, salt, or fats. They are typically ready-to-eat products designed to be appealing in flavor and appearance. Examples include pre-made pastas, pizzas, cakes, sugary drinks, breakfast cereals, instant soups, and most breads.

Source: Monteiro C.A. 2009. Nutrition and health. The issue is not food, nor nutrients, so much as processing. Public Health Nutrition, 12(5): 729-731. doi:10.1017/ S1368980009005291

Food processing has several important benefits, such as creating products with a much longer shelf life than raw foods. For example, frozen fruits and vegetables have a longer shelf life and retain much of their vitamins and nutrients. Also, food processing protects the health of the consumer from food spoilage, can improve the flavor and appearance of foods, 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 included during processing, such as high fructose corn syrup, can affect consumers' health. Ultra-processed foods can contain almost 10 times more added sugars than minimally processed foods, and eating ultra-processed foods has been found to be associated with weight gain.[14-15]

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** that are chemicals added to foods to improve safety, texture, appearance, or flavor. People have been using food additives for thousands of years. Today, more than 3000 substances are used as food additives. Salt, sugar, and corn syrup are by far the most widely used additives in food in this country.[16] Table 3.2.2 lists some common food additives and their uses.

Table 3.2.2. Common Food Additives

Table displays the common food additives and the reason for adding them.

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

Source: Center for Science in the Public Interest. Chemical Cuisine: Learn about Food Additives.[17] ©2012. Center for Science in the Public Interest. http://www.cspinet.org/reports/chemcuisine.htm.

The Pros and Cons of Food Additives

The FDA and USDA work 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. Additives are used to maintain or improve safety, freshness, nutritional value, taste, texture, and appearance. The increased production of prepared, processed, and convenience foods has made the use of food additives more prominent in recent years. 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 food-borne illnesses.

Food additives can also be used to boost their nutritional value. **Enriched foods** have nutrients added 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. **Fortified foods** have new nutrients added 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.

Food additives aren't always beneficial, however. For example, some food additives can cause allergic or hypersensitivity reactions. It is estimated that these reactions occur in 0.5% of the general population, with more likelihood in individuals who are allergic to other food components. Sulfites, used to preserve fruits and vegetables, can cause asthma attacks, heart rate fluctuations,

and fever in some individuals. Monosodium glutamate (MSG) is a flavor enhancer that can cause headaches, hot flashes, numbness, and even fainting. Often, allergic reactions are more common when a large amount of the additive is ingested.[18]

Regulating Modern Food Systems: Bioengineered Foods

Another aspect of modern food systems that is regulated in the United States is the use of **bioengineered** or **genetically modified organisms (GMOs)** in foods. Bioengineered foods contain ingredients from plants or animals that have genetic material that could not be obtained through conventional breeding or found in nature and has been modified through certain laboratory techniques. For example, some plants have been engineered to produce a toxin found in bacteria. This toxin kills insects that eat the plants, thereby protecting the plants from the insect pest.[19] Bioengineered crops are readily available in the United States. In 2020, GMO soybeans made up 94% of all soybeans planted, GMO cotton made up 96% of all cotton planted, and 92% of corn planted was GMO corn. Most GMO crops are used to feed animals like cows, chickens, and fish. They are also used to make ingredients that are then used in food products like cereal, snack chips, and vegetable oils. Even though you won't find many GMO fruits or vegetables in the produce section of your grocery store, GMOs are a common part of today's food supply.[20] The National Bioengineered Food Disclosure Law, passed by Congress in July of 2016, directed the USDA to establish a national mandatory standard for disclosing foods that may be bioengineered. Retail food products that are bioengineered or contain bioengineered ingredients will say so on the label (Figure 3.2.2).

Bioengineered Food Labels[21]



Figure 3.2.2: Bioengineered Food Labels. The USDA is responsible for ensuring foods with bioengineered ingredients are labeled for consumers. Image Source: https://www.ams.usda.gov/rules-regul...s/be/consumers

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 are also some concerns about 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-resistant genes. Genetically modified plants may adversely affect the environment as well and could lead to the contamination of non-genetically engineered organisms.[22]

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 before 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.[20]

Attributions

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3.3: Food Security

Food Security

Over 330 million people live in America and just over 8 billion on the entire Earth. Modern food systems are regulated for food safety, but they must also be designed to feed everyone in communities across the world. In a perfect world, everyone would have **food security** or the ability to physically access and afford to buy sufficient and safe, nutritious food for a healthful, active lifestyle. Unfortunately, millions of people across the world experience **food insecurity** and do not have access to enough nutritious foods.

Hunger and Malnutrition

Food insecurity leads to hunger and malnutrition. 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 results from a prolonged lack of food. People who suffer from this form of hunger typically experience poor growth and development.

A person living in a food-insecure household may also 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. One is **undernutrition**, which includes stunting (low height for age), wasting (low weight for height), underweight (low weight for age), and micronutrient deficiencies or insufficiencies (a lack of important vitamins and minerals). The other is **overweight**, obesity, and diet-related noncommunicable diseases (such as heart disease, stroke, diabetes, and cancer) (Figure 3.3.1).[1]

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. In 2022, between 691 and 783 million people, or almost 9% of the world's population, faced hunger.[2] Every night, millions of people go to sleep hungry because they lack the money or resources needed to acquire an adequate amount of food.

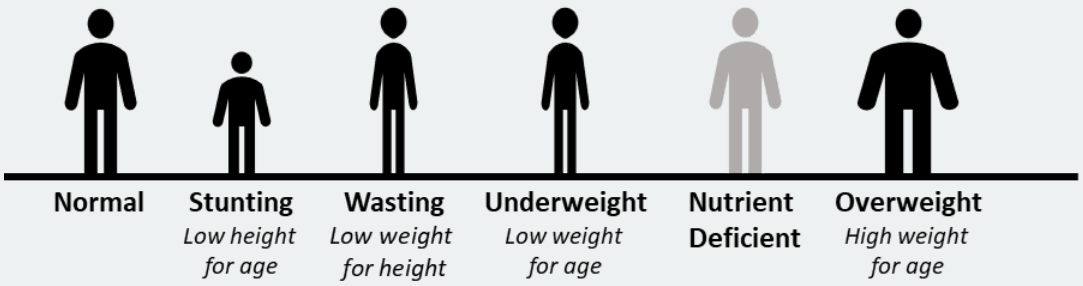


Figure 3.3.1. Five types of malnutrition. Source: Erin Shanle licensed under CC BY 4.0.

Food Insecurity in the United States

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, approximately 10% of US households experienced food insecurity at certain points during 2021, and 3.8% experienced very low food security, which occurs when one or more household members experienced reduced food intake and disrupted eating patterns due to limited resources for obtaining food. Unfortunately, this has been a consistent finding over the past 20 years (Figure 3.3.2). In addition, food insecurity affects African American and Hispanic households at a much higher rate, with almost 20% of these households experiencing food insecurity in 2021.[3] Households experiencing food insecurity report some common issues they face (Figure 3.3.3). For example, almost all households with very low food security worried about food running out, could not afford a balanced meal, and ate less than they felt they should. Even a small percentage of households considered food secure could not afford a balanced meal.[4]

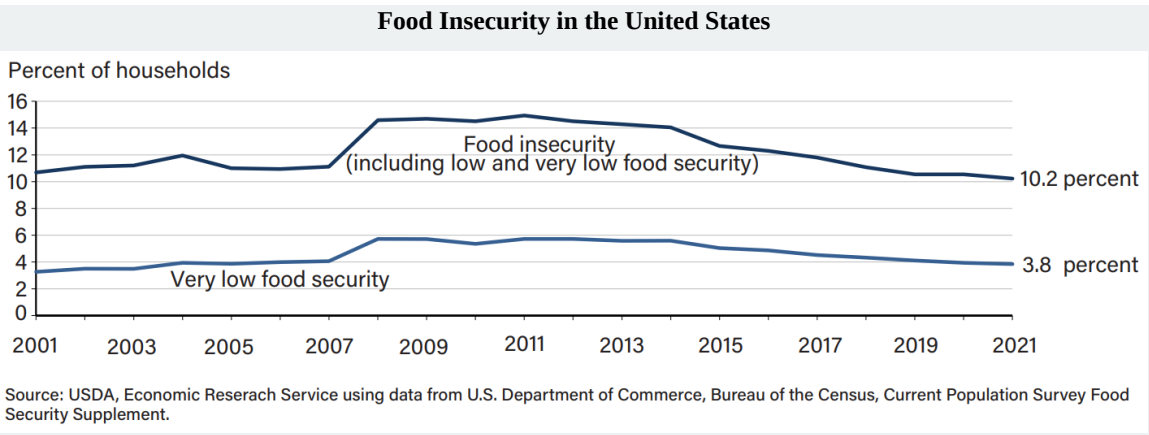


Figure 3.3.2. Percent of households experiencing food insecurity between 2001 and 2021.[3] Source: Coleman-Jensen, Alisha, Matthew P. Rabbitt, Christian A. Gregory, Anita Singh, September 2022. Household Food Security in the United States in 2021, ERR-309, U.S. Department of Agriculture, Economic Research Service.

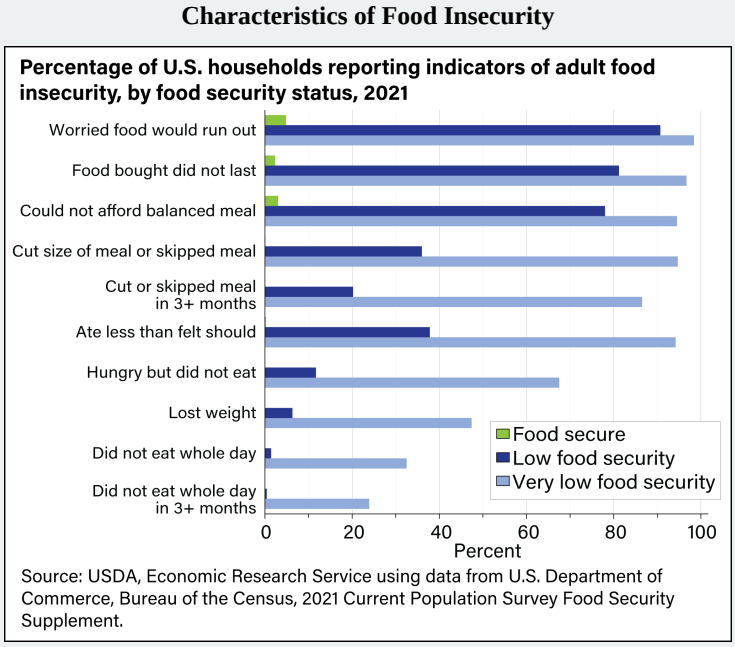


Figure 3.3.3. Percentage of U.S. households reporting indicators of adult food insecurity in 2021.[4] Source: U.S. Department of Agriculture Economic Research Service (2022, October 17). *Definitions of Food Security*. Retrieved July 21, 2023, from https://www.ers.usda.gov/topics/food...food-security/

Risk Factors for Food Insecurity

Worldwide, several risk factors contribute to food insecurity. Urbanization, wars, and the pandemic have impacted food insecurity throughout the world. Food insecurity is more prevalent for women, people with low incomes living in rural areas, and people affected by natural disasters and conflicts. Malnutrition is also fueled by the increased availability of cheaper, pre-packaged, and fast foods that are often high in calories, fats, sugars, and/or salt. Globally, there is insufficient availability of vegetables and fruits to meet everyone's daily requirements for a healthy diet, and food costs have steadily increased. These challenges have contributed to increases in the number of overweight children, especially in urban areas.[5]

In the United States, there are additional subgroups that 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, and certain ethnic

and racial groups.[3]

Senior citizens are also a major at-risk group, and it is estimated that 1 in 14 seniors face hunger.[6] Many elderly people are frail and isolated, which affects their ability to meet their dietary requirements. In addition, many have low incomes, limited resources, and difficulty purchasing or preparing food due to health issues or poor mobility.

Food insecurity has a major impact on children, who need proper nutrition to grow and develop. 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. Children who are overweight have an increased risk for cardiovascular problems, infections, and diabetes.[7] In the United States, it is estimated that over 9 million children face food insecurity.[6]

Community Nutrition Programs in the United States

The field of **community nutrition** aims to improve the overall health of individuals and groups by providing education and support for good nutrition. Private organizations, community members, and government agencies can all work towards improving community nutrition. Community nutrition programs can be designed to target specific groups, such as children, the elderly, pregnant women, or low-income households. In the United States, the USDA organizes and operates several programs to improve food security for different groups or communities through its Food and Nutrition Service Division.[8] They provide low-income households with access to food, the tools for consuming a healthy diet, and education about nutrition. The USDA also 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.

The **federal poverty level (FPL)** is used to determine eligibility for many federal food-assistance programs. This monetary figure is the minimum amount 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.

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. Like most USDA programs, this program is funded through the USDA and administered by state agencies. 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. 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 2021, the average benefit was about $218 per person per month, and total federal expenditures for the program were $113.8 billion.[3]

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. Similar to SNAP, state agencies are responsible for administering the benefits provided by the USDA. Most state WIC agencies have replaced paper vouchers with the WIC EBT system. Benefits are issued to participants on WIC EBT cards for redemption at WIC-authorized grocery stores. In 2021, WIC served about 6.2 million participants per month at an average monthly cost for food (after rebates to WIC from manufacturers) of about $35 per person.[3]

The National School Lunch, School Breakfast, and Summer Food Service Programs

The USDA funds several programs to ensure school-age children have access to healthy meals. The **National School Lunch Program (NSLP)** and the **School Breakfast Program (SBP)** ensure that children and teens in schools receive at least one healthy meal each school day, or two if both the NSLP and SBP are provided. The National School Lunch Program (NSLP) operates in more than 97,000 public and nonprofit private schools and residential childcare institutions. All children attending participating schools are eligible to receive lunch, with lunches available for free to low-income children or at a reduced price. Schools are reimbursed by the USDA for all meals served under the program on a sliding scale based on whether meals are free, reduced-price, or full-price. The **Summer Food Service (SFS) Program** provides meals at summer sites in low-income communities, where sponsors often also offer enrichment activities, or in approved rural communities facing access issues via grab-n-go or delivery.[3]

Vegetables for Lunch



Figure 3.3.4. The US Department of Agriculture's (USDA) Agriculture Marketing Service (AMS) Commodity Procurement staff helps qualified companies sell their products to USDA for the National School Lunch Program and other federal nutrition programs.[9] Photo by Hakim Fobia. Source: "School Lunch Veggies" by USDAgov is licensed under CC BY 2.0.

Child and Adult Care Food Program

Through the Child and Adult Care Food Program (CACFP), eligible children and adults are enrolled for care at participating childcare centers, daycare homes, and adult daycare centers. CACFP also provides reimbursements for meals served to children and youth participating in afterschool care programs, children residing in emergency shelters, and adults over the age of 60 or living with a disability and enrolled in daycare facilities. CACFP contributes to the wellness, healthy growth, and development of young children and elderly adults in the United States.[10]

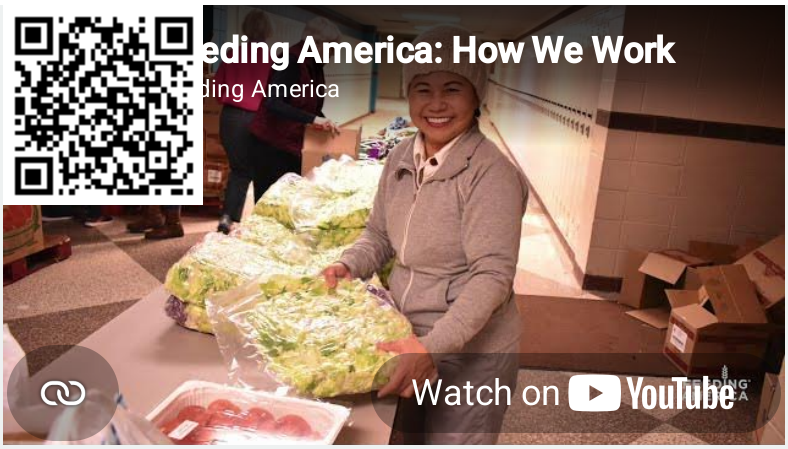
Non-Profit Organizations

Other forms of assistance include locally operated charitable organizations that 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 and religious institutions to provide an additional safety net for those in need of food.

Feeding America

The Feeding America network is a nationwide charitable organization that consists of 200 **food banks** and 60,000 **food pantries** across America. Food banks collect and store large amounts of food distributed to smaller food pantries run by local organizations. People facing food insecurity can get food from food pantries in their community. Feeding America also provides nutrition education and food insecurity research to help fight hunger and malnutrition. They help individuals apply for SNAP benefits, set up mobile food pantries, and connect individuals with nutrition services in their local community.[11]

Feeding America



Video 3.3.1. Feeding America is a non-profit organization that helps fight hunger in the United States.[12]Source: [Feeding America]. (2021, October 8). *How We Work 2021 - Feeding America* [Video]. YouTube. https://www.feedingamerica.org/

Congregate Meal Programs

In 1965, the Older Americans Act (OAA) was passed by the United States Congress in response to a lack of community social services for older Americans. The Administration for Community is a part of the U.S. Department of Health and Human Services that uses funds from the OAA to **congregate meal programs** that serve older Americans nutritious meals in a group setting. The goal is to provide not only nutritious meals but also opportunities for older adults to socialize with each other and connect with services in their community.[13] Congregate meal programs can be organized at senior centers, churches, schools, or farmer's markets. Participants pay what they can and enjoy an experience that supports the social and emotional dimensions of wellness with a hot, nutritious meal.[14]

Meals on Wheels

An organization called Meals on Wheels delivers meals to elderly people who have difficulty buying or making their own food because of poor health or limited mobility. It is the oldest and largest program dedicated to addressing the nutritional needs of senior citizens. Each day, Meals on Wheels volunteers deliver more than one million meals across the United States. The first Meals on Wheels program began in Philadelphia in the 1950's. In the decades since, the organization has expanded into a vast network that serves the elderly in all fifty states and several US territories. Today, Meals on Wheels remains committed to ending hunger among the senior citizen community.[15]

Meals on Wheels



Figure 3.3.5: MINNEAPOLIS (July 18, 2017) Special Operator 1st Class Brandon Peterson, a member of the U.S. Navy parachute demonstration team, the Leap Frogs, delivers Meals-on-Wheels to elderly and homebound residents as part of Minneapolis/St. Paul Navy Week.[16] (US Navy photo by Mass Communication Specialist 2nd Class Pyoung K. Yi/Released)170718-N-VY375-309 Source: "Sailor delivers Meals-on-Wheels to elderly and homebound residents." by Official U.S. Navy Imagery is licensed under CC BY 2.0.

Attributions

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3.4: Food Sustainability

Food Sustainability

In addition to being safe and productive enough to feed the world's growing population, modern food systems must be sustainable. A **sustainable food system** provides food security and nutrition for everyone today and into the future without compromising economic, social, and environmental factors (Figure 3.4.1).[1]

Features of Sustainable Food Systems

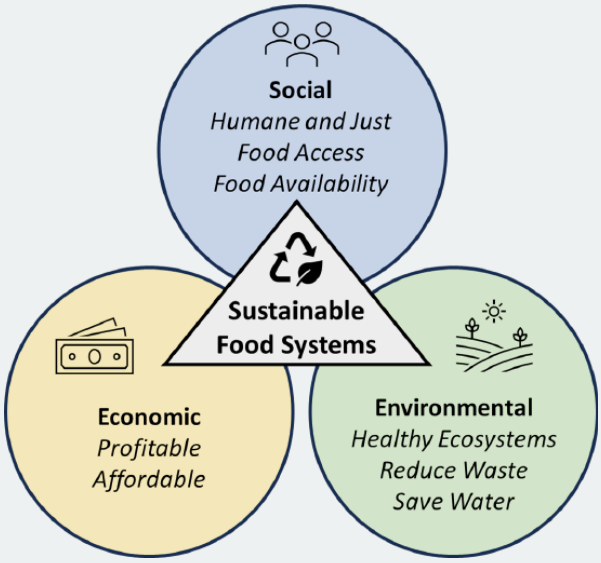


Figure 3.4.1: Three requirements of a sustainable food system. Source: Erin Shanle licensed under CC BY 4.0.

Environmental Factors

Sustainable food systems use environmental resources, such as land or water, without depleting the resources in the process. Currently, modern food systems are not sustainable and fail to feed the world without depleting key resources like fresh water and Earth's natural environments or ecosystems. An **ecosystem** is defined as the biological and physical environments and their interactions with the community of organisms that inhabit those environments as well as the interactions among those organisms. Food production from grains to meats uses more than 40% of Earth's land that is free of deserts or ice, which means these ecosystems have been largely replaced with agricultural fields for growing crops or grazing livestock.[2]

Water is at the core of creating a sustainable food system because fresh water is a nonrenewable resource on Earth. That means there is a set amount of freshwater that cycles throughout the Earth, and every person needs it to drink and produce food. According to the World Health Organization and UNICEF, 1 in 3 people on Earth do not have access to clean, safe drinking water.[3] Moreover, 70% of the freshwater used daily on Earth is used for agriculture to produce our food.[4] This global water crisis requires a balance between using water for drinking and sanitation and using water for food production. Sustainable food systems must be developed that address the global water crisis to continue producing food for everyone on Earth.

Modern food systems also have a large carbon footprint, which means they emit large amounts of carbon dioxide and other greenhouse gasses into Earth's atmosphere. It is estimated that our food systems produce 26% of human-derived greenhouse gases.[2] One way to reduce the carbon footprint of modern food systems is to reduce food waste. The EPA estimates that in 2019 alone, about 66 million tons of wasted food were generated in the food retail, food service, and residential sectors, and most of this waste (about 60%) was sent to landfills. The EPA estimated that in 2018 in the United States, more food reached landfills and combustion facilities than any other single material in our everyday trash (24% of the amount landfilled and 22% of the amount combusted with energy recovery).[5] Globally, food loss and waste accounts for 8% of greenhouse gas emissions.[6] Although there are many other environmental factors to consider in modern food systems, making changes to promote healthy ecosystems, reduce waste and

carbon emissions, and conserve clean water will help move us toward food systems that can continue to produce food for generations to come.

Modern Food Systems Use Resources



Figure 3.4.2: Modern food systems use resources, including land and fresh water, to produce food.[7] Source: "File:Tractor at work on a field in Idaho (cropped).jpg" by Sam Beebe is licensed under CC BY 2.0.

Economic Factors

Money and profits are important drivers in modern food systems. Agriculture, food, and related industries contributed roughly $1.264 trillion to US gross domestic product (GDP) in 2021, a 5.4% share.[8] Consumers can influence food systems by choosing to buy or avoid certain food products. However, factors such as improved shelf-life, protective packaging, and highly productive crops greatly improve profits for food industries. Food industries have increased production and profits by using genetically engineered plants, herbicides, and pesticides. Public policy also shapes modern food systems. For example, the USDA offers **subsidies**, or money given to farmers, to support over 20 crops in the US. However, feed grains are the most highly supported through these programs.[9] These types of policies have the power to influence the development of sustainable food systems using economic and financial support for diverse crops and small- or medium-sized farms.

The American Public Health Association (APHA) states that a sustainable food system also provides food availability, accessibility, and affordability to all while remaining humane and just for everyone.[10] A sustainable food system does not just include the food and those who consume the food but also those who produce the food, such as farmers and fishermen, and those who process, package, distribute, and regulate food. Sustainable food systems must be profitable for each person in the food system, from the farmer to the distributor. In the United States, farmers only receive 14 cents of every dollar spent on food. The rest of that dollar goes to the market share of the food system, which includes transportation, packaging, processing, and advertising (Figure 3.4.3)[11] Future sustainable food systems will need to ensure farmers, farm workers, and food producers can sustain profits while keeping foods affordable for consumers.

The affordability of a healthy diet is a major concern throughout the world. Sustainable food systems should provide nutritious foods that everyone can afford. Unfortunately, modern food systems are currently operating in a way that makes healthy diets more expensive. On average across the world, a diet that provides enough calories through the least expensive foods but lacks essential nutrients is estimated to be about 80 cents per day. However, a diet that provides sufficient nutrients through the incorporation of fruits and vegetables costs almost 5 times more.[12] Many factors increase the costs of nutritious foods, but the lack of diverse, nutritious crops increases the cost and availability of nutritious foods throughout the world.

The Food Dollar in America

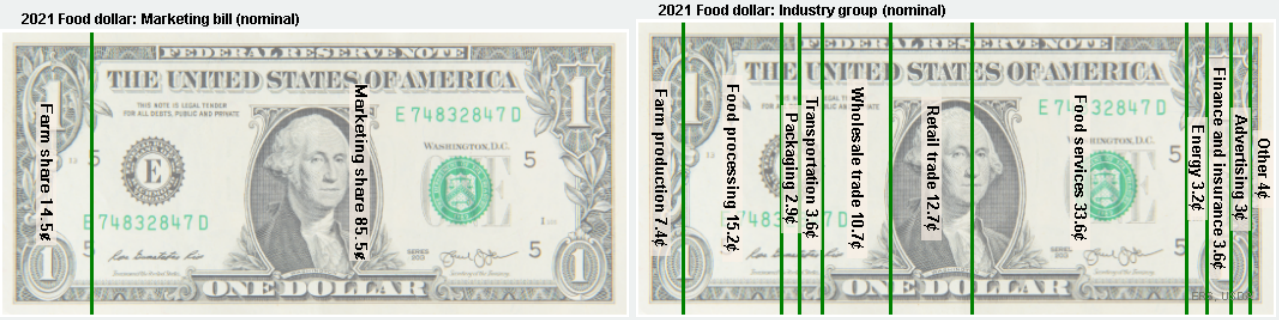


Figure 3.4.3. A typical food dollar. For every $1 spent on food in America, approximately 14 cents goes to the farm that produces the food. Further breakdown of the food dollar shows that food services and food processing get almost half of the money spent on food.[11] Source: USDA Economic Research Service (2023, February 15). *Food Dollar Application*. Retrieved July 22, 2023, from https://data.ers.usda.gov/reports.aspx?ID=17885

Social Factors

The most prominent challenge to building a sustainable food system is to make food available and accessible to all. In the previous section, we learned that food insecurity is a problem throughout the world and in the United States. Modern food systems are not providing nutritious foods to all communities, which has led to a growing **food justice** movement. This movement aims to improve access to nutritious food for disadvantaged communities, including low-income communities and communities of color, by advocating for change in food systems.[13]

Location and income have a great impact on a person's access to nutritious foods. In urban areas, for example, food deserts have increased. A **food desert** is a location that does not provide access to affordable, high-quality, nutritious food. An estimated 18.8 million people in these low-income and low-access census tracts lived far from a supermarket in 2019.[8] One of the best examples of a "food desert" is in Detroit, Michigan (Figure 3.4.4). The lower socioeconomic status of the people who live in this city does not foster the building of grocery stores in the community. Therefore, the most accessible foods are the cheap, high-caloric ones sold in convenience stores. As a result, people who live in Detroit have some of the highest incidences of obesity, type 2 diabetes, and cardiovascular disease in the country.

Food Deserts in Detroit, Michigan

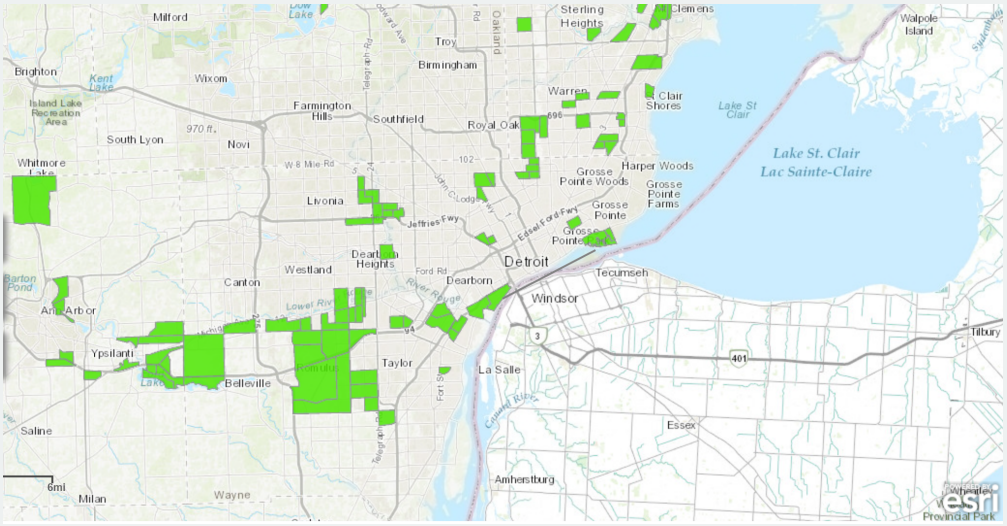


Figure 3.4.4: Map of food deserts in Detroit, MI. Regions highlighted in green have a significant number of low-income households that live at least 1 mile from a grocery store.[14] Source: USDA Economic Research Service (2023, July 6). *Food Access Research Atlas*. Retrieved July 22, 2023, from https://www.ers.usda.gov/data-produc...-to-the-atlas/

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3.5: Global Perspectives

Nutrition Across the World

As we learned in the previous section, modern food systems are not sustainable, and many people do not have access to nutritious foods. Each country and culture in the world faces challenges to food security and sustainability. These challenges vary across countries depending on income level, as discussed below. However, many parts of the world share common issues, such as ensuring that sensitive groups like children have access to nutritious foods. Nutrition education, outreach, and services throughout the world aim to improve nutrition for everyone.

In 2015, United Nations member states adopted 17 sustainable development goals to improve the well-being and health of people and the planet. One of these goals is to eliminate world hunger by 2030. More specifically, this goal centers around reducing hunger by improving food security and sustainability and aims to ensure access to nutritious foods, end malnutrition, and increase food production and sustainability.[1] Unfortunately, there are many challenges in achieving this goal. In 2022, an estimated 30% of the world's population experienced moderate or severe food insecurity and almost 10% or nearly 750 million people were undernourished worldwide.[2]

Global Issues in Food Security

Income

Income and economic development are major factors affecting food security and nutrition. Countries throughout the world vary in their income, business activities, government organization, populations, and infrastructure, including access to clean water and waste management systems. The term **developing country** has been widely used to describe countries with lower economic and industrial activity. However, there is no universal definition or list of developing countries. According to the United Nations, **least developed countries (LDCs)** are low-income countries that have significant challenges to sustainable development, including limited infrastructure and resources.[3] The World Bank uses similar measures to define countries as **low-income countries**, so these terms are often used interchangeably. Low-income countries are more sensitive to local and global changes, such as conflicts, natural disasters, or economic downturns. As such, they also face unique challenges in meeting the goal to eliminate hunger and reduce malnutrition.

Many low-income countries are found in sub-Saharan Africa, where approximately 60% of the population experiences moderate or severe food insecurity. In Europe and North America, only 8% of the population experiences moderate or severe food insecurity. Europe and North America have more **high-income countries**, or developed countries, that have more industry, infrastructure, and money. High-income countries have greater food access and availability than low-income countries, so fewer people go hungry.[2]

Urbanization

Urbanization, or an increase in the number of people living in cities, also has a major effect on food security throughout the world. As populations grow in urban areas, more people can purchase food at markets, and food is generally more accessible and available. Urban diets often have more variety, but there is also an increase in the consumption of pre-packaged, highly processed foods that are often less nutritious. Recent reports have found that **rural areas** far from cities have more food insecurity than urban areas in low-income countries. However, there is an opposite trend in high-income countries, and urban areas have slightly higher rates of food insecurity.[2] This may be due to the presence of food deserts and lower incomes present in urban areas of high-income countries.

Gender Gaps

Women across the globe are at higher risk of food insecurity. In 2021, the gender gap reached 3.8%, with 28.6% of women in the world being moderately or severely food insecure compared with 24.8% of men.[2] This difference in food security between men and women was observed in every continent in the world, but women in Africa and rural regions experienced the biggest increases in food insecurity over men.[2]

Overweight Malnutrition in Children

Although many people in the world face hunger and malnutrition such as stunting and wasting, there has been a global increase in overweight and obesity malnutrition. Children who are overweight are more likely to be overweight in adulthood, which is associated with diabetes and cardiovascular disease.[4] According to UNICEF, an agency of the United Nations that focuses on the

well-being of children, the proportion of overweight children increased from 1 in 10 to almost 1 in 5 between 2000 and 2016.[5] Historically, overweight malnutrition was considered a problem only for high-income countries, but low-income countries are experiencing the fastest increases in the number of overweight children. In fact, the number of overweight children in Africa rose by 44% between 2000 and 2018. Overweight malnutrition is also linked to household income, and low-income children are more likely to be overweight in the United States and other high-income countries.[5] This trend is likely due to increased consumption of foods that are high in calories, such as sugary drinks, prepackaged and highly processed foods, and less physical activity for many children throughout the world.

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3.6: Nutrition in Action

Nutrition in Action

The field of nutrition goes beyond the foods you choose to eat to get necessary nutrients. We need to understand modern food systems to keep ourselves and the people in our communities healthy, both locally and globally. Feeding our world, today and into the future, will require some changes to improve access, availability, food security, and food sustainability. We cannot make large changes and help improve nutrition in communities across the world unless we think about how our choices play a role in modern food systems. As a consumer, you have the power of choice to support the production and availability of nutritious foods for your community. However, there are many other actions you can take to help build sustainable food systems for your community and across the world. As you continue learning about nutrition in this book, keep in mind how your actions can support healthy nutrition for yourself, those around you, and everyone throughout the world by supporting the growth of sustainable food systems.

Tools for Change

Modern food systems must become more sustainable, and your actions can help support this change. Even small changes in your daily activities can add up to large changes that can improve food security and sustainability in your community and across the world. As previously discussed, sustainable food systems are environmentally friendly, remain profitable and affordable, and ensure access and availability of nutritious foods for everyone. There are actions you can take to support each of these factors (environmental, economic, social) to promote sustainability in our modern food systems.

Environmental Actions

1. **Eat a low-carbon diet.** Because almost half of the greenhouse gas emissions in agriculture come from livestock, a low-carbon diet has more plant-based foods. Beans, vegetables, fruits, and whole grains are more energy efficient than beef, pork, and chicken. The United Nations Climate Action website has more information, including links to sustainable food recipes.
2. **Reduce food waste.** Food waste increases the amount of trash that ends up in landfills and wastes critical resources in our modern food systems. Planning ahead is a key step in preventing food waste. If you make a meal plan for the week, you only buy what you need. Another action you can take is to ensure proper food storage so food doesn't spoil, buy in bulk only when you need to, and freeze foods before they spoil. You can also buy imperfect fruits and vegetables to avoid nutritious food ending up in a landfill. The US EPA website on Preventing Wasted Food at Home has many helpful resources for reducing food waste.
3. **Grow your food.** If you grow your own food, you save the resources required for shipping and marketing foods. It is helpful to start small with an herb container garden or one vegetable you know you like to eat. Gardening doesn't require a lot of land—you can start a window garden, join a community garden, or volunteer at a garden in your community. Learn more about growing herbs, fruits, and vegetables at the University of Maryland Extension site.
4. **Cook in batches.** Cooking meals in large batches is a great way to save time, money, and resources. Even though you may only eat one bowl of soup for dinner, you can make a large pot and freeze the leftovers in small portions or batches. Batch cooking helps save resources by reducing the energy required to cook the food and reducing the amount of food waste by storing leftovers for later meals.
5. **Conserve water.** Fresh water is a natural resource that must be conserved to ensure sustainability. When cooking, you can conserve water by using only what you need. If you boil pasta, you can avoid wasting water by using just what you need. Steaming vegetables uses much less water than boiling. Rinse vegetables in a bowl instead of under running water in a strainer.

Community Gardens



Figure 3.6.1: A community garden at an elementary school in Washington, DC. Community gardens are gardens where community members can pay to have a plot or volunteer to support the gardening in the community. This garden in Washington, DC, is at an elementary school where kids learn about growing healthy foods, help maintain the gardens, and share the harvest with the school and community. Source: Erin Shanle licensed under CC BY 4.0.

Economic Actions

1. **Buy locally produced foods.** Buying from local farmers at farmer's markets, roadside stands, or a food CSA (community-supported agriculture) helps the environment by reducing the need to ship and distribute foods using fossil fuels. It also helps support the local economy in your community by giving farmers fair pay for the crops they grow. Supporting this food source ensures that nutritious foods are available in your community, thus ensuring that food is available to community members at risk for food insecurity.
2. **Buy in bulk.** Buying foods in bulk can help you save money if you plan to use the foods to batch cook meals, for example. Bulk foods often have less packaging, which reduces the overall cost of the food.
3. **Buy foods with less packaging.** As described above, you can keep your food prices lower and help the environment by choosing foods with less plastic packaging. For example, you can buy a large bag of carrots instead of individually wrapped snack packs. This saves resources and money for the consumer and the parts of the food system that package and distribute the food.
4. **Shop intentionally.** You can support sustainable food systems if you use your food dollar intentionally. Shop organically to reduce the use of chemicals in modern food systems, buy fair trade products to ensure everyone in the food system is equitably compensated, and buy products from companies that support sustainability.

Social Actions

1. **Become a food citizen.** A food citizen is more than someone who shops intentionally. As a food citizen, you recognize that you are not just a consumer: you can be a member of modern food systems. Food citizens support policies and organizations that promote sustainable food systems. For example, you can contact local representatives to advocate or ask for policies that ensure food security for everyone in your community. Food citizens can volunteer at food banks or food pantries to help support access and availability of nutritious foods. Overall, food citizens work to advocate for change through policies or projects in their communities.
2. **Educate your community.** An easy way to fight malnutrition and food insecurity is to talk to your friends, family, and peers about nutrition issues. Many people are unaware of the issues, and educating people about nutritious food options, federal

assistance programs, and food policy can help promote more sustainable food systems.

3. **Find out where food comes from.** When you go to a restaurant or grocery store, you can ask where the food comes from. For example, you can ask about the source of fish to determine if the food was sustainably harvested from the ocean. When consumers show interest in sustainable foods, restaurants and stores may try to support sustainable food sources.
4. **Celebrate cooking with others.** When you cook your own food, you are more likely to use fresh ingredients and avoid highly processed, pre-packaged foods. If you celebrate cooking with others, especially kids, you have an opportunity to talk about nutrition. Cook with family members or host a cooking class at the local community center or church. These small actions can go a long way to fight malnutrition in your community.

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CHAPTER OVERVIEW

4: Basics of Digestion

4.1: Introduction
4.2: Structure and Function of Digestive Organs
4.3: Other Body Systems Involved
4.4: Disorders of the GI Tract
4.5: Food Intolerances, Allergies, and Celiac Disease

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4.1: Introduction



Learning Objectives

1. Explain the function of the digestive system.
2. Compare the roles of the gastrointestinal tract and accessory organs in the digestion process.
3. Explain the difference between mechanical and chemical digestion.
4. Describe the role of each organ involved in the digestion process.
5. Explain how the circulatory system, central nervous system, muscular system, endocrine system, and immune system can affect the nutrition process.
6. Relate the process of digestion to metabolism and provide examples of enzymes involved in digestion.
7. Compare and contrast anabolism and catabolism.
8. Describe a chronic disease or injury that affects each step of the digestion process.
9. Justify dietary recommendations for chronic conditions, such as celiac disease and GERD.
10. Compare and contrast food intolerance and food allergy.

We will begin our deeper dive into the macronutrients and micronutrients with a chapter on the basics of digestion. This chapter will prepare you to better understand the process of breaking down our food and building new molecules in our bodies.

By the end of this chapter, you will be able to explain the function and structure of the digestive system. You will also be able to describe the steps in the digestion process, from ingestion to elimination of waste. After going through the digestive process, you will learn about metabolism or the breakdown and building of molecules in your body. Finally, you will be able to describe injuries and diseases that affect the digestion process, justify dietary recommendations for chronic conditions, and compare and contrast food intolerance and food allergy.

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4.2: Structure and Function of Digestive Organs

What is digestion?

Our bodies must break down the molecules we eat to build new tissues, such as our muscles or fat tissue. The process of breaking down the foods you eat is called **digestion**. In this section, you will learn about the organs involved and the main processes involved in digestion.

An Overview of the Organs Involved in Digestion

The function of the digestive system is to break down the foods you eat, release their nutrients, and absorb those nutrients into the body. Although the small intestine is the workhorse of the system where the majority of digestion and absorption occurs, each digestive system organ makes a vital contribution to this process.

The easiest way to understand the digestive system is to divide its organs into two main categories: the gastrointestinal tract (GI tract) and the accessory organs.

- The **GI tract** is a one-way tube about 25 feet in length, beginning at the mouth and ending at the anus. Between these two points, the GI tract also contains the pharynx, esophagus, stomach, small and large intestines, and the rectum. The small intestine comprises three parts: the duodenum, the jejunum, and the ileum. The large intestine, also called the colon, is similarly divided into three sections: the ascending colon, transverse colon, and descending colon. Both the mouth and anus are open to the external environment; thus, food and wastes within the GI tract are technically considered to be outside the body. Only through the process of absorption do the nutrients in food enter into and nourish the body's "inner space."
- **Accessory organs**, despite their name, are critical to the function of the digestive system. They are considered accessory organs because they are not actually part of the intestinal tract itself but have ducts that deliver digestive juices into the tract to aid in digestion. There are four accessory organs: the salivary glands, liver, gallbladder, and pancreas. All of these organs secrete fluids containing a variety of chemicals, such as enzymes and acids, that aid in digestion.

Digestive Organs

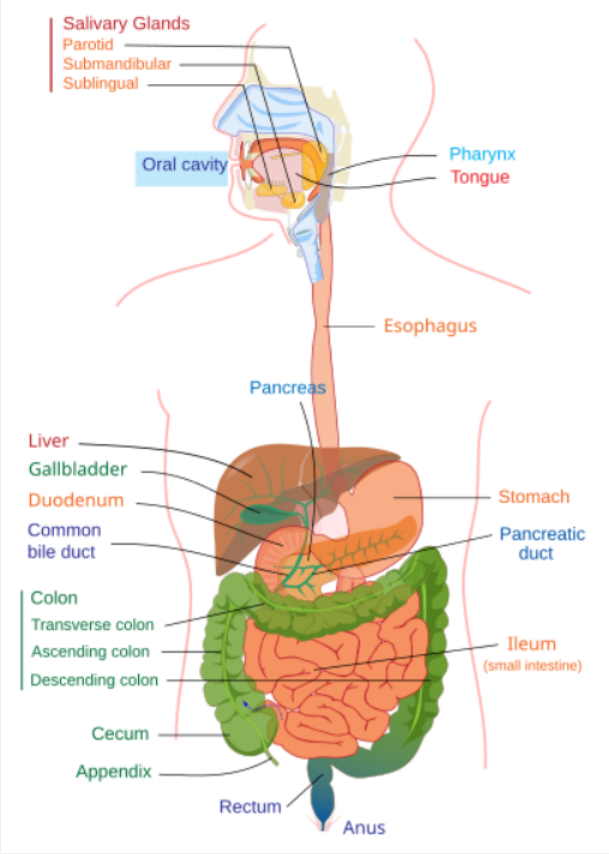


Figure 4.2.1: An overview of the organs involved in digestion. The parts of the GI tract are highlighted in blue, and the accessory organs are highlighted in yellow. ("GI tract and accessory organs" by Alice Callahan is licensed under CC BY 4.0; edited from "Digestive system diagram edit" by Mariana Ruiz, edited by Joaquim Alves Gaspar, Jmarchn is in the Public Domain)

An Overview of the Digestive Process

The process of digestion includes five main activities: ingestion, mechanical digestion, chemical digestion, absorption, and excretion.

The first of these processes, **ingestion**, refers to the entry of food into the GI tract through the mouth. There, the food is chewed and mixed with saliva, which contains enzymes that begin breaking down the carbohydrates and lipids in food. **Mastication** (chewing) increases the surface area of the food and allows for food to be broken into small enough pieces to be swallowed safely.

Food (now called a **bolus** since it has been chewed and moistened) leaves the mouth when the tongue and pharyngeal muscles propel the bolus into the esophagus. The bolus travels down the esophagus through an involuntary process called peristalsis. **Peristalsis** consists of sequential, alternating waves of contraction and relaxation of the smooth muscles in the GI tract, which act to propel food along (Figure 4.2.2). These waves also play a role in mixing food with digestive juices. Peristalsis is so powerful that that foods and liquids you swallow enter your stomach even if you are standing on your head.

Peristalsis

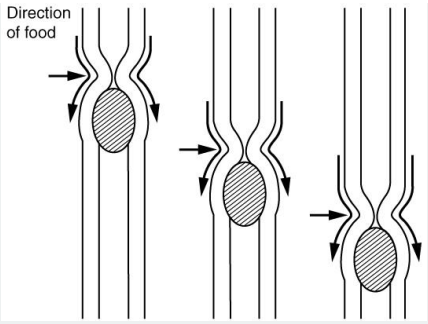


Figure 4.2.2: Peristalsis moves food through the digestive tract with alternating waves of muscle contraction and relaxation. ("Peristalsis" by J. Gordon Betts, Kelly A. Young, James A. Wise, Eddie Johnson, Brandon Poe, Dean H. Kruse, Oksana Korol, Jody E. Johnson, Mark Womble, Peter DeSaix, Anatomy and Physiology, OpenStax, licensed under CC BY 4.0.

Digestion includes both mechanical and chemical processes. **Mechanical digestion** is a purely physical process of making food particles smaller to increase both surface area and mobility. Mechanical digestion does not change the chemical nature of the food. It includes mastication, tongue movements that help break food into smaller bits and mix it with saliva, mixing and churning of the stomach to further break food apart and expose more of its surface area to digestive juices, and peristalsis to help move food along the intestinal tract. Segmentation is also an example of mechanical digestion. **Segmentation**, which occurs mainly in the small intestine, consists of localized contractions of circular muscle of the GI tract. These contractions isolate small sections of the intestine, moving their contents back and forth while continuously subdividing, breaking up, and mixing the contents. By moving food back and forth in the intestinal tract, segmentation mixes food with digestive juices and facilitates absorption.

Segmentation

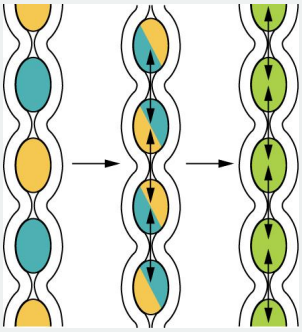


Figure 4.2.3: Segmentation separates chyme and then pushes it back together, mixing it and providing time for digestion and absorption. ("Segmentation" by OpenStax College is licensed under CC BY 3.0)

In **chemical digestion**, digestive secretions that contain enzymes start to break down the macronutrients into their chemical building blocks (for example, starch into glucose). **Enzymes** are chemicals that help speed up or facilitate chemical reactions in the body. They bring together two compounds to react without undergoing any changes themselves. For example, the main chemical reaction in digestion is hydrolysis. **Hydrolysis** is the splitting of one molecule into two with the addition of water. For example, the sugar sucrose (a double sugar) must be broken down into its building blocks, glucose and fructose (both single sugars), before it can be absorbed. This breakdown happens through hydrolysis, and the enzyme sucrase brings together the sucrose molecule and the water molecule to react. This process is illustrated in the following animation.

Enzymes in Action[1]



Video 4.2.1: Enzyme Action and the Hydrolysis of Sucrose by McGraw-Hill Animations, YouTube (June 3, 2017). 1:46 minutes.

Nutrients are of little value to the body unless they enter the bloodstream. This occurs through **absorption**, a process that takes place primarily within the small intestine. There, most nutrients are absorbed from the **lumen** (or inside space) of the GI tract into the bloodstream. Lipids are absorbed into lymph but eventually enter the bloodstream as well.

In **excretion**, the final step of digestion, undigested materials are removed from the body as **feces**. The feces is stored in the rectum until it leaves the body through the anus.

Functions of the Digestive Organs

Now that you have an overview of the digestive organs and the digestive process, let's discuss in more detail what types of mechanical and chemical digestion take place in each of the organs of the GI tract. Let's imagine eating a peanut butter and jelly sandwich that contains carbohydrates, proteins, fats, vitamins, and minerals. How does each organ participate in breaking this sandwich down into units that can be absorbed and utilized by cells throughout the body?

Mouth

Ingestion of the peanut butter and jelly sandwich happens in the **mouth** or oral cavity. This is where mechanical and chemical digestion also begin. Teeth physically crush and grind the sandwich into smaller particles and mix the food particles with saliva. **Salivary amylase** (a digestive enzyme) is secreted by **salivary glands** (salivary glands produce **saliva,** which is a mixture of water, enzymes, and other chemicals) and begins the chemical breakdown of carbohydrates in the bread, while **lingual lipase** (another digestive enzyme) starts the chemical breakdown of triglycerides (the main form of fat in food) in the peanut butter.

Esophagus

The **esophagus** is a muscular tube that transports food from the mouth to the stomach. No chemical digestion occurs while the bolus is mechanically propelled through this tube by peristalsis.

Stomach

The **stomach** is an expansion of the GI tract that links the esophagus to the first part of the small intestine (the duodenum). The empty stomach is only about the size of your fist but can stretch to hold as much as 4 liters of food and fluid—more than 75 times its empty volume—and then return to its resting size when empty. An important function of the stomach is to serve as a temporary holding chamber. You can ingest a meal far more quickly than it can be digested and absorbed by the small intestine. Thus, the stomach holds food and secretes only small amounts into the small intestine at a time. (The length of time food spends in the stomach varies by the macronutrient composition of the meal. A high-fat or high-protein meal takes longer to break down than one rich in carbohydrates. It usually takes a few hours after a meal to empty the stomach contents completely into the small intestine.)

When the peanut butter and jelly sandwich enters the stomach, a highly muscular organ, powerful peristaltic contractions help mash, pulverize, and churn it into chyme. **Chyme** is a semiliquid mass of partially digested food and gastric juices secreted by cells in the stomach. These gastric juices contain **hydrochloric acid**, which lowers the pH of the chyme in the stomach. This acidic environment kills many bacteria or other germs that may have been present in the food, and it causes the three-dimensional

structure of dietary proteins to unfold. Gastric juices also contain the enzyme **pepsin**, which begins the chemical breakdown of proteins in the peanut butter and bread. **Gastric lipase** continues the breakdown of fat from the peanut butter.

Small Intestine

Chyme released from the stomach enters the **small intestine**, where most digestion and absorption occur. The small intestine is divided into three parts, all part of one continuous tube: the duodenum, the jejunum, and the ileum.

Once the chyme enters the **duodenum** (the first segment of the small intestine), the pancreas and gallbladder are stimulated to release juices that aid in digestion. The **pancreas** (located behind the stomach) produces and secretes pancreatic juices, which consist mostly of water but also contain bicarbonate that neutralizes the acidity of the stomach-derived chyme and enzymes that further break down proteins, carbohydrates, and lipids. The small intestine's absorptive cells also synthesize digestive enzymes that aid in the breakdown of sugars and proteins.

The **gallbladder** (a small sac located behind the liver) stores, concentrates, and secretes bile, a fluid that helps to digest fats. Bile is made in the **liver** and stored in the gallbladder. **Bile** is an emulsifier; it acts like a detergent (that would remove grease from a frying pan) by breaking large fat droplets into smaller fat droplets so they can mix with the watery digestive juices.

Peristalsis and segmentation control the movement and mixing of chyme through the small intestine. As in the esophagus and stomach, peristalsis consists of circular waves of smooth muscle contractions that propel food forward. Segmentation helps to mix food with digestive juices and facilitates absorption.

Nutrient absorption takes place mainly in the latter part of the small intestine, the **ileum**.

The small intestine is perfectly structured to maximize nutrient absorption. Its surface area is greater than 200 square meters—about the size of a tennis court! The large surface area is due to the multiple levels of folding, villi, and microvilli that cover the internal tissue of the small intestine. ***Villi*** are tiny finger-like projections that are covered with **enterocytes** or absorptive cells. The absorptive cell membrane is made of even smaller projections called **microvilli** (Figure 4.2.4). These microvilli are referred to collectively as the brush border because their appearance resembles the bristles on a brush.

Cells in the Small Intestines

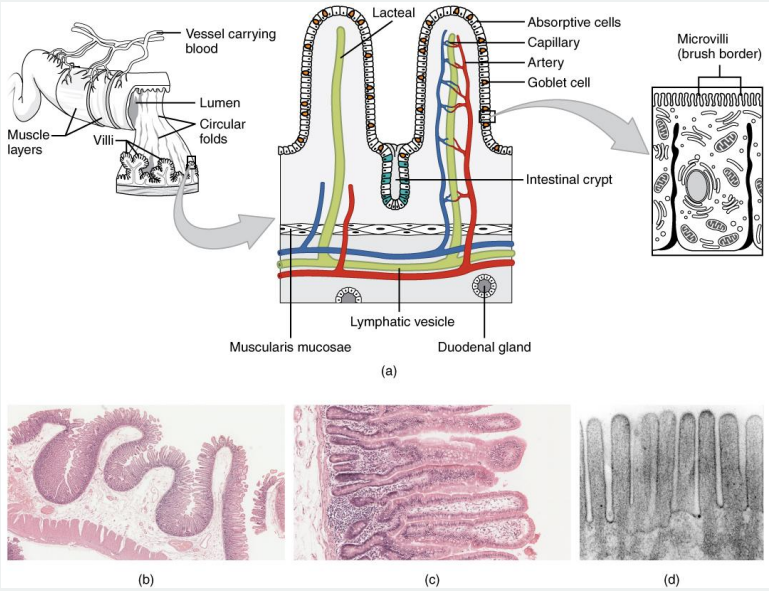


Figure 4.2.4: istology of the small intestine. (a) The absorptive surface of the small intestine is vastly enlarged by the presence of circular folds, villi, and microvilli. (b) Micrograph of the circular folds. (c) Micrograph of the villi. (d) Electron micrograph of the microvilli. ("Histology Small Intestines" by OpenStax College is licensed under CC BY 3.0)

Digested nutrients are absorbed into either capillaries or lymphatic vessels within each villus. Amino acids (from protein digestion), small fatty acids (from triglyceride digestion), sugars (from carbohydrate digestion), water-soluble vitamins, and minerals are transported from the intestinal cells into the bloodstream through capillaries. The larger fatty acids, fat-soluble vitamins, and other lipids (packaged in lipid transport particles) are transported first through lymphatic vessels and eventually meet up with the blood. Water-soluble nutrients that enter the bloodstream are transported directly to the liver, where the liver processes, stores, or releases these nutrients to other body cells.

Absorption

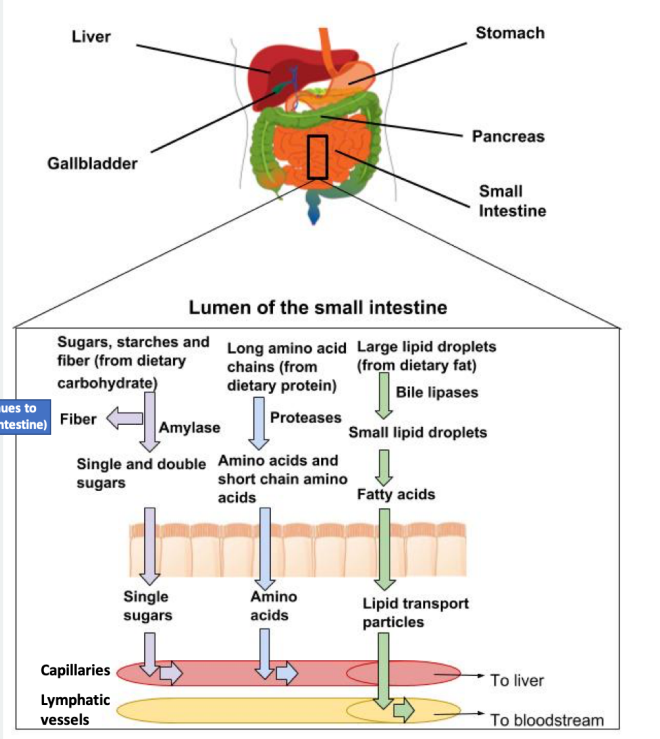


Figure 4.2.5: The digestion and absorption of nutrients in the small intestine. (“Absorption of Nutrients” by Tamberly Powell is licensed under CC BY 4.0; edited from University of Hawai‘i at Mānoa Food Science and Human Nutrition Program, “The Digestive System,” CC BY-NC 4.0)

Large Intestine

Most of the nutrients from the peanut butter and jelly sandwich have now been digested and absorbed. Any components that still remain (usually less than 10% of food consumed) and the indigestible fiber move from the small intestine to the **large intestine** (colon). A main task of the large intestine is to absorb much of the remaining water. Water is present not only in the solid foods and beverages consumed but also in the digestive juices released by the stomach and pancreas. As water is reabsorbed, liquid chyme becomes a semisolid, referred to as feces. **Feces** comprises undigested food residues, unabsorbed digested substances, millions of bacteria, old cells from the lining of the GI tract, inorganic salts, and enough water to let it pass smoothly out of the body.

Feces is stored in the **rectum** (a temporary holding area) until it is expelled through the anus via defecation. No further chemical breakdown of food takes place in the large intestine except that accomplished by the bacteria that inhabit this portion of the GI tract. There are trillions of bacteria residing in the large intestine (referred to as the bacterial flora), exceeding the total number of cells in the human body. This may seem rather unpleasant, but the great majority of bacteria in the large intestine are harmless, and many are even beneficial—facilitating chemical digestion and absorption, improving immune function, and synthesizing vitamins such as biotin, pantothenic acid, and vitamin K.

The figure below summarizes the functions of the digestive organs.

Overview of Digestion

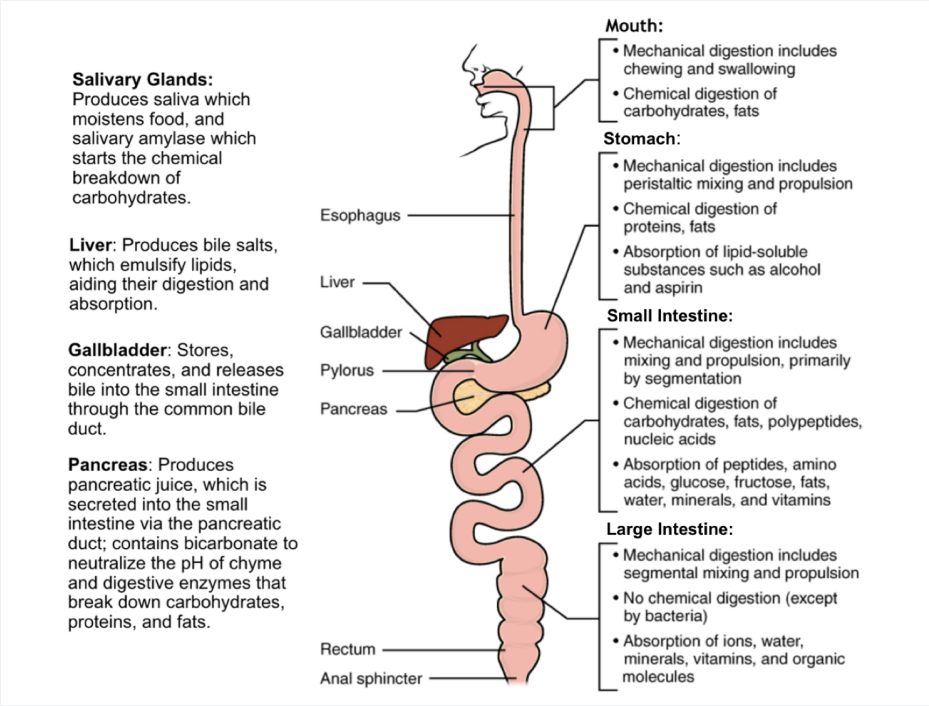


Figure 4.2.6: Summary of digestion and absorption. Digestion begins in the mouth and continues as food travels through the small intestine. Most absorption occurs in the small intestine. ("Functions of the Digestive Organs" by Tamberly Powell is licensed under CC BY 4.0; edited from "Figure 23.28 Digestion and Absorption" by J. Gordon Betts, Kelly A. Young, James A. Wise, Eddie Johnson, Brandon Poe, Dean H. Kruse, Oksana Korol, Jody E. Johnson, Mark Womble, Peter DeSaix , Anatomy and Physiology, OpenStax, licensed under CC BY 4.0)

Overview of Digestion[2]



Video 4.2.1: How the Digestive System Works. Source: [Ted-Ed]. (2017, December 14). *How Your Digestive System Works* [Video]. YouTube. https://youtu.be/Og5xAdC8EUI

Attributions

- Callahan, Leonard, and Powell. "Nutrition Science and Everyday Application (Callahan, Leonard, and Powell).", CC BY-NC-SA 4.0. *A new video link was put in the original content.*

References

1. Deckara Fluke. *Enzyme Action and the Hydrolysis of Sucrose* [Video]. YouTube. https://youtu.be/XAw6DH1SMAc. Published July 15, 2013. Accessed July 22, 2023.
2. Bryce E. *How Your Digestive System Works* [Video]. YouTube. https://youtu.be/Og5xAdC8EUI?si=Zls6OJm4CTWbknKG. 2017. Accessed July 25, 2023.

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4.3: Other Body Systems Involved

What happens after molecules are absorbed?

When the digestive system has broken down food into its nutrient components, they are ready to be absorbed. **Absorption** is the movement of the nutrient molecules from the digestive tract into the blood or lymph. If the absorbed nutrient is water soluble, it will be absorbed into the blood, and if the nutrient is fat soluble, it will be packaged into a special transport package called a chylomicron and absorbed into the lymph. For water-soluble nutrients, the first stop is the liver. The **liver** can store some nutrients, send some to other parts of the body, and/or change some into other molecules the body needs! Fat-soluble nutrients, because they are absorbed into the lymph and only later spill into the blood, travel first to the heart, but eventually, they too will end up in the liver.

The liver is the only organ in the human body capable of exporting nutrients for energy production to other tissues. Therefore, when a person is between meals (fasted state), the liver exports nutrients, and when a person has just eaten (fed state), the liver itself stores nutrients. Nutrient levels and the hormones that respond to their levels in the blood provide the input so that the liver can distinguish between the fasted and fed states and distribute nutrients appropriately.

The Liver

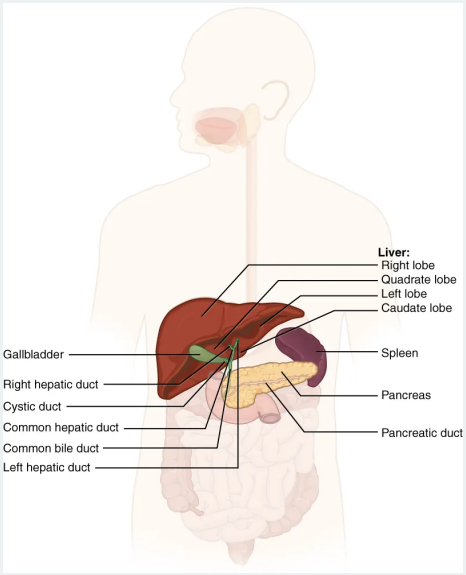


Figure 4.3.1: The liver. Water-soluble nutrients in the blood liver (shown in dark red) is the first place nutrients are stored, changed, and distributed in the body after they are absorbed. Source: Betts J, Young K, Wise J, et al. *Anatomy and Physiology*. OpenStax. https://openstax.org/details/books/anatomy-and-physiology-2e

Other Organ Systems Involved in Digestion

All eleven organ systems in the human body require nutrient input to perform their specific biological functions. No energy in means no work output. Nutrients fuel both overall health and the ability to carry out all of life's basic processes. Without them, organ systems would fail, humans would not reproduce, and the race would disappear. In this section, we will discuss some of the critical nutrients that support specific organ system functions.

The Circulatory System (Cardiovascular System)

The **circulatory system**, part of the cardiovascular system, is one of the 11 organ systems of the human body. Its main function is to transport nutrients to cells and wastes from cells (Figure 4.3.2). This system consists of the heart, blood, and blood vessels. The heart pumps the blood, and the blood is the transportation fluid. The transportation route to all tissues is a highly intricate blood vessel network comprising arteries, veins, and capillaries. Nutrients absorbed in the small intestine travel mainly to the liver through the hepatic portal vein. From the liver, nutrients travel upward through the inferior vena cava blood vessel to the heart. The

heart forcefully pumps the nutrient-rich blood first to the lungs to pick up some oxygen and then to all other cells in the body. Arteries become smaller and smaller on their way to cells so that by the time blood reaches a cell, the artery's diameter is extremely small, and the vessel is now called a capillary. The reduced diameter of the blood vessel substantially slows the speed of blood flow. This dramatic reduction in blood flow gives cells time to harvest the nutrients in the blood and exchange metabolic wastes.

The Circulatory System Moves Nutrients

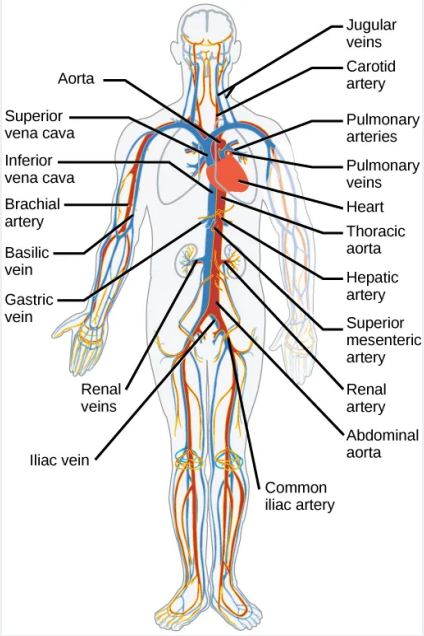


Figure 4.3.2: The circulatory system transports nutrients to all cells and carries wastes out. The heart pumps blood through blood vessels (shown above in red and blue). Source: Fowler, S., Roush, R., & Wise, J. (2022). *Concepts of Biology*. OpenStax. https://openstax.org/books/concepts-...1-introduction

The Nervous System

The human brain (which weighs only about 3 pounds, or 1,300 kilograms) is estimated to contain over 100 billion specialized cells called **neurons**. Neurons form the core of the **nervous system**, which consists of the brain, spinal cord, and other nerve bundles in the body. The main function of the nervous system is to sense changes in the external environment and create a reaction to them. For instance, if your finger comes into contact with a thorn on a rose bush, a sensory neuron transmits a signal from your finger up through the spinal cord and into the brain. Another neuron in the brain sends a signal that travels back to the muscles in your hand and stimulates muscles to contract, causing you to jerk your finger away. All of this happens within a tenth of a second.

The **enteric nervous system** is the part of the nervous system that controls gastrointestinal function. Nerves in the enteric nervous system are embedded around the gastrointestinal tract, from the esophagus to the anus. These nerves control key parts of the digestive process, including peristalsis, segmentation, and the secretion of digestive enzymes. The enteric nervous system can operate autonomously, which means it can operate without input from the brain and spinal cord. The brain and spinal cord make up the **central nervous system**, which plays a role in sensing hunger and regulating appetite.

Every day, the brain uses over 20% of the energy obtained from nutrients. Its main fuel is glucose, and only in extreme starvation does it use anything else. For acute mental alertness and clear thinking, glucose must be systematically delivered to your brain. This does not mean that sucking down a can of sugary soda before your next exam is a good thing. Just as too much glucose is bad for other organs, such as the kidneys and pancreas, it also produces negative effects on the brain. Excessive glucose levels in the blood can cause a loss of cognitive function, and chronically high blood-glucose levels can damage brain cells. The brain's cognitive functions include language processing, learning, perceiving, and thinking.

All nerve impulses travel by the movement of charged sodium, potassium, calcium, and chloride atoms. These are some of the essential minerals in our diets—essential because they are absolutely required for central nervous system function. Nerves communicate with each other via chemicals built from amino acids called neurotransmitters. Eating adequate protein from a variety of sources will ensure the body gets all of the different amino acids that are so important for central nervous system function.

The Nervous System Aids Digestion

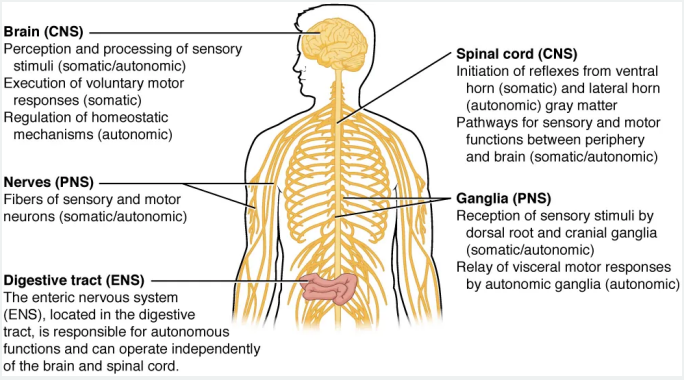


Figure 4.3.3: The nervous system aids digestion by regulating key digestive processes like peristalsis, segmentation, and the secretion of digestive enzymes. Source: Betts J, Young K, Wise J, et al. *Anatomy and Physiology*. OpenStax. https://openstax.org/details/books/anatomy-and-physiology-2e

Nutritional Research: The MIND Diet and Cognitive Health

Over 55 million people live with **dementia**, which is a broad term that describes disorders affecting memory, thinking, behavior, and emotions.[1] Alzheimer's disease is the most common form of dementia. There is currently no cure for dementia, but recent research has shown that nutrition and diet can have an impact on cognitive function and dementia. The **MIND diet**, which recommends whole grains, vegetables, and fruits while limiting red meat, cheese, and processed foods, has been shown to slow the decline in cognitive function associated with age. In a study of 960 participants over the course of nearly 5 years, people who adhered to the MIND diet demonstrated cognitive function that was equivalent to being 7.5 years younger than people who did not adhere to the MIND diet.[2]

The Muscular System

The **muscular system** allows the body to move voluntarily, but it also controls involuntary movements of other organ systems, such as heartbeat in the circulatory system and peristaltic waves in the digestive system. Muscle cells receive signals from the nervous system to expand and contract, which is responsible for voluntary and involuntary movements. The muscular system consists of over six hundred skeletal muscles, as well as the heart muscle, the smooth muscles that surround your entire alimentary canal, and all your arterial blood vessels.

Muscle contraction relies on energy delivery to the muscle. Each movement uses up cellular energy, and without an adequate energy supply, muscle function suffers. Muscle, like the liver, can store the energy from glucose in the form of glycogen, a slow-releasing carbohydrate. But unlike the liver, muscles use up all of their own stored energy and do not export it to other organs in the body. When muscle energy stores are diminished, muscle contraction weakens. However, muscle is not as susceptible to low levels of blood glucose as the brain because it will readily use alternate fuels, such as fatty acids and protein, to produce cellular energy.

"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 a few

days before the event. This will maximize an athlete's 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 fat. 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.



To avoid "hitting the wall," athletes consume large amounts of carbohydrates before and during events to ensure enough glucose is available for optimal performance, especially during endurance activities such as cycling. (TourDeFrance 2005 07 09 by Vzach has been released into the Public Domain).

The Endocrine System

The functions of the **endocrine system** are intricately connected to the body's nutrition. This organ system is responsible for regulating appetite, nutrient absorption, nutrient storage, and nutrient usage, in addition to other functions, such as reproduction. The glands in the endocrine system are the pituitary, thyroid, parathyroid, adrenals, thymus, pineal, pancreas, ovaries, and testes. The glands secrete **hormones**, biological molecules that regulate cellular processes in other target tissues, so they require transportation by the circulatory system. These hormones can have a major impact on nutrient status. For example, the adrenal gland can release corticosteroid hormones, such as cortisol, that can increase the amount of glucose in the bloodstream by promoting the release of stored sugars in the liver. The pancreas also regulates blood glucose levels by releasing the hormone **insulin** (see Connection box below). Adequate nutrition is critical for the functioning of all the glands in the endocrine system. A protein deficiency impairs the release of hormones from reproductive tissues, thereby preventing reproduction. Children who are malnourished usually do not produce enough growth hormone and may exhibit stunted growth.

The Endocrine System

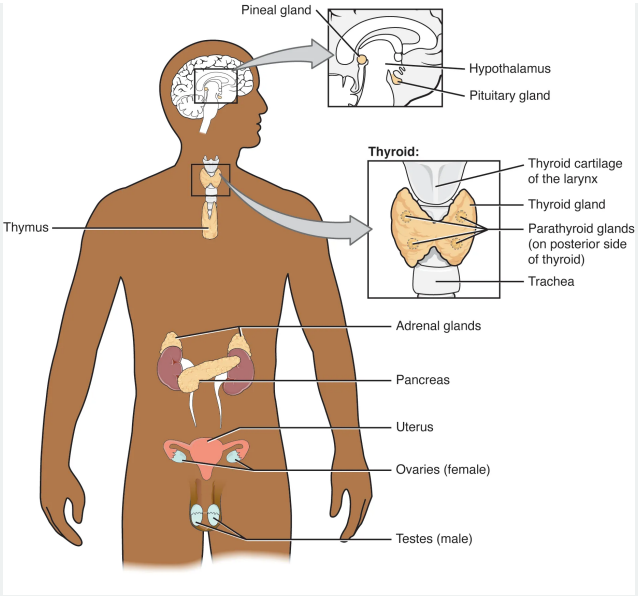


Figure 4.3.4: The Endocrine System. The endocrine system regulates appetite and the absorption, storage, and usage of nutrients. Source: Betts J, Young K, Wise J, et al. *Anatomy and Physiology*. OpenStax. https://openstax.org/details/books/anatomy-and-physiology-2e[3]

Connection: Diabetes and Obesity

Diabetes is a condition in which blood glucose levels are not regulated correctly, resulting in high levels of glucose in the blood. This damages the heart and blood vessels, nerves, kidneys, and many other organs in the body. In Type 2 diabetes, which often occurs in older adults, the pancreas fails to produce enough insulin, and the body's other cells do not respond to insulin correctly. The Centers for Disease Control and Prevention (CDC) estimates that 37.3 million Americans have Type 2 diabetes, which accounts for 11.3% of the US population.[4]

People diagnosed with diabetes may see an **endocrinologist**, a doctor who specializes in the endocrine system. One of the greatest risk factors for type 2 diabetes is being overweight and inactive. Although it is not clear how increased fat tissue causes diabetes, research suggests that several factors are responsible for the connection between obesity and diabetes. Increased fat tissue is initially associated with increased insulin release from the pancreas. Over time, the pancreas begins to fail to release appropriate amounts of insulin, which leads to insulin resistance in other organs. Increases in inflammation and circulating fatty acids in the blood may also play a role in the progression to diabetes.[5]



Video 4.3.1: Understanding Type 2 Diabetes.[6]

The Immune System

The **immune system** is comprised of several types of white blood cells that circulate in the blood and lymph. Their jobs are to seek, recruit, attack, and destroy foreign invaders, such as bacteria and viruses. Other less realized components of the immune system are the skin (which acts as a barricade), mucus (which traps and entangles microorganisms), and even the bacteria in the large intestine (which prevent the colonization of bad bacteria in the gut).

Immune system functions are completely dependent on dietary nutrients. In fact, malnutrition is the leading cause of immune system deficiency worldwide. When immune system functions are inadequate, there is a marked increase in the chance of getting an infection. Children in many poor, developing countries have protein- and/or energy-deficient diets that can cause two different syndromes, **kwashiokor** and **marasmus**. These children often die from infections that their bodies could normally have fought off, but because their protein and/or energy intake is so low, the immune system cannot perform its functions. Other nutrients, such as zinc, selenium, copper, folate, and vitamins A, B_6, C, D, and E, all provide benefits to immune system function. Deficiencies in these nutrients can increase the risk of infection and death. Zinc deficiency results in suppression of the immune system's barrier functions by damaging skin cells; it is also associated with a decrease in the number of circulating white blood cells.

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

Connection: The Immune System and the Microbiome

Our bodies have trillions of microbes, such as bacteria, living inside our gut that help us digest our foods. This collection of microbes that live in and on us is called our **microbiome**, and some scientists consider the microbiome another organ system because it is so important in our health. Most of the microbes are **beneficial**, which means they help us in some way. In the large intestines, microbes help break down complex sugars by releasing digestive enzymes. A healthy gut microbiome is critical for regulating the immune system in all stages of life. For example, infants with less diverse microbiomes were more likely to develop allergic reactions such as eczema.[7] Diets high in fiber, or **prebiotic foods,** can protect against infections by harmful bacteria, such as *Clostridium difficile*, by making the colon more acidic. In fact, patients with severe *C. difficile* infections can sometimes be treated with fecal transplants, in which the stool of a healthy donor is administered to a patient to restore a healthy microbiome.[8] **Probiotics**, or live cultures of beneficial bacteria, can also be taken as supplements or found in fermented foods such as yogurt to promote a healthy microbiome. Probiotics have been associated with several health outcomes, including reduced risks of infection.[9]



Figure 4.3.5: Yogurt contains live cultures of beneficial bacteria. Source: "Yogurt 364" by ljguitar is licensed under CC BY 2.0.

Attributions

- Zimmerman, "An Introduction to Nutrition (Zimmerman)", CC BY-NC-SA 3.0. *Figures were updated and the flow of information was slightly changed.*

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4.4: Disorders of the GI Tract

Now that we've covered the structures and functions of the digestive system, it should be clear that the digestion of food requires the coordinated action of multiple organs. If any of these aren't working well, it can wreak havoc on the function of the entire system and interfere with health and quality of life. Let's look at some common discomforts and disorders of the GI tract.

Heartburn and Gastroesophageal Reflux

Heartburn is a burning, often painful, sensation in the chest (behind the breastbone) or throat. Heartburn is caused by **gastroesophageal reflux (GER)**, when the acidic chyme in the stomach escapes back into the esophagus and even into the mouth. Normally, this reflux is prevented by the lower esophageal sphincter (a tight ring of muscle) that sits between the esophagus and stomach. The muscles of the sphincter contract to keep it closed, only relaxing to allow food boluses and liquid to pass from the esophagus into the stomach and then quickly contracting again to keep the contents of the stomach separate from the esophagus. The lower esophageal sphincter can be weakened because of increased pressure on the abdomen from obesity or pregnancy, exposure to tobacco smoke, and some medications, so the risk of GER is increased in these scenarios.

Gastroesophageal Reflux

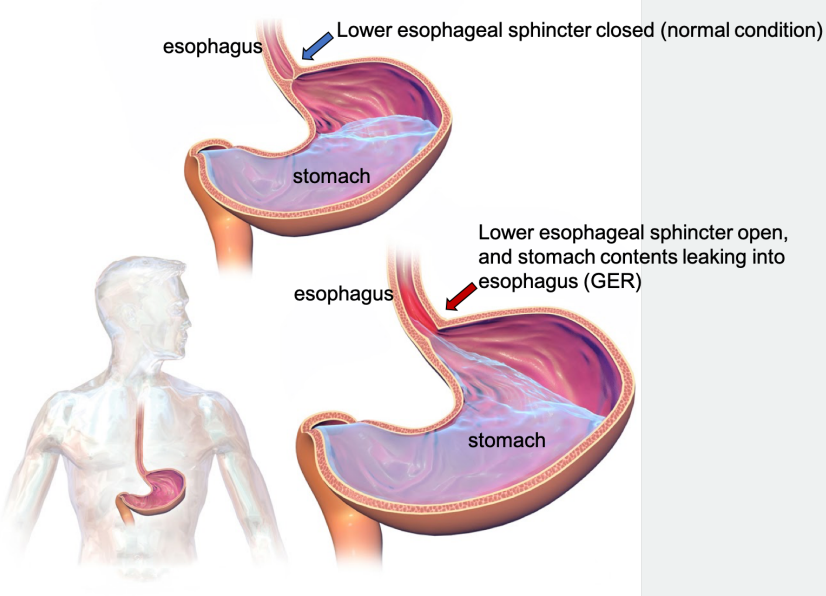


Figure 4.4.1: In gastroesophageal reflux, the acidic contents of the stomach escape backwards into the esophagus, causing pain and burning sensations in the chest and/or throat. ("GastroEsophageal Reflux Disease" by BruceBlaus is licensed under CC BY-SA 4.0)

Occasional heartburn is a common complaint, especially after eating large, greasy, or spicy meals. However, if it occurs more than twice per week, it may be diagnosed as **gastroesophageal reflux disease (GERD)**, which should be treated not only to relieve the discomfort that it causes but also to prevent damage to the tissues of the esophagus, which can increase the risk of cancer. In addition to heartburn, GER and GERD can cause difficult and painful swallowing, a persistent sore throat or cough, a sense that there's a lump in your throat, and nausea and vomiting.

The symptoms of GER and GERD can often be addressed through diet and lifestyle changes, including the following:

- Avoid foods that seem to trigger symptoms. Common culprits are greasy or spicy foods, chocolate, coffee, peppermint, alcohol, and acidic foods such as tomatoes or citrus.
- Eat smaller, more frequent meals instead of large meals.
- Avoid eating 3 hours before bedtime, and stay upright for 3 hours after eating.
- Wear clothing that is loose around the abdomen.

- Raise the head of your bed by 6 to 8 inches by placing blocks under the bedposts. (Extra pillows will not help.)
- Quit smoking and avoid secondhand smoke, if needed.
- Lose weight, if needed.

Over-the-counter medications like antacids (Maalox, Mylanta, Rolaids) can also help with occasional heartburn. If symptoms are persistent and frequent, it's wise to see a doctor to be checked out for GERD and to discuss other treatment and medication options.[1,2]

Peptic Ulcers

Peptic ulcers are sores on the tissues lining the esophagus, stomach, or duodenum (the first section of the small intestine). They occur when the mucous coating of the GI tissues is damaged, exposing the tissue to pepsin and hydrochloric acid. This further erodes the tissues, causing pain if it damages a nerve and bleeding if it damages a blood vessel. Ulcers are most serious if they perforate the wall of the GI tract, which can cause a serious infection. Peptic ulcers cause stomach pain, often when the stomach is empty, and may go away when you eat or take antacids. In the most serious cases, blood may be seen in vomit and/or stool, and the patient may have very sharp and persistent stomach pain.

Peptic Ulcers

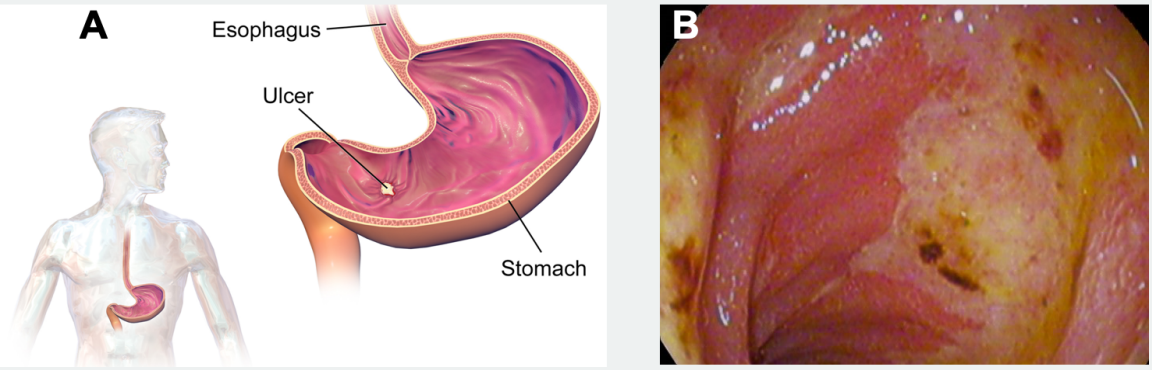


Figure 4.4.2: Peptic ulcers. (A) The location of a peptic ulcer in the stomach. (B) A photo from an endoscopy of a patient with an ulcer in the duodenum. ((a) "Gastric ulcer" by BruceBlaus is licensed under CC BY-SA 4.0 ; (b) "Duodenal ulcer A2 stage, acute duodenal mucosal lesion(ADML)" by melvil is licensed under CC BY-SA 4.0)

Doctors used to believe that stress and excessive stomach acid caused peptic ulcers, so they would recommend a bland diet, stress reduction, and acid-suppressing medications as treatment. However, these treatments often didn't work because they weren't treating the root cause of the ulcers. We now know that there are two main causes of peptic ulcers. The first and most common cause is infection with a bacteria called ***Helicobacter pylori* (*H. pylori*)**. *H. pylori* infection is very common, with about 50% of the population worldwide harboring the bacteria, most of them living without any symptoms. It's not certain how people are infected with *H. pylori* or why they cause ulcers in some people and not in others. However, understanding the link between *H. pylori* and ulcers was an important discovery because it led to effective treatments. The *H. pylori* bacteria are able to survive the acidic environment of the stomach, and they damage the mucous coating of the GI tract, leaving it vulnerable to further damage from acid and pepsin. Ulcers caused by *H. pylori* infection are treated with antibiotics to kill the bacteria, with the addition of an acid-suppressing medication to allow the tissue to heal.

The second major cause of peptic ulcers is long-term use of ***nonsteroidal anti-inflammatory drugs (NSAIDs)***, such as aspirin or ibuprofen. One of the side effects of NSAIDS is that they block the production of an enzyme that protects the stomach lining, so using these medications frequently and chronically can increase the risk of developing a stomach ulcer. To treat an ulcer caused by NSAIDs, doctors recommend stopping or reducing the use of NSAIDs. They may also prescribe an acid-reducing medication to allow the tissue to heal.[3]

Diarrhea and Constipation

Both diarrhea and constipation can occur if the normal function and rhythm of the GI tract are disrupted. If waste matter moves too quickly through the large intestine, not enough water is absorbed, resulting in the loose, watery stools characteristic of **diarrhea**.

This is most commonly caused by ingesting food or water contaminated with bacteria (e.g., *E. coli*, *Salmonella*), viruses (e.g., norovirus, rotavirus), or parasites (e.g., *Cryptosporidium enteritis*, *Giardia lamblia*). Dietary allergies and intolerances can also cause diarrhea, as we'll discuss on the next page. Complications of diarrhea include dehydration and malabsorption of nutrients.[4]

On the other end of the spectrum is **constipation**, characterized by infrequent bowel movements (fewer than 3 times per week) with stools that are hard, dry, or lumpy and often painful to pass. Sometimes, constipation is caused by holding stool and delaying defecation. That gives the colon and rectum additional time to absorb water, making the feces too hard and dry. Delaying defecation is common in children or others who may fear that it will hurt to pass a stool, but of course, holding it only worsens the problem. Constipation can also occur because of other disruptions in daily rhythms, such as changing what or how much you eat, travel, or medication changes. Constipation is common in pregnancy because of hormonal changes. It also becomes more common with age, which may be due to decreased physical activity, medication use, or weakness in the smooth muscle of the intestine. Constipation can be a sign of another medical problem, so chronic constipation should be checked out by a doctor.

Constipation can often be addressed by dietary changes, including eating more high-fiber foods (whole grains, legumes, fruits, vegetables, nuts, etc.) and drinking more water. It can also be helpful to attempt a bowel movement after meals, when the intestine is more active, and to make that a habit to try to establish more regularity in bowel movements. A caffeinated beverage with breakfast can help, as can increasing physical activity.

Fiber supplements such as Metamucil, Citrucel, or Benefiber can be helpful for increasing fiber intake and addressing constipation, at least in the short term. However, it's preferable to transition to dietary sources of fiber, as they come packaged with many other valuable nutrients.

Laxatives may also be helpful in addressing constipation in the short term but are usually not a good long-term solution. It's possible to become dependent on some types of laxatives for bowel movements, meaning that the colon doesn't contract normally on its own. In these cases, a doctor can help make a plan to gradually reduce laxative use and find other ways to improve bowel regularity.[4]

Pain from Diarrhea and Constipation



Figure 4.4.3: Abdominal pain. Diarrhea and constipation can cause abdominal pain. (Colico by derneuemann is in the Public Domain, CC0)

Irritable Bowel Syndrome (IBS)

Irritable bowel syndrome (IBS) is a type of functional GI disorder, meaning that it's caused by a disruption in the signals between the brain and gut. People suffering from IBS often experience abdominal pain, bloating, the feeling that they can't finish a bowel movement, as well as diarrhea or constipation or both, often in cycles. IBS is common; about 12% of people in the U.S. are thought to have it. It's more common in women, seems to run in families, and is often associated with stress, a history of trauma, or severe GI infections. IBS isn't well understood. It's not clear what causes it, and it may have different causes in different people.[5]

Of course, because the cause of IBS isn't understood, that lack of understanding makes it difficult to treat. Some people find that eating more fiber-rich foods and increasing physical activity improve their symptoms, so these are good first steps (and good for health regardless of their effect on IBS). Others find that following a diet low in carbohydrates called FODMAPs helps their symptoms. FODMAPs are fermentable carbohydrates found in many foods and can usually be eaten without issue by most people. Foods that are high in FODMAPs include fruits, vegetables, legumes, dairy products, wheat, and honey, so this is a *very* restrictive diet and should only be attempted with the guidance of a dietitian. Without careful planning, a low-FODMAP diet can be deficient in fiber, vitamins, and minerals. It is usually followed for just a few weeks, and if it helps with symptoms, foods are gradually added back to see what can be tolerated.[6,7]

In addition to dietary strategies, physicians sometimes prescribe medications to treat the symptoms of diarrhea or constipation associated with IBS.[8]

Inflammatory Bowel Disease (IBD)

Inflammatory bowel disease (IBD) includes two types of disorders: ulcerative colitis and Crohn's disease. **Ulcerative colitis** is specific to the large intestine (colon) and rectum, whereas **Crohn's disease** can affect any part of the GI tract. Both are chronic inflammatory conditions where symptoms may periodically flare and become more severe. IBD is often confused with IBS because of the similarities in their names and some symptoms. However, they are different disorders with different causes. IBD is generally more severe and long-lasting, and it causes damage to the GI tract that can be seen on **endoscopy** (when a camera is inserted into the GI tract to visualize the interior). It's important to get an accurate diagnosis of IBD in order to treat the disorder appropriately.[9]

Common symptoms of IBD are diarrhea, cramping and abdominal pain, feeling tired, and weight loss. IBD may be caused by autoimmune reactions (in which the immune system attacks the body's own cells, in this case, the cells of the GI tract) or certain genes; and other causes are being investigated. IBD often develops in people during adolescence or in their 20s. It may be treated with medications to reduce inflammation or modulate the immune system, or sometimes surgery.[10,11]

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4.5: Food Intolerances, Allergies, and Celiac Disease

Food is a source of nutrients for our bodies, and as we've learned, the GI tract functions to extract those nutrients from food and absorb them into the body. But sometimes, specific foods can cause problems for the GI tract and the body, including food intolerances, food allergies, and celiac disease. These conditions are often confused for one another, but they have different causes, symptoms, and approaches to treatment.

Food Intolerances

A **food intolerance** occurs when a person has difficulty digesting a specific food or nutrient, causing unpleasant GI symptoms such as gas, bloating, flatulence, cramping, and diarrhea. Food intolerances are commonly caused by the body not producing enough of a particular digestive enzyme, so the symptoms generally involve the digestive system, and the severity of symptoms usually correlates with how much of the food was eaten. Unlike food allergies, the immune system does not play a role in food intolerance, and while the symptoms are unpleasant, they are generally not dangerous and will subside once the food passes out of the GI tract. People with food intolerances can also often consume small amounts of the offending food without symptoms.[1]

Lactose intolerance is a common food intolerance. People with lactose intolerance do not produce enough of the enzyme lactase, which is responsible for digesting the milk sugar lactose into single sugar molecules that can be absorbed in the small intestine. Undigested lactose can't be absorbed, so it continues on to the large intestine. There, it draws more water into the large intestine, and bacteria metabolize the lactose, resulting in gas and acid production. These conditions cause the uncomfortable symptoms of gas, bloating, and diarrhea within about 30 minutes to two hours of consuming dairy foods.

As with most food intolerances, people with lactose intolerance can often consume some amount of lactose without discomfort, although this varies from person to person. Aged hard cheese, buttermilk, and yogurt (as long as it doesn't include added milk solids) are often well-tolerated because they are low in lactose, which is consumed by bacteria during fermentation and aging. In addition, lactose-free milk and lactase enzyme supplements are available. Dairy products are some of the main dietary sources of calcium and vitamin D, so people who avoid dairy need to take special care to include other sources of these nutrients in their diets.[2]

The vast majority of humans are born with the ability to digest lactose. All mammalian milk, including human milk, contains lactose, so historically, infants with lactose intolerance wouldn't have survived. (Today, infants with lactose intolerance can consume soy-based infant formula.) Beyond infancy, lactose intolerance depends on your genes. In much of the world, it's common for the activity of the lactase gene to decline with age, resulting in less lactase production and more lactose intolerance. Worldwide, 65% of the human population has some degree of lactose intolerance in adulthood. On the other hand, lactose tolerance is common in cultures where early domestication of dairy animals provided an important source of nutrition. In the US, adults of European descent can often tolerate lactose, whereas lactose intolerance is common among Asian Americans, African Americans, Mexican Americans, and Native Americans.[3]

Lactose Intolerance



Figure 4.5.1. Taking a lactase enzyme supplement allows many people with lactose intolerance to eat dairy products without suffering symptoms. ("Home-breakfast (lactaid photo)" by Ernesto Andrade is licensed under CC BY-ND 2.0)

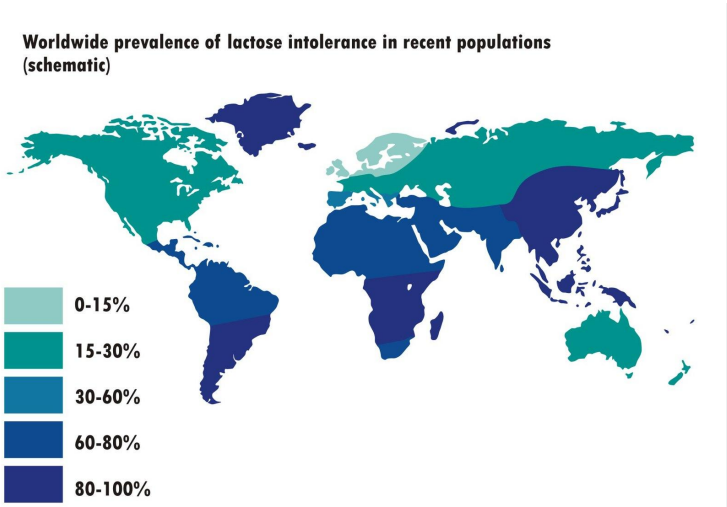


Figure 4.5.2. The prevalence of lactose intolerance worldwide. ("Worldwide prevalence of lactose intolerance in recent populations" by NmiPortal is licensed under CC BY-SA 3.0)

Food Allergies

In addition to its role in digestion, the GI tract serves an important immune function. Intestinal cells form the barrier between the interior of the body and the lumen, or tube, of the GI tract, which is technically outside of the body and teeming with potential pathogens. Immune tissue in the GI tract and other parts of the body produce immune cells that target foreign invaders, in part through the production of **antibodies**, protective proteins that bind to foreign substances. However, this function requires the immune system to accurately distinguish between normal food proteins and invading pathogens. A **food allergy** is what happens if the immune system mistakenly identifies a food protein as an invasive threat.

The most common type of food allergy involves **immunoglobulin E (IgE)**, a type of antibody produced by the immune system in response to a specific substance, or **allergen**. Symptoms of an allergic reaction usually occur immediately after consuming the food (i.e., within seconds to minutes), although reactions can sometimes be delayed by two hours or more. Because an allergic reaction is caused by the immune system, it can lead to symptoms all over the body, including skin rashes; swollen lips, face, or throat; wheezing and difficulty breathing; nausea and vomiting; cramping; diarrhea; and rarely, a dangerous drop in blood pressure. A severe allergic reaction involving more than one organ system—a rash coupled with difficulty breathing, for example—is called **anaphylaxis**. Anaphylaxis can be life-threatening and should be treated immediately with epinephrine, commonly administered by injection with a device such as an EpiPen, and the person should seek immediate medical attention.[1]

Common Food Allergens



Figure 4.5.3. Common food allergens: peanuts, dairy, wheat, eggs, and shrimp.[4] Source: https://www.fda.gov/food/food-labeli...food-allergies

The most common food allergies in the US are caused by proteins in peanuts, tree nuts, milk, shellfish, eggs, fish, wheat, soy, and sesame.[5,6] A 2019 study reported that 19% of adults in the US believe they're allergic to at least one food. After asking people about their symptoms, the researchers estimated that the true incidence of food allergies is closer to 11%, while the remaining 8% of people likely have a food intolerance.[5]

Food allergies are common in children, affecting about 8% of US children, although allergies can also develop later in life.[6] It's common for young children to outgrow allergies to egg, dairy, wheat, or soy, but peanut, tree nut, and shellfish allergies are often lifelong. Recent research has found that letting babies eat common food allergens, particularly peanut products, can prevent the development of allergies, perhaps by allowing the immune system an early opportunity to learn to differentiate between food proteins and invading pathogens.[7]

If you think you may have a food allergy, it's important to see an allergist to ensure you have an accurate diagnosis. Food allergies are diagnosed based on symptoms after consuming a food, specific IgE blood tests, and/or skin prick tests, where a tiny amount of food protein is scratched onto the skin to test for a reaction. Blood and skin tests determine whether a person is sensitized to an allergen, meaning that they're producing IgE antibodies to the food. However, the presence of IgE antibodies doesn't definitively mean a person has a food allergy; it's common to have a positive IgE test but still be able to eat the food without symptoms. The gold standard test for diagnosing is an oral food challenge—consuming a small amount of the food and watching for signs of a reaction—although time, cost, and risk may prohibit conducting these tests. If you are diagnosed with a food allergy, you will be counseled to strictly avoid the food and carry injectable epinephrine in case of accidental consumption. Unlike food intolerances, consuming even a small amount of food can cause a serious reaction in those with food allergies.[1]

Some promising new therapies for treating food allergies involve exposing a person to small amounts of the allergen to try to teach the body to tolerate it. These don't cure the allergy completely but may reduce the risk of a severe allergic reaction. The first of these therapies was approved by the U.S. Food and Drug Administration in January 2020.[8]

There are blood tests available that claim to screen for as many as 90 to 100 food allergies from one blood sample. These measure a different type of antibody called IgG, but the presence of IgG does not indicate a food allergy. Therefore, these tests are not

recommended by allergy experts because they may cause a person to unnecessarily fear and avoid a long list of foods to which they are not allergic.[9]

Celiac Disease

Celiac disease is an autoimmune disorder affecting between 0.5 and 1.0% of people in the U.S. or one in every 100 to 200 people.[10] In **autoimmune diseases**, the immune system produces antibodies that attack and damage the body's own tissues. In the case of celiac disease, the body has an abnormal immune reaction to **gluten** (a group of proteins found in wheat, rye, and barley), causing antibodies to attack the cells lining the small intestine. This results in damage to the villi, decreasing the surface area for nutrient absorption. There is no cure for celiac disease, but it's treated very effectively by eliminating gluten from the diet.[11]

Symptoms of celiac disease can range from mild to severe and can include pale, fatty, loose stools, gastrointestinal upset, constipation, abdominal pain, and skin conditions. Nutrient malabsorption can lead to weight loss and in children, a failure to grow and thrive. Symptoms can appear in infancy or much later in life, as late as age seventy. Celiac disease is not always diagnosed, because the symptoms may be mild. Even without symptoms, the disease can still damage the small intestine and impair nutrient absorption. Nutrient deficiencies can cause health problems over time, particularly in children and the elderly. For example, poor absorption of iron and folic acid can cause anemia, which impairs oxygen transport to cells in the body. Calcium and vitamin D deficiencies can lead to osteoporosis, a disease in which bones become brittle.

Diagnosis of celiac disease begins with a blood test for specific antibodies that are elevated in those with the disease. If the blood test is positive, the diagnosis is confirmed with a biopsy of the small intestine, a procedure in which a small amount of tissue is removed for examination. These tests may not accurately detect celiac disease in people already consuming a gluten-free diet, because without gluten, antibody levels may be low, and damage to the small intestine may not be visible. This is why it's best to be tested for celiac before eliminating gluten from the diet.

It isn't clear what causes celiac disease; genetics play a role, but other factors also seem to influence its development. Celiac disease is most common in people of European descent and is rare in people of African American, Japanese, and Chinese descent. It is more prevalent in women and people with type 1 diabetes, autoimmune thyroid disease, and Down and Turner syndromes.

Celiac disease is treated by completely avoiding gluten, as consuming even small amounts can cause intestinal damage. People with celiac can consume grains that don't contain gluten, including rice, corn, millet, buckwheat, and quinoa. Oats can be consumed, although they are often contaminated with gluten from neighboring fields or shared processing equipment, so it's best to buy oats labeled gluten-free. There are also an increasing number of gluten-free products available in stores. After eliminating gluten from the diet, the tissues of the small intestine usually heal within six months.

Celiac Disease



Figure 4.5.4. Celiac disease is caused by an autoimmune response to gluten, found in wheat, rye, and barley. At right is a section of the small intestine from a biopsy, visualized under a microscope, from a celiac patient. The villi, which would normally be finger-like projections, are blunted and flattened by damage caused by the disease. ("bread" by Wesual Click on Unsplash (license information); "coeliac path" by Samir is licensed under CC BY-SA 3.0)

Celiac disease is different from a wheat allergy in both cause and symptoms. Because celiac disease is an autoimmune condition, the cells of the small intestine come under attack, and damage causes chronic symptoms. A wheat allergy, on the other hand, is caused by antibodies attacking an allergen in the wheat itself, and the symptoms are usually immediate and acute.

Sometimes, people test negative for celiac disease but still believe that consuming gluten is causing symptoms, usually gastrointestinal. They may eliminate gluten from their diet and find that they feel better. This is often called **non-celiac gluten sensitivity (NCGS)**. It's unclear what causes NCGS or why a gluten-free diet is helpful. In some cases, it may be a placebo effect. In others, it seems that it's not gluten causing the problem but other dietary components, such as FODMAPs, that happen to also be low in a gluten-free diet. And in some cases, gluten does seem to cause symptoms in people without celiac disease, although researchers don't understand why.[12,13]

Except in the case of celiac disease, wheat allergy, or confirmed NCGS, gluten-free foods or a gluten-free diet are not inherently more healthful. In fact, packaged gluten-free foods are often more highly processed, with more added sugar, salt, and fat, compared with foods containing wheat. A gluten-free diet can also be lower in fiber, so those following the diet should be sure to include naturally gluten-free whole grains, legumes, nuts, fruits, and vegetables to provide adequate fiber.[14]

Attributions

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CHAPTER OVERVIEW

5: Carbohydrates- Sugars, Starches, and Fibers

5.1: Introduction
5.2: Types of Carbohydrates
5.3: Sources and Requirements of Carbohydrates
5.4: Digestion and Use of Carbohydrates
5.4.1: Digestion and Absorption of Carbohydrates
5.4.2: The Functions of Carbohydrates in the Body
5.5: Conditions Related to Deficient and Excessive Carbohydrate Intake
5.6: Diabetes and Hypoglycemia

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5.1: Introduction



Learning Objectives

1. Describe the types of carbohydrates (monosaccharides, disaccharides, polysaccharides) and provide examples of each.
2. Distinguish between sugars, starches, and fibers.
3. Contrast the structures and functions of simple and complex carbohydrates.
4. Describe the recommended dietary intake for carbohydrates.
5. Evaluate a meal for the relative abundance of carbohydrates.
6. Provide strategies for choosing healthy foods that contain carbohydrates.
7. Explain how carbohydrates are digested and used by the human body.
8. Explain the consequences of carbohydrate excess and deficiency.
9. Describe the relationship between diabetes and hypoglycemia.
10. Provide strategies for choosing healthy foods that contain carbohydrates.

Carbohydrates are essential macronutrients that give us the energy we need to live. Carbohydrates are found in many foods, not just bread and potatoes. Although some people try to cut carbohydrates to promote their health, carbohydrates are critical components of a healthy diet. In this chapter you will learn that a healthy diet is more about the types of carbohydrates than the amount of carbohydrates a person eats. Some carbohydrates, like whole grains that contain fiber, support a healthy diet. However, other carbohydrates, like sugars, can be unhealthy when eaten in excess. By the end of this chapter, you will be able to distinguish between healthy and unhealthy foods based on the types of carbohydrates in the foods.

Diabetes is a condition that is closely connected to carbohydrates. There are nearly 40 million people in America living with diabetes, and these individuals cannot regulate blood sugar levels properly. In this chapter, you will learn more about this condition, and the ways dietary carbohydrates can affect the condition.

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5.2: Types of Carbohydrates

Simple and Complex Carbohydrates

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, 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. In this section, you will learn about the different types of carbohydrates based on the way they release energy in your body.

The word "carbohydrate" means carbon (carbo-) and water (hydrate). Carbohydrates are a group of organic compounds containing a ratio of one carbon atom (C) to two hydrogen atoms to one oxygen atom. Basically, they are hydrated carbons. All carbohydrates have this same formula, $(CH_20)_n$, but each carbohydrate can vary in the number of carbons and how the carbon atoms are connected. Carbohydrates are classified based on the structure of the carbon atoms (Figure 5.2.1). The simplest carbohydrates are called **monosaccharides.** This term originates from the Greek word "mono," which means one, and "saccharide," which means sugar. Simple sugars in our diet usually have 5 or 6 carbons. Monosaccharides are the building blocks for **disaccharides**, which contain two connected monosaccharides, and **polysaccharides**, which contain many monosaccharides connected in long chains. Monosaccharides and disaccharides are also called **simple sugars** because they have simple structures and are more easily broken down for energy. Polysaccharides are also called **complex sugars** because they have complicated structures and are slowly broken down to release energy. Some complex carbohydrates, like fibers, are not broken down to release energy but are still important for digestion and overall health. Because carbohydrates are so important for energy, we will describe each type of carbohydrate below based on the way energy is released when we eat them.

Types of Carbohydrates

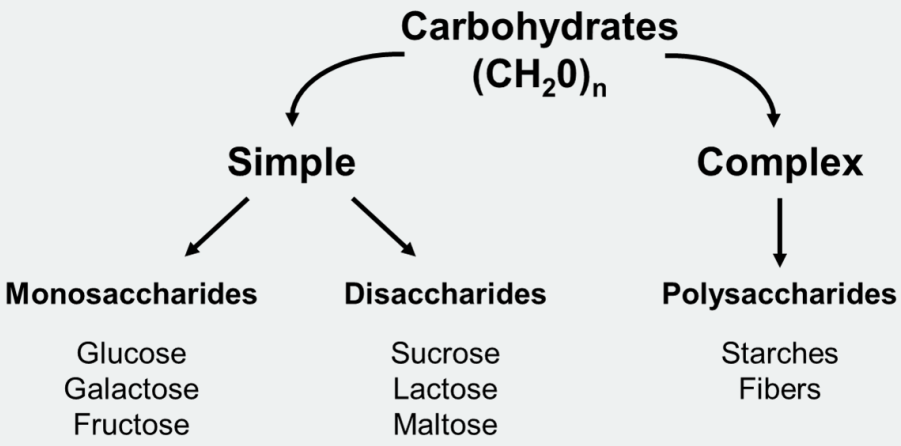


Figure 5.2.1: Classification of carbohydrates. Carbohydrates are classified based on the structure of the carbon atoms. Source: Erin Shanle licensed under CC BY 4.0(opens in new window).

Fast-Releasing Carbohydrates

In nutrition, carbohydrates can be broadly classified into two subgroups based on the way energy is released in our bodies. Monosaccharides and disaccharides are **fast-releasing carbohydrates** and are known more simply as **sugars.** As discussed later in this chapter, fast-releasing carbohydrates are quickly absorbed and released into the bloodstream. This can give a fast boost of energy because our cells can easily use these sugars, but that energy boost does not last long.

Monosaccharides

In our diets, the most common monosaccharides include glucose, fructose, and galactose (Figure 5.2.2). These simple sugars are the building blocks for disaccharides and polysaccharides.

Glucose is the preferred energy source for all organisms, from bacteria to plants to animals. The brain is completely dependent on glucose as its energy source (except during extreme starvation conditions). In fact, it is the most abundant carbohydrate in the human body. Glucose has 6 carbons, so its chemical formula is $C_6H_{12}0_6$. Plants synthesize glucose through the process of photosynthesis using carbon dioxide, water, and the sun's energy. When we eat plants, we harvest the energy stored in glucose to support life's processes. So, the ultimate energy source for all of us is the sun!

The monosaccharide **galactose** differs from glucose only in that a hydroxyl (−OH) group faces in a different direction on the number four carbon (Figure 5.2.2). 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 (Figure 5.2.2). 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.

Less common monosaccharides are the pentoses, which have only 5 carbons and not 6. The pentoses are abundant in the nucleic acids RNA and DNA, and also as components of fiber.

Finally, the **sugar alcohols** are industrially synthesized derivatives of monosaccharides. Some examples of sugar alcohols are sorbitol, xylitol, and glycerol. Xylitol is similar in sweetness to table sugar, so it is often used in place of table sugar to sweeten foods. Sugar alcohols are incompletely digested and absorbed and are therefore less caloric. The bacteria in your mouth oppose them; thus, sugar alcohols do not cause tooth decay. However, consuming too much sugar alcohol can lead to digestive issues, such as diarrhea. Interestingly, the sensation of "coolness" that occurs when chewing gum that contains sugar alcohols comes from their dissolving in the mouth, a chemical reaction that requires heat from the inside of the mouth.

Common Monosaccharides

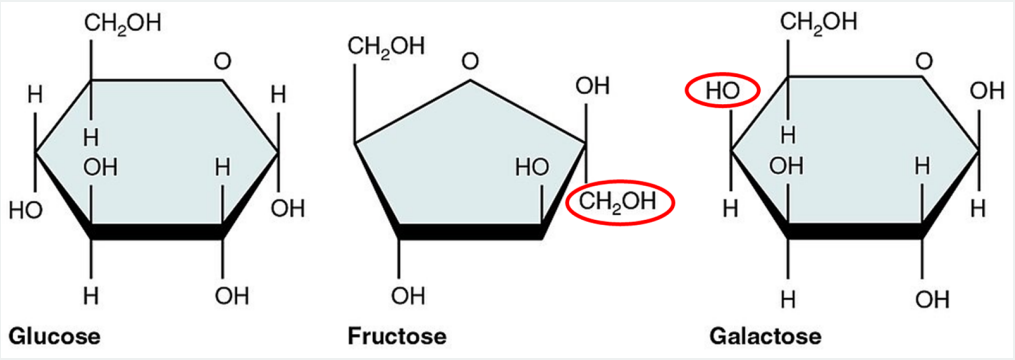


Figure 5.2.2: Structures of the three most common monosaccharides: glucose, galactose, and fructose. Red circles indicate the major structural differences between glucose and the other two monosaccharides. Source: Adapted from [1].

Disaccharides

Disaccharides are composed of pairs of two monosaccharides linked together. Disaccharides include sucrose, lactose, and maltose (Figure 5.2.3). Each of these disaccharides contains 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 sugar cane, which are used to make table sugar. You may have also heard of high fructose corn syrup, which is a common sweetener used in many processed foods. High-fructose corn syrup is produced by processing corn starch to change some of the glucose into fructose. This creates a sweetener that is cheaper and easier to handle than table sugar. However, there are some health concerns about eating too much high-fructose corn syrup.

Lactose, commonly known as milk sugar, comprises 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.

Common Disaccharides

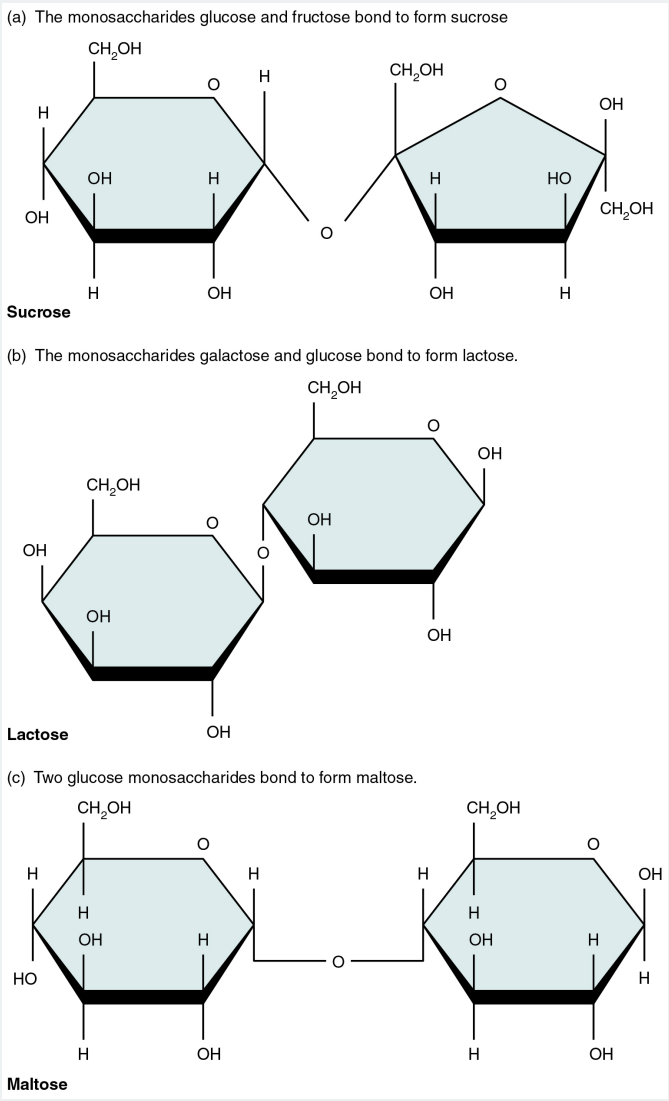


Figure 5.2.3: Structures of the three most common disaccharides: sucrose, lactose, and maltose.[2]

Slow-Releasing Carbohydrates

Slow-releasing carbohydrates are complex carbohydrates or polysaccharides that contain long chains of monosaccharides. These chains may be branched or not branched, which means there can be a lot of variety in their structures. Slow-releasing carbohydrates take longer to digest and break down, so energy is released gradually. There are two main groups of slow-releasing carbohydrates: starches and fibers (Figure 5.2.4).

Starches

Starches 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 amylopectine) are contained together in foods, but the smaller one, amylose, is more 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.

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.

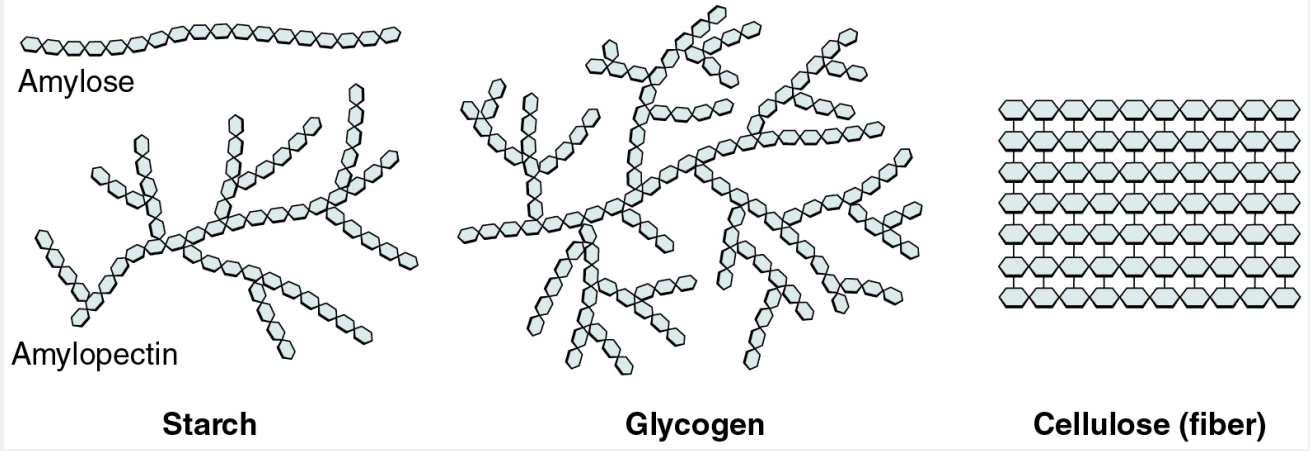


Figure 5.2.4: Structures of polysaccharides. Polysaccharides can be branched or unbranched chains of monosaccharides (shown as hexagons).[3]

Dietary Fibers

Dietary fibers are polysaccharides that are highly branched and cross-linked. Some dietary fibers are pectin, gums, cellulose, and lignin. Humans do not produce the enzymes that can break down dietary fiber into simple sugars; however, bacteria in the large intestine (colon) can break down some fibers. Dietary fibers are very beneficial to our health. Diets with adequate fiber reduce the risk for obesity and diabetes, which are primary risk factors for cardiovascular disease. However, more than 90%t of women and 97% of men in America do not meet recommended intakes for dietary fiber, so it was recognized as a dietary component of public health concern in the 2020-2025 Dietary Guidelines for Americans.[4]

Dietary fiber is categorized as either water-soluble or insoluble. Some examples of **soluble fibers** are inulin, pectin, and guar gum and are found in peas, beans, oats, barley, and rye. Soluble fibers can help regulate blood sugar levels, reduce blood cholesterol levels, and modulate the gut microbiome.[5] **Insoluble fibers** help materials pass through the digestive system and can prevent constipation. 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.

Some fibers can be classified as **functional fibers**. Functional fibers may be extracted from plants or synthetically made, and they are added to foods to provide health benefits to humans. 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.[6] Total dietary fiber intake is the sum of dietary fiber and functional fiber consumed.

Attributions

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5.3: Sources and Requirements of Carbohydrates

How Many Carbohydrates Does a Person Need?

The Food and Nutrition Board of 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%. This means that on a 2,000-calorie diet, a person should consume between 225 and 325 grams of carbohydrates each day. According to the IOM, not more than 25% of total calories consumed should come from added sugars. The World Health Organization and the *2020-2025 Dietary Guidelines for Americans* recommend much lower intakes of added sugars—10% or less of total calories consumed.[1] In the most recent version of the *Dietary Guidelines for Americans*, all added sugars should be avoided in diets. However, this is a difficult recommendation to achieve, so the most recent guidelines suggest that meals should not contain more than 10 grams of added sugars.[2] 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 on the intake levels known to prevent heart disease.

Table 5.3.1: Dietary Reference Intakes for Carbohydrates and Fiber

Carbohydrate Type	RDA (g/day)	General Recommendations
Total Carbohydrates	130	45–65% of Daily Calories (AMDR)
Added Sugars		Avoid entirely or no more than 10 grams per meal
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, whereas slow-releasing carbohydrates are more plentiful in starchy vegetables, beans, and whole grains. Fast-releasing carbohydrates are also found in large amounts in processed foods, soft drinks, and sweets. On average, a serving of fruits, whole grains, or starches contains 15 grams of carbohydrates. A serving of dairy contains about 12 grams of carbohydrates, and a serving of vegetables contains about 5 grams of carbohydrates. Table 5.3.2 gives the specific amounts of carbohydrates, fiber, and total sugars of various foods.

Table 5.3.2: Carbohydrate Content of Common Foods

Table displays common foods and the measure of Carbohydrates, Total Sugars, and Fiber in grams.

Food	Carbohydrates (g)	Total Sugars (g)	Fiber (g)
Apple, Fuji, Medium	15.6	13.3	2.1
Banana, Medium	26.4	18.2	2.0
Lentils, 1 cup	36	3.2	14.2
Snap Beans, 1 cup	7.4	2.3	3.0
Corn Tortilla, Medium	12.5	0.2	1.8
Bread, Wheat Bran, Medium Slice	15.6	2.3	2.7
Bread, White, Medium Slice	13.8	1.5	0.6
Brownie, Medium	32.0	18.3	1.0

Food	Carbohydrates (g)	Total Sugars (g)	Fiber (g)
Pretzels, 1 cup	32.2	0.9	1.4
Popcorn, 1 cup popped	7.8	0.04	1.4
Skim Milk, 1 cup	12.0	12.0	0
Cheddar Cheese, 1 slice	0.5	0.1	0
Non-fat Yogurt, Plain, 1 cup	18.8	18.8	0
Non-fat Yogurt, Fruit, 1 cup	36.8	30.9	0.2

Source: USDA. Food Data Central.[3]

Carbohydrates in a Healthy Diet: Quality over Quantity

You may have heard of diets that count the number of carbohydrates or that cutting out carbohydrates can help weight loss and overall health. It is important to remember that carbohydrates are essential for a healthy diet, and in some ways, the quality of the carbohydrates is more important than the quantity. The best dietary sources of carbohydrates 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.

Interactive 5.3.1

There are many tools that can help you identify nutrient-dense foods that contain carbohydrates. Fresh fruits and vegetables are great sources of carbohydrates, as are beans. Use the links below to find more nutrient-dense foods with carbohydrates.

- How to Cook with Dry Beans (US Dry Bean Council)
- Hacks to Help You Eat More Produce (Produce for Better Health)
- MyPlate (USDA)

Identifying High-Quality Carbohydrates on Nutrient Labels

Although nutrition facts labels help determine the amount or quantity of carbohydrates you eat, they do not help determine the quality of the carbohydrates. 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. To achieve a healthy diet with carbohydrates, it is important to increase the amount of whole grains and reduce the amount of processed and added sugars in your foods.

Eat Whole-Grain Foods

Whole-grain products, such as whole wheat flour and brown rice, are made using the entire grain, which includes more fiber and nutrients. **Refined grains**, such as white flour or white rice, have been processed to remove parts of the grain, which removes fiber and nutrients. Because many nutrients are lost during this process, refined grains may be **enriched** with nutrients to restore some of the lost nutrients. However, enriched grains still do not have as much fiber and nutrients as whole grain products. 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. Based on research showing that whole grains and fiber reduce the risk of disease, the *Dietary Guidelines for Americans* recommends that at least half of the grains you eat each day should be whole grains.[2]

Avoid Excess Added Sugars

Many processed foods have a lot of added sugars. For a healthy diet, eat fewer products that list high fructose corn syrup and other sugars such as sucrose, honey, dextrose, and cane sugar in the first five ingredients. If you want to eat fewer processed foods in general, stay away from products with long ingredient lists. Claims such as "sugar-free," "reduced sugar," or "high fiber" may also

be included on the front of food and beverages. The Nutrition and Labeling Act of 1990 has defined for the food industry and consumers what these labels mean (Table 5.3.3).

Table 5.3.3: Food Labels Pertaining to Carbohydrates

Label	Meaning
Sugar-free	Contains less than 0.5 grams of sugar per serving
Reduced sugar	Contains 25%t less sugar than similar product
Less sugar	Contains 25% 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% of daily value of fiber in each serving
A good source of fiber	Contains between 10 and 19% of the daily value of fiber per serving
More fiber	Contains 10%t or more of the daily value of fiber per serving

Source: US Food and Drug Administration. “Appendix A: Definitions of Nutrient Claims.” *Guidance for Industry: A Food Labeling Guide*.[4]

The Bottom Line

Read food labels and ingredient lists to determine your carbohydrate intake and know the types of carbohydrates you consume.

Personal Choices

Carbohydrates are in most foods so you have a great variety of choices to meet the carbohydrates recommendations for a healthy diet. The *Dietary Guidelines for Americans* recommends eating more unrefined carbohydrates and fiber and reducing consumption of foods 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 equals 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% fruit juice added to water or soda water.

Attributions

- Zimmerman, "An Introduction to Nutrition (Zimmerman)(opens in new window)", CC BY-NC-SA 3.0(opens in new window). *Figures were updated and the flow of information was slightly changed. More information about whole grains was added.*

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5.4: Digestion and Use of Carbohydrates

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5.4.1: Digestion and Absorption of Carbohydrates

The Taste of Carbohydrates

Part of the reason we eat food is because it tastes good. Some people have a sweet tooth, which means they love sweet foods with fast-releasing carbohydrates. Sweetness is one of the five basic taste sensations and is sensed by protein receptors in cells of the taste buds. Fast-releasing 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. See Table 5.4.1.1 for sweetness comparisons among different naturally-occurring carbohydrates.

Less-sweet whole grains containing more starches and fiber are actually more satisfying for a longer time. Whole grains take longer to chew and get sweeter the more you chew them. Additionally, once in the stomach, whole-grain foods take longer to digest and keep you full longer. Remember, too, that they contain fiber, which makes elimination much smoother. Whole-grain foods satisfy the body the entire way through the digestive tract and provide nutrients that better satisfy the body's functional needs. In this section, you will learn more about the digestion of carbohydrates.

Sweet Simple Sugars



Figure 5.4.1.1: Blueberry pancakes.[1] *Whole grains provide satisfaction from the beginning to the end of the digestion process, but simple sugars taste sweeter.*

Table 5.4.1.1: Sweetness Comparison of Carbohydrates[2]

Carbohydrate	Sweetness (percentage of sucrose)
Sucrose	100
Glucose	50-75
Galactose	54
Fructose	80-180
Maltose	30-50
Lactose	15-40
Xylitol	90-100
Fiber	0

From the Mouth to the Stomach

As discussed ing Chapter 4, 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**, which breaks the bonds between the simple sugar

subunits of disaccharides and polysaccharides, such as starch. The salivary amylase breaks down amylose and amylopectin into smaller chains of glucose, called dextrins and maltose (Figure 5.4.1.2). 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 5% 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 the mechanical breakdown is ongoing—the strong **peristaltic contractions** of the stomach mix the carbohydrates into the more uniform mixture of chyme.

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 are sucrase, maltase, and lactase (Figure 5.4.1.2). **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 can 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, Native Americans, and Asian Americans have much higher incidences of lactose intolerance, whereas those of northern European descent have the least.[3] Most people with lactose intolerance can tolerate some amount of dairy in their diet. The severity of the symptoms depends on how much lactose is consumed and the degree of lactase deficiency.

Chemical Digestion of Carbohydrates

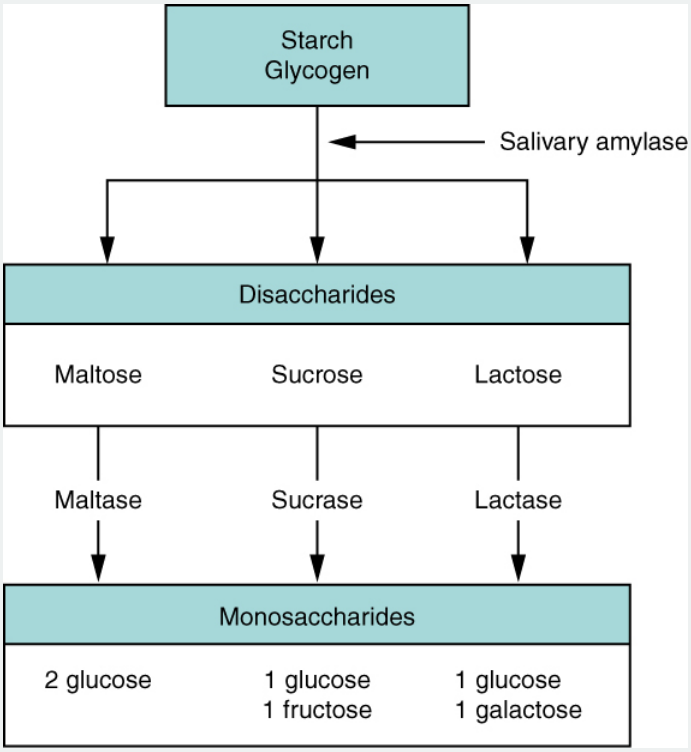


Figure 5.4.1.2: Enzymes involved in polysaccharide digestion.[4] Salivary amylase starts breaking down starch and glycogen in the mouth. Maltase, sucrase, and lactase continue breaking down disaccharides in the small intestines.

Absorption: Going to the Blood Stream

The cells in the small intestine have membranes that contain many transport proteins 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.

Maintaining Blood Glucose Levels: The Pancreas and Liver

Glucose levels in the blood are tightly controlled, as having either too much or too little glucose in the blood can have health consequences. Glucose regulates its levels in the blood via a process called **negative feedback**. An everyday example of negative feedback is in your oven because it contains a thermostat. When you set the temperature to cook a delicious homemade noodle casserole at 375°F, the thermostat senses the temperature and sends an electrical signal to turn the elements on and heat 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, and two hormones are key for regulating blood glucose levels: insulin and glucagon. These two hormones keep blood glucose levels within the target range, also called **homeostasis.**

After you eat 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 hormonal message, **insulin**, into the blood. Insulin sends a signal to the body's cells to remove glucose from the blood by transporting it to the insides of cells and to use it to make energy or for building macromolecules. 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 it has just been fed and to use the fuel. Insulin has an opposing hormone called glucagon. As the time after a meal increases, glucose levels decrease in the blood. 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.

Negative Feedback in Glucose Homeostasis

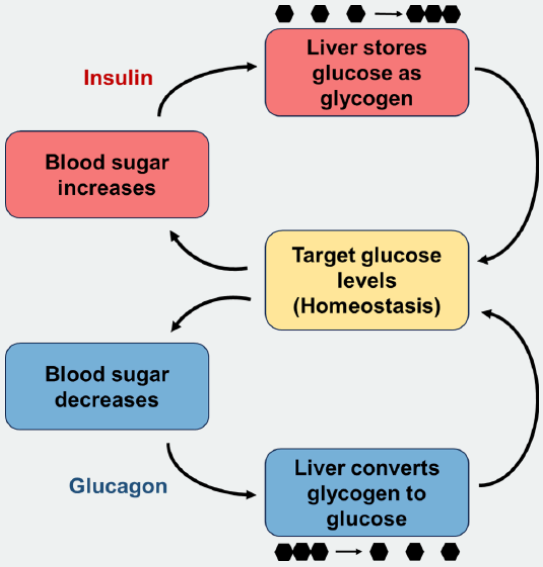


Figure 5.4.1.3: Glucose homeostasis negative feedback loop. Two hormones, insulin and glucagon, regulate blood glucose levels. When glucose increases in the bloodstream after a meal, insulin increases glucose uptake by cells throughout the body and stimulates glycogen production in the liver. If glucose levels decrease in the bloodstream, glucagon is released, and the liver starts to convert glycogen to glucose to maintain homeostasis. Source: "Glucose homeostasis negative feedback loop" by Erin Shanle is licensed under CC BY 4.0.

Leftover Carbohydrates: The Large Intestine

Almost all 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 the cells of the colon, with a small amount being transported to the liver. Colonic cells use 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. Because 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 smaller 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.

Thanksgiving Dinner: A Carbohydrate Feast



Figure 5.4.1.4:Thanksgiving dinner.[5]

It's Thanksgiving, and you have just consumed turkey with mashed potatoes, stuffing smothered in gravy, green beans topped with crispy fried onions, a hot roll dripping with butter, and cranberry sauce. Less than an hour later, you top it all off with a slice of pumpkin pie and then lie down on the couch to watch the football game. What happens in your body after digesting and absorbing the whopping amount of nutrients in this Thanksgiving feast? The "hormone of plenty," insulin, answers the nutrient call. Insulin sends out the physiological message that glucose and everything else is in abundant supply in the blood, so cells absorb and then use or store it. The result of this hormone message is the 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. In contrast, foods containing high amounts of fiber are like time-release sugar capsules, and insulin levels don't spike so rapidly.

Glycemic Index and Glycemic Load

It can be difficult to know how a food may affect blood glucose levels based on information in the nutrition label. However, there are tools available to determine if foods will cause a rapid spike in blood glucose levels. A measurement of the effects of a carbohydrate-containing food on blood glucose levels is called the **glycemic response** (Figure 5.4.1.4). The glycemic responses of various foods have been measured and then ranked in comparison with a reference food, usually a slice of white bread or just straight glucose, to create a numeric value called the **glycemic index (GI)**. Foods that have a low GI do not raise blood-glucose levels neither as much nor as fast as foods that have a higher GI. A diet of low-GI foods has been shown in epidemiological and clinical trial studies to increase weight loss and reduce the risk of obesity, Type 2 diabetes, and cardiovascular disease.[6]

The carbohydrate type within a food affects the GI, but so does its fat and fiber content (which reduce the GI). Increased fat and fiber in foods increase the time required for digestion and delay the rate of gastric emptying into the small intestine. Processing and cooking additionally affect a food's GI by increasing their digestibility. Advancements in food processing technologies and high consumer demand for convenient, precooked foods in the United States have 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. Table 5.4.1.2 provides the GI for various foods.

The GI can be used as a guide for healthier carbohydrate choices but has some limitations. One is that the 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.) Finally, meats and fats do not have a GI because they do not contain carbohydrates. Because of these limitations, the glycemic load is more often used in practice. **Glycemic load (GL)** is calculated by multiplying the glycemic index by the amount of carbohydrates per serving and dividing by 100. For example, a banana has a GI of 51 and contains 26 grams of carbohydrates, so the GL would be (51x26)/100 or 13.2, which is much higher than an apple that has a GL of 6. Foods with a lower GL have lower glycemic response after they are consumed.

Glycemic Index Measures Blood Glucose Response

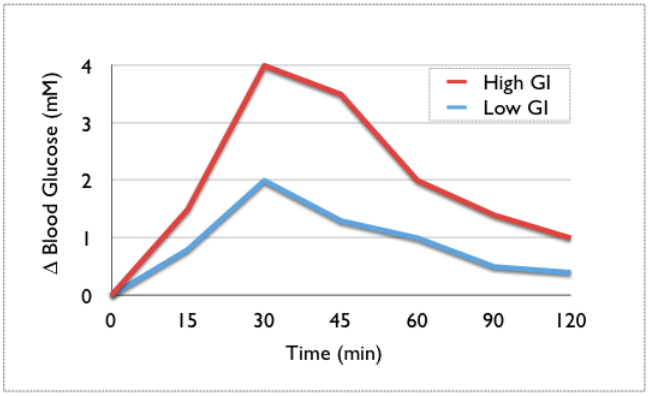


Figure 5.4.1.4: The glycemic index measures the effects of foods on blood glucose levels. Foods with a high glycemic index (red) cause blood glucose levels to increase much faster than foods with low glycemic index (blue).[7]

Table 5.4.1.2: The Glycemic Index: Foods in Comparison with Glucose[8]

Foods	GI Value
Low GI Foods (< 55)	
Apple	44
Pear	38
Banana (under-ripe)	51
Grapefruit	25
Barley	25
Navy beans	38
Green peas	48
Oat bran (Quaker Oats)	50
Spaghetti (whole wheat)	37
Mashed sweet potatoes	54
Baked beans	48
Butter beans	44
Banana bread	47

Foods	GI Value
Bread (sourdough)	52
Soy milk	31
Skim milk	32
Whole milk	27
Yogurt (sweetened)	33
Yogurt (plain, artificial sweetener)	14
Medium GI Foods (56–69)	
Apricots	57
Cantaloupe	65
Mashed potatoes	70
Whole-wheat pita bread	57
Whole-wheat bread	69
Couscous	65
Brown rice	55
Cheese pizza	60
Rye bread	65
Hamburger bun	61
Black bean soup	64
Macaroni and cheese	64
Coca-Cola	63
High GI Foods (70 and higher)	
Dates	103
Banana (over-ripe)	82
Parsnips	97
Corn chips	72
Pretzels	83
White bread	70
White rice	72
Spaghetti (durum flour)	78
White rice (instant)	87
French baguette	95
Bagel	72
Bread stuffing	74
Cheerios	74
Cream of wheat	71

Foods	GI Value
Raisin Bran	73
Fruit roll-up	99
Gatorade	78

Interactive 5.4.1.1: Balancing the Thanksgiving Feast

Visit this online database of glycemic indices of foods.

To balance the high-GI foods on the Thanksgiving table with low-GI foods, follow some of these suggestions:

- Serve a winter fruit salad.
- Leave the skins on the potatoes. The skin contains fiber and adds texture to mashed potatoes. Do not use instant potatoes.
- Instead of canned green beans with cream of mushroom soup and fried onions for a side dish, combine butter beans and green peas for a colorful, low-GI food.
- Make your stuffing with whole-grain bread and add mushrooms and extra celery and onions.
- Try a new low-sugar pumpkin pie recipe and make the crust from whole-grain flour.
- Offer homemade banana bread for dessert.

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5.4.2: The Functions of Carbohydrates in the Body

Carbohydrates have five primary functions in the human body: energy production, energy storage, building macromolecules, sparing protein, and sparing lipids.

Energy Production

The primary role of carbohydrates is to supply **energy** to all cells in the body. Energy is defined as the ability to do work. The cells in our body are constantly working by building new molecules, breaking down molecules, and sending or receiving chemical signals. The work our cells are doing all the time allows our bodies to do the work we are more familiar with, such as running or thinking.

Many cells prefer glucose as an energy source to other compounds, such as fatty acids. Some cells, such as red blood cells, can produce cellular energy only 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% 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 photosynthesis. Cells in our bodies break these bonds and capture the energy to perform cellular respiration. **Cellular respiration** is basically a controlled burning of glucose versus an uncontrolled burning. A cell uses many chemical reactions in multiple enzymatic steps to slow the release of energy (no explosion) and more efficiently capture the energy held within the chemical bonds in glucose.

The first stage in the breakdown of glucose is called **glycolysis**, which occurs in an intricate series of ten enzymatic-reaction steps. The second stage of glucose breakdown occurs in the energy factory organelles called **mitochondria**. One carbon atom and two oxygen atoms are removed, yielding more energy. The energy from these carbon bonds is carried to another area of the mitochondria, making the cellular energy available in a molecule called **ATP** (adenosine triphosphate), which cells can use to do work (Figure 5.4.2.1).

The Overall Reaction of Cellular Respiration

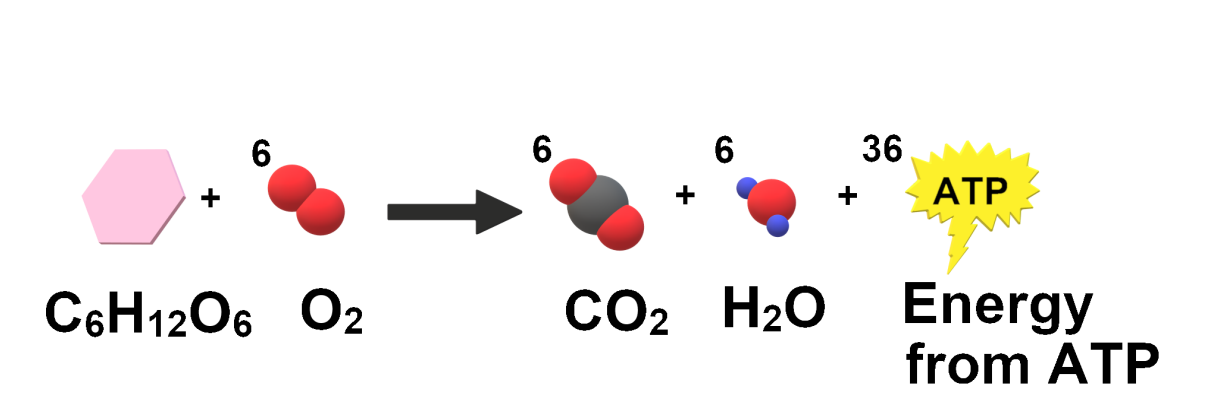


Figure 5.4.2.1: Cellular respiration. Glucose (C6H12O6) is broken down to carbon dioxide and water to release energy.[1]

Energy Storage

If the body already has enough energy to support its functions, the excess glucose is stored as **glycogen** (most of which is stored in the muscle and liver). A molecule of glycogen may contain more than fifty thousand single glucose units and is highly branched, allowing for the rapid dissemination of glucose when it is needed to make cellular energy (Figure 5.4.2.2).

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 into 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% of total calories three to five days before 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 before a race because, 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 to maintain metabolic homeostasis.

Glycogen Contains Glucose

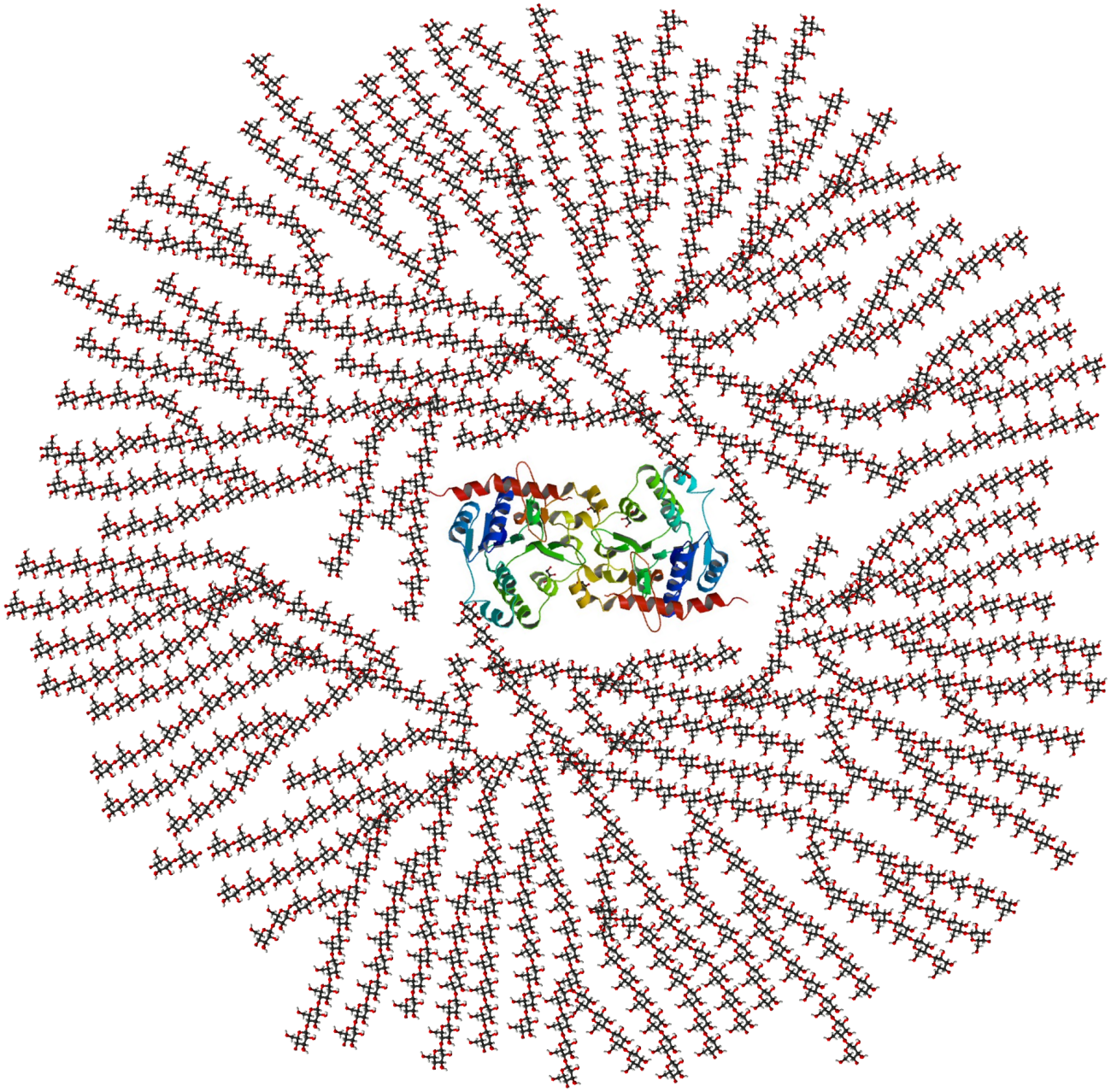


Figure 5.4.2.2: The structure of glycogen. Glycogen contains many molecules of glucose (shown as black, white, and red chains).[2]

Building Macromolecules

Although most absorbed glucose is used to make energy, some glucose is converted to **ribose** and **deoxyribose**, essential building blocks of important large biological molecules 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.

Sparing Protein

When there is not enough glucose to meet the body's needs, glucose is synthesized from **amino acids**, which are the building blocks of proteins. 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.

Sparing Lipids

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 the 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 elevated 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 individuals who have Type 1 diabetes. The minimum carbohydrate in the diet required to inhibit ketosis in adults is 50 grams per day.

Attributions

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5.5: Conditions Related to Deficient and Excessive Carbohydrate Intake

Healthy means being in a state that is free from disease. What we eat can help us be healthy, and we will see the nutrients in the foods we eat can increase, and in some cases decrease, the risk of getting certain diseases. Carbohydrates, which provide energy and regulate how our bodies use fat and protein, can play a pivotal role in disease development. Excess carbohydrates can contribute to becoming overweight, especially when foods with added sugars and highly processed carbohydrates are a major part of a person's diet. As discussed in Chapter 3, increasing rates of overweight malnutrition and obesity in children and adults is a major global health concern. As you will learn throughout the book, overweight and obesity are associated with diabetes and cardiovascular disease, which are two of the leading causes of death in adults ages 18 and older in the United States.[1] In this section, we will discuss health concerns associated with excess carbohydrates from added sugars. We will also consider health conditions associated with carbohydrate deficiency, particularly fiber deficiency.

Excess Carbohydrates: Added Sugars

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 states, "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). It is helpful to read the ingredients on a nutrition label to identify the types of added sugars in the foods you eat.

As of 2020, nutrition labels on most foods will also provide the amount of added sugars (Figure 5.5.1). The *2020-2025 Dietary Guidelines for Americans* recommended that no more than 10% of daily calorie intake should come from added sugars. The percent daily value is based on 50 grams of added sugars in a 2,000 Calorie diet. According to the *2025-2030 Dietary Guidelines for Americans*, no amount of added sugars is recommended. However, added sugars can be difficult to avoid so each meal should have no more than 10 grams of added sugars. It is helpful to remember that 1 teaspoon is equivalent to four grams of sugars. On average, adults in America consume 17 teaspoons (68 grams) of added sugar each day, which is far exceeds the recommended amount.[2] Excess sugars are associated with weight gain and oral diseases, as discussed below. Diabetes will be discussed in more detail in the next section.

Understanding the Amount of Added Sugars in Your Foods



Figure 5.5.1: Nutrition label with added sugars. The amount of added sugars is shown below the total carbohydrates on the nutrition label (highlighted in yellow). It is helpful to remember that 4 grams of sugar is equal to one teaspoon.[3,4]

Weight Gain

Each gram of sugar contains four Calories of energy. This may not seem like a lot, but consuming excess added sugars and excess calories causes a "fat-sparing" effect as described in the previous section. As more glucose is available for energy, lipids are stored as fats. Excess fat storage can lead to weight gain, which we will discuss further in Chapter 10. Although many foods contain added sugars, sugary drinks like sodas, lemonade, sweet teas, or some energy drinks are a primary source of added sugars with no other nutritional value. For example, a 12-ounce soda contains 7-10 teaspoons of added sugars with no nutritional value. In fact, people continue to feel hungry after consuming high-calorie sugary drinks.[5] In a review of studies that tracked health outcomes in people who consumed sugar-sweetened beverages, an association between consuming sugary drinks and weight gain was consistently observed. In addition, reduced consumption of these drinks was associated with weight loss.[6]

It is important to remember that added sugars are also found in foods that you may consider healthy. For example, fortified cereals can have several minerals, vitamins, and even whole grains listed on the nutrient label. However, some of these cereals contain up to 16 grams of added sugar in one bowl. Other "healthy" foods that may contain excess added sugars include flavored yogurts, snack bars, and even applesauce.

Interactive 5.5.2

The Harvard School of Public Health *Nutrition Source* has developed a guide called "How Sweet Is It?" that notes the calories and sugar contents of many popular beverages. Visit the site to determine drinks that are better for your oral and overall health.

Oral Disease

Oral health refers not only to healthy teeth and gums but also to the health of all the supporting tissues in the mouth, such as ligaments, nerves, jawbone, chewing muscles, and salivary glands. In 2000, the Surgeon General produced its first report dedicated to oral health, stating that oral health and health in general are not separate entities. Instead, oral health is an integral part of overall health and well-being.[7]

The most common oral disease in the world is **tooth decay**, also known as **dental caries** or **cavities**. Natural sugars and added sugars are the most important drivers of tooth decay.[8] Bacteria living on and around the teeth will break down these sugars in a process known as **fermentation**. Glucose, fructose, and maltose are three examples of fermentable sugars. Bacteria that inhabit the mouth metabolize fermentable sugars and starches in refined grains to acids that erode tooth enamel and deeper bone tissues. The acid creates holes (cavities) in the teeth that can be extremely painful (Figure 5.5.2). Gums are also damaged by bacteria produced by acids, leading to **gingivitis**, which is characterized by inflamed and bleeding gums. Saliva is actually a natural mouthwash that neutralizes the acids and aids in building up teeth that have been damaged.

According to the National Institutes of Health, almost 1 in 4 preschool children have cavities, and at least 1 in 6 children aged 6-11 have at least one cavity in a permanent tooth.[9] Cavities are an epidemic health problem in the United States and are associated with poor diet, but other contributors include poor dental hygiene and the inaccessibility to regular oral health care. Childhood tooth decay is more likely in low-income households, which are also more at risk for food insecurity, poor nutrition, and obesity.[9]

Tooth Decay



Figure 5.5.2: Dental caries.[10] Gingivitis. One way to prevent tooth decay is to lower consumption of sugary drinks.

Tools for Change

Save your teeth and gums, and choose to drink a beverage that does not contain excess added sugars. An idea: brew some raspberry tea, add some sparkling mineral water, a raspberry or two, some ice, and a mint leaf. Then sit back and refresh. The American Heart Association also makes the recommendations below to avoid excess sugars in your diet:[11]

- **Skip the sugar.** Cut back on the table sugar, syrup, honey, and molasses. Try cutting the amount of sugar you might add to cereal, pancakes, coffee, or tea in half. Then, reduce little by little until you are satisfied without the addition of sugar.
- **Drink less soda.** Choose water first, but you can find ways to make drinks with less sugar. Try to mix juice with sparkling water or unsweetened tea.
- **Eat fruits without added sugars.** Choose canned fruits in water or natural juice, and avoid canned fruits in syrup. Drain and rinse canned fruits to remove excess sugars.
- **Read food labels and choose foods with less added sugars.** Dairy and fruit products naturally contain some sugars, but added sugars can be excessive in foods like yogurts or juices.
- **Cut back when you cook**. Try switching out sugars with unsweetened applesauce in recipes, or cut back the sugar in cookie or cake recipes by 1/3 to 1/2. Often, the recipe will taste similar or better without the excess sugar.
- **Add flavors**. Add almond, vanilla, orange, or lemon to flavor recipes instead of adding sugar. Try ginger, allspice, cinnamon, or nutmeg.

Carbohydrate Deficiencies: 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 Atkin's 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. For example, in a 12-month weight loss study of 609 participants, there was no significant difference in weight change between a healthy low-fat diet and a healthy low-carbohydrate diet.[12] Some studies do provide evidence that in comparison with other diets, low-carbohydrate diets improve insulin levels and other risk factors for type 2 diabetes and cardiovascular disease.[13] 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

Although excessive consumption of fast-releasing carbohydrates is potentially bad for your health, consuming more slow-releasing carbohydrates is extremely beneficial to health. There is a wealth of scientific evidence supporting that replacing refined grains with whole grains decreases the risk of 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. The *2020-2025 Dietary Guidelines for Americans* recommended that at least half of the daily grains a person eats are whole grains. The most recent version of the *Dietary Guidelines for Americans* furthers recommends that whole grains should be prioritized in a healthy diet. However, most Americans do not get the recommended amount of whole grains, which means they are not getting the fiber and health benefits of whole grains. Based on a survey conducted from 2013 to 2016 by the US Department of Health and Human Services, the average adult in America gets about 16% of the daily grains as whole grains. This is much lower than the recommended amount, but data from 2005-2006 show that Americans have increased the amount of whole grains in their diets.[14]

Diets high in whole grains have repeatedly been shown to have health benefits. 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%.[15] The Nurses' Health Study found that women who consumed two to three servings of whole grain products daily were 30% less likely to have a heart attack.[16] In a review of studies conducted across several countries with thousands of participants, researchers found that individuals who consumed more whole grains had reduced overall mortality rates, cancer mortality, and heart disease.[17] These studies, and many more, demonstrate the benefit of maintaining a diet sufficient in beneficial carbohydrates.

Colon Health

A substantial health benefit of whole grain foods is that fiber actively supports digestion and optimizes colon health. This health benefit can be more specifically attributed to the insoluble fiber content of whole grains, which aids in digestion. There is good

evidence supporting that insoluble fiber prevents the irritating problem of constipation and the development of diverticulosis and diverticulitis. **Diverticulosis** is a benign condition characterized by out-pocketing of the colon. **Diverticulitis** occurs when the out-pocketings in the lining of the colon become inflamed. Interestingly, diverticulitis did not make its medical debut until the early 1900s, and in 1971 was defined as a deficiency of whole-grain fiber. According to the National Digestive Diseases Information Clearinghouse, more than 30% of Americans over between the age of 50 and 59 have diverticulosis, and 70% of people over the age of eighty have the disorder.[18] Less than 5% of people who have diverticulosis go on to develop diverticulitis.[18] Symptoms include lower abdominal pain, nausea, and alternating between constipation and diarrhea.

Diverticulitis

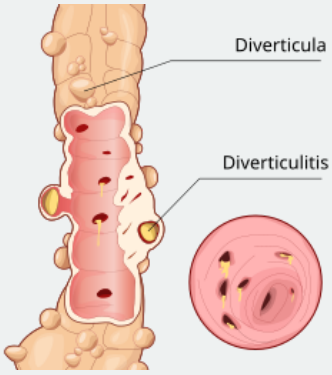


Figure 5.5.3: Diverticulitis in the colon.[19] Out-pockets of the colon and inflammation can cause pain and other digestive issues.

The chances of developing diverticulosis 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 protecting 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 phenomenon of consuming foods high in fiber is increased gas because the byproducts of bacterial digestion of fiber are gases.

Some 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 *American Journal of Clinical Nutrition* did not find that dietary fiber intake was associated with reduced colon cancer risk. Still, high dietary fiber was associated with a reduced risk of mortality from cardiovascular disease.[20] There is some evidence that specific fiber types (such as inulin) may protect against colon cancer, but more studies are needed to determine conclusively how certain fiber types (and at what dose) inhibit colon cancer development.

Attributions

- Zimmerman, "An Introduction to Nutrition (Zimmerman)," CC BY-NC-SA 3.0. *The original material was updated. New figures and references were added.*

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5.6: Diabetes and Hypoglycemia

What is diabetes?

Diabetes is one of the top three diseases in America. It affects millions of people and causes tens of thousands of deaths each year. **Diabetes** is a metabolic disease of insulin deficiency and glucose oversufficiency. Like other diseases, genetics, nutrition, environment, and lifestyle are all involved in determining a person's risk for developing diabetes. One sure way to decrease your chances of getting diabetes is to maintain an optimal body weight by adhering to a diet balanced in carbohydrate, fat, and protein intake. There are three different types of diabetes: type 1 diabetes, type 2 diabetes, and gestational diabetes.



Video 5.6.1. Introduction to Diabetes.[1]

Type 1 Diabetes

Type 1 diabetes is a metabolic disease in which insulin-secreting cells in the pancreas are killed by an abnormal response of the immune system, causing a lack of insulin in the body. Its onset typically occurs before the age of thirty. The only way to prevent the deadly symptoms of this disease is to inject insulin under the skin. Before this treatment was discovered, people with Type 1 diabetes died rapidly after disease onset. Death was the result of extremely high blood-glucose levels affecting brain function and leading to coma and death. Up until 1921, patients with Type 1 diabetes, the majority of them children, spent their last days in a ward where they lapsed into a coma awaiting death. One of the most inspiring acts in medical history is that of the scientists who discovered, isolated, and purified insulin and then went on to find out that it relieved the symptoms of Type 1 diabetes, first in dogs and then in humans. Frederick Banting, Charles Best, and James Collip went into a hospital ward in Toronto, Canada, and injected comatose children with insulin. Before they completed their rounds, children were already awakening to the cheers of their families.

A person with Type 1 diabetes usually has a rapid onset of symptoms that include hunger, excessive thirst and urination, and rapid weight loss. Because the main function of glucose is to provide energy for the body, when insulin is no longer present, no message is sent to cells to take up glucose from the blood. Instead, cells use fat and proteins to make energy, resulting in weight loss. If Type 1 diabetes goes untreated, individuals with the disease will develop a life-threatening condition called **ketoacidosis**. This condition occurs when the body uses fats and not glucose to make energy, resulting in a build-up of **ketone bodies** in the blood. It is a severe form of ketosis with symptoms of vomiting, dehydration, rapid breathing, confusion, and eventually coma and death. Upon insulin injection, these severe symptoms are treated, and death is avoided.

Unfortunately, although insulin injection prevents death, it is not considered a cure. People who have this disease are affected by many symptoms (Figure 5.6.1). They must adhere to a strict diet to prevent serious complications. Individuals diagnosed with Type 1 diabetes are advised to consume a diet low in the types of carbohydrates that rapidly spike glucose levels (high-glycemic index foods), count the carbohydrates they eat, consume healthy-carbohydrate foods, and eat small meals frequently. These guidelines are

aimed at preventing large fluctuations in blood glucose. Frequent exercise also helps manage blood glucose levels. Type 1 diabetes accounts for between 5 and 10% of diabetes cases.

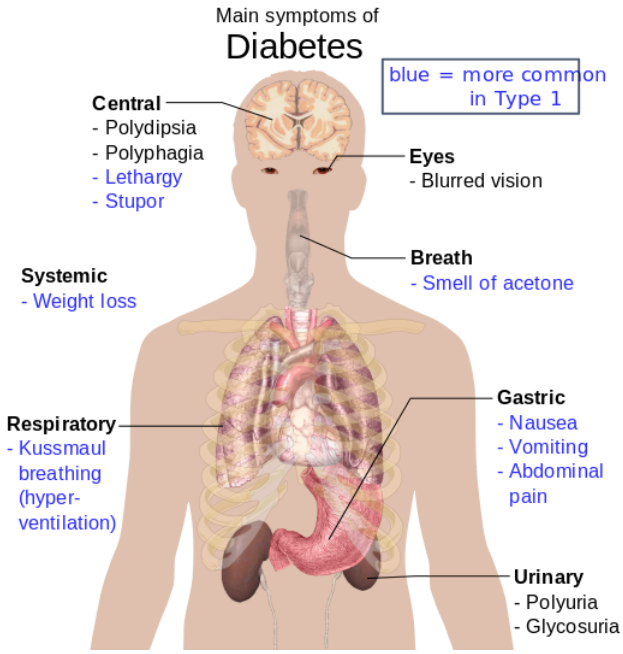


Figure 5.6.1. Overview of the most significant possible symptoms of diabetes.[2]

Type 2 Diabetes

The other 90 to 95% of diabetes cases are **type 2 diabetes**. Type 2 diabetes is defined as a metabolic disease of insulin insufficiency, but it is also caused by muscle, liver, and fat cells no longer responding to the insulin in the body. In brief, cells in the body have become resistant to insulin and no longer receive the full physiological message of insulin to take up glucose from the blood. Thus, similar to patients with Type 1 diabetes, those with Type 2 diabetes also have high blood-glucose levels.

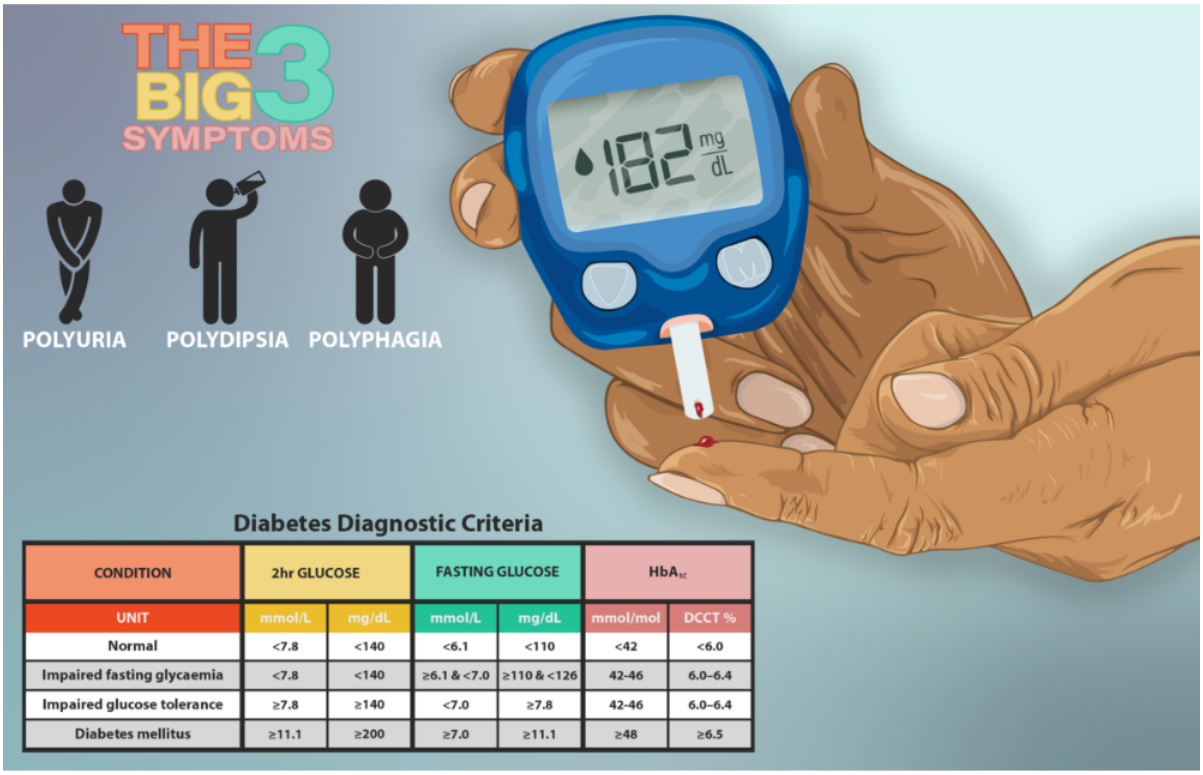
For individuals with Type 2 diabetes, the onset of symptoms is more gradual and less noticeable than for those with Type 1 diabetes. The symptoms are increased thirst (**polydipsia**), increased urination (**polyuria**), unexplained weight loss, and hunger (**polyphagia**). Diabetes can be diagnosed by blood tests that determine the amount of glucose in the blood (Figure 5.6.2). The **A1C** test measures how much blood sugar is attached to hemoglobin, a protein in the blood that carries oxygen. High A1C results suggest high blood sugar levels for an extended period. Blood glucose levels can also be measured during fasting or after a drinking a sugary drink.

The first stage of Type 2 diabetes is characterized by high glucose and insulin levels. This is because the insulin-secreting cells in the pancreas attempt to compensate for insulin resistance by making more insulin. In the second stage of Type 2 diabetes, the insulin-secreting cells in the pancreas become exhausted and die. At this point, individuals with Type 2 diabetes also have to be treated with insulin injections. Healthcare providers aim to prevent the second stage from happening. As with Type 1 diabetes, chronically high-glucose levels cause big detriments to health over time, so another goal for patients with Type 2 diabetes is to properly manage their blood-glucose levels. The front-line approach for treating Type 2 diabetes includes eating a healthy diet and increasing physical activity.

The Centers for Disease Control Prevention (CDC) estimates that as of 2023, 37 million Americans have diabetes, which is over 10 percent of the population.[3] In 2017, the cost of diabetes to the United States was estimated at $327 billion.[4] The incidence of Type 2 diabetes has more than doubled in America in the past thirty years, and the rise is partly attributed to the increase in obesity in this country. Genetics, environment, nutrition, and lifestyle all play a role in determining a person's risk for Type 2 diabetes. We have the power to change some of the determinants of disease but not others. The Diabetes Prevention Trial that studied lifestyle and drug interventions in more than three thousand participants who were at high risk for type 2 diabetes found that intensive lifestyle intervention reduced the chances of getting type 2 diabetes by 58%.[5]

Having more than one risk factor for Type 2 diabetes substantially increases a person's chances of developing the disease. **Metabolic syndrome** refers to a medical condition in which people have three or more risk factors for Type 2 diabetes and cardiovascular disease (Figure 5.6.2). According to the International Diabetes Federation (IDF) people are diagnosed with this syndrome if they have central (abdominal) obesity and any two of the following health parameters: triglycerides greater than 150 mg/dL; high-density lipoproteins (HDL) lower than 40 mg/dL; systolic blood pressure above 100 mmHg or diastolic above 85 mmHg; or fasting blood glucose levels greater than 100 mg/dL.[6]

About 1 in 3 adults in the United States have metabolic syndrome.[7] Studies vary, but people with metabolic syndrome have between a 9 and 30 times greater chance of developing Type 2 diabetes than those who do not have the syndrome.[6]



CONDITION	2hr GLUCOSE		FASTING GLUCOSE		HbA_{1c}	
UNIT	mmol/L	mg/dL	mmol/L	mg/dL	mmol/mol	DCCT %
Normal	<7.8	<140	<6.1	<110	<42	<6.0
Impaired fasting glycaemia	<7.8	<140	≥6.1 & <7.0	≥110 & <126	42-46	6.0–6.4
Impaired glucose tolerance	≥7.8	≥140	<7.0	≥7.8	42-46	6.0–6.4
Diabetes mellitus	≥11.1	≥200	≥7.0	≥11.1	≥48	≥6.5

Figure 5.6.2. Diabetes Symtoms and Diagnostics.[10] Blood tests for glucose help diagnose diabetes.

Gestational Diabetes

During pregnancy, some women develop gestational diabetes. **Gestational diabetes** is characterized by high blood-glucose levels and insulin resistance. The exact cause is not known, but it does involve the effects of pregnancy hormones on how cells respond to insulin. Gestational diabetes can cause pregnancy complications, and it is common practice for healthcare practitioners to screen pregnant women for this metabolic disorder. The disorder normally ceases when the pregnancy is over, but women who have had gestational diabetes have a 10-fold risk of developing type 2 diabetes as they age.[8] Gestational diabetes not only affects the health of a pregnant woman but also is associated with an increased risk of obesity and Type 2 diabetes in her child.[3]

Prediabetes

As the term infers, **prediabetes** is a metabolic condition in which people have moderately high glucose levels but do not meet the criteria for diagnosis of diabetes. Over 96 million Americans are prediabetic and at increased risk for type 2 diabetes and cardiovascular disease.[3] Prediabetes is reversible, and lifestyle changes such as eating healthy and exercising can help. The Centers for Disease Control (CDC) leads the National Diabetes Prevention Program, which can help support lifestyle changes. According to the CDC, participation in this program could lower the risk of developing type 2 diabetes by almost 60%.[9]

Long-Term Health Consequences of Diabetes

The long-term health consequences of diabetes are severe. They result from chronically high glucose concentrations in the blood accompanied by other metabolic abnormalities such as high blood-lipid levels. People with diabetes are between 2 and 4 times

more likely to die from cardiovascular disease. Diabetes is the number one cause of new cases of blindness, lower-limb amputations, and kidney failure. Many people with diabetes develop peripheral neuropathy, characterized by muscle weakness, loss of feeling, and pain in the lower extremities. More recently, there is scientific evidence to suggest people with diabetes are also at increased risk for Alzheimer's disease.

Diabetes Treatment

Keeping blood glucose levels in the target range (70–130 mg/dL before a meal) requires careful monitoring of blood glucose levels with a blood glucose meter, strict adherence to a healthy diet, and increased physical activity. Individuals with type 1 diabetes begin insulin injections as soon as they are diagnosed. Individuals with type 2 may require oral medications and insulin injections to maintain blood glucose levels in the target range. The symptoms of high blood glucose, also called **hyperglycemia**, are difficult to recognize, diminish in the course of diabetes, and are mostly not apparent until levels become very high. The symptoms are increased thirst and frequent urination.



Figure 5.6.3. Insulin Delivery Devices.[11] Insulin treatements help maintain blood glucose levels in the target range.

Having glucose levels that are too low, known as **hypoglycemia**, is also detrimental to health. Hypoglycemia is more common in type 1 diabetes and is most often caused by injecting too much insulin or injecting it at the wrong time. The symptoms of hypoglycemia are more acute and include shakiness, sweating, nausea, hunger, clamminess, fatigue, confusion, irritability, stupor, seizures, and coma. Hypoglycemia can be rapidly and simply treated by eating foods containing about ten to twenty grams of fast-releasing carbohydrates. If symptoms are severe, a person is either treated by emergency care providers with an intravenous solution of glucose or given an injection of glucagon, which mobilizes glucose from glycogen in the liver. Some people who are not diagnosed with diabetes may experience reactive hypoglycemia. This is a condition in which people are sensitive to the intake of sugars, refined starches, and high-GI foods. Individuals with reactive hypoglycemia have some symptoms of hypoglycemia. Symptoms are caused by a higher-than-normal increase in blood insulin levels. This rapidly decreases blood-glucose levels below what is required for proper brain function.

The major determinants of Type 2 diabetes that can be changed are overnutrition and a sedentary lifestyle. Therefore, reversing or improving these factors through lifestyle interventions markedly improves the overall health of individuals with type 2 diabetes and lower blood-glucose levels. In fact, it has been shown that when people are overweight, losing as little as nine pounds (four kilograms) decreases blood-glucose levels in individuals affected by Type 2 diabetes. The Diabetes Prevention Trial demonstrated that by adhering to a diet containing between 1,200 and 1,800 kilocalories per day with a dietary fat intake goal of less than 25% and increasing physical activity to at least 150 minutes per week, people at high risk for type 2 diabetes achieved a weight loss of 7% and significantly decreased their chances of developing Type 2 diabetes.[5]

An unfortunate problem is that most individuals diagnosed with diabetes do not adhere to lifestyle interventions long-term. This is partly because of individual disinclination but also because health insurance companies do not provide continued financial support for dietary guidance and because primary care physicians do not prescribe dietary guidance from a dietitian. This shifts the way diabetes is treated away from lifestyle intervention toward medications, as the goal remains to manage blood-glucose levels. Numerous oral medications are available on the market and are often prescribed to treat Type 2 diabetes in combination.

Interactive 5.6.1

The American Diabetes Association (ADA) has a website that provides information and tips for helping individuals with diabetes answer the question, “What Can I Eat?” Regarding carbohydrates, the ADA recommends that individuals with diabetes keep track of the carbohydrates they eat and set a limit. These dietary practices will help keep blood glucose levels in the target range.

Visit the ADA meal-planning website to learn more on making nutritious meals that help keep blood sugar levels in balance.

Attributions

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CHAPTER OVERVIEW

6: Lipids- Fats, Oils, and Other Lipids

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6.1: Introduction



Learning Objectives

1. Describe the types of lipids: triglycerides (fat), phospholipids, and sterols.
2. Explain the functions of lipids in the body and in food production.
3. Distinguish between essential and nonessential fatty acids.
4. Describe the Dietary Recommended Intake (DRI) for lipids.
5. Evaluate a meal for the relative abundance of lipids.
6. Provide strategies for choosing healthy foods that contain lipids.
7. Summarize the steps in lipid digestion.
8. Explain the health consequences of lipid excess and deficiency.
9. Describe the relationship between nutrition and cardiovascular disease.

Lipids are a category of nutrients that include fats and cholesterol. Like carbohydrates, fat is an essential macronutrient that provides energy. In this chapter we will explore the role these lipids have in our body's everyday function, along with what happens to our health when we overeat or undereat lipids. Heart disease will be highlighted throughout this chapter as a condition that is impacted by our lifestyle choices, including dietary lipid intake. The Mediterranean diet will be introduced as an example of a healthy food plan that combines the value of carbohydrates from our prior chapter with the value of fats learned in this chapter.

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6.2: Types of Lipids

Lipid Overview

Lipids are important substances that serve different roles in the human body. A common misconception is that fat, one major form of lipid, 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 signal that metabolic processes are efficient and a person is healthy.

Lipids are a family of organic (meaning they contain carbon) compounds that are **mostly insoluble in water**. Lipids 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 triacylglycerols, phospholipids, and sterols.

Triacylglycerols

Triacylglycerols (also known as triglycerides or fat) make up more than 95% of lipids in the diet. They are commonly found in both plant and animal food sources, including nuts, seeds, avocados, olives, fried foods, vegetable oil, butter, whole milk, cheese, meats, poultry, and fish. We commonly call the triacylglycerols in our food “fats” and “oils.” Fats are lipids that are solid at room temperature, whereas oils are liquid. As with most fats, triacylglycerols **do not dissolve in water**. The terms fats, oils, and triacylglycerols can be used interchangeably. In this chapter, when we use the word fat, we are referring to triacylglycerols.

Phospholipids

Phospholipids make up only about 2% 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

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 in the liver. Cholesterol is an important component of the cell membrane and is required for the synthesis of sex hormones, vitamin D, and bile salts.

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

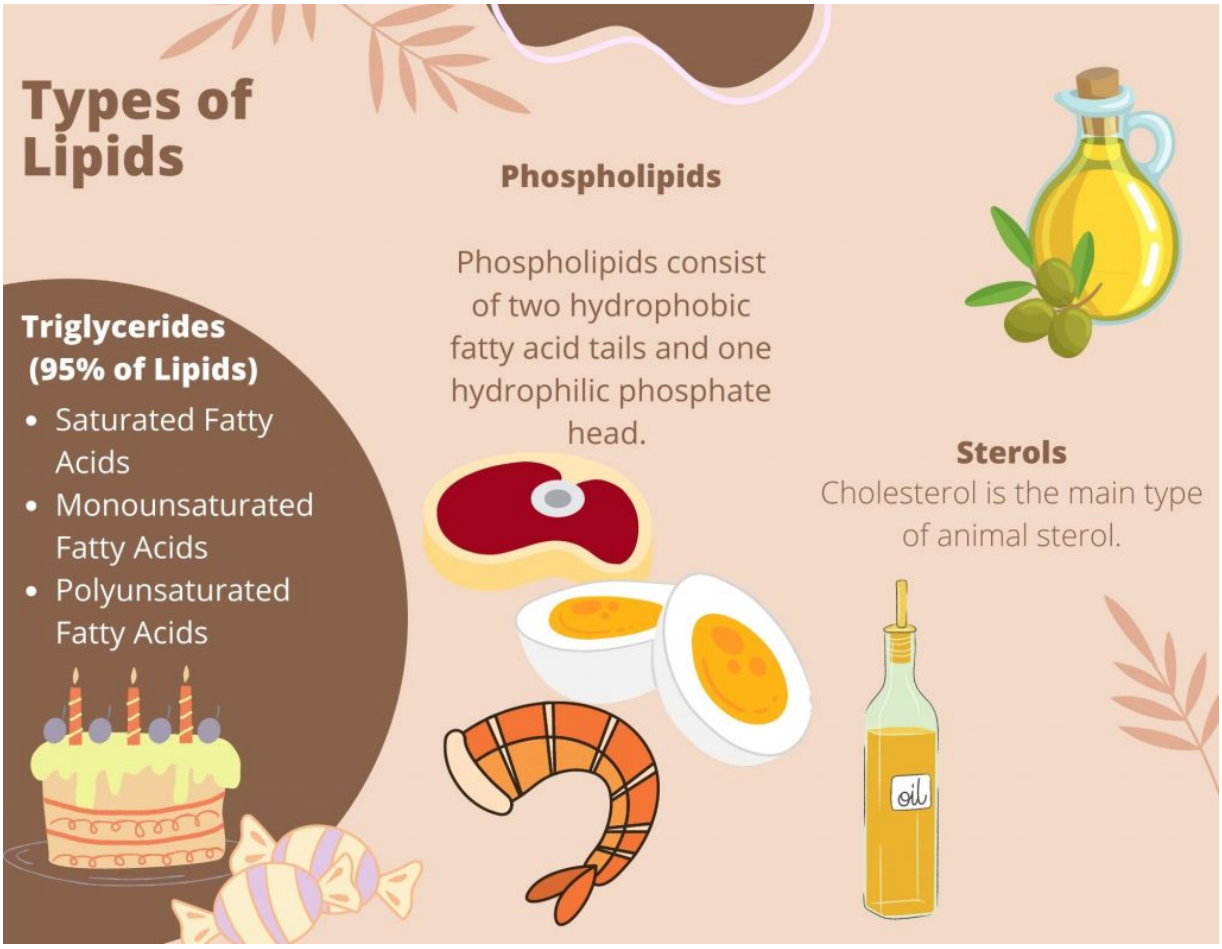


Figure 6.2.1: Types and sources of lipids.[1]

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6.2.1: Functions of Lipids in the Body and in Food

Functions of Lipids in the Body: Storing Energy

The excess energy from the food we eat is digested and incorporated into **adipose tissue**, or fatty tissue. Carbohydrates and lipids provide most of the energy the human body requires. As discussed in the previous chapter, glucose is stored in the body as glycogen. While glycogen provides a ready energy source, lipids primarily function as an energy reserve. Glycogen is quite bulky and has a heavy water content; thus, the body cannot store too much for long. Alternatively, fats are packed together tightly without water and store far greater 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 our physical work and play. 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 can 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.

Functions of Lipids in the Body: Regulating and Signaling

Fats control the body's internal climate, maintaining a constant temperature. Those who don't have enough fat tend to feel cold sooner, are often fatigued, and have pressure sores on their skin from fatty acid deficiency. Fats 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 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 function. They help form nerve cell membranes, insulate neurons, and facilitate the signaling of electrical impulses throughout the brain.

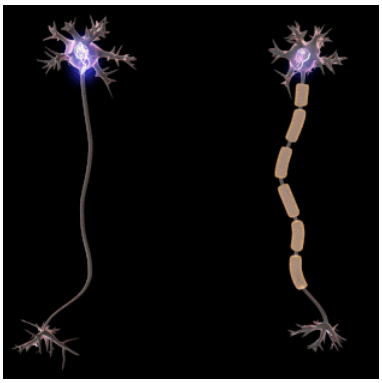


Figure 6.2.1.1: Lipids serve as signaling molecules; they are catalysts of electrical impulse activity within the brain. Nerve response in myelinated neurons (covered with a myelin coating on the right that is 70% lipids in dry mass) propagates faster than in unmyelinated neurons (left).[1]

Functions of Lipids in the Body: Insulating and Protecting

Did you know that up to 30% of body weight consists 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% 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 skating or roller skating, horseback riding, or snowboarding.

Functions of Lipids in the Body: 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 substances 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.

Note that removing the fat from food may lessen the food's fat-soluble vitamin content. When products such as grain and dairy are processed, these essential nutrients are lost.

Label Reading Activity

Remember, fat-soluble nutrients require fat for effective absorption. The next time you pick up a food with a nutrient facts panel, check the Percent Daily Value for Vitamin A and Vitamin D (a high source is 20% or higher). Next check if the food contains any fat that increases bioavailability (absorption) of the vitamins. If not, think of ways to add a bit of healthy fat to the snack or meal to aid in fat-soluble vitamin absorption.

Role of Lipids in Food: High Energy Source

Fat-rich foods naturally have a high caloric density. Foods that are high in fat contain more Calories than foods high in protein or carbohydrates. As a result, high-fat foods are a convenient source of energy. For example, 1 gram of fat or oil provides 9 calories of energy, compared with 4 calories in 1 gram of carbohydrate or protein. Depending on the level of physical activity and 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 appropriate 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. Higher-fat foods may also help someone with a poor appetite reach their Calorie goals to maintain or gain weight.



Figure 6.2.1.2: Athletes have high-energy requirements.[2]

Depending on the intensity, duration, and training level of a person engaging in exercise, the proportion of carbohydrate and fat used for energy changes. Fat is an important fuel in lower to moderate aerobic exercise, but it also comes in handy as a long-term fuel supply when carbohydrate levels drop during long-duration activities. 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. That same swimmer, however, may want to choose lower-fat foods before training as this may be more comfortable for digestion. In contrast, if a person who leads a sedentary lifestyle eats the same high-density fat foods, they will take in 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.

Role of Lipids in Food: 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? It is possible to have great-tasting food with little or no fat for those with health conditions that require such. Adding aromatic herbs and spices in the cooking process is a great way to flavor food!

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

Tools for Change

Although fats provide delicious smells, tastes, and textures to our foods, they also provide numerous Calories. To allow your body to experience the satiety effect of the fat before you overindulge, try savoring rich foods. Eating slowly will allow you to both fully enjoy the experience and be satiated (feeling of fullness) with a smaller portion. Remember to take your time. Drink water between bites or eat a lower-fat food before and after a higher-fat food. The lower-fat foods will provide bulk but fewer Calories.

Attributions

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6.2.2: Lipid Structures

Triacylglycerols Structure

Triacylglycerols are the main form of lipid found in the body and the diet. **Fatty acids** and **glycerol** are the building blocks of triacylglycerols. Glycerol is a thick, smooth, syrupy compound often used in the food industry. To form a triacylglycerol, a glycerol molecule is joined to three fatty acid chains (Figure 6.2.2.1). Triacylglycerols contain varying mixtures of fatty acids, which are discussed in further detail below.

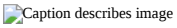


Figure 6.2.2.1: Triglyceride structure.[1] Triglycerides or triacylglycerols are made of glycerol joined to three fattey acid chains that can vary.

Fatty Acids

Fatty acids consist of a carboxylic acid (−OOH) group on one end of a carbon chain and a methyl group ($-CH_3$) on the other end (Figure 6.2.2.2). Fatty acids can differ from one another in two important ways—carbon chain length and degree of saturation.

Fatty Acid Chain Length

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 lowers—and the fatty acid becomes more liquid. Fatty acid composition in the food determines if the food is solid or liquid at room temperature.

Degrees of Saturation

Fatty acid chains are held together by carbon atoms that attach to one another 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 with only one double bond is a **monounsaturated fatty acid (MUFA)**, an example of which is olive oil (75% 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 (PUFA)** is a fatty acid with two or more double bonds or two or more points of unsaturation (Figure 6.2.2.2). 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.

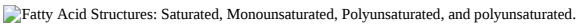


Figure 6.2.2.2: Fatty acids.[2] Fatty acids can be saturated, monounsaturated, or polyunsaturated based on the number of carbon-carbon bonds in the carbon chain.

Foods with a high percentage of saturated fatty acids tend to be solid at room temperature. Examples 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 shift your intake of fat products, choosing unsaturated fat is more beneficial than choosing a saturated fat. This choice is easy 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 because they are solid at room temperature yet high in saturated fat. Palm oil (often used in food processing) is highly saturated and may raise blood cholesterol. Shortening, margarine, and commercially prepared foods (in general) are reported to use only vegetable-derived fats in their processing. But even so, much of their fat may be in the saturated and trans fat categories.

Trans Fatty Acids

Introducing 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 6.2.2.3).

In a **trans fatty acid**, the hydrogen atoms are attached on opposite sides of the carbon chain and have a flatter structure. Unlike cis fatty acids, most trans fatty acids are not found naturally in foods but result from a process called hydrogenation. **Hydrogenation** is the process of adding hydrogen to the carbon double bonds, thus making the fatty acid saturated (or less unsaturated, in the case of partial hydrogenation). This is how vegetable oils are converted into semisolid fats for use in the manufacturing process. Note: Partially hydrogenated oils (PHOs), the major source of artificial trans fat in the food supply, are no longer Generally Recognized as Safe (GRAS). Therefore, PHOs are no longer added to foods under this FDA regulation.

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% of the total trans-fat intake in our diet. While we know that trans fats are not exactly harmless, it seems that any negative effects 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.

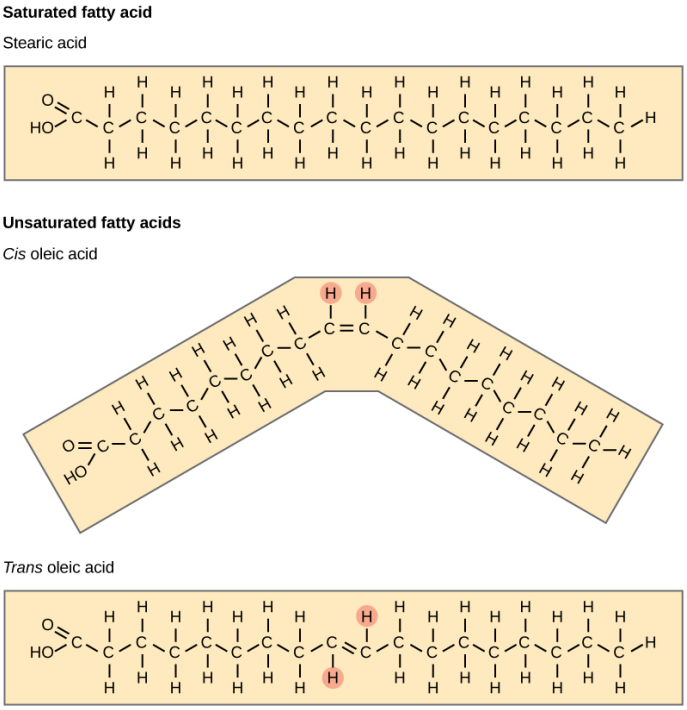


Figure 6.2.2.3: Saturated and unsaturated fatty acids.[3] Saturated fatty acids do not have carbon-carbon double bonds. Cis- and trans-unsaturated fatty acids have different locations of the hydrogens in the carbon-carbon double bonds.

Nonessential and Essential Fatty Acids

Fatty acids are vital for the normal operation of all body systems. The circulatory system, respiratory system, integumentary system, immune system, brain, and other organs require fatty acids for proper function. The body is capable of synthesizing most of the fatty acids it needs. 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" 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 (ω-3)** and **omega-6 (ω-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 (Figure 6.2.2.2). Omega-3 and omega-6 fatty acids are precursors to important compounds called eicosanoids. **Eicosanoids** are powerful hormones that control many other hormones and important body functions, such as the central nervous system and the immune system.

Eicosanoids derived from omega-6 fatty acids are known to increase blood pressure, immune response, and inflammation (all of which serve a purpose in the human body). In contrast, eicosanoids derived from omega-3 fatty acids are known to have heart-healthy effects. Given the contrasting effects of the omega-3 and omega-6 fatty acids, a proper dietary balance between the two must be achieved to ensure optimal health benefits. Both omega-3 and omega-6 fatty acids fall in the category of polyunsaturated fatty acids.

Essential fatty acids play an important role in the life and death of cardiac cells, immune system function, and blood pressure regulation. **Docosahexaenoic acid (DHA)** is an omega-3 essential fatty acid shown to play important roles in synaptic transmission in the brain during fetal development. **EPA (eicosapentaenoic acid)** is another valuable omega-3 essential fatty acid. DHA and EPA are often referred to as "marine omega-3," as a primary food source is fish. **ALA (alpha-linolenic acid)** is a type of omega-3 found in food that can be converted to EPA. This is a valuable omega-3 fatty acid source for vegetarians. Food sources of ALA include chia seeds, flaxseed oil, hemp, walnuts, and leafy vegetables. Because these essential fatty acids are easily accessible, essential fatty acid deficiency is extremely rare.



Figure 6.2.2.4: Wild salmon.[4] Fish are good sources of DHA and EPA.

Fatty-Acid Composition in the Diet and 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 triacylglycerols in the body. Evidence confirms that saturated fatty acids are linked to higher rates of weight retention when compared with other types of fatty acids. Alternatively, the fatty acids found in fish oil are proven to reduce the rate of weight gain compared with other fatty acids.[5]

Phospholipids

Like triacylglycerols, **phospholipids** have a glycerol backbone. But unlike triacylglycerols, phospholipids are **diglycerides** (two fatty-acid molecules attached to the glycerol backbone). In contrast, their third fatty-acid chain has a phosphate group coupled with a nitrogen-containing group (Figure 6.2.2.5). 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 (like 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 allowing for transport of fat and water through the membrane.

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, is a popular food emulsifier. Mayonnaise demonstrates lecithin's ability to blend vinegar and oil to create the stable, spreadable condiment that so many enjoy. Food emulsifiers play an important role in making the appearance of food appetizing. Adding emulsifiers to sauces and creams not only enhances their appearance but also increases their freshness.

Lecithin's crucial role within the body is clear because it is present in every cell throughout the body; 28% of brain matter is composed of lecithin, and 66% of the lipid 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 that broadcast these claims. However, as the body can make most phospholipids, it is not necessary to consume them in a pill. The body makes all of the lecithin that it needs.

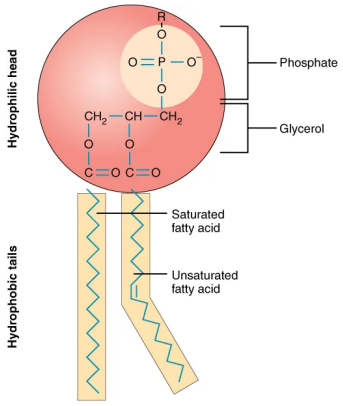


Figure 6.2.2.5: Phospholipid structure.[6] Phospholipids are emulsifiers and provide the barrier around all cells.

Sterols

Sterols have a very different structure from triacylglycerols and phospholipids. Most sterols do not contain any fatty acids but rather multi-ring structures. They are complex molecules that contain interlinking rings of carbon atoms, with side chains of carbon, hydrogen, and oxygen attached (Figure 6.2.2.6). **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 that it performs in the body. Like phospholipids, cholesterol is present in all body cells as it is an important substance in **cell membrane structure**. Approximately 25% of cholesterol in the body is localized in brain tissue. Cholesterol is used in the body to make several 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 a vital substance in the body that poses a concern only when there is excess accumulation in the blood. Like lecithin, the body can synthesize cholesterol.

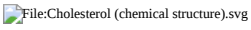


Figure 6.2.2.6: Cholesterol structure.[7]

Attributions

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6.3: Sources and Requirements of Lipids

There are various recommendations for lipid intake, depending on your age, activity level, and risk of certain health conditions. In this section, we will focus on both the quantity and the quality of lipids to consider when planning a healthy diet. Remember that most foods contain all macronutrients, including some carbohydrates, some protein, and some fat, just as our dietary intake should include all three macronutrients. Oil is one example of a food that is 100% fat. For this reason, we should be mindful how much (portion) fits into our ideal food plan, as well as which type (food source and level of processing) of oil may be best for our health. This section provides an opportunity to learn the terminology, science, and current nutrition recommendations.

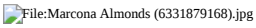


Figure 6.3.1: "Marcona Almonds" by Jonathan Pincas is licensed under CC BY 2.0.

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6.3.1: Balancing Your Diet with Lipids

Dietary Recommendations for Fats

Fats are an important part of a healthy diet, and the following recommendations are provided by the Food and Nutrition Board Dietary Reference Intakes and the Dietary Guidelines for Americans:[1,2]

- Fat calories should be limited to 20–35% of total calories with most fats coming from polyunsaturated and monounsaturated fats. This is the AMDR for adults 19 and older.
- Consume fewer than 10% of calories from saturated fats.
- Keep the consumption of trans fats and cholesterol as low as possible without compromising the nutritional adequacy of the diet.
- Lean and low-fat meats, poultry, milk, and milk products will help avoid consuming excessive amounts of saturated fats.

Lipid Recommendations

Lipid Category	Dietary Reference Intakes and Recommendations
Total Fat	AMDR: Adults 19 and older: 20% to 35% of total calories
Saturated Fat	Less than 10% total calories
Linoleic Acid	Adequate Intake: 10 to 17 grams (varies by age and gender)
Linolenic Acid	Adequate Intake: 0.7 to 1.6 grams (varies by age and gender)

Table 6.3.1.1: Lipid recommendations from the Dietary Reference Intake Committee[1] and the Dietary Guidelines for Americans[2].

Identifying Sources of Fat

When we eat food, we eat a variety of fats. 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, extra virgin 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, such as nuts, oils, and fish.
  - **Omega-3 fatty acids (linolenic acid).** Good sources of these are canola oil, flaxseed oil, soybean oil, olive oil, nuts (walnuts, almonds, hazelnuts, pecans), 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.
  - The Omega-3 to Omega-6 ratio, as it relates to reducing heart disease risk, is no longer a recommendation of the American Heart Association, which states that there is value in adequate intake of both types of fat.[2]
- **Saturated fat.** This fat is found in animal products, full-fat dairy products, palm and coconut oils, and cocoa butter. Limit these products to less than 10 percent of your overall dietary fat consumption. The current average intake of saturated fat is 11 percent of calories, and only 23 percent of people eat amounts of saturated fat consistent with the limit of less than 10% of calories. The top sources of saturated fat for adults are sandwiches (deli sandwiches, burgers, tacos, burritos, grilled cheese, hot dogs) and other grain-based mixed dishes (e.g. spaghetti and meatballs, casseroles, quesadillas).[3]
- **Trans fatty acids.** Stick margarines, fast foods, commercial baked goods, and some snack foods contain trans fats. Limit your consumption of these products to keep your trans fat intake low, as trans fats have been linked to increasing LDL cholesterol and lowering HDL cholesterol, which increases heart disease risk. Since 2020, manufacturers can no longer add processed trans fats (partially hydrogenated oils, or PHOs) to foods in more than 0.5 grams per serving and you can still get small amounts from natural sources. The FDA has removed trans fats from the GRAS list (Generally Recognized as Safe).[4]



Figure 6.3.1.1: Enjoy a delicious vegetable burger as an alternative to a traditional beef hamburger with French fries to reduce saturated fat.[6]

Attribution

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6.4: Digestion and Use of Lipids

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

From the Mouth to the Stomach

The first step in the digestion of triacylglycerols 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 first of several enzymes specific to fat digestion ("lip"=lipid and "ase" = 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. Although lingual lipase is excreted in the mouth, it is fully activated in the stomach.

In the stomach, the enzyme **gastric lipase** starts to break down triacylglycerols into diglycerides and fatty acids. Within two to four hours after eating a meal, roughly 30% of the triacylglycerols 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.

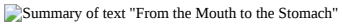


Figure 6.4.1: "Lipid digestion and absorption" by Allison Calabrese is licensed under CC BY 4.0.

Going to the Bloodstream

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

Once the stomach contents have been emulsified, fat-breaking enzymes work on the triacylglycerols and diglycerides to sever fatty acids from their glycerol foundations. As the enzyme **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 mucous 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.

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 triacylglycerols. Triacylglycerols, cholesterol, and phospholipids form lipoproteins when joined with a protein carrier. **Lipoproteins** have an inner core primarily comprising triacylglycerols 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**, a large lipoprotein that now enters the lymphatic system and will soon be released into the bloodstream via the jugular vein in the neck. Chylomicrons transport food fats perfectly through the body's water-based environment to specific destinations such as the liver and other body tissues.

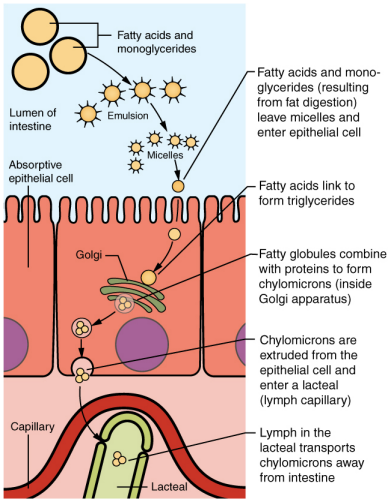


Figure 6.4.2: "Lipid absorption" from Anatomy & Physiology by OpenStax is licensed under CC BY 3.0.

Cholesterol is poorly absorbed compared with phospholipids and triacylglycerols. Cholesterol absorption is aided by increased 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 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.

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 is by transforming carbohydrates into glycogen that, in turn, is 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 triacylglycerols and then stored as fat.

Similarly, much of the triacylglycerols 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 triacylglycerols 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 triacylglycerol and fatty-acid core. Capillary walls contain an enzyme called **lipoprotein-lipase** that dismantles the triacylglycerols 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 triacylglycerols 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 triacylglycerols and dispensing glycerol and fatty acids directly into the blood. Upon receipt of these substances, the energy-hungry cells break them down further into tiny fragments. These fragments go through a series of chemical reactions that yield energy, carbon dioxide, and water.

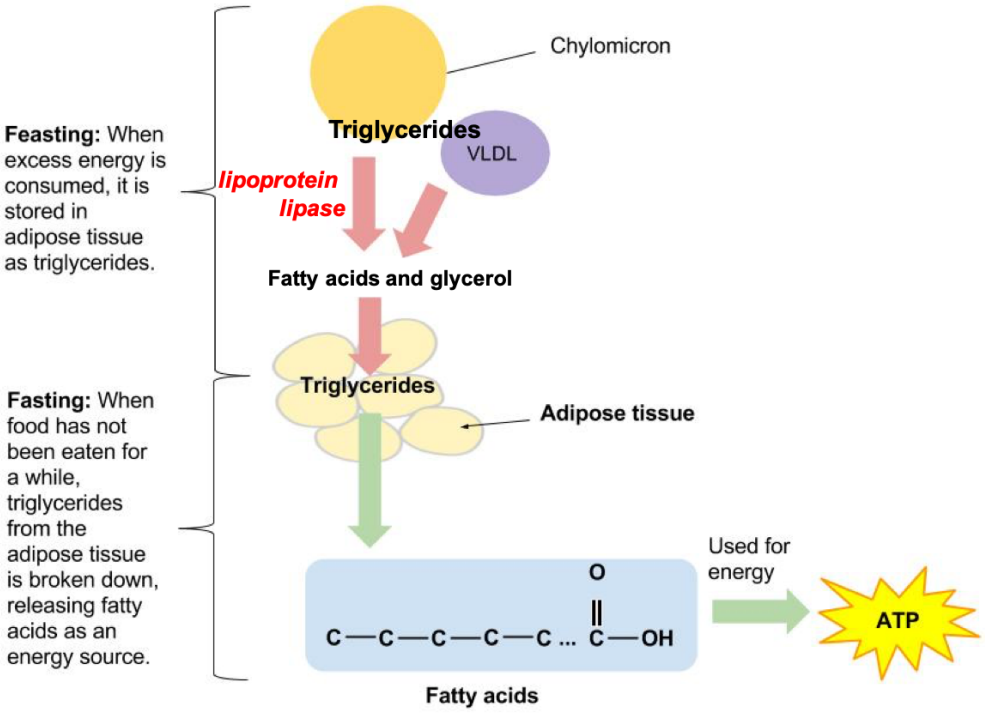


Figure 6.4.3: "Storing and using fat" by Allison Calabrese is licensed under CC BY 4.0; with modifications by Alice Callahan.

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6.5: Conditions Related to Deficient and Excessive Lipid Intake

Deficient Lipid Intake: Essential Fatty Acid Deficiency

An **essential fatty acid (EFA)** is a fatty acid that is necessary for human function but a substance we cannot produce in adequate amounts; therefore, it is required that we obtain some essential fatty acids in the diet. Linoleic acid and linolenic acid are the primary essential fatty acids in humans. They are necessary for maintaining cell membranes and keeping the skin intact. In addition, substances synthesized from essential fatty acids are important for the brain and retina. **EFA deficiency,** characterized by a dry scaly rash, can result in decreased growth in infants and children, poor wound healing, and increased risk of infection. EFA deficiency in humans is rare but can occur. Babies fed an inferior baby formula can develop EFA deficiency, as can a patient who receives long-term parental nutrition (nutrition given by IV) without appropriate additions of fatty acids in the nutrition formula. Diseases and conditions in which fat malabsorption occurs (cystic fibrosis and some gastric surgeries, for example) or conditions of high metabolic needs (patients with severe burns, for example) can also increase the risk of EFA deficiency.[1] In anorexia nervosa (a psychological disorder that results in severe weight loss), an increased risk of EFA deficiency may be linked to the associated malnutrition, extreme lack of fat intake, and altered fat metabolism.[2,3]

Excessive Lipid Intake and Chronic Diseases

Cardiovascular (heart and blood vessel) disease, stroke, diabetes, and cancer are among the leading causes of death in the United States. These conditions are considered **chronic diseases**, defined as "conditions that last one year or more and require ongoing medical attention or limit activities of daily living or both." There are risk factors associated with these diseases. A **health risk factor** is defined as anything that can increase the chance of getting a disease or condition. It is critical to address dietary and lifestyle choices that will ultimately decrease risk factors for disease. According to the Centers for Disease Control and Prevention (CDC), the following are risk factors that we can control: being overweight, and obesity, diabetes, high blood cholesterol, poor diet, physical inactivity, high blood pressure, excess alcohol intake, and nicotine use.[4] One or many of these risk factors may be present at the same time and often overlap in how they impact disease. *A more detailed review of overweight and obesity risk factors common to multiple health conditions is available in Chapter 10.* In this section, we will introduce how the amount of fat and the type of fat in a person's food pattern can impact health.

Excess Fat Intake and Cancer

Cancer is defined as "a disease in which some of the body's cells grow uncontrollably and spread to other parts of the body."[5] A review of evidence-based research on dietary fat and cancer resulted in several observations related to cancer development. The general theme was that lipids alter the **microbiome,** which can impact chronic inflammation. The microbiome consists of trillions of microorganisms (microbes or microbiota) that live in and on our bodies. Some microbiota are helpful, while others are potentially harmful and promote disease. Certain illness, eating patterns, and medication use can offset the balance within the microbiome, making us more susceptible to disease, including certain cancers, cardiovascular disease, intestinal diseases, kidney disease, and type 2 diabetes.[6]

> **Total Fat**: Total fat alone was not associated with cancer risk unless the excess fat intake contributed to obesity. Obesity is associated with an increased risk of many chronic diseases, including cancer. **Obesity** is defined as a body mass index of 30 or higher.
>
> **Fatty Acids**: Diets higher in saturated fatty acids may have a negative impact on cancer risk, whereas omega-3 rich diets may have beneficial effects against cancer. However, the research reports that even different chain lengths of saturated fatty acids can have differing effects. Given that foods contain variations in fatty acid content, it is difficult to identify any one particular fatty acid as a link to cancer. There is evidence that red meat and processed meats may increase colon, lung, prostate, and pancreatic cancer risk, but this link is due to factors other than saturated fat content. The Mediterranean diet, reviewed in section 2.6, was associated with a lower risk of cancer death, including cancers of the colon, breast, stomach, liver, head and neck, and prostate. The Mediterranean Diet emphasizes monounsaturated fatty acids from olive oil, as well as an abundance of vegetables, fruits, whole grains, legumes, nuts, and fish. The many components of this pattern of eating may jointly be responsible for the positive news regarding cancer rather than one single nutrient.

Excess Fat Intake and Diabetes

Diabetes, reviewed in a prior chapter, is a group of metabolic disorders characterized by increased blood glucose concentration. A high-fat diet has been associated with higher Hemoglobin A1C (three-month average blood glucose level) in children and

adolescents with type 1 diabetes. In addition, it was reported that high-fat meals increased glucose levels to the point of needing to adjust insulin doses. Long-term increased risk of cardiovascular disease may also be associated with how a high-fat diet impacts the gut microbiome.[7]

Total Fat: In type 2 diabetes, a review of research concluded that a low-fat diet did not increase or decrease the risk of this condition. However, excess body weight is associated with type 2 diabetes risk, and the authors recommended a balance between Calorie intake and physical activity to maintain weight as a means of diabetes risk reduction.[8]

Fatty Acids: The type of fat has also been addressed. Study participants with diabetes who replaced saturated fatty acids with monounsaturated fatty acids and polyunsaturated fatty acids had positive benefits in cardiovascular disease risk and better long-term survival rates.[9] Additional studies were more specific to foods rich in saturated fat, noting that higher intakes of all fatty acids from meat were "adversely associated with markers of insulin resistance and insulin secretion, whereas the fatty acids from dairy and plant sources were not."[10]

Excess Fat Intake and Non-Alcoholic Liver Disease

Non-alcoholic fatty liver disease (NAFLD), a chronic liver disease, is defined as the presence of fat accumulation in the liver without significant alcohol intake. NAFLD can progress to non-alcoholic steatohepatitis (NASH), liver cirrhosis, and liver cancer. It is strongly associated with obesity, especially central obesity (more fat around the midsection), type 2 diabetes, insulin resistance, hypertension, and metabolic syndrome.

Total fat: Weight loss is a primary treatment for NAFLD. A review of studies related to dietary interventions reported that both a low fat eating pattern and a low carbohydrate eating pattern could provide benefit if weight loss occurs and can be sustained.[11]

Fatty acids: Both clinical investigation trials and observational studies support that the Mediterranean Diet, which emphasizes monounsaturated fatty acids, may prevent NAFLD through its impact on body weight, insulin sensitivity/resistance, and lipid metabolism. In a smaller observational study, an eating pattern characterized by high intakes of fruits, vegetables, nuts, olive oil, low-fat dairy, fish, and garlic was associated with lower risk of NAFLD, whereas a dietary pattern with high amounts of fast foods, soft drinks, processed meat, high-fat dairy, hydrogenated fats, mayonnaise, salty snacks, sugar-sweetened desserts, organ meats, and refined grains was linked to a greater risk of NAFLD.[12]

Excess Fat Intake and Female Reproduction

Although studies in humans are limited, a high-fat diet impairs female reproductive function, with or without obesity. However, the reproductive function was worse when obesity was in place. Reproductive function was defined as an alteration in "menstrual cycle length, changes in reproductive hormone levels, and embryo quality in assisted reproductive technology cycles."[13]

Excess Saturated Fatty Acids and Heart Disease

This section provides an overview of excess lipid intake related to heart disease. Detailed information is provided in Section 6.6 Cardiovascular Disease.

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-cholesterol and low blood HDL-cholesterol have been stated as indicators of blood cholesterol risk, but we are learning more about LDL-cholesterol size, with not all types of LDL-cholesterol being a heart disease risk concern. The American Heart Association and the Dietary Guidelines for Americans promote that the largest influence on blood cholesterol levels rests in the **saturated fatty acid (SFA)** content in the diet. 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. Yet the question remains: is it the excess of saturated fat that is associated with heart risk, or is it the foods we lack (fresh vegetables, fruits, and fibers), or the primary Calories we take in from processed foods? The American College of Cardiology states, "The current information suggests that genetic predisposition modulates the association between saturated fat intake and cardiovascular risk. It is this segment of the population (the SFA-sensitive) in which the reduction in SFA intake may be beneficial and could therefore be recommended."[14] This supports the concept that not one food or one nutrient can be tied to disease risk, but rather we need to look at the synergy of **moderating** all nutrients within a **balance** between the **variety** of food groups.

Excess Dietary Cholesterol and Heart Disease

Dietary cholesterol does have a small impact on overall blood cholesterol levels, but not as much as some people once thought. The average American female consumes 237 milligrams of dietary cholesterol per day, and for males, the figure is slightly higher—about 358 milligrams. The USDA Dietary Guidelines suggest a daily limit intake of cholesterol not to exceed 300 milligrams for healthy people and 200 milligrams for those who may be suffering from high cholesterol. 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. Therefore, more emphasis is being placed on the balance of the entire pattern of eating rather than a single nutrient.

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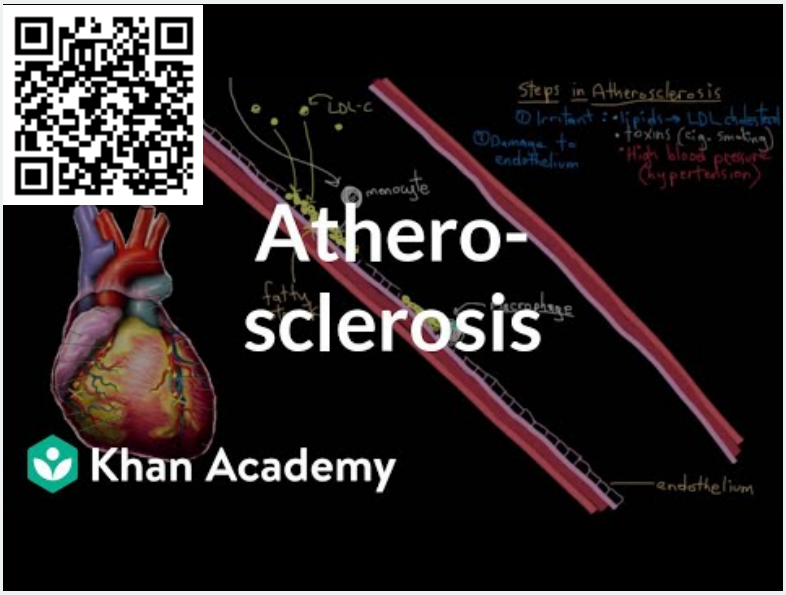
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6.6: Cardiovascular Disease

Types of Cardiovascular Disease

Cardiovascular disease refers to conditions of the heart and blood vessels. It is the leading cause of death worldwide. Most cardiovascular diseases can be prevented with lifestyle modifications, including healthy food choices, a physically active lifestyle, and not smoking. In this section, terms common to cardiovascular disease are described.[1-3]

- **Atherosclerosis.** Over time, plaque buildup thickens and hardens the arteries, causing restricted or, at times, low or no blood flow to selected areas of the body. This process is also referred to as "hardening of the arteries." Check out this video to see how atherosclerosis forms.



Video 6.6.1: Source: Khan Academy. Atherosclerosis.[4] Accessed August 4, 2023. Available at: https://www.youtube.com/watch?v=g3kDdg8r6NY

- **Coronary heart disease (coronary artery disease).** A disease of blood vessels supplying the heart muscle.
- **Heart attack (myocardial infarction)**. 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. The following video provides more details on signs, symptoms, and possible treatment for a heart attack.



Video 6.6.2: What happens during a heart attack?[5] Approximately seven million people around the world die from heart attacks every year. Cardiovascular disease, which causes heart attacks and other problems like strokes, is the world's leading killer. So, what causes a heart attack? Krishna Sudhir examines the leading causes and treatments of this deadly disease. Source: Krishna Sudhir (https://youtu.be/3_PYnWVoUzM).

- **Congestive heart failure (CHF)** is a condition in which 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. *Nutrition interventions for CHF often involve sodium and fluid restriction, topics covered in future chapters in this book.*
- **Cerebrovascular disease.** A disease of the blood vessels supplying the brain.
  - **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.
  - **Hemorrhagic stroke** occurs when a blood vessel within the brain bursts. This is most often caused by uncontrolled **hypertension** (high blood pressure). *Nutrition interventions for hypertension, such as the DASH diet, were addressed in Chapter 2 and will be covered in future chapters in this book.*
- **Peripheral arterial disease.** This is a disease of blood vessels supplying the arms and legs.
- **Deep vein thrombosis and pulmonary embolism.** These conditions involve blood clots in the leg veins, which can dislodge and move to the heart and lungs.
- **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 in which the heart valves lose 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.
- **Rheumatic heart disease.** In this heart condition, rheumatic fever, associated with streptococcal bacteria, damages the heart muscle and valves.
- **Congenital heart disease.** Attributed to birth defects, this condition results in heart structure malformations and dysfunction.

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6.6.1: Understanding Blood Cholesterol

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. 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 triacylglycerols until all that is left of their composition is cholesterol-rich remnants. The liver uses these remnants as raw materials 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 triacylglycerols from the liver to various tissues in the body. As the VLDLs travel through the circulatory system, the lipoprotein lipase strips the VLDL of triacylglycerols. As triacylglycerol 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 triacylglycerol in composition. While traveling 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 lipoproteins.
- **LDLs.** As **low-density lipoproteins** are commonly known as the “bad cholesterol," it is imperative that we understand their function in the body so we can make healthy dietary and lifestyle choices. LDLs, which carry cholesterol and other lipids from the liver to tissue throughout the body, consist of very small amounts of triacylglycerols 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 removed, and 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. Thus, LDL receptors are critical for regulating cholesterol levels. An elevated LDL cholesterol level is a primary cause of atherosclerosis.[1] **Lipoprotein a (Lp(a))** is an LDL-cholesterol-like lipoprotein that increases heart disease risk. It is considered to have a genetic component. Research is ongoing to consider possible therapies for elevated Lp(a) levels.[2]
- **HDLs. High-density lipoproteins** carry 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 and low cholesterol content (20-30%) compared with other lipoproteins. Thus, these high-density lipoproteins are commonly called “good cholesterol.”

Contrasting LDL and HDL

Heart attack and atherosclerosis are conditions often caused by cholesterol that has accumulated and thickened in the walls of arteries. HDLs and LDLs are directly connected to these life-threatening ailments. By comparing and contrasting the roles each of these lipoproteins serves in the health of heart and blood vessels, you will be able to construct and evaluate a plan of action for your personal health. Consider the following lipoprotein facts:

- **LDL/HDL composition**. LDL is approximately 25% protein and 75% cholesterol and other fats. LDL is bigger (yet lighter) and richer in cholesterol than HDL. HDL is 50% protein and 50% cholesterol and other fats. HDL is smaller, more dense, and richer in protein.
- **LDL/HDL function**. LDLs carry cholesterol into cells for normal usage, but LDLs can also deposit cholesterol into the walls of blood vessels, which can lead to harmful disease. HDLs scavenge excess cholesterol from the cells, tissues, and blood vessels and deliver these back to the liver, where they are either reused or excreted.
- **LDL/HDL and inflammation**. LDLs carry pro-inflammatory lipids that may contribute to heart disease. HDLs transport anti-inflammatory lipids that may reduce the occurrence of heart disease.
- **LDL/HDL warnings**. High LDL values warn of increased health risks for heart disease, while high HDL values indicate a reduced risk for heart disease.

- **Oxidized LDL**. LDLs become more dangerous when oxidized. **Oxidation** is defined as the loss of electrons between two substances via a chemical reaction. If an LDL oxidation occurs, the oxidized LDL is left unstable. Oxidized LDL can speed up the process of plaque formation in the arteries. It is believed to hasten the deposition of cholesterol into the arterial walls and to induce a chronic inflammatory effect throughout the body's vast network of vessels. This activity promotes atherosclerosis and significantly increases the risk of heart attack or stroke.

Testing Your Lipid Profile

Testing your lipid levels can provide the foreknowledge necessary to take action to help prevent or treat cardiovascular disease. Talk to your healthcare provider about these tests. Current guidelines recommend testing as follows:[3]

- **Age 19 or younger:** Screen at ages 9 to 11 and repeat every 5 years. If there is a family history of high blood cholesterol, heart attack, or stroke, screening may be as early as age 2.
- **Age 20 to 65:** Screen every 5 years. Men aged 45 to 65 and women ages 55 to 65 should be screened every 1 to 2 years.
- **Older than 65:** Screen yearly.
- Testing requires a blood sample to be drawn after 9 to 12 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 have stabilized.)

Blood Cholesterol Recommendations

According to the National Institutes of Health (NIH), the following total cholesterol values are used to target treatment.[4]

Desirable cholesterol numbers for adults

- Total cholesterol less than 200 mg/dL
- LDL cholesterol less than 100 mg/dL
- HDL cholesterol greater than or equal to 60 mg/dL
- Triglycerides less than 150 mg/dL

Note: Cholesterol levels are measured in milligrams (mg) of cholesterol per deciliter (dL) of blood.

For healthy total blood cholesterol, the desired range you would want to maintain is under 200 mg/dL. More specifically, for 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, whereas an LDL level above 160 milligrams per deciliter would be considered high. In contrast, a low value of HDL is a sign that a person is not benefiting from the protection the HDL can offer. Values of less than 40 milligrams per deciliter for men and 50 milligrams per deciliter for women mark a risk factor for developing heart disease. In short, elevated LDL blood lipid profiles indicate an increased risk of heart attack, whereas elevated HDL blood lipid profiles indicate a reduced risk.



Figure 6.6.1.1: A 4-ml sample of hyperlipidemic blood with lipids separated into the top fraction (sample is in an EDTA collection tube.). This is a standard EDTA (cell count) tube, as may be used to obtain a full blood count or iron studies. The tube was set upright for four hours and was not centrifuged. This sample was not analyzed; however, a similar sample showed a serum triglyceride of over 130mmol/L (over 5000mg/dl) and an LDL over 40mmol/L (over 1540mg/dl). "Hyperlipidaemia - lipid in EDTA tube" by Mark-shea is in the Public Domain.

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6.6.2: Risk Factors for Heart Disease

Risk Factors for Heart Disease

Because heart disease is the leading causes of death in the United States, it is critical to address lifestyle choices that will ultimately decrease risk factors. The 2023 Report of the American Heart Association/American College of Cardiology Joint Committee on Clinical Practice Guidelines state the following as risk factors that can be modified with lifestyle.[1] The following list is provided here in alphabetical order.

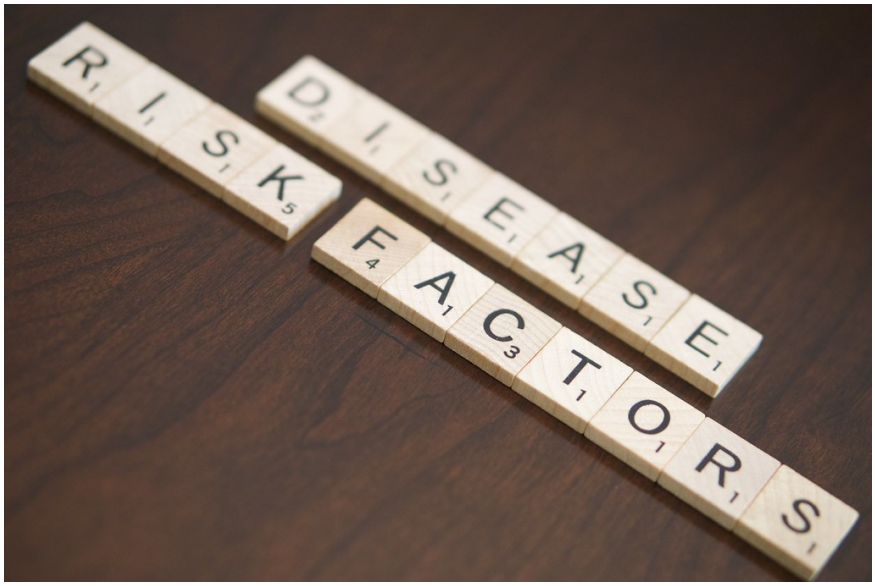


Figure 6.6.2.1: "Disease Risk Factors" by sinclair.sharon28 is licensed under CC BY 2.0.

- **Alcohol Use:** Although light to moderate alcohol use (5 to 25 grams alcohol daily) may have favorable impact on lipids, endothelial function, insulin resistance, and platelet clumping, drinking alcohol for protection from heart disease is no longer recommended. One standard drink containing 14 grams of alcohol is equivalent to one 12-ounce beer, 5 ounces of wine, or 1.5 ounces of distilled spirits, so small amounts of alcohol add up quickly. Heavy alcohol use and binge drinking increase heart disease risk. Patients with known heart disease are at risk with alcohol intake because of interactions with many prescription medications and an increase in blood pressure. There is also a genetic component to how alcohol increases heart disease risk, which cancels out some of the proposed favorable impact.[2]
- **Diabetes:** Manage your blood sugar levels, as heart disease risk doubles when you have diabetes.[3]
- **Family history of premature heart disease.** If possible, learn about your family's history and share that with your healthcare provider.
- **Food Choices:** Studies are consistent that a food pattern with a higher intake of whole grains and fiber, along with lower intake of saturated fat, sodium, refined carbohydrates, and sweetened beverages, supports heart health. These food choices are consistent with the Mediterranean diet food pattern, which helps reduce cardiovascular risk factors, including insulin resistance, diabetes, elevated lipid levels, high blood pressure, and obesity.[1]
- **Hyperlipidemia** (high blood lipids, including LDL-C and Lp(a)): Know your numbers and work with your healthcare provider to treat as necessary.
- **Hypertension:** Know your numbers. Shift your food choices to align with the DASH Diet food pattern introduced in Chapter 2, maintain a healthy weight, and keep physically active.
- **Obesity:** Balance food choices and physical activity to maintain a healthy weight.
- **Recreational substance use (marijuana):** The American Heart Association states that there are no well-documents benefits of marijuana use to prevent or treat heart disease. In fact, studies indicated the risk of heart attack, stroke, heart failure, and abnormal heart rhythms increase with marijuana use.[4]
- **Physical inactivity:** Increasing your energy expenditure by just twenty minutes of physical activity at least three times weekly 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 decreasing triacylglycerols and plaque buildup in the arteries.

Calories are burned consistently, making it easier to lose and manage weight. Circulation improves, the body is better oxygenated, and the heart and blood vessels function more efficiently.

- **Social determinants of health:** Mental health, psychosocial stressors, health literacy, sociocultural influences, financial strain, transportation, insurance status, food security, neighborhood or environmental exposures, options for regular physical activity, and social support are all factors that can impact heart health at all levels (from prevention to testing to treatment). This reflects our prior learning of the **Dimensions of Wellness** (Chapter 1). Seeking resources to handle these potential barriers is recommended.
- **Tobacco use:** Exposure to tobacco smoke increases heart disease risk. Cigarette smoke has a negative effect on endothelial function, increases atherosclerosis, and increases blood clot risk. Smokeless tobacco also increases the risk of heart disease. Assistance is available to help you stop using tobacco, including 1-800-QUIT-NOW, Texting QUITNOW to 333888 for free help in English and Spanish, The National Cancer Institute's quitSTART app, and the National Cancer Institute's Smokefree.gov website.[5]

Additional risk factors can influence your risk of heart disease, such as age, genetic factors, and other health conditions. You may not be able to change these risk factors, but knowing they exist can help you make lifestyle decisions that work in your favor. In addition, many prescription medications are effective in the treatment of heart disease, but that topic is beyond the scope of this book.

American Heart Association Life's Essential 8 Quiz

Interested in doing a self-assessment of your heart health, or just want to learn more about these risks? Visit the Life's Essential 8 checklist.

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6.7: Planning Meals with Healthy Fats in Mind

There are many ideas to consider when planning out your food choices for grocery shopping, choosing a quick snack or beverage, and ordering food at a restaurant. Consider the following tips related to shifting the **quality** (type) and **quantity** (amount) of lipids to help you meet your health goals.



Figure 6.7.1: "A cart of healthy groceries, fresh fruits and vegetables, basket, WinCo, market, Federal Way, Washington, USA" by Wonderlane is licensed under CC BY 2.0.

Ten Lipid-Friendly Shopping Tips

It is helpful to get organized with a grocery shopping list. Having a list helps you stay in your budget and minimize the random and sometimes not-so-healthy choices that catch your attention.

1. Read the nutrition fact panels on food labels to compare brands for both total fat to meet your Calorie goals and low saturated fat to meet your health goals. In some instances, it is cheaper and more delicious to make the item at home (for example, a microwavable breakfast sandwich). Also, remember that low fat does not always equal healthy, as some of these manufactured foods could be higher in sugar or salt and lack nutrient density.
2. Fill your shopping cart with fruits, vegetables, and whole grains as a means of "crowding out" the higher fat meals and snacks. Pair these foods with cheeses and meats instead of just eating the higher-fat cheeses and meats.
3. Protein-rich foods can make or break your lipid goals. Include at least two servings of fish weekly, and opt for more poultry with less beef and pork. Beans and eggs are both budget-friendly sources of protein.
4. When buying beef or pork, look for the words "lean" and "loin," as these are typically lower-fat choices. If the meat you choose is a higher fat-content cut, as seen with more white marbling throughout the meat, consider buying a smaller portion per person.
5. For a change of pace, try some "meatless" proteins, such as a chickpea or black bean burger or marinated tofu (made from soybeans).
6. Consider the fat content of the dairy you buy (milk, yogurt, frozen desserts). Match the fat content to your Calorie needs and health goals. Lower-fat dairy choices still provide good amounts of vitamins and minerals with fewer Calories from less fat. Plant-based dairy alternatives are now common in most grocery stores and are often fortified with vitamins and minerals to match traditional dairy foods. When buying regular dairy products, such as cheese, opt for higher flavor in smaller quantities (examples: Parmesan, feta, and sharp cheddar).
7. Purchase a collection of nuts and seeds to keep in your freezer that can be added to your salads, stir-fry, one-dish foods, soups, desserts, and yogurts. Freezing foods such as almonds, walnuts, and pecans extends their life, as higher-fat foods can go rancid over time.
8. Stock your fridge and pantry with herbs, spices and condiments (examples: sriracha and bold mustards) to give your food a lot of flavor for the lower-fat meals you are planning.
9. Select less processed fats and oils for meal preparation and condiments. Extra virgin olive oil (EVOO) is a lower-processed oil. Several plant-based spreads and butter/oil blends are available as an alternative to processed stick margarines. When possible,

choose liquid oils over solid fats. Oils that have a more intense flavor, such as sesame oil and peanut oil, may allow you to use less in a recipe.

10. Think about your snack food choices. Popcorn is a great whole grain option and can be purchased with lower fat ingredients (or made at home). Consider making your own cookies at home with ingredients you can control. Nuts such as almonds, walnuts, and pecans make a great snack, such as in a trail mix. When you choose a processed snack, select a brand that offers single serving portions to help you manage your intake.

Lipid Storage and Cooking Tips

Be careful of exposing fats and oils to heat, light, and oxygen, as they can be easily damaged.

- Exercise caution when heating oils. Polyunsaturated fats are the most fragile and lose beneficial properties when exposed to heat.
- For proper storage and freshness, place your oils in opaque containers and keep them refrigerated.
- Buy oils in smaller quantities. This may help remind you to consider portions and assures you can use all the product before it spoils.
- Do not use any oil that has a bitter or fishy smell or taste, as this indicates it is likely spoiled (rancid).
- Substitute unsweetened applesauce or yogurt for oil in recipes for baked goods.
- Coat pans with a mist of oil instead of using butter or shortening called for in recipes.

Tips for Lipid-Friendly Restaurant Choices

- Choose a lower-fat preparation method: baked, grilled, poached, stir-fried, or steamed instead of deep fried. Ask your server if there are alternative preparation methods or side-dish substitutes (and don't forget to tip them for their effort!).
- Opt for red sauces (marinara) over white sauces (Alfredo).
- Enjoy hearty salads with grilled chicken, shrimp, or beans.
- Try oil-based dressings over creamy dressings, or ask for the dressing on the side to control the portion.
- Select side dishes with vibrant colors (vegetables/salad, fruit) to compliment the proteins.
- View the appetizer and a la carte sections with caution. You may find some healthy options but could also get distracted by the many fried options. However, these sections of the menu may be where you find the fruits and veggies to complement your main dish, as well as a more reasonably portioned option for your entree.
- Remember to consider your beverage and dessert options, as they can add up to more than the meal!
- Share dessert!

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 strengthened. 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 adventure.

Becoming aware of the need to limit your total fat intake will facilitate your ability to make better choices. In turn, making better nutrition choices requires gaining knowledge. As you understand that your food choices impact not only 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 in the years to come.

Popular Diets and Heart Disease



Video 6.7.1: CBS News. Popular diets may increase risk of heart disease, American Heart Association says.[1] (Source: Accessed July 31, 2023. Available at: https://youtu.be/9sype80dh_Q)

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6.8: Mediterranean Diet

The Mediterranean diet, named for the regional cuisine it represents, was introduced in Section 2.6 of this book. Both the American College of Cardiology and the American Heart Association state that the Mediterranean Diet food pattern is supported for heart health. Their primary recommendations are as follows:[1]

- Focus on a food pattern that includes vegetables, fruits, legumes, nuts, whole grains, and lean protein.
- Reduce saturated fat to less than 6% of total calories, and replace those fat calories with monounsaturated and polyunsaturated fats, complex carbohydrates, and fiber.
- Avoid trans fat.
- Limit refined carbohydrates (those containing less than 25% whole grain by weight) and sugar-sweetened beverages.
- Keep daily sodium intake to less than 2300 mg, but optimally less than 1500 mg, and limit processed meats.
- Go for a food-first approach to your health. For heart health, don't depend on supplements. Dietary supplements, including omega-3 fatty acids, vitamins C, D, and E, beta-carotene, and calcium, have not been proven to reduce the risk of heart disease.



Figure 6.8.1:Digital rendering of the satellite view of the Mediterranean Sea. This globe rendering is a screenshot from the Globe Master geography game, shared by the game authors. For the globe texture, Whole world - land and oceans composite image was used, created by NASA/Goddard Space Flight Center (public domain). This file is licensed under CC BY 3.0.

Mediterranean Diet Score Quiz

1. Take the Mediterranean Diet Score Quiz. A higher score has been linked to better health outcomes related to heart health, diabetes, cancer, obesity, and mental health.
2. Give yourself **one point for every YES answer** and zero points for every NO answer.
3. For each NO answer, read the suggestions to see if there are areas of your food intake that could improve to match the recommendations. Research indicates that for every **2-point increase** (two small changes) in your score, there is a reduction in risk factors for disease.[2]

Instructions describe table elements

	Question	**YES**	**NO**	**Suggestions to Align with a Mediterranean Food Pattern**
1	Fruit: do you eat 3 fruit servings daily? One serving = 1 whole fruit or 1/2 cup fruit).			Colorful fruits from a variety of sources provide the fiber and nutrients that support heart health.
2	Vegetables: do you eat 2 servings of vegetables daily? One serving = 1 cup fresh or cooked or 2 cups fresh salad greens			Colorful vegetables from a variety of sources provide the fiber and nutrients that support heart health.

3	Do you eat vegetables, pasta, or rice dishes with a homemade sauce of garlic, onions, olive oil, and tomatoes twice or more weekly?			In the Mediterranean Diet, it is common to include homemade sauces made with garlic, onions, olive oil, and tomatoes.
4	Red meat: do you eat less than 1 serving of red meat, hamburger, sausage, or processed meats daily? One serving=3 1/2 to 5 ounces			Choose lean meats and cooking methods that require less fat (e.g., grilling, baking, and broiling). Try more white meat, fish, and plant sources of protein.
5	Chicken or turkey: do you choose chicken or turkey more often than beef, pork, hamburger, or sausage?			Ideal lean proteins are those without visible fat or skin.
6	Fish or seafood: do you eat fish or seafood at least 3 times per week? One serving=3 1/2 to 5 ounces of fish or 4 to 5 pieces of seafood.			Eat more white or oily fish. Fish rich in Omega-3 fatty acids include salmon, trout, herring, sardines, and anchovies.
7	Legumes (beans, lentils, peas): do you eat 3 servings or more each week?			Legumes provide soluble fiber, protein, and nutrients that support heart health. Legumes are a budget-friendly option.
8	Nuts: do you eat nuts at least 3 times per week? 1 serving=one ounce			Nuts, such as walnuts, almonds, and pistachios, provide healthy fats, fiber, and vitamins that support heart health.
9	Olive oil: is olive oil the main source of fat you use for cooking?			Olive oil is high in monounsaturated fatty acids.
10	Olive oil: do you have 4 tablespoons or more of olive oil each day?			Olive oil is a healthy choice for cooking and preparing foods.
11	Butter, margarine, and cream: do you eat less than 1 Tablespoon of butter, margarine, and cream daily?			Consider plant-based alternatives for the dairy additions.

12	Sugar-sweetened beverages: do you drink less than one can (12 ounces) daily?			Consider drinks that are lower in sugar. High-sugar drinks have a negative impact on diabetes and heart disease.
13	Baked goods: do you eat commercial or packaged baked goods (cookies, cake, doughnuts) less than twice per week?			Try baking snacks with healthier ingredients, or choose packaged snacks that are lower in processed sugars, fat, and sodium.
14	Wine: do you drink 3 or more glasses of wine per week? 1 serving = 5 ounces			If you don't drink alcohol, don't start for the sake of improving your diet score!

Attributions

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CHAPTER OVERVIEW

7: Proteins and Amino Acids

7.1: Introduction
7.2: Types of Protein
7.3: Sources and Requirements of Proteins
7.4: Protein Digestion and Absorption
7.5: Protein's Functions in the Body
7.6: Health Consequences of Too Little and Too Much Dietary Protein
7.7: Protein Food Choices and Sustainability
7.8: Protein Considerations for Vegetarians and Athletes

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7.1: Introduction



Learning Objectives

1. Explain the relationship between amino acids and proteins.
2. Contrast the structure of proteins, carbohydrates, and lipids.
3. Describe how amino acids are categorized and provide examples of each.
4. Calculate your Recommended Dietary Allowance for protein.
5. Evaluate a meal for the relative abundance of protein.
6. Provide strategies for choosing healthy foods that contain proteins.
7. Explain how proteins are digested and used by the human body.
8. Explain the consequences of protein excess and deficiency.
9. Choose foods that meet the protein needs of different vegetarian diets and activity levels.

Compared with carbohydrates and lipids, proteins have even more variety in both structure and function. In our bodies, the enzymes we use to digest food are proteins. Proteins also help our muscles move and transport molecules like oxygen throughout our bodies. Because proteins have so many important jobs in our bodies, obtaining enough protein in our diet is critical. Most people associate meats and dairy with protein in the diet, but many plant-based, protein-rich foods can provide sufficient protein. In this chapter, you will learn about the structure, function, digestion, and requirements for protein in the diet. Sustainability and the health consequences of protein excess and deficiency are also discussed.

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7.2: Types of Protein

Protein makes up approximately 20% 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. More than 100,000 different proteins are estimated to 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.



Figure 7.2.1: Proteins in action. Proteins allow us to move, think, process energy, and perform a vast array of functions. Source: "Baseball at Dodgers Stadium" by Rafael Amado Deras is licensed under CC BY 2.0.

What Is Protein?

There are over one hundred thousand different proteins in the human body. Different proteins are produced because twenty types of naturally occurring **amino acids** are combined in unique sequences. 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 is possible for the seven musical notes to create songs. As a result, enormous numbers of variations and potential amino acid sequences 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!

Amino Acids: The Building Blocks of Proteins

Proteins, simply put, are macromolecules composed of amino acids. **Amino acids** are commonly called protein’s building blocks (Figure 7.2.2). 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**, **a carboxylic *acid* group**—hence the name “amino acid.” Amino acids differ from one another based on which specific side chain is bonded to the carbon center.

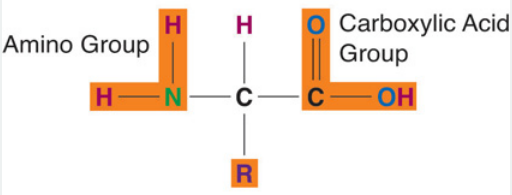


Figure 7.2.2: Amino acid structure. Amino acids contain four elements. The arrangement of elements around the carbon center is the same for all amino acids. Only the side chain (R) differs. Source: “Amino acid structure” from *An Introduction to Nutrition (v. 1.0)* is licensed under CC BY-NC-SA 3.0.

It’s All in the Side Chain (or R group)

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 different different groups based on their chemical properties (Figure 7.2.3). Two important chemical properties are affected by the type of R group on an amino acid. First, R groups can determine if an amino acid can interact with water. **Nonpolar amino acids** do not interact well with water because the R groups are bulky. These amino acids are also called **hydrophobic**, which means "water-fearing." Nonpolar amino acids include alanine (Ala), leucine (Leu), isoleucine (Ile), proline (Pro), tryptophan (Trp), valine (Val), phenylalanine (Phe), and methionine (Met). **Polar amino acids** interact well with water. They are also called **hydrophilic**, which means "water-loving". Polar amino acids include serine (Ser), threonine (Thr), cysteine (Cys), tyrosine (Tyr), asparagine (Asn), and glutamine (Gln). The acidity or charge of the amino acid is also affected by the R group. Some amino acids are **acidic** or negatively charged. These amino acids are hydrophilic and include aspartic acid (Asp) and glutamic acid (Glu). Basic amino acids are positively charged. These amino acids are also hydrophilic and include lysine (Lys), arginine (Arg), and histidine (His).

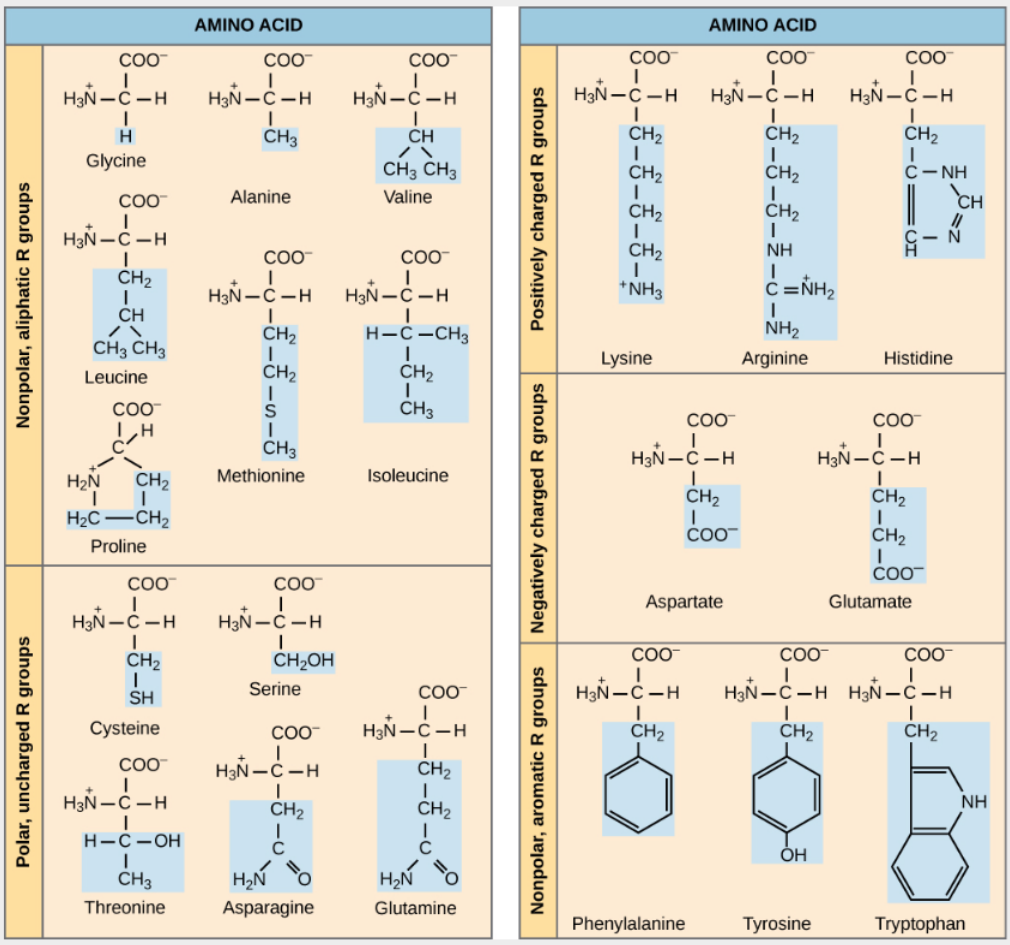


Figure 7.2.3: Amino acids are classified into four groups. These are nonpolar, polar, acidic, and basic. "Amino acids diagram" from *Biology, 2e* by OpenStax is licensed under CC BY 4.0.

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 (Table 7.2.1). Eleven are called **nonessential amino acids** because the body can synthesize them. However, nine amino acids are called **essential amino acids** because we cannot synthesize them at all or in sufficient amounts. These must be obtained from the diet. Sometimes, during infancy and growth, and in diseased states, the body cannot synthesize enough of some of the nonessential amino acids, and more of them are required in the diet. These types of amino acids are called **conditionally essential amino acids**. The nutritional value of a protein is dependent on what amino acids it contains and in what quantities.

Table 7.2.1: Essential and Nonessential Amino Acids

Essential	Nonessential
Histidine	Alanine
Isoleucine	Arginine*
Leucine	Asparagine
Lysine	Aspartic acid
Methionine	Cysteine*

*Conditionally essential

Essential	Nonessential
Phenylalanine	Glutamic acid
Threonine	Glutamine*
Tryptophan	Glycine*
Valine	Proline*
	Serine
	Tyrosine*
*Conditionally essential	

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 messenger macromolecule **ribonucleic acid** (RNA). RNA is chemically similar to DNA, but it can travel throughout the cell to carry instructions for making a specific protein (Figure 7.2.4).

The RNA that is created, or transcribed, using information from a given piece of DNA instructs the cells to gather all the necessary amino acids and add them to the growing protein chain in a very specific order. This is the second step in building a protein, and this process is referred to as **translation**. 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.

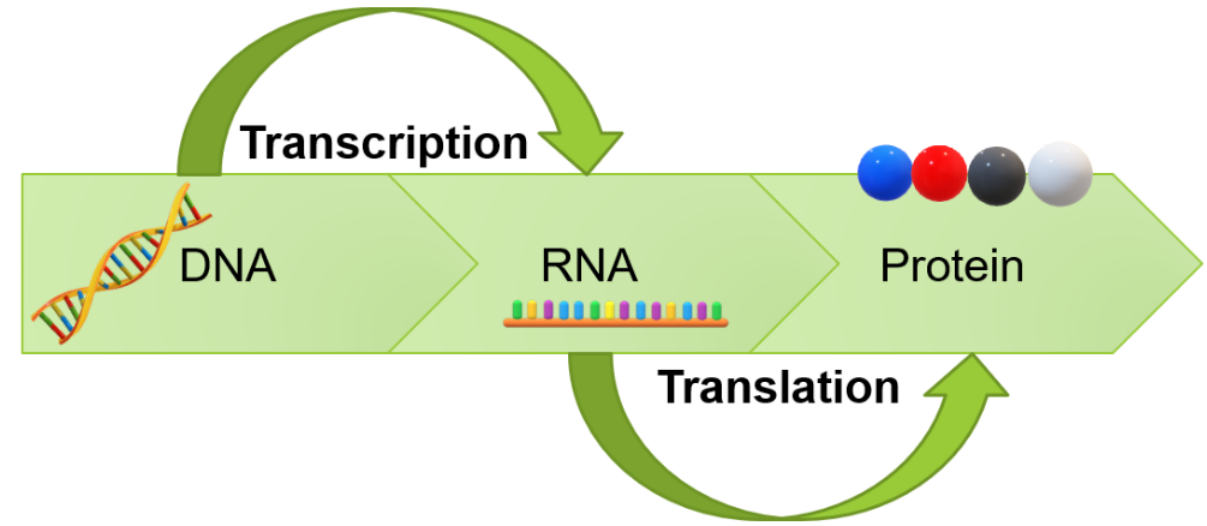


Figure 7.2.4: Building a protein involves three steps: transcription, translation, and folding. "Transcription and Translation" by Christinelmiller is licensed under CC BY-SA 4.0.

The third step in protein production involves **folding** it into its correct shape (Figure 7.2.5). Specific amino acid sequences contain all the information necessary to fold into a particular shape spontaneously. 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, which can sometimes cause disease.

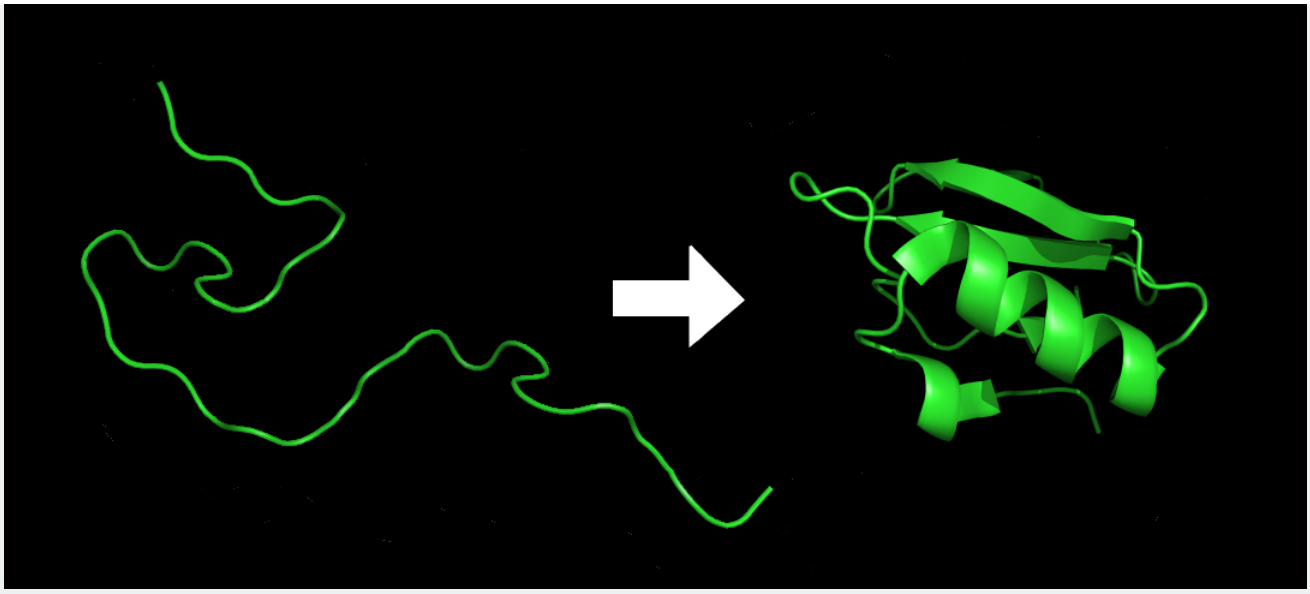


Figure 7.2.5: Protein folding. Proteins are a series of amino acids connected by peptide bonds. After transcription, the string of amino acids is folded to give a protein a specific shape. "Protein Folding" by DrKjaergaard, Public domain, via Wikimedia Commons.

Video 7.2.1: From DNA to Protein



See the process of building a protein in real time in this animation.[1] (https://youtu.be/gG7uCskUOrA?si=arCZt8gWSz4wYE01).

Attributions

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7.3: Sources and Requirements of Proteins

How Much Protein Does a Person Need in Their Diet?

Protein recommendations for adults are 0.8 grams of protein for every kilogram of body weight per day (0.36 grams protein per pound).[1] Based on these recommendations, the Recommended Daily Allowance (RDA) and AMDR for protein for different age groups are listed in Table 7.3.1.[1,2] A Tolerable Upper Intake Limit for protein has not been set, but it is recommended that you not exceed the upper end of the AMDR.

Table 7.3.1: Dietary Reference Intakes for Protein

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

Source: Institute of Medicine[1,2]

Nitrogen Balance

The appropriate amount of protein in a person's diet 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 and amino acids are are broken down, nitrogen is released. 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 per kilogram of body weight.

The IOM used data from multiple studies that determined nitrogen balance in people of different age groups to calculate the RDA for protein (Figure 7.3.2). 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 exceeds 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 because they are taking in less protein than 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.

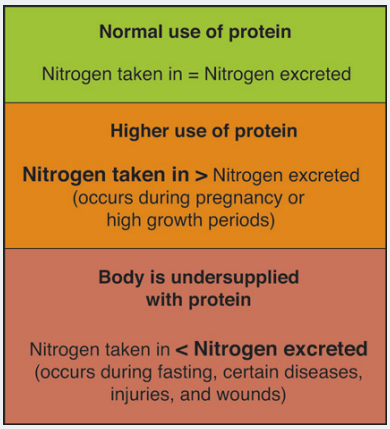


Figure 7.3.2: Nitrogen balance. There are three states of nitrogen balance. When nitrogen input and output are equal, a person is in nitrogen balance (green). If more nitrogen is taken in than excreted, a person is in positive nitrogen balance (orange). If less nitrogen is taken in than excreted, a person is in negative nitrogen balance (red). "Nitrogen Balance" from An Introduction to Nutrition (Zimmerman) is licensed under CC BY-NC-SA 3.0

Dietary Sources of Proteins



Figure 7.3.3: Protein-rich foods include meats, eggs, nuts, and beans. "Protein-rich Foods" by Smastronardo is licensed under CC BY-SA 4.0.

According to the Dietary Guidelines for Americans, the **protein food group** consists of seafood; meat, poultry, and eggs; beans, peas, and lentils; and nuts, seeds, and soy products.[3] According to the Harvard School of Public Health, “When we eat foods for protein, we also eat everything that comes alongside it: the different fats, fiber, sodium, and more. It’s this protein 'package' that’s likely to make a difference for health."[4] Simply put, different protein sources differ in their additional components, so it is necessary to pay attention to the whole nutrient “package.”

Research suggests that replacing red meats and processed meats with protein-rich foods such as beans, nuts, fish, and poultry can reduce the risk of several diseases, including heart disease and cancer.[5] 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. As we will discuss later in this chapter, individuals who choose not to eat animal protein can still obtain a complete amount of protein by varying the protein sources in the diet.

When choosing your dietary sources of protein, take note of both the other nutrients and the non-nutrients, such as calories, saturated fat, cholesterol, dyes, and preservatives, to make good selections that will benefit your health. For more comparisons of protein-rich foods, see the USDA data in Table 7.3.2.

Table 7.3.2: Sources of Dietary Protein

Food	Protein Content (g)	Saturated Fat (g)	Cholesterol (mg)	Calories
Hamburger patty, 3 ounces (95% lean)	22.0	2.3	60	139
Hamburger patty, 3 ounces (80% lean)	22.0	5.7	77	230
Top sirloin, 3 ounces	25.8	2.0	76	158
Beef chuck, 3 ounces (lean, trimmed)	22.2	1.8	51	135
Pork tenderloin, 3 ounces	22	1.0	60	120
Pork spareribs, 3 ounces	24	9	100	330
Chicken breast (roasted, 3 ounces)	25	2	70	170
Chicken thigh (roasted,3 ounces)	21	4.5	80	210
Chicken leg (roasted, 3 ounces)	23	2.5	70	180
Salmon, 3 ounces	18.8	2.1	54	175
Tilapia, 3 ounces	22.2	0.8	48	109
Halibut, 3 ounces	22.7	0.4	35	119
Shrimp, 3 ounces	17.8	0.2	166	84
Shrimp (breaded, fried, 6-8 pieces)	18.9	5.4	200	454
Tuna, 3 ounces (canned)	21.7	0.2	26	99
Kidney beans, cooked 1/2 cup	8	0.1	0	113
Sunflower seeds, 1 cup, edible portion	9.6	2.0	0	269
Peanut Butter, 2 tablespoons	7.2	3.0	0	191

Tools for Change

The USDA provides some tips and tools for choosing your dietary protein sources. Their motto is “Vary your protein routine.” 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 ensure they are getting the healthy omega-3 fatty 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 or stir-fry or use them as a topping for steamed vegetables instead 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, pay attention to the whole nutrient package and remember to select from a variety of protein sources to get all the other essential micronutrients.

Interactive 7.3.1

There are so many options for incorporating a variety of proteins into your diet. Try some new, healthy, protein-rich, plant-based foods by visiting the Harvard School of Public Health.

Protein Quality

Although a wide variety of foods contain protein, it differs in **quality**. High-quality protein contains all the essential amino acids in the proportions the human body needs. 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, whereas 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 consists of the protein collagen.



Figure 7.3.4: Complete and incomplete protein sources. Milk, cheese, eggs, meat, and soy are complete protein sources. Corn, whole wheat bread, and nuts are incomplete protein sources. Image Source: "Edamame" by UnitedSoybeanBoard is licensed under CC BY 2.0. "Milk jug with cottage cheese and eggs on burlap" by wuestenigel is licensed under CC BY 2.0. "Fresh salmon fillet on a cutting board" by Jakub Kapusnak is marked with CC0 1.0. "Raw rib-eye steak of beef with herbs and spices on cutting board" by wuestenigel is licensed under CC BY 2.0. "corn" by Muffet is licensed under CC BY 2.0. "light wheat bread" by Stacy Spensley is licensed under CC BY 2.0. "STOP & SHOP Deluxe Mixed Nuts" by s58y is licensed under CC BY 2.0.

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 do not contain methionine or tryptophan. Because grains and legumes are not deficient in the same amino acids, they can complement each other in a diet. Incomplete protein foods are called complementary foods because, when consumed in tandem, they contain all nine essential amino acids at adequate

levels. Some examples of complementary protein foods are given in Table 7.3.3. 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.

Tools for Change

Explore some ethnic grocery markets to find new high-protein foods for your diet or experiment with much cheaper plant-based protein sources. See Table 7.3.3 for complementing protein sources the vegan way.

Table 7.3.3: 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

Protein Digestibility Corrected Amino Acid Score (PDCAAS)

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 digestion, whereas plant-based proteins are not. This is because some proteins are contained in the plant's fibrous cell walls, and they pass through the digestive tract unabsorbed by the body. The **Protein Digestibility Corrected Amino Acid Score (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. 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' rankings are listed in Table 7.3.4.

Table 7.3.4: 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
Legumes	0.70
Cereals	0.59
Whole wheat	0.42
*1 is the highest rank, 0 is the lowest	

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7.4: Protein Digestion and Absorption

Digesting Proteins

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 individual amino acids, which cells absorb and use to build other proteins and a few other macromolecules, such as DNA. Let's follow the specific path that proteins take down the gastrointestinal tract and into the circulatory system. We'll use eggs, a good dietary source of protein, as our example to describe the path of proteins in digestion and absorption. One egg, whether raw, hard-boiled, scrambled, or fried, supplies about six grams of protein.



Figure 7.4.1: White, speckled (red), and brown chicken eggs. The egg is a good dietary source of protein. "Egg Colours" by Timothy Titus is licensed under CC BY-SA 3.0.)

From the Mouth to the Stomach

Unless you are eating it raw, the first step in egg digestion (or that of any other protein food) involves **chewing** or **mastication**. 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 chemical breakdown of the protein (Figure 7.4.2). The chemical breakdown of protein through the actions of enzymes is known as **proteolysis.** Stomach acids unfold proteins that retain part of their three-dimensional structure after cooking and help break down the protein aggregates formed during cooking. Pepsin, which is secreted by the cells that line the stomach, begins the proteolysis process by breaking the protein chains into smaller and smaller fragments. Egg proteins are large globular molecules whose 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 time required to break down the meal in the stomach sufficiently. Food remains in the stomach longer, making you feel full longer.

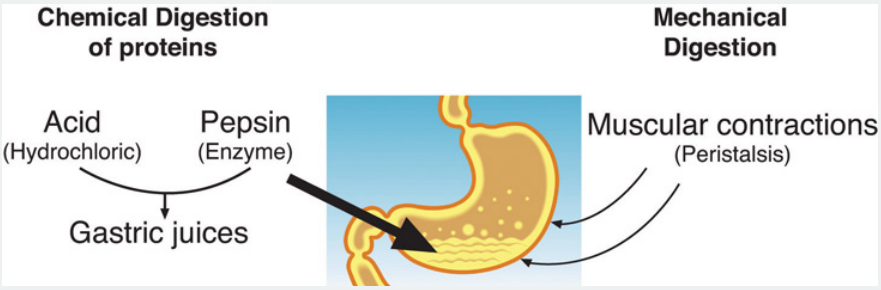


Figure 7.4.2: Overview of protein digestion in the stomach. Protein digestion requires the chemical actions of gastric juice and the mechanical actions of the stomach. "Protein digestion in the stomach" from An Introduction to Nutrition (v. 1.0) is licensed under CC BY-NC-SA 3.0.

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 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 (Figure 7.4.3). 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 breakdown 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 to synthesize other proteins, more than 90% of the protein ingested does not get broken down further than the amino acid monomers.

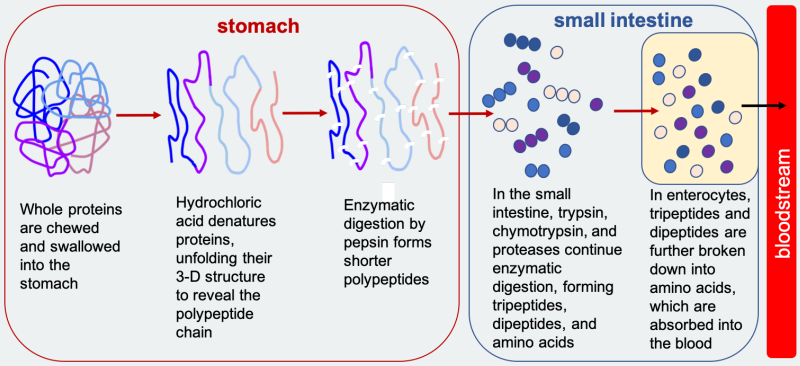


Figure 7.4.3: Protein digestion and absorption. In the stomach, proteins are digested into smaller pieces called polypeptides that contain more than one amino acid (shown as lines). In the small intestines, polypeptides are broken down into single amino acids (shown as circles), which are absorbed into the bloodstream. "Summary of protein digestion" by Alice Callahan is licensed under CC BY 4.0.

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."** Although 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 and 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; otherwise, 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 1% of total body-protein content (Figure 7.4.4). Thus, the body does not store protein as it does carbohydrates (as glycogen in the muscles and liver) or lipids (as triglycerides in adipose tissue).

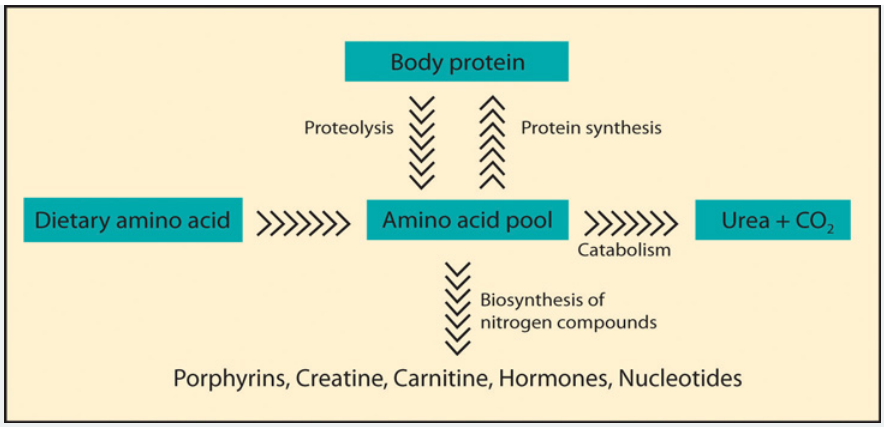


Figure 7.4.4: Amino acids in the cellular pool come from dietary protein and the destruction of cellular proteins. The amino acids in this pool must be replenished because amino acids are outsourced to make new proteins, energy, and other biological molecules. “Protein Digestion and Absorption” from An Introduction to Nutrition (v. 1.0) is licensed under CC BY-NC-SA 3.0.

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7.5: Protein's Functions in the Body

Diverse Functions of Proteins

Proteins are the "workhorses" of the body and participate in many bodily functions. They are responsible for doing most of the work in your body, from breaking down molecules during chemical digestion to providing structure. Just as proteins have diverse functions, they come in all sizes and shapes (Figure 7.5.1). For example, some hormones can be made from fewer than 10 amino acids, whereas the largest human protein has 27,000 amino acids. Each protein has a specific structure that allows it to perform a specific function in the body. Table 7.5.1 summarizes the functions of proteins with examples of proteins found in the human body.

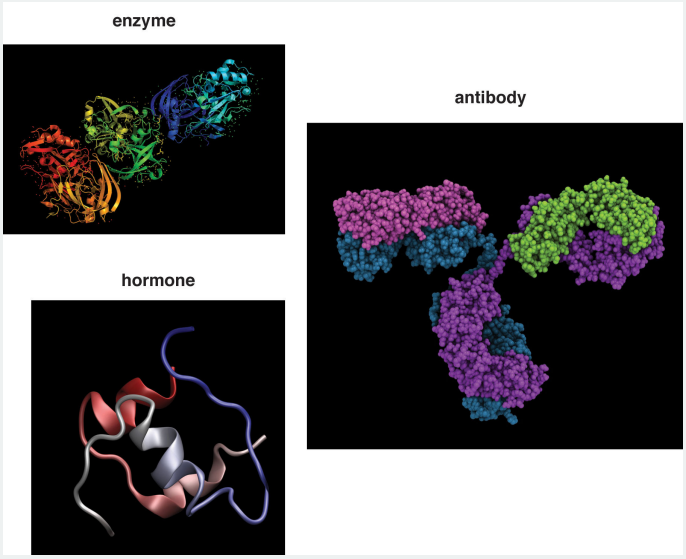


Figure 7.5.1: Diversity in proteins. Small proteins, such as hormones, have fewer amino acids than larger proteins, such as enzymes or antibodies. Source: "Enzyme, antibody, and hormone" from An Introduction to Nutrition (v. 1.0) is licensed under CC BY-NC-SA 3.0.

Table 7.5.1: Functions and Examples of Proteins in the Human Body.

Protein functions with examples of protein types

Protein Functions	Examples
Structure: Provide strength and structure to tissues.	Collagen, Elastin, Keratin
Motion: Provide movement for cells and the body.	Actin, Myosin
Enzymes: Speed up chemical reactions, including digestion and synthesis of biological molecules	Pepsin, Salivary amylase
Hormones: Chemical signals that help regulate body functions	Insulin, Glucagon
Fluid and pH Balance: Maintain the balance of pH and fluid content in cellular and body compartments.	Albumin
Transport: Move molecules in and out of cells and throughout the body.	Albumin, Hemoglobin
Immunity: Provide defense against foreign pathogens, such as viruses	Lysozyme, Antibodies

Structure

More than 100 different structural proteins have been discovered in the human body, but the most abundant by far is collagen, which makes up about 6% of total body weight. Collagen makes up 30% of bone tissue and comprises large amounts of tendons, ligaments, cartilage, skin, and muscle. **Collagen** is a strong, fibrous protein consisting mostly of glycine and proline amino acids. In its functional form, collagen comprises three protein strands that twist around each other like a rope, and then these collagen ropes overlap with others (Figure 7.5.2). 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 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 return 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. **Keratin** is another strong, fibrous protein that makes up skin, hair, and nails.

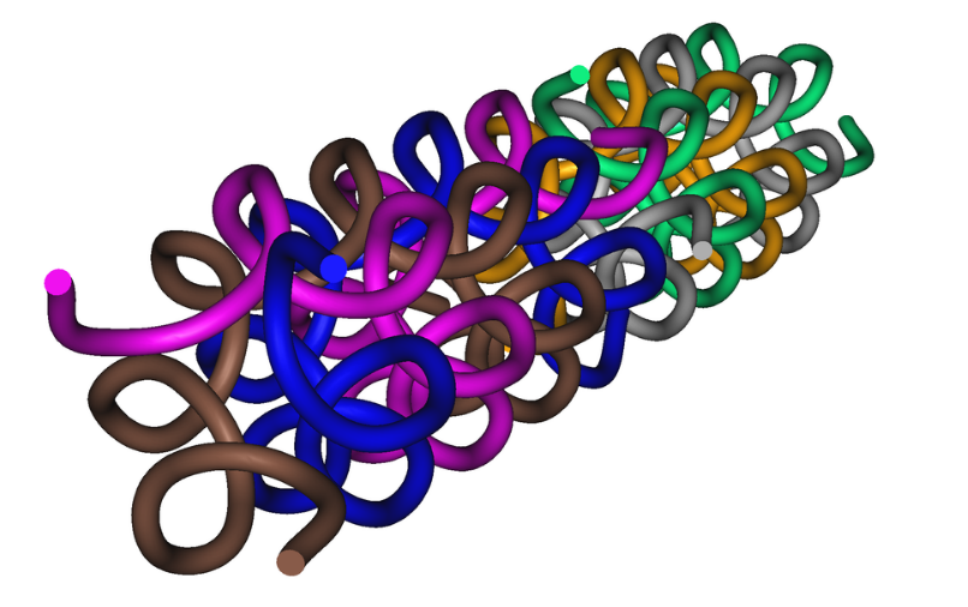


Figure 7.5.2: Collagen. Collagen is a strong protein made of intertwined chains of amino acids. Each chain is simply shown as a line in this diagram. Source: "1K6F Crystal Structure Of The Collagen Triple Helix Model Pro- Pro-Gly103 03" by Nevit Dilmen is licensed under CC BY-SA 3.0.

Motion

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. Move your fingers and watch the synchrony of your knuckle movements. To move, muscles must contract. The contractile parts of muscles are the proteins **actin** and **myosin**. When a nerve impulse stimulates these proteins, they slide across each other, causing a shortening of the muscle cell. Upon stimulation, multiple muscle cells shorten simultaneously, resulting in muscle contraction.

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. Enzymes are protein **catalysts**, which lower the amount of energy and time it takes for a specific chemical reaction to occur. 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 1000 enzyme systems. Enzymes are specific and will use only particular **substrates** or starting materials that fit into their **active site**, similar to the way a lock can be opened only with a specific key (Figure 7.5.3). Nearly every chemical reaction requires a specific enzyme. Fortunately, an enzyme can fulfill its role as a catalyst repeatedly, 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 the building of all macromolecules, including protein itself, involve enzymes.

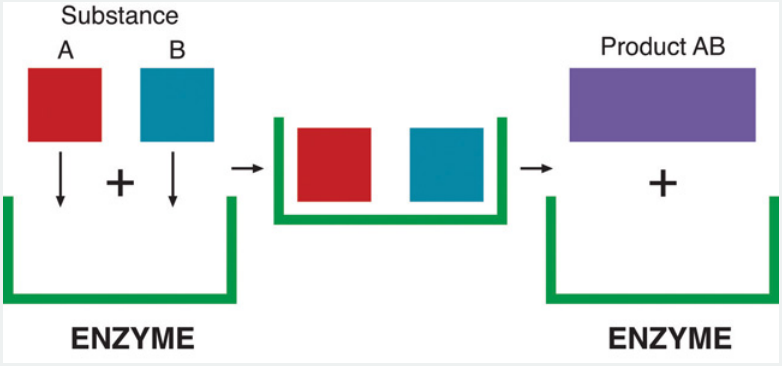


Figure 7.5.3: Enzymes catalyze chemical reactions. Enzymes are proteins that bind specific starting substances, or substrates, shown as blue and red squares (A and B). In the active site, the enzyme speeds up a chemical reaction between the substrates to form the product (AB), shown as a purple rectangle. “Enzyme activity” from An Introduction to Nutrition (v. 1.0) is licensed under CC BY-NC-SA 3.0.

Video 7.5.1: Introduction to Enzymes



Watch this video to learn more about how enzymes function.[1] Source: https://youtu.be/qgVFkRn8f10?si=idsFXYZNw_7bcP1C

Hormones

Proteins are responsible for hormone synthesis. **Hormones** are the chemical messages produced by the endocrine glands. When an endocrine gland is stimulated, it releases a hormone. The hormone is then transported in the blood to its target cell, where it communicates a message to initiate a specific reaction or cellular process. For instance, after you eat a meal, your blood glucose levels rise. In response to the increased blood glucose, the pancreas releases the hormone **insulin**. Insulin tells the body's cells that glucose is available and instructs them 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 are.

Fluid and Acid-Base Balance

Proper protein intake enables the body's basic biological processes 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 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 7.5.4). 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 extreme but rather minimized to preserve the status quo.

Protein is also essential in maintaining proper pH balance in the blood. The **pH scale** is a measure of acidity or alkalinity of a solution. A pH greater than 7 indicates a solution is **basic**, and a pH less than 7 indicates a solution is **acidic**. 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. Acidic conditions can cause proteins to change shape or misfold, which is also known as **denaturation.** When proteins are denatured, they can no longer function properly. 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 hydrogen protons (H^+) and 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 hydrogen protons.



Figure 7.5.4: Albumin. The butterfly-shaped protein, albumin, has many functions in the body including maintaining fluid and acid-base balance and transporting molecules. Cartoon representation of the molecular structure of protein registered with 1ao6 code. "PDB 1ao6 EBI" by Jawahar Swaminathan and MSD staff at the European Bioinformatics Institute is in the Public Domain.

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 many transport proteins are present in the cell membrane to get the required nutrients and molecules into the cell. Some of these proteins are channels that allow particular molecules to move in and out of cells, whereas others act as one-way taxis and require energy to function (Figure 7.5.5).

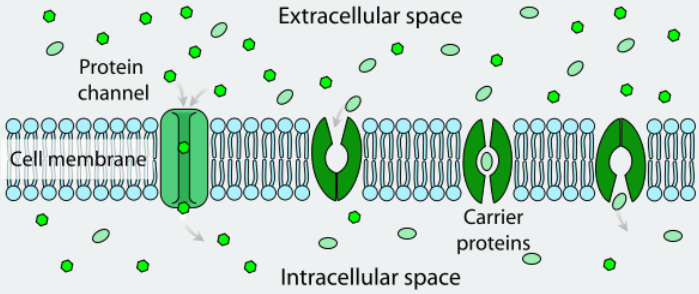


Figure 7.5.5: Cell Transport. Molecules move in and out of cells through transport proteins, which are either channels or carriers. Facilitated diffusion in cell membrane, showing ion channels (left) and carrier proteins (three on the right). "Scheme facilitated diffusion in cell membrane-en" by Lady of Hats is in the Public Domain.

Immunity

Earlier, we discussed how the strong collagen fibers in the 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.

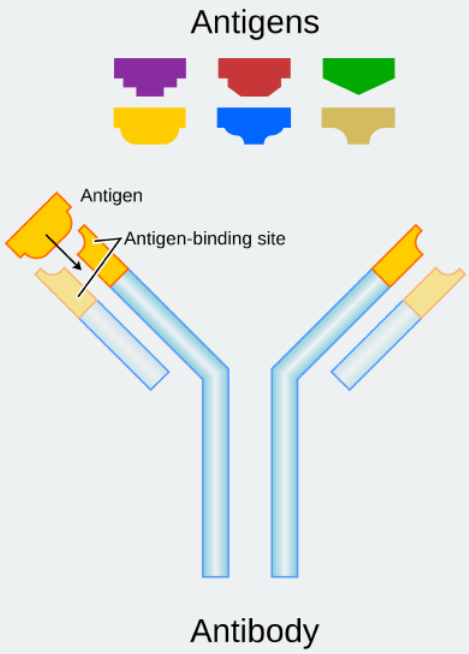


Figure 7.5.6: Antibodies. Proteins play a role in protecting the body against unwanted intruders. Antibodies surround and attack an influenza virus via "antigens" on their surface. Each antibody binds to a specific antigen; an interaction similar to a lock and key. "Schematic diagram of an antibody and antigens" by Fvasconcellos is in the Public Domain.

Energy Production

Some of the amino acids in proteins can be disassembled and used to make energy. Only about 10% of dietary proteins are catabolized daily to make cellular energy. The liver can 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.

Attributions

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References

1. Amoeba Sisters. *Enzymes* (Updated). [Video]. YouTube. https://youtu.be/qgVFkRn8f10?si=B4D8fRXrvxscWxwo. Published August 28, 2016. Accessed August 3, 2023.

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7.6: Health Consequences of Too Little and Too Much Dietary Protein

A healthy diet incorporates all nutrients in moderation, meaning that there's neither too little nor too much. As with all nutrients, having too little or too much protein can have health consequences.

The AMDR for protein for adults is between 10 and 35% of kilocalories.[1] That's a fairly wide range, encompassing typical protein intakes of many traditional human cultures.




Figure 7.6.1: Diverse human cultures have survived on different levels of dietary protein. The photo on the left shows Inuit families sharing frozen, aged walrus meat. Their traditional diet is very dependent on meat and high in both protein and fat. "Walrus meat" by Ansgar Walk is licensed under CC BY-SA 2.5. On the right is a traditional vegetarian meal in India, high in carbohydrates but still providing adequate levels of protein. "Vegetarian Curry" by GracinhaMarco Abundo is licensed under CC BY 2.0.

Protein intake below the RDA is inadequate to support the body's needs for synthesizing structural and functional proteins. However, there are some concerns that high protein intake is associated with chronic disease. However, as we'll discuss, it's not just the quantity of protein that matters but also the nutritional package it comes in.

According to a 2018 study published in the American Journal of Clinical Nutrition, most Americans get enough protein, averaging about 88 grams per day and 14 to 16% of caloric intake. The study also found that diets with protein above 35 percent of caloric intake, the upper end of the AMDR, were extremely rare.[2]

Health Consequences of Protein Deficiency

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

Kwashiorkor affects millions of children worldwide. When it was first described in 1935, more than 90% 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 occurs most commonly in children recently weaned from breastfeeding, usually because the mother had a new baby and the older child was switched to a diet of watery porridge made from low-protein grains. The child may be consuming enough calories but not enough protein.

Kwashiorkor is characterized by swelling (edema) of the feet and abdomen, poor skin health, poor growth, low muscle mass, and liver malfunction. Recall that one role of protein in the body is fluid balance. Diets extremely low in protein do not provide enough amino acids for synthesizing the protein 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, iodine, iron, and vitamin C, all contribute to the many health manifestations of this syndrome.

Children and adults with ***marasmus*** are protein deficient, but at the same time, they're also not taking in enough calories. Body weights of children with marasmus may be up to 80% less than that of a healthy child of the same age. Marasmus is a Greek word

meaning “starvation.” The syndrome affects more than 50 million children under age 5 worldwide. It is characterized by an extreme emaciated appearance, poor skin health, poor growth, and an increased risk of infection. The symptoms are acute fatigue, hunger, and diarrhea.



Figure 7.6.2: Health consequences of protein deficiency. The photo on the left shows a child suffering from ***kwashiorkor*** *(note the swollen belly) in the late 1960s in a Nigerian relief camp during the Nigerian-Biafran War.* “Child with kwashiorkor” by Centers for Disease Control and Prevention is in the Public Domain. *The photo on the right shows an Indian child suffering from* ***marasmus****.* “Child with marasmus” by Centers for Disease Control and Prevention is in the Public Domain

Kwashiorkor and marasmus often coexist as a combined syndrome termed marasmic kwashiorkor. Children with the combined syndrome have variable amounts of edema and the characterizations and symptoms of marasmus. Although organ system function is compromised by undernutrition, the ultimate cause of death is usually infection. Undernutrition is intricately linked with suppression of the immune system at multiple levels, so undernourished children commonly die from severe diarrhea and/or pneumonia resulting from bacterial or viral infection. According to the United Nations Children’s Fund (UNICEF), nearly half of all deaths of children under age five are related to malnutrition.[3] That translates to about 3 million child deaths each year.

While severe protein deficiency is rare in the US, several groups are at risk of low protein intake. A 2018 study found that 23% of US adolescent girls (aged 14 to 18 years old) and 11% of adolescent boys were consuming below the RDA for protein, which may compromise their growth and development.[2] This is thought to be related to the growing independence in food choices and the high prevalence of dieting in this group.

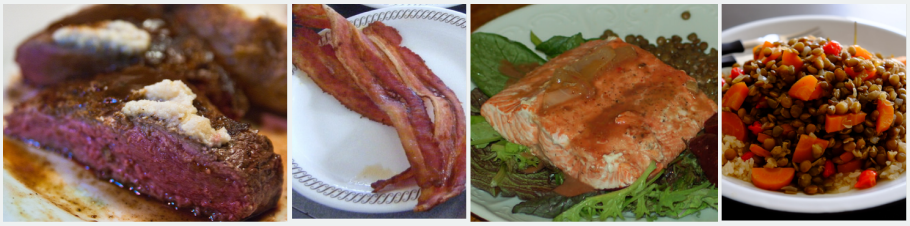
Low protein intake is also a concern for the elderly in the U.S. The same 2018 study found that among those 71 years and older, 19% of women and 13% of men consume less protein than the RDA.[2] This is a particular concern in this age group, as loss of muscle accelerates with aging, leading to greater frailty, loss of balance, and greater risk of falls. Some researchers argue that older adults actually need more protein than recommended by the RDA to maintain muscle mass and function.[4]

Health Consequences of Too Much Protein in the Diet

When the Food and Nutrition Board of the Institute of Medicine wrote the DRI for macronutrients, published in 2005, they concluded that there wasn’t enough evidence to establish an Upper Limit for protein. The high end of the AMDR, 35% of kilocalories for protein, was set to allow the total diet to be well-balanced with carbohydrates and fat.[1] Higher levels of protein intake haven’t been well-studied, but over the years, there have been many concerns with high-protein diets. However, current evidence indicates it’s large amounts of animal protein (particularly from red meat or processed meats) that can be problematic, not high amounts of protein per se.[5]

For example, **a diet containing lots of steak, bacon, and sausage would be high in protein, but it also might be high in saturated fat, cholesterol, salt, and nitrates.** Eating more red meat and processed red meat is linked to an increased risk of heart disease, stroke, and cancer (especially colorectal, stomach, pancreatic, prostate, and breast cancers). This link doesn’t seem to be caused by the protein but rather by the nutritional package that it comes in. In addition, the link to cancer may be related to the carcinogens that can form when meat is cooked at high temperatures, particularly when it’s charred by grilling.[5]

On the other hand, **studies show that when protein comes from lean meat and plant sources, the risk of chronic diseases may be reduced.** For example, a 2015 study found that frequent consumption of red meat in adolescence was associated with a higher risk of breast cancer later in life, whereas consuming poultry, fish, legumes, and nuts instead lowered the risk.[6] Other studies have shown that higher protein diets can reduce the risk of heart disease, provided the protein comes from healthier sources.



4 oz. sirloin steak
- 33 g protein
- 4.6 g saturated fat
- 4.9 g monounsaturated fat
- 0.4 g polyunsaturated fat
- 66 mg sodium
- 0 g fiber

3 slices bacon
- 12 g protein
- 4 g saturated fat
- 5 g monounsat fat
- 2 g polyunsat fat
- 581 mg sodium
- 0 g fiber

4 oz. salmon
- 30 g protein
- 1.1 g saturated fat
- 2.1 g monounsat fat
- 1.5 g polyunsat fat
- 104 mg sodium
- 0 g fiber

1 cup lentils
- 18 g protein
- 0.1 g saturated fat
- 0.1 g monounsat fat
- 0.3 g polyunsat fat
- 4 mg sodium
- 15 g fiber

Figure 7.6.3 . Compare several different “protein packages.” The steak and bacon provide protein but also large amounts of saturated fat and sodium. Salmon provides as much protein as the steak but with less saturated fat and more polyunsaturated fats. Lentils are a good source of protein, are low in fat, and are a great source of fiber. “Sirloin steak Outback Steakhouse March 13, 20112 ” by Steven Depolo is licensed under CC BY 2.0; “bacon” by Bradley Gordon is licensed under CC BY 2.0; “Wild Salmon Dinner” by Ketzirah Lesser and Art Drau is licensed under CC BY-SA 2.0; “ASCF1853 (lentils)” by Lucas Falcao is licensed under CC BY-NC-ND 2.0.

Several other concerns about high protein diets haven’t turned out to be problematic after all:

- **Osteoporosis** – High protein diets were once thought to increase the risk of osteoporosis because researchers noticed that urinary calcium excretion increases when people consume high amounts of protein. However, a 2017 systematic review and meta-analysis from the National Osteoporosis Foundation found that this is not a concern, and some studies even show that higher protein intake is associated with greater bone mineral density.[7]
- **Kidney function** – Another concern was that high protein diets would strain the kidneys because of the increased need to filter and excrete nitrogen. A 2018 meta-analysis concluded that this is not a concern. However, people with chronic kidney disease should avoid high protein diets and maintain protein intake around the RDA of 0.8 g/kg, a lower intake than many Americans consume.[8] A 2009 study tested a very low protein diet of 0.6 g/kg protein per day in people with chronic kidney disease and found that it did not prevent the development of kidney failure but did increase the risk of death, underscoring the importance of adequate protein even in people with kidney disease.[9]

From all of this research, there’s little evidence that a high protein diet is inherently harmful, so long as the protein doesn’t come packaged with a lot of saturated fat and red meat consumption is limited. Still, there’s little research directly testing the health effects of very high protein diets, including those achieved using protein supplements of purified protein, so it’s probably wise to keep protein balanced with the other macronutrients, focusing on whole foods from all the food groups.

Attributions:

- Lindshield, B. L. *Kansas State University Human Nutrition (FNDH 400) Flexbook.* goo.gl/vOAnR, CC BY-NC-SA 4.0
- “Diseases Involving Proteins," section 6.5 from the book *An Introduction to Nutrition* (v. 1.0), CC BY-NC-SA 3.0

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7.7: Protein Food Choices and Sustainability

Before it gets to our plates, every food has a story. Maybe it started as a seed, planted in soil and nurtured to maturity with water, sunlight, and fertilizer. Or maybe it came from an animal, one raised for its meat or to produce milk or eggs. We choose foods based on their taste, price, convenience, and nutritional value, but it's also worth considering their backstories. This is particularly true for protein foods, because animal protein production generally consumes more resources and is less sustainable than plant protein sources. Agricultural animals need care, feeding, housing, disposal of their waste, and sometimes medication use throughout their lives. It's worth considering where our protein comes from and how our choices affect the planet, especially given that most of us consume more protein than we need.

Animal Agriculture and Resource Use

The World Resources Institute, a global research non-profit organization with a mission "to move human society to live in ways that protect Earth's environment," has compiled data on the environmental impact of protein choices. In the graphic below, you'll see that in terms of greenhouse gas emissions, plant-based protein sources have a much lower impact than animal protein sources. Most plant proteins, with the exception of nuts, are also less expensive. Beef, lamb, and goat meat come at a higher cost to the environment and your wallet.

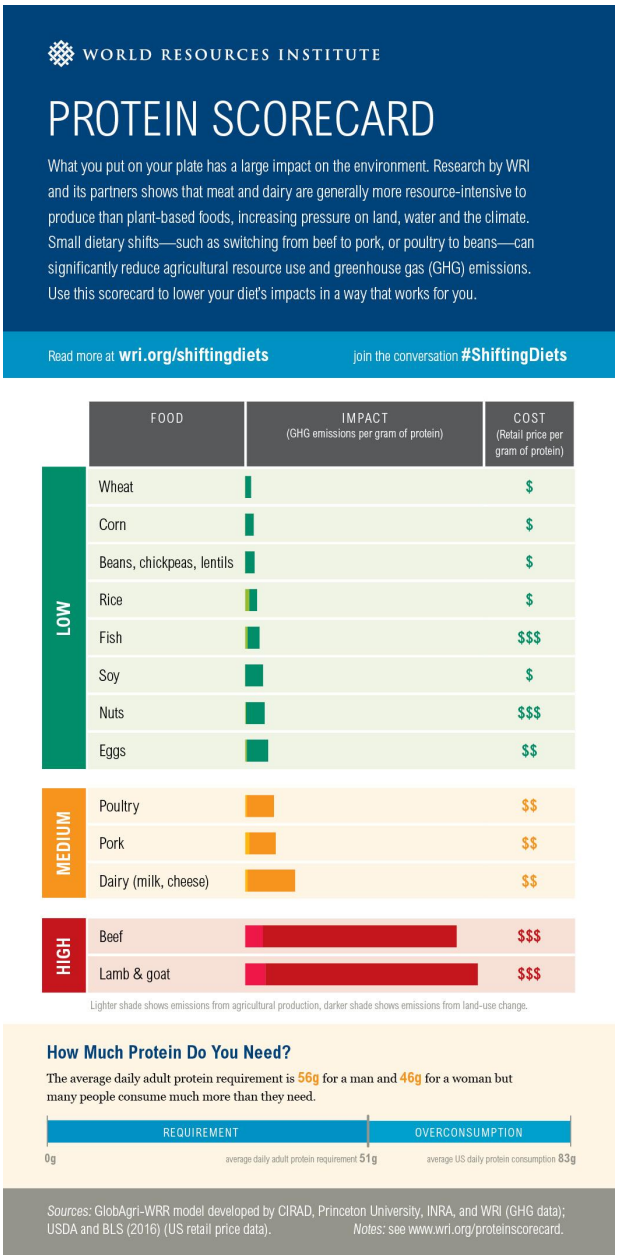


Figure 7.7.1: Protein Scorecard from the World Resources Institute. "Protein Scorecard" from the World Resources Institute is licensed under CC BY 4.0

Beef is among the most resource-intensive sources of protein. A 2014 study published in the Proceedings of the National Academy of Sciences calculated that beef production uses 28 times more land and 11 times more irrigation water than the average of dairy, poultry, pork, and egg production.[1]

It's important to point out that animal agriculture does fill some important roles that plants can't. For example, much of the world's pasture land is on steep terrain that wouldn't work well for growing food crops. And animal waste—in the form of manure—is an important fertilizer, including in organic food systems. So, animal agriculture and eating meat aren't inherently bad for the environment, but it would probably be good for the planet if we ate less meat, as shown in the graphic below.

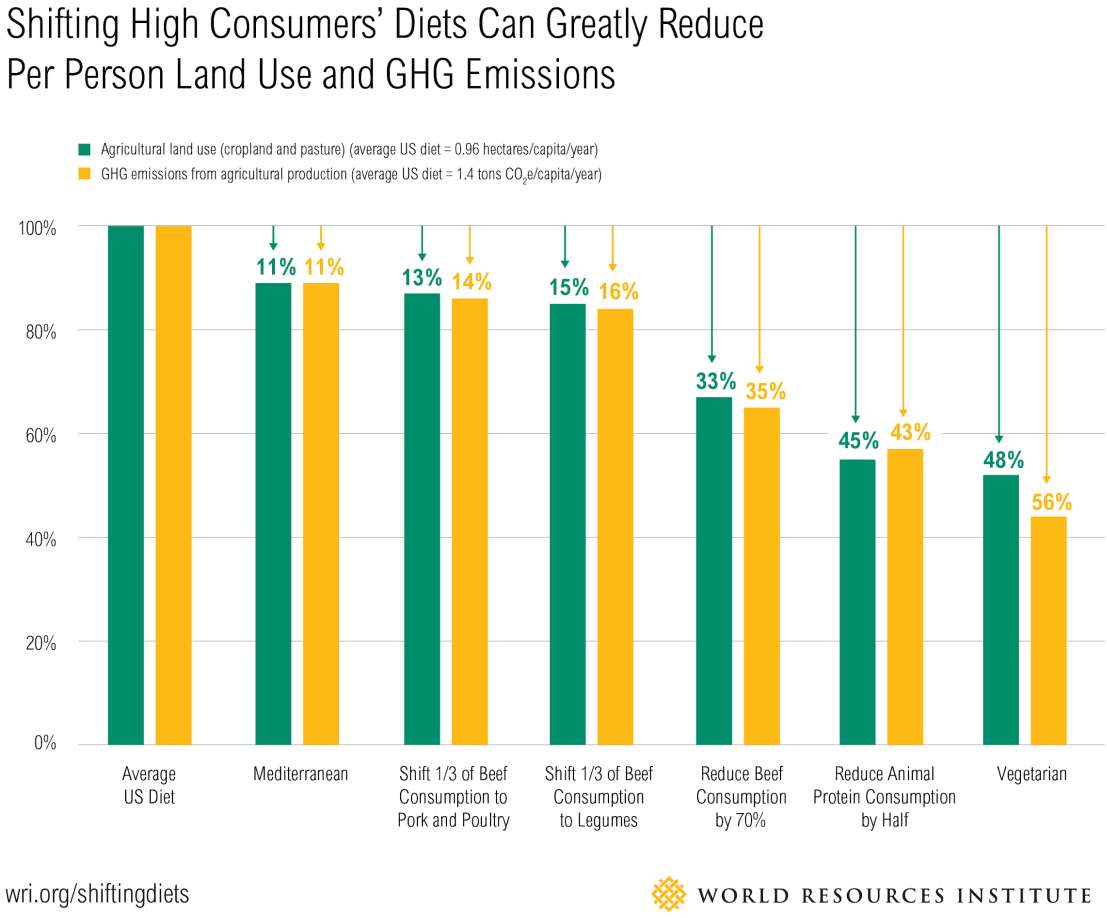


Figure 7.7.2: Shifting high consumers' diets can greatly reduce per-person land use and GHG emissions. Source: "Shifting High Consumers' Diets Can Greatly Reduce Per Person Land Use and GHG Emissions" from the World Resources Institute is licensed under CC BY 4.0

In terms of environmental impact, making small shifts can have a significant impact. Consider the following approaches[2]:

- If you eat meat every day, try adding a "meatless Monday" into your week and experiment with some vegetarian recipes. Once you've adapted to that, try adding another day.
- Replace some of your beef meals with dishes featuring chicken, pork, eggs, fish, or legumes.
- Eat smaller portions of meat and add more plant foods to your plate. For example, if you enjoy spaghetti and meat sauce, try using less meat in your sauce and adding in vegetables like mushrooms, bell peppers, and carrots. Your meal will be more nutrient-dense and maybe even more flavorful.

When you consider that moderate shifts like these would not only be good for the planet but also good for our health, then they don't seem like much of a sacrifice. A 2016 study published in the Proceedings of the National Academy of Sciences concluded that just following standard dietary guidelines (which recommend a variety of protein sources, including plant proteins, and eating more whole grains, fruits and vegetables) could reduce mortality by 6 to 10% *and* cut greenhouse gas emissions by 29 to 70%.[3,4]

This page from the World Resources Institute provides more information: Sustainable Diets: What You Need to Know in 12 Charts, by Janet Ranganathan and Richard Waite, April 20, 2016.

Animal Agriculture and Antibiotic Resistance

One of the biggest current threats to public health is ***antibiotic resistance***. Antibiotics are life-saving drugs, but over time, bacteria can develop resistance to them. This means that the antibiotics no longer work to kill the bacteria causing infections, leaving people

with more severe illnesses and fewer treatment options, which often necessitates different antibiotics that have more side effects. There are now some bacterial infections for which we have no working antibiotics to treat them. According to the CDC, at least 2.8 million people are infected with antibiotic-resistant bacteria each year in the US, and these infections are thought to kill at least 35,000 people annually.[5] Addressing this problem will require us to be more careful about how we use antibiotics, invest in research to develop new ones, and develop other ways of preventing bacterial disease, such as new vaccines.

Antibiotics are important to both human and animal medicine. When we're sick with a bacterial illness, we may need antibiotics to treat it, and the same is true of animals, whether they're raised for agriculture or form part of our families as our pets. The problem is that the more we use antibiotics, the more chances bacteria have to evolve resistance to them, and the less effective those antibiotics become.

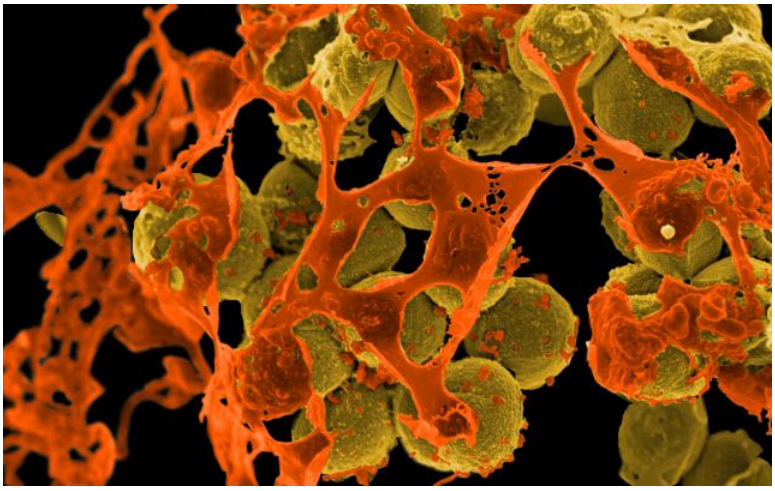


Figure 7.7.3. Scanning electron micrograph of methicillin-resistant Staphylococcus aureus (MRSA, brown) surrounded by cellular debris. MRSA resists treatment with many antibiotics. "Methicillin-Resistant Staphylococcus aureus (MRSA) Bacteria" by NIAID is licensed under CC BY 2.0



Video 7.7.1: "Watch antibiotic resistance evolve" by Science News.[6] YouTube (September 8, 2016), 2:02 minutes. Watch how quickly bacteria can develop resistance to antibiotics when they're exposed to them and how resistant populations can grow.

The overuse of antibiotics in both human medicine and animal agriculture has contributed to the growth of antibiotic-resistant bacteria. For example, taking antibiotics for an illness caused by a virus, such as the common cold or the flu, won't make you better and just gives harmful bacteria chances to evolve resistance. Historically, antibiotics were also routinely given to food-production animals to make them fatter, and that allowed for the growth of antibiotic resistance. As of 2017, the FDA ruled that antibiotics can no longer be used for growth promotion in animal agriculture, a significant step in reducing the overuse of these drugs that are important to both humans and animals. Data released by the FDA in December 2018 show that antibiotic sales for farm animals have dropped significantly after this rule change.[7]

Antibiotics can still be used to treat sick farm animals or stop the spread of disease, which is important for animal health and welfare. However, antibiotics can also be used to *prevent* disease in animals that might become sick. Many experts argue that allowing antibiotics to be used for disease prevention leaves a loophole for the continued use of large amounts of antibiotics, especially in farming systems where animals are crowded and diseases can spread quickly. The World Health Organization has called for this practice to stop, reserving antibiotics only for use in animals that are already sick, not healthy animals. The goal is to reduce antibiotic use to reduce the development of antibiotic-resistant bacteria so that we can still use these valuable medicines to treat sick animals and humans when needed.

When antibiotics are used in food animals, bacteria can evolve resistance to those antibiotics. Those antibiotics-resistant bacteria can then be present in your meat, and they can spread in the environment from animal feces, including into the water used to irrigate fruits and vegetables. Humans exposed to these bacteria by handling or eating contaminated food can then become sick with infections that are resistant to antibiotic treatment, as shown in this infographic from the CDC:

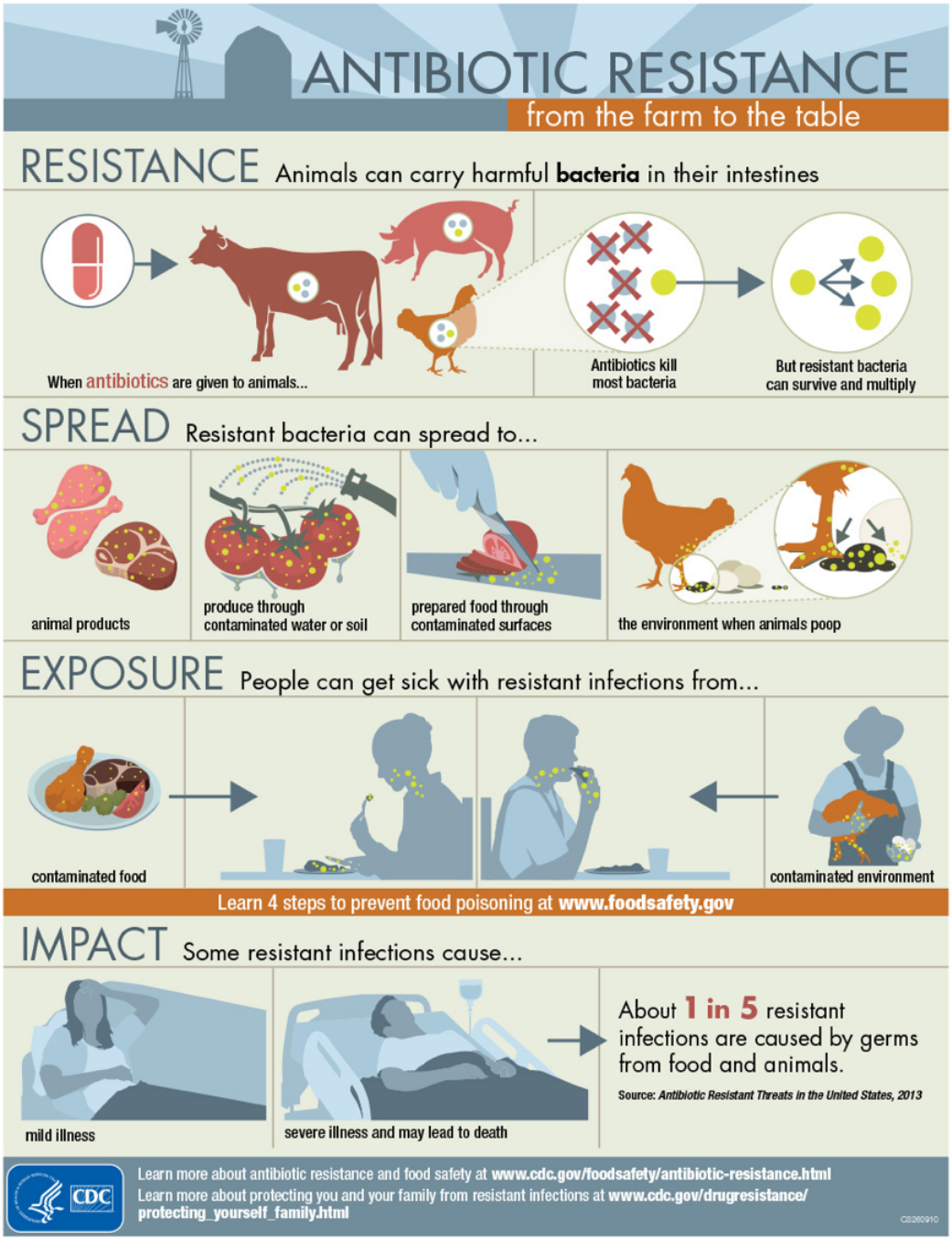


Figure 7.7.4: Antibiotic resistance from farm to table. "Antibiotic Resistance Infographic" by the Centers for Disease Control and Prevention is in the Public Domain.



Video 7.7.2**:** How industrial farming techniques can breed superbugs by PBS NewsHour.[8] YouTube (August 9, 2017), 9:37 minutes. This video explains the link between agriculture and development of antibiotic-resistant bacteria.

What can you do to prevent yourself and your family from getting sick with antibiotic-resistant infections? The CDC offers these tips, most of which are useful for reducing your risk of foodborne illness in general:

- **Take antibiotics only when needed**.
- **Follow simple food safety tips:**
  - **COOK.** Use a food thermometer to ensure that foods are cooked to a safe internal temperature: 145°F for whole beef, pork, lamb, and veal (allowing the meat to rest for 3 minutes before carving or consuming), 160°F for ground meats, and 165°F for all poultry, including ground chicken and turkey.
  - **CLEAN.** Wash your hands after touching raw meat, poultry, and seafood. Also, wash your work surfaces, cutting boards, utensils, and grill before and after cooking.
  - **CHILL.** Keep your refrigerator below 40°F and refrigerate foods within 2 hours of cooking (1 hour during the summer heat).
  - **SEPARATE.** Germs from raw meat, poultry, seafood, and eggs can spread to produce and ready-to-eat foods unless you keep them separate. Use different cutting boards to prepare raw meats and any food that will be eaten without cooking.
- **Wash your hands** after contact with poop, animals, or animal environments.
- Report suspected outbreaks of illness from food to your local health department.
- **Review CDC's Traveler's Health recommendations** when preparing to travel to a foreign country.

When you shop for meat, milk, and eggs, you'll see lots of different types of labels making claims about how the animals were raised. Does any of this matter when it comes to antibiotic resistance? First, it's important to note that no animal products—however they're labeled—should ever contain antibiotics, as required by federal law. If an animal is treated with an antibiotic, it can't be sold for slaughter or have its milk sold until the antibiotic is cleared from its system. However, if animals were routinely treated with antibiotics earlier in their lives, those practices could have contributed to the growing problem of antibiotic resistance.

Choosing products that are certified organic ensures that antibiotics weren't used in their production, because organic farms are not allowed to use antibiotics even for sick animals.[9] (If an animal becomes sick and requires antibiotic treatment to get better, its milk, meat, or eggs can no longer be sold as organic, but it can be sold to a conventional farm.)

You'll also see labels stating "raised without antibiotics," and buying these products helps to support farmers and companies that have committed to reducing antibiotic use in their production systems, even if they aren't certified organic. However, ***antibiotic-resistant bacteria*** (bacteria that have evolved resistance to antibiotics so could cause hard-to-treat infections) may still be present in products that are labeled certified organic or "raised without antibiotics" (the bacteria could have spread to these animals from somewhere else), so follow the food safety rules no matter where your meat comes from.[10]



Figure 7.7.5. These eggs are certified organic, so you can be confident that antibiotics weren't used in their production. The sausage is not organic, but it is made from chickens raised without antibiotics, so its production is unlikely to have contributed to the problem of antibiotic resistance. Source: "Egg and sausage labels" by Alice Callahan is licensed under CC BY 4.0

More and more companies are also recognizing how the overuse of antibiotics can contribute to antibiotic resistance, and they're changing their practices. In December 2018, a large consortium of companies and industry groups, including Walmart, McDonald's, and Tyson Foods, committed to a framework for more responsible use of antibiotics.[11]

Additional reading:

How Drug-Resistant Bacteria Travel from the Farm to Your Table (https://www.scientificamerican.com/article/how-drug-resistant-bacteria-travel-from-the-farm-to-your-table/)

By Melinda Wenner Moyer, Scientific American, 12/1/16

Issues of Fish Sustainability

Fish are a good source of protein and healthful polyunsaturated fats, as well as micronutrients like vitamin D, so they're often mentioned as a good choice. From the charts at the top of this page, you can also see that fish are a relatively sustainable source of protein in terms of using little land and freshwater and producing low levels of greenhouse gases.

However, the oceans have been overfished, and global supplies of wild-caught fish are dwindling. Aquaculture, or fish farming, has also created new environmental challenges. Both issues are being solved with good management, like careful limits on wild-caught fishing and new management practices for fish farming. You can encourage these practices by purchasing sustainably sourced seafood.[12] The Monterey Bay Aquarium Seafood Watch program can help with this. You can download their app to help with buying decisions in the grocery store and find more information on their website: Monterey Bay Aquarium Seafood Watch.

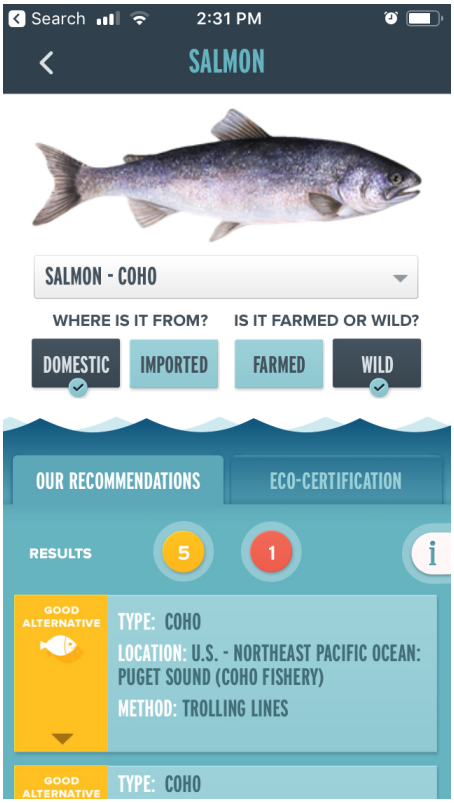


Figure 7.7.1: A screenshot from the Seafood Watch app, showing how it can help you make sense of seafood buying options. Source: "Screenshot from Seafood Watch app" by Alice Callahan licensed under CC BY 4.0



VIDEO: Can the Oceans Keep Up with the Hunt? by the Monterey Bay Aquarium.[13] YouTube (July 20, 2012), 15:57 minutes. Learn more about problems with fish sustainability and solutions by watching this video.

You may have also heard that fish can contain dangerous levels of mercury. This is true of some large species of fish that are higher up the food chain because they accumulate mercury from their smaller prey. Then we get a big dose when we eat them. **Fish that have dangerous levels of mercury include king mackerel, marlin, orange roughy, shark, swordfish, tilefish, and bigeye tuna**. Pregnant women and growing children, in particular, should avoid these types of fish because mercury can interfere with brain development. However, the same groups also stand to benefit from healthful omega-3 fatty acids, like DHA and EPA, which are

helpful for brain development. Thus, it's good for pregnant women and children to eat fish, so long as they avoid the ones with high levels of mercury. Most common types of fish have lower levels of mercury and can be eaten at least once per week, if not two or three times per week.[14] Learn more at this FDA page: Eating Fish: What Pregnant Women and Parents Should Know.

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7.8: Protein Considerations for Vegetarians and Athletes

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 and athletes.

Vegetarian Diets

A vegetarian eating pattern focuses on their primary food choices from vegetation, more specifically plants including fruits, vegetables, whole grains, legumes, nuts and seeds. Choosing to eat a vegetarian diet requires that you focus on nutrient-dense choices to assure adequate nutrition. A diet that just skips eating meat without the focus on plants is missing the point of choosing a vegetarian diet. A person may choose to follow a vegetarian lifestyle for many reasons. Thinking of the Dimensions of Wellness, a person may choose to be vegetarian for cultural or religious reasons, for health benefits, to save on the food budget, for ethical concerns regarding the treatment of animals, or to reduce the environmental impact of animal production.[1] In the United Stated, approximately five percent of the population report following a vegetarian diet.[2]

Categories of vegetarian diets

Vegan. This strict form of vegetarianism includes all plants but nothing of animal origin, including beef, pork, poultry, fish, egg, dairy, honey, or anything containing animal byproducts. A vegan lifestyle also includes not using animal-sourced products or ingredients, including clothing, cosmetics, household cleaners, or products on which animal testing occurred. Following a vegan diet and getting the recommended protein intake can be a challenge because plant-based protein sources are less digestible than animal-based protein sources. However, with good planning, including a variety of complementary protein discussed earlier in this chapter, a vegan can consume adequate protein to meet their structural and functional protein needs. It is also a challenge to consume adequate Vitamin B12, Vitamin D, zinc, calcium and iron on a vegan diet, but a careful selection of whole food choices, along with fortified foods, makes nutrient adequacy possible. A variety of plant-based micronutrient food sources will be addressed in the Vitamin and Mineral chapter.

Lacto-ovo vegetarian. This type of vegetarian diet includes all plants, dairy, and eggs, but all other animal products are avoided. With this pattern of eating, it is easier to meet protein needs due to the higher quality protein in dairy and eggs. Complementary proteins are still encouraged. Calcium and Vitamin B12 are easier to obtain on a lacto-ovo vegetarian diet, although iron and zinc intake may still be challenging. Related vegetarian diets include lacto-vegetarian, including plants and dairy, but no eggs, and ovo-vegetarian diet, including plants and eggs, but no dairy.

Flexitarian. This food pattern is considered "plant-forward" or "plant-based," meaning the food focus is on plant sources of food with limited animal products. It is not technically a vegetarian diet as this person may occasionally include meat in their meals. The Meatless Monday campaign discussed earlier in this chapter is an example of how a person can learn to shift their diet to include the benefits of eating more plants without the full commitment of a vegetarian diet. The Mediterranean Diet and DASH Diet, highlighted earlier in an earlier chapter, are two well-researched food patterns that promote a higher intake of plant foods.



Figure 7.8.1:A vegetarian meal that includes a variety of foods is not only a healthy choice, but can also look fabulous and taste delicious! Source: "Vegetarian Meal" by D-Stanley is licensed under CC BY 2.0.

Protein Content in Plant-Based Foods

The following table provides the protein content in grams per serving.[3] To put these grams in the context of food, one egg provides 6 grams of protein, one cup cow's milk provides 8 grams of protein, and one ounce of chicken provides 9 grams protein. To put these grams in the context of a typical day's intake, an average adult needs 46-56 grams per day based on the Dietary Reference Intakes.[4]

Table with food choices and their protein content in grams.

Food	Protein Content in Grams
Nuts and Seeds: 1-ounce portion	
Hemp Seeds	9.5
Pumpkin Seeds	8.5
Chia Seeds, Flax Seeds, Almonds	6
Sunflower Seeds	5
Cashews, Walnuts	4.5
Legumes: 1/2 cup cooked	
Tofu (soybean)	10
Black Beans, Edamame, Lentils, Kidney Beans, Peas	8
Peanut Butter: 2 Tablespoons	8
Pinto Beans, Chickpeas	7
Non-Dairy Milks: 1 cup	
Soy Milk, Pea Protein Milk	8
Almond Milk, Oat Milk	1
Whole Grains	
Quinoa: 1/2 cup cooked	4.5
Whole Wheat Bread (one 1 ounce slice)	3.6
Oats, Brown Rice: 1/2 cup cooked	3
Vegetables	
Broccoli: 1 cup raw	2.5
Sweet Potato: 1 medium size, cooked	2
Spinach: 3 cups raw	2

Tools for Change

Looking for more vegetarian resources, such as myths about vegetarian diets, feeding kids a vegetarian diet, and the Dietary Guidelines for American's Healthy Vegetarian Dietary Patterns? Check out the USDA Vegetarian Nutrition.[5]

Athletes

Muscle tissue is rich in protein composition and has a very high turnover rate. During exercise, muscle tissue is broken down, and some 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 stresses muscle tissue so that afterward, the body adapts by building bigger, stronger, and healthier muscle tissue. The American College of Sports Medicine,

in joint efforts with the Academy of Nutrition and Dietetics and the Dietitians of Canada, has issued a position statement on nutrition for athletic performance.[6]

- Protein goals for athletic performance range from 1.2 to 2.0 grams per kilogram of body weight per day compared with 0.8 grams per kilogram of body weight for a non-athlete. The range allows for variations in kcalorie intake and level of training. An athlete who weighs 170 pounds should take in 93 to 155 grams of protein per day ((170 ÷ 2.2) × 1.2 and (170 ÷ 2.2) × 2.0). On a 3,000-kilocalorie diet, that amount is between 12 and 21 percent of total kilocalories and within the Acceptable Macronutrient Distribution Range (AMDR) of 10 to 35%.
- Protein intake is most important one to two hours after resistance training when protein uptake is at its peak. However, this higher protein uptake continues for 24 hours after the training. Therefore, a protein-containing post-exercise recovery snack is suggested if the next meal is not in sight.
- Protein intake spaced over the day rather than in one meal is recommended for amino acid uptake.
- High-quality proteins are suggested to supply all the essential amino acids needed to build proteins. Dairy proteins, such as milk and yogurt, may offer advantages related to a higher leucine content. Leucine, along with isoleucine and valine, is a branched-chain amino acid. These essential branched-chain amino acids are well absorbed by the body, a benefit for protein synthesis.[7]
- Ideally, protein should be eaten in the context of a meal or snack to support overall athletic performance. A snack of a banana with a glass of milk, a bowl of whole-grain cereal with soy milk, or a container of yogurt with fresh berries provides not only protein but also carbohydrates for energy and micronutrients needed for metabolism.
- Exercise performance does not appear to differ between vegetarian and non-vegetarian recreational athletes, although the long-term health benefits of a vegetarian food pattern are supported.[8]

Protein supplements are made from compounds such as whey or soy and amino acids that either come in powder, bar, shake, or capsule form. We have noted that the protein requirements for most people, even those who are active, are not high. Is taking protein supplements ever justified, then? Few protein or 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 continue to use protein or amino supplements. Here are some pros and cons of opting for a supplement instead of food for your fuel:

Pros: Supplements provide an advantage when sports nutrition goals need to be met but time is limited because of tournament plans or access to food is limited, such as during travel. Supplements may also assist the athlete in meeting their high kcalorie goals when their needs exceed their hunger level.

Cons: The cost of sports supplements is greater than getting similar nutrients from whole foods. Supplements provide a single nutrient, but whole foods provide multiple nutrients. Some supplements may promote stomach discomfort if the athlete has not trained with the supplement to assure tolerance during the activity, but other supplements may fill in the nutrition gaps for an athlete with a sensitive stomach. Supplements can provide excess kcalories, leading to unwanted weight gain. The biggest caution with supplement use, however, is that there is a higher contamination risk because of the lack of regulation in the supplement industry. The Food and Drug Administration is not required to check supplements for potency, purity, or safety before a supplement goes on the market. Therefore, buyer beware!



Figure 7.8.2: Make a shake and use your personal nutrition goals as a guide when filling up the blender. Source: "A gift of a new blender brings slushies!" by waitscm is licensed under CC BY 2.0.

Before you buy any supplement, do your homework. Read the label, be selective, and don't use them as meal replacements but rather as occasional exercise-recovery snacks. Some protein bars have a high amount of carbohydrates from added sugars and are

not actually the best source of 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. Supermarket and health food store shelves offer numerous high-protein shake mixes. Although the carbohydrate count is lower now in some of these products than a few years ago, they still contain added fats and sugars. If you want more nutritional bang for your buck, make your own shakes from whole foods. Use your personal nutrition goals 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.

Note

The US Olympic Committee is a great resource for sports performance nutrition.



Figure 7.8.3:Many Olympic athletes have adopted a vegetarian diet which, when implemented effectively, supports a very active and athletic lifestyle. Source: "Kristin Armstrong (USA) in London 2012 Olympic women's time trial" by EEPaul is licensed under CC BY 2.0.

Attributions

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CHAPTER OVERVIEW

8: Vitamins and Minerals

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8.1: Introduction



Learning Objectives

1. Compare and contrast the definitions of vitamins and minerals.
2. Distinguish between trace minerals and major minerals.
3. Distinguish between fat-soluble and water-soluble vitamins.
4. List food sources for each vitamin and mineral.
5. Evaluate a meal for the relative presence of vitamins and minerals.
6. Describe the sources and benefits of dietary antioxidants and phytochemicals.
7. Describe the role of vitamins and minerals in maintaining vision.
8. Describe the role of vitamins and minerals in maintaining bone health.
9. Describe the role of vitamins and minerals in metabolism and blood function.
10. Explain the risks and benefits of dietary supplements.

Vitamins and minerals are considered micronutrients, as they are needed in smaller amounts than macronutrients (carbohydrates, proteins, and fats). Although micronutrients do not provide energy themselves, many of them support energy production in the body. Micronutrient deficiencies can manifest as fatigue and many other signs and symptoms. In this chapter, we will review the categories of micronutrients introduced in Chapter 1.3 and focus on food sources of these necessary nutrients that can support our goal of optimal wellness, including preventing deficiencies. In addition to learning about the traditional vitamin categories, we will also explore how our health can be improved with nutrients categorized as **antioxidants** and another grouping of substances in food with health value called **phytochemicals**. This chapter will also provide the latest evidence-based review of dietary supplements.

Cover Art: "#vitamix 34 (1 kale leaf, handful of spinach & grapes, 1/2 banana, 1 clementine, 1/4 star fruit, 1 carrot, a sliver of ginger, 1/4 cucumber, scoop of protein powder & OJ)" by GlitterandFrills is licensed under CC BY 2.0.

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8.2: Classification of Vitamins and Minerals

Vitamins and minerals are needed only in small quantities in the body, but their role is essential to overall health and proper functioning of all body systems. And while many vitamins and minerals work together to perform various functions in the body, they are classified based on their independent characteristics. These characteristics impact not only how we obtain them in our diets but also how we absorb them and store them, as well as how we experience deficiencies or toxicities when too little or too much is consumed. After we review the classifications for vitamins and minerals, we will examine key vitamins and minerals based on their similar functions to highlight further the importance of how these micronutrients work together.



Figure 8.2.1: "Green shop" by ja_ma is in the Public Domain.

Vitamins

The name “vitamin” comes from Casimir Funk, who in 1912 thought “vital amines,” similar to amino acids, were responsible for preventing what we know now as vitamin deficiencies. He coined the term “vitamines” to describe these organic substances that were recognized as essential for life. Yet, unlike the other organic nutrients we know as carbohydrates, protein, and fat, they do not provide energy to the body. Eventually, when scientists discovered that these compounds were not amines, the "e" was dropped to form the term “vitamins.”[1]

Classification of Vitamins

Vitamins are essential, non-caloric, organic micronutrients. There is energy contained in the chemical bonds of vitamin molecules, but our bodies don’t make the enzymes to break these bonds and release their energy; instead, vitamins serve other essential functions in the body. Vitamins are traditionally categorized into two groups: **water-soluble or fat-soluble**. Whether vitamins are water-soluble or fat-soluble can affect their functions and sites of action. For example, water-soluble vitamins often act in the cytosol of cells, which is the fluid inside of cells, or in extracellular fluids such as blood. Fat-soluble vitamins play roles such as protecting cell membranes from free radical damage or acting within the cell’s nucleus to influence gene expression.

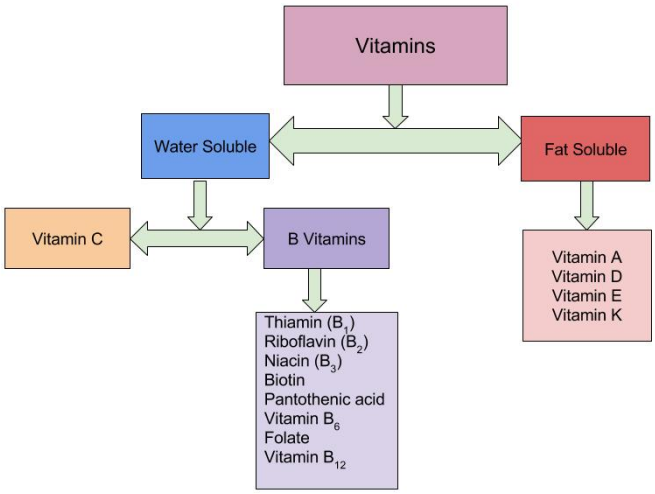


Figure 8.2.2: "Classification of vitamins as water-soluble or fat-soluble" by Allison Calabrese is licensed under CC BY 4.0.

One major difference between water-soluble and fat-soluble vitamins is how they are absorbed in the body. Water-soluble vitamins are absorbed directly from the small intestine into the bloodstream. Fat-soluble vitamins are first incorporated into chylomicrons, along with fatty acids, and transported through the lymphatic system to the bloodstream and then on to the liver. The amount that gets absorbed, or ***bioavailability,*** of these vitamins is dependent on the food composition of the diet. Because fat-soluble vitamins are absorbed along with dietary fat, if a meal is very low in fat, the absorption of the fat-soluble vitamins in that meal may be impaired.

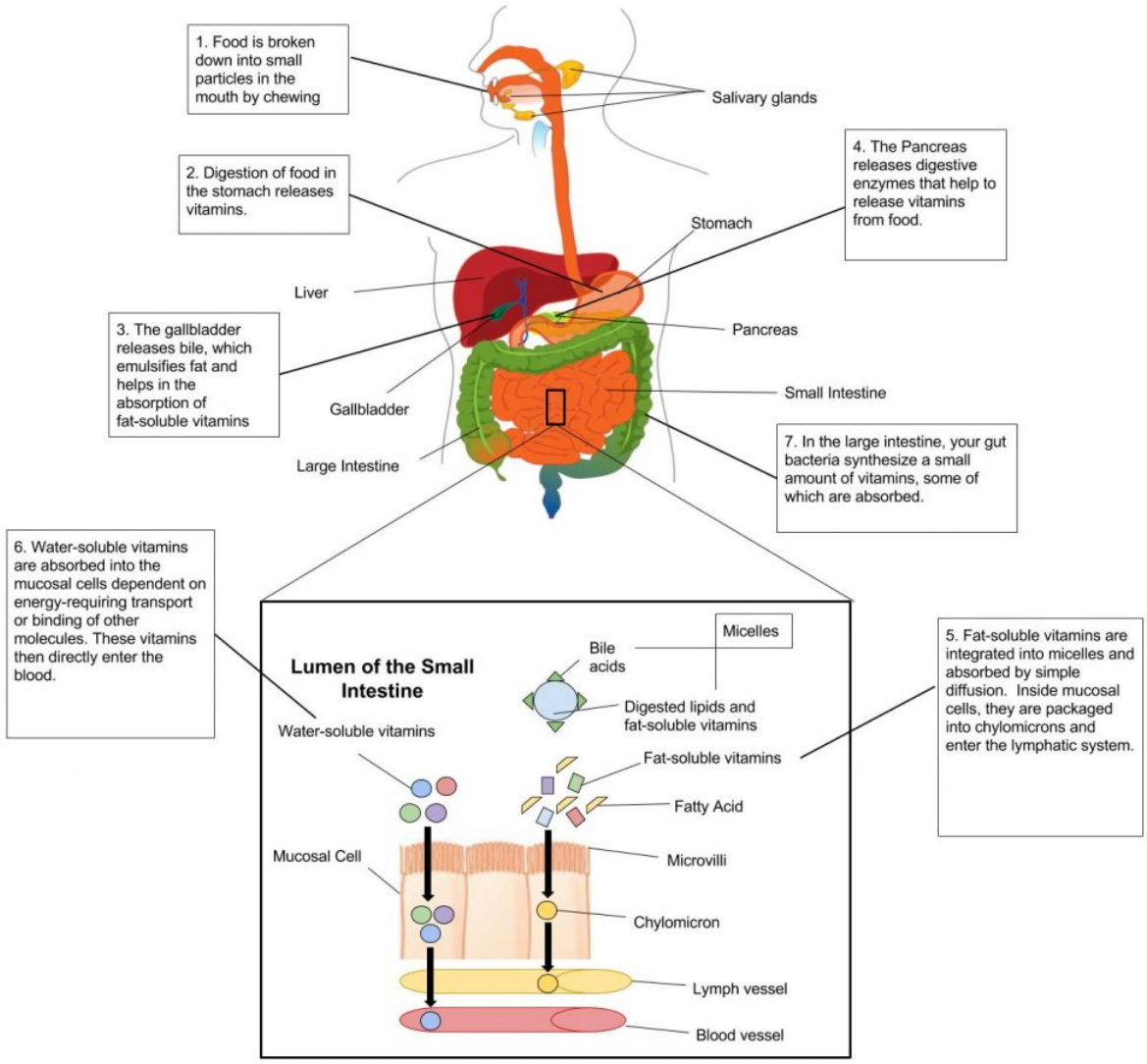


Figure 8.2.3: "Absorption of fat-soluble and water-soluble vitamins" by Allison Calabrese is licensed under CC BY 4.0.

Fat-soluble and water-soluble vitamins also differ in how they are stored in the body. **The fat-soluble vitamins—vitamins A, D, E, and K—can be stored in the liver and the fatty tissues of the body.** The ability to store these vitamins allows the body to draw on these stores when dietary intake is low, so deficiencies of fat-soluble vitamins may take months to develop as the body stores become depleted. On the flip side, the body's storage capacity for fat-soluble vitamins increases the risk for toxicity. While toxic levels are typically only achieved through vitamin supplements, if large quantities of fat-soluble vitamins are consumed, either through foods or supplements, vitamin levels can build up in the liver and fatty tissues, leading to symptoms of toxicity.

There is limited storage capacity in the body for water-soluble vitamins, thus making it important to consume these vitamins on a daily basis. Deficiency of water-soluble vitamins is more common than fat-soluble vitamin deficiency because of this lack of storage. That also means toxicity of water-soluble vitamins is rare. Because of their solubility in water, intake of these vitamins in amounts above what is needed by the body can, to some extent, be excreted in the urine, leading to a lower risk of toxicity. Like fat-soluble vitamins, a toxic intake of water-soluble vitamins is not common through food sources but is most frequently seen due to supplement use.

Table showing characteristics of fat-soluble and water-soluble vitamins

Characteristics of Fat-Soluble Vitamins	Characteristics of Water-Soluble Vitamins

Protect cell membranes from free radical damage; act within the cell's nucleus to influence gene expression	Act in the cytosol of cells or in extracellular fluids such as blood
Absorbed into lymph with fats from foods	Absorbed directly into blood
Large storage capacity in fatty tissues	Little to no storage capacity
Do not need to be consumed daily to prevent deficiency (may take months to develop)	Need to be consumed regularly to prevent deficiency
Toxicity is more likely	Toxicity is rare

Table 8.2.1. "Characteristics of fat-soluble and water-soluble vitamins" by Heather Leonard is licensed under CC BY 4.0.

Minerals

Similarly to vitamins, minerals are micronutrients that 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. ***Minerals*** are inorganic elements in their simplest form, originating from the Earth. They can't be broken down or used as an energy source, but like vitamins, they serve essential functions based on their individual characteristics. Living organisms can't make minerals, so the minerals our bodies need must come from the diet. Plants obtain minerals from the soil they grow in. Humans obtain minerals from eating plants, as well as indirectly from eating animal products. This is because the animal consumed minerals in the plants it ate. We also get minerals from the water we drink. The mineral content of soil and water varies from place to place, so the mineral composition of foods and water differs based on geographic location.[2]



Figure 8.2.4: "Green-leafed Vegetables" by Kenan Kitchen is licensed under the standard Unsplash License.

Classification of Minerals

Minerals are classified as either major minerals or trace minerals, depending on the amount needed in the body. **Major minerals** are those that are required in the diet in amounts larger than 100 milligrams each day. These include sodium, potassium, chloride, calcium, phosphorus, magnesium, and sulfur. These major minerals can be found in many foods. While deficiencies are possible with minerals, consuming a varied diet significantly improves an individual's ability to meet their nutrient needs. We'll discuss the concern of both deficiencies and toxicities of specific minerals later in this unit.

Trace minerals are classified as minerals required in the diet in smaller amounts, specifically 100 milligrams or less per day. These include iron, copper, zinc, selenium, iodine, chromium, fluoride, manganese, and molybdenum. Although trace minerals are needed in smaller amounts, a deficiency of a trace mineral can be just as detrimental to your health as a major mineral deficiency.

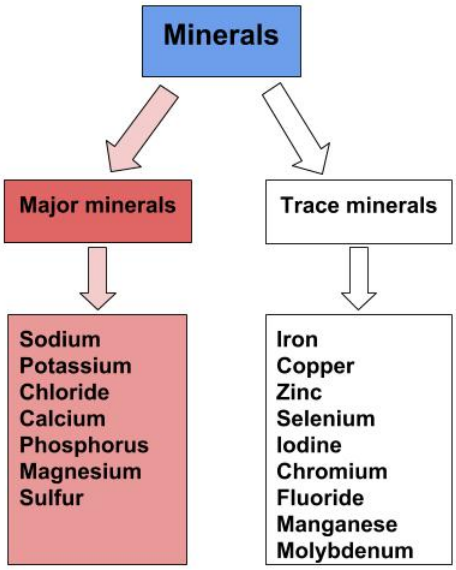


Figure 8.2.5: "The classification of minerals as either major minerals or trace minerals" by Allison Calabrese is licensed under CC BY 4.0.

Minerals are water-soluble and do not require enzymatic digestion. They are absorbed directly into the bloodstream, although some minerals need the assistance of transport proteins for absorption and transport in blood.

Minerals are not as efficiently absorbed as most vitamins, and many factors influence their bioavailability:

- Minerals are generally better absorbed from animal-based foods. Plant-based foods often contain compounds that can bind to minerals and inhibit their absorption. Two of these compounds are oxalates and phytates. This should not discourage a person from eating plant-based foods, but rather that person needs to be mindful of this difference when planning their food choices.
- In most cases, if dietary intake of a particular mineral increases, absorption will decrease.
- Some minerals influence the absorption of others. For instance, excess zinc in the diet can impair iron and copper absorption. Conversely, certain vitamins enhance mineral absorption. For example, vitamin C boosts iron absorption, and vitamin D boosts calcium and magnesium absorption.
- As is the case with vitamins, mineral absorption can be impaired by certain gastrointestinal disorders and other diseases, such as Crohn's disease and kidney disease, as well as the aging process. Thus, people with malabsorption conditions and the elderly are at higher risk for mineral deficiencies.

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8.3: Sources of Vitamins and Minerals

Vitamins and Minerals in Food

Eating a variety of foods from all food groups is the best way to ensure you are getting all the micronutrients needed for a healthy diet. Each food group lends itself to specific vitamins and minerals. Keep in mind that whole foods, such as fresh fruits and vegetables, whole grains, lean meats, and low-fat dairy foods, contain more vitamins and minerals than their processed counterparts. A whole baked potato contains more vitamin C, folate, and potassium than a potato that has been cut, soaked, and fried to make a french fry.

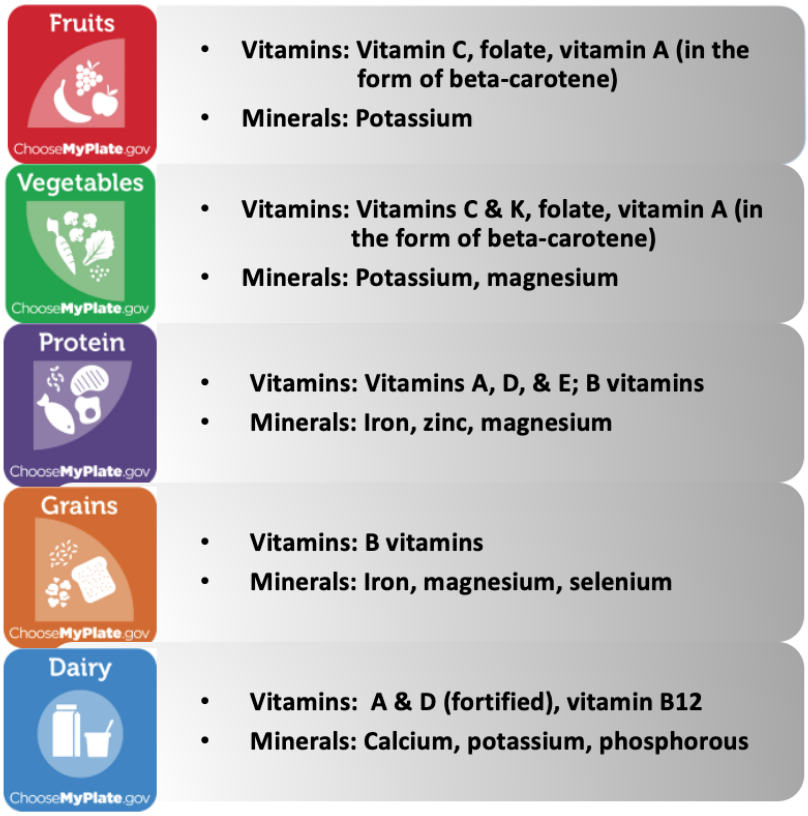


Figure 8.3.1: "Common vitamins and minerals found in each food group" by Heather Leonard is licensed under CC BY 4.0 using MyPlate graphics from the USDA Center for Nutrition Policy and Promotion, which are in the Public Domain.

Effects of Processing on Nutrient Content in Foods

The nutrient content of foods is typically highest when foods are allowed to ripen on the plant, allowing the plant to fully develop the nutrients and **phytochemicals**, plant compounds with added health value, it needs to sustain life. Harvesting plants in the peak state of ripeness helps to ensure maximum vitamin and mineral content, and consuming freshly picked or harvested produce usually maximizes how much of those nutrients make it into our bodies to be put to use by cells. However, not all foods can be consumed immediately after harvest. How foods are handled, processed, stored, and prepared can impact how much of that peak nutrient level remains in the food.[1]

Processing of food is an important step in our food supply. Harvesting and transporting foods to communities increases access to a variety of foods. Preservation techniques like canning and freezing extend the shelf life of foods and increase their availability outside of their peak harvest season. In fact, because fresh foods can deteriorate rapidly, food processing techniques may result in better nutrient retention over time when compared to fresh items. However, some vitamins are more stable than others, and the amount retained depends on the specific vitamin and the processing technique. Water-soluble vitamins are the most susceptible to the effects of processing, though other nutrients can also be impacted.

Table displays the method of processing food, effects on nutrient retention, and then how to minimize nutrient loss.

Method of Processing	Effect on Nutrient Retention	How to Minimize Nutrient Loss

Air exposure and time	Enzymes present in foods and exposure to air can destroy nutrients because as soon as the food is harvested, it begins to slowly decompose.	Purchase fresh items in quantities that can be used as soon as possible. Cut up foods only when ready to use. Buy local produce to cut back on transport time and air exposure.
Temperature	Cooking helps kill bacteria, makes foods more appealing, and, in some situations, improves the bioavailability of nutrients. However, high temperatures for prolonged amounts of time can destroy some vitamins.	Use fast cooking methods like stir-frying, steaming, and microwaving.
Water	Minerals and water-soluble vitamins can leach into the water.	Don't soak produce in water. Limit the amount of water used to cook foods, such as steaming vegetables rather than boiling them. Use cooking water in food preparation, such as when adding water in a recipe.
Canning	High temperatures may be used, which can destroy water-soluble vitamins, but commercial techniques usually use rapid heating, which helps to reduce nutrient loss.	Choose a variety of canned goods without added sugars or sodium to maximize nutrient density.
Freezing	Freezing does not reduce nutrient content, but blanching foods before freezing may slightly reduce levels of water-soluble vitamins.	To maximize nutrient density, choose a variety of frozen goods without added sugars, syrups, or sauces.
Refining of grains	Many B vitamins, minerals, phytochemicals, and fiber are lost when whole grains are refined.	Choose whole grains whenever possible.

Table 8.3.1. "The effects of processing on nutrient retention" by Heather Leonard is licensed under CC BY 4.0.

There is a notable exception to the effects of processing described here. In contrast to most vitamins, the bioavailability of beta-carotene, a precursor to vitamin A, and similar phytochemicals called carotenoids is actually increased by the cooking process. This is because cooking, chopping, and homogenizing releases carotenoids from the plant matrix. Thus, cooked carrots can be a better source of vitamin A than raw carrots. However, overcooking transforms some of the carotenoids into inactive products, and in general it is best to chop and lightly steam vegetables containing carotenoids to maximize their availability from foods.

Vitamin Synthesis in the Body

In addition to the vitamins we get from the foods we eat, some vitamins can be synthesized in the body. There are two ways the body can make vitamins: certain vitamins can be made from a ***provitamin***, or a *precursor* substance that can be converted into the active form of a vitamin; other vitamins can be synthesized by bacteria living in the intestinal tract.

Vitamins Made From Precursors

Vitamins made in the body from precursors include vitamin A, vitamin D, and niacin, one of the B vitamins.



Figure 8.3.2: "Fresh carrots" by Jonathan Pielmayer is licensed under the standard Unsplash License.

- The active form of **vitamin A**, called retinol, is found in animal foods, but plants contain beta-carotene, a provitamin that can be converted to vitamin A in the body. This red-orange pigment found in fruits and vegetables is converted to vitamin A primarily in the small intestine.[2] We will discuss this conversion in more depth later in this unit.
- **Vitamin D** can be made when ultraviolet light from sunlight strikes cholesterol in the skin. Cholesterol, which our body can make, is a precursor for vitamin D. This process of making vitamin D from cholesterol is limited by geographic location, including both latitude and altitude, and seasonal changes, both of which influence the quality, quantity, and intensity of ultraviolet rays that reach the skin.[3] We will discuss this conversion in more depth later in this unit.
- **Niacin** can be made in the liver from the amino acid tryptophan when tryptophan is available in quantities greater than needed for protein synthesis. The efficiency in which tryptophan is converted to niacin varies greatly in individuals.[4]

Vitamins Made by Intestinal Bacteria

Some vitamins can be synthesized not by our bodies but by the helpful bacteria living within us. **Bacteria in the gut can make vitamin K and B vitamins.**



- Bacteria that colonize the large intestine can synthesize one form of vitamin K, although the total amount made in the large intestine is not clear.[5]
- Gut bacteria are also able to make all B vitamins, though the amount synthesized of each vitamin is dependent on the composition of each individual's microbiome.[6,7] Dietary choices, such as the intake of high-fiber foods or probiotics, and medication use can alter a person's microbiome, possibly promoting or inhibiting the production of vitamins in the large intestine.[8]

Figure 8.3.3: "Yogurt and berries" by Maëliss Demaison is licensed under the standard Unsplash License.

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8.4: Vitamins and Minerals as Antioxidants

What Are Antioxidants, and Why Do We Need Them?

Atoms consist of a nucleus, which contains neutrons and protons, and electrons, which orbit the nucleus. Atoms are most stable when they have an even number of electrons, which allows them to orbit the nucleus in pairs.

An atom or group of atoms with an unpaired electron is called a *free radical*. Free radicals are inherently unstable and highly reactive. They steal electrons from other molecules to stabilize themselves, but in doing so, they create additional free radicals. This electron-grabbing is called ***oxidation*** and can set up a chain reaction, creating new free radicals and damaging important molecules along the way, similar to how one falling domino can bring down countless more.

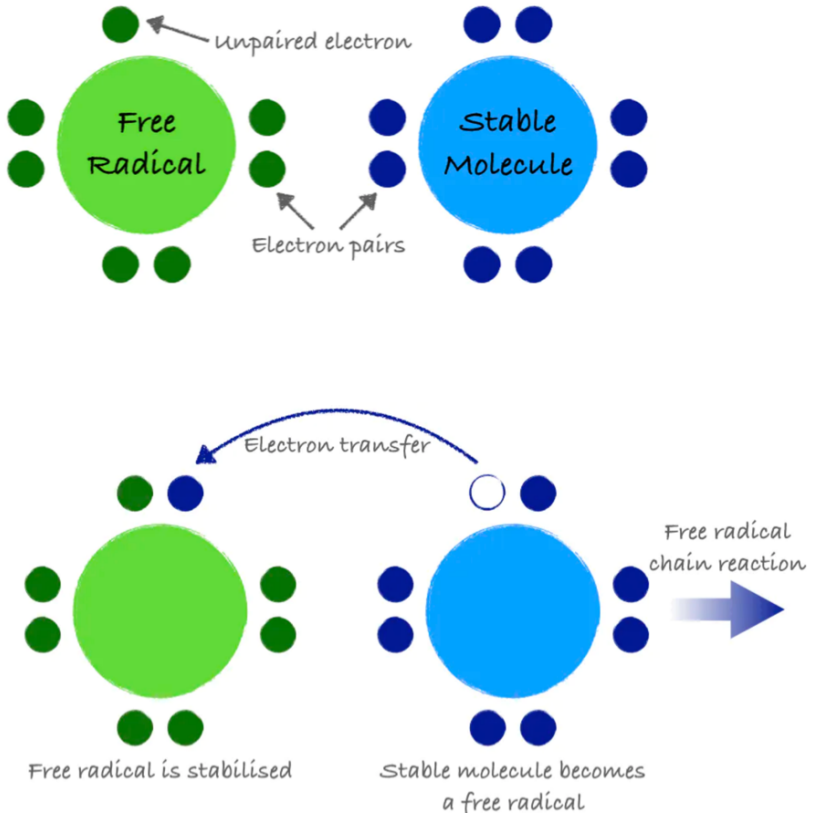


Figure 8.4.1: A free radical is a molecule with an unpaired electron. It can steal electrons from a stable molecule, creating a new free radical and initiating a chain reaction. "Free radical chain reaction" by Jacqui Adcock is licensed under CC BY-ND 4.0.

***Antioxidants* are molecules that can donate an electron to stabilize and neutralize free radicals.** Like a domino that refuses to fall, an antioxidant can stop the free radical chain reaction in its tracks. In donating an electron, the antioxidant itself becomes a free radical. However, antioxidants are special in that they are not very reactive themselves and have processes for quick stabilization.

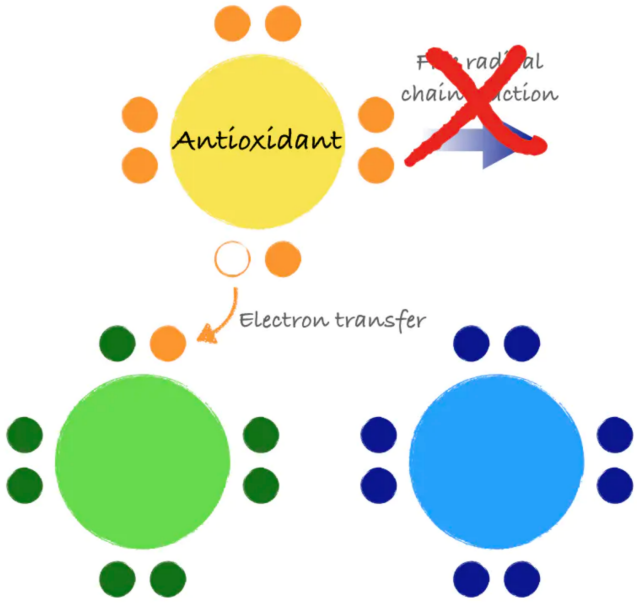


Figure 8.4.2: Antioxidants stabilize free radicals by donating electrons, preventing the chain reaction that can create more free radicals. "Antioxidant action" by Jacqui Adcock is licensed under CC BY-ND 4.0.

Some antioxidants are produced by the body, and some are consumed in the diet. Examples of dietary antioxidants include vitamins C and E, the mineral selenium, and phytochemicals, such as beta-carotene. We'll focus on vitamins C and E and selenium on this page, and we'll discuss beta-carotene later in this chapter.

Free radicals are a natural byproduct of metabolic reactions and exercise, and it's normal to have low levels of free radicals in the body. In fact, free radicals play a role in the normal functioning of the body, including the ability to fight off pathogens and to send signals from one cell to another. And with enough antioxidants present, free radicals can be kept in check so that they aren't dangerous.[1]

However, **too many free radicals and insufficient protection from antioxidants create a situation called *oxidative stress*.** Free radical-induced damage, when left unrepaired, destroys lipids, proteins, RNA, and DNA and can contribute to disease. Oxidative stress has been implicated as a contributing factor to cancer, cardiovascular disease, arthritis, diabetes, kidney disease, Alzheimer's disease, Parkinson's disease, and eye diseases such as cataracts.[2]

Substances and energy sources from the environment can add to or accelerate the production of free radicals within the body. Exposure to UV radiation from sunlight, air pollution, tobacco smoke, heavy metals, ionizing radiation, asbestos, and other toxic chemicals increases the amount of free radicals in the body. They do so by being free radicals themselves or by adding energy that provokes electrons to move between atoms. Excessive exposure to environmental sources of free radicals can contribute to disease by overwhelming the free radical detoxifying systems and those processes involved in repairing oxidative damage.

Oxidative stress is associated with the development of chronic diseases, and eating a diet rich in antioxidant-containing foods like fruits, vegetables, and whole grains seems to protect against many of these diseases. It was thus natural for researchers to hypothesize that taking antioxidants in supplement form might also offer protection from these diseases. However, several decades of research investigating this hypothesis have revealed disappointing results. Not only have these studies shown that antioxidant supplements generally aren't beneficial, but some have shown that they can cause health risks. For example, high doses of beta-carotene increased the risk of lung cancer in smokers, and high doses of vitamin E increased the risk of prostate cancer in men. Antioxidant supplements may also interact with other medications, further emphasizing the importance of talking with your doctor before taking supplements.[2]

Researchers aren't sure why some antioxidant supplements have turned out to be dangerous. It may come back to the fact that free radicals play important roles in the body, and adding high doses of antioxidant supplements overwhelms the normal balance of free radicals and does more harm than good. It may also be that the benefits of eating antioxidant-rich foods come not just from the antioxidants but from the entire package of nutrients, like fiber and phytochemicals in whole foods, a combination that simply can't be replicated in a pill. Regardless, you can obtain adequate levels of dietary antioxidants simply by eating a healthy diet.[1,2]

Let's take a closer look at several of the most important dietary antioxidants: vitamin E, vitamin C, and selenium.

Vitamin E

When we talk about vitamin E, we're actually referring to eight chemically similar substances, of which alpha-tocopherol appears to be the most potent antioxidant. Because vitamin E is fat-soluble, its antioxidant capacity is especially important to lipids, including those in cell membranes and lipoproteins. For example, free radicals can oxidize LDL cholesterol by stealing an electron from it. This damaged LDL lodges in blood vessels and forms the fatty plaques characteristic of atherosclerosis, increasing the risk of heart attack, stroke, and other complications of cardiovascular disease.

After 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.

In addition to its antioxidant functions, vitamin E, mainly as alpha-tocopherol, plays a role in the immune system, regulation of gene expression, and cell signaling. It also enhances the dilation of blood vessels and inhibits blood clot formation.

Food Sources of Vitamin E

Excellent dietary sources of vitamin E include nuts, seeds, and vegetable oils, with additional amounts provided by green leafy vegetables and fortified cereals.[3]

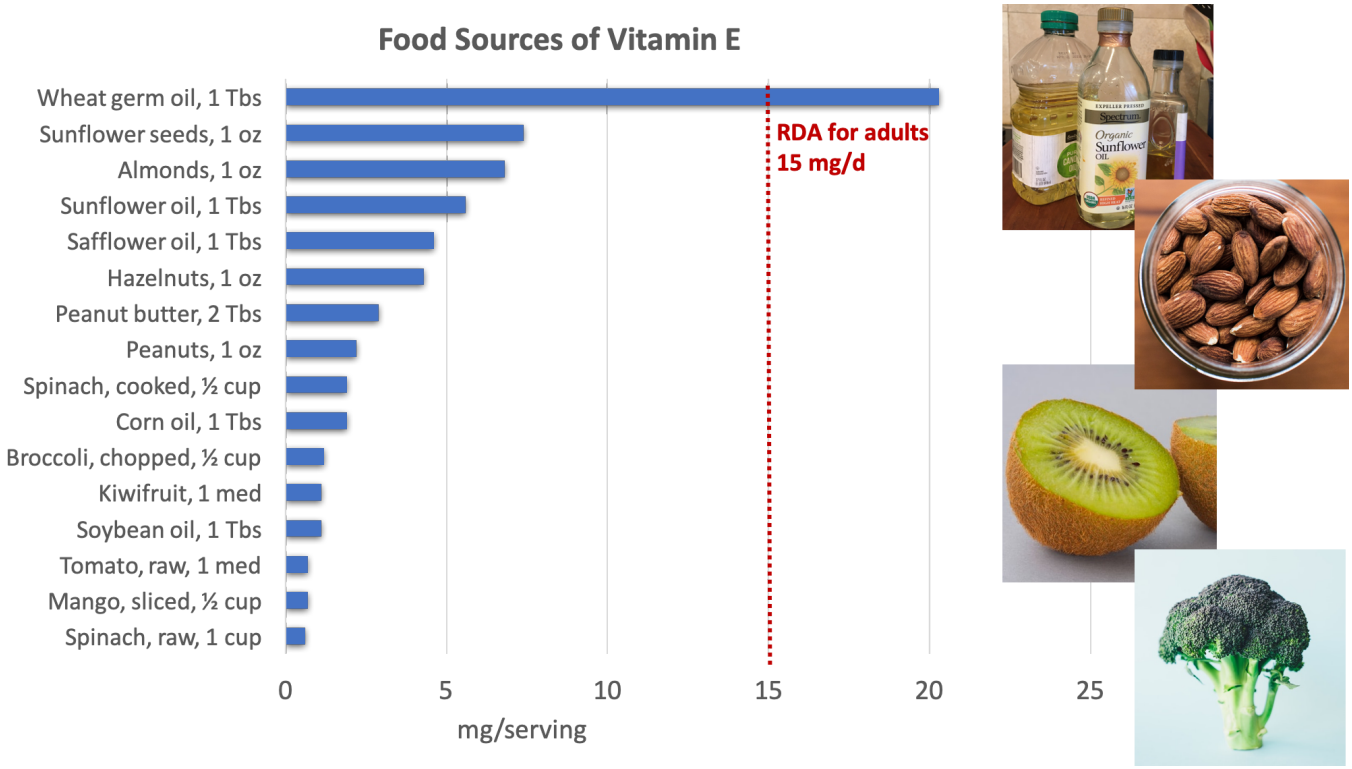


Figure 8.4.3: Dietary sources of vitamin E. [3] "Food sources of Vitamin E" by Alice Callahan is licensed under CC BY 4.0, with images from top to bottom by "Organic Sunflower Oil" by Alice Callahan is licensed under CC BY 4.0, with the following images "Almonds" by Remi Yuan, "Green Broccoli" by Annie Spratt, and "Fresh Kiwi Halves" by engin akyurt which are licensed under the standard Unsplash License.

Surveys of Americans' diets often find they provide less than the RDA for vitamin E. However, these studies may underestimate the amount of vitamin E in the diet because they don't fully account for vegetable oils in the diet, as these are rich sources of vitamin E. Vitamin E can be destroyed at high temperatures, especially when reheated repeatedly, so oils used in deep frying are not good sources of the vitamin.

Vitamin E Deficiency and Toxicity

Outright vitamin E deficiency with obvious deficiency symptoms is very rare in healthy people. It most often occurs in people with an underlying disorder that impairs the digestion and absorption of fat. Symptoms of vitamin E deficiency include nerve and muscle damage, vision problems, and a weakened immune system.[3]

Studies have not found any risks of consuming vitamin E in foods. The UL for vitamin E is set at 1,000 mg for adults, far above the RDA of 15 mg and far higher than could naturally be obtained from food. These amounts are available in supplement form, however. As mentioned, high-dose vitamin E supplements were shown to increase the risk of prostate cancer in men. Other studies have found that high-dose vitamin E supplements are associated with an increased risk of hemorrhage, stroke, and death.

Vitamin C

Vitamin C, also called ascorbic acid, is a water-soluble vitamin essential in the human diet. Interestingly, most other mammals can readily synthesize vitamin C and don't require it in their diets. Vitamin C's ability to easily donate electrons makes it a highly effective antioxidant. Since it is water-soluble, it acts both inside and outside cells to protect molecules in aqueous environments. Vitamin C also plays a vital role in regenerating vitamin E after it has acted as an antioxidant, allowing it to be recycled and used again.

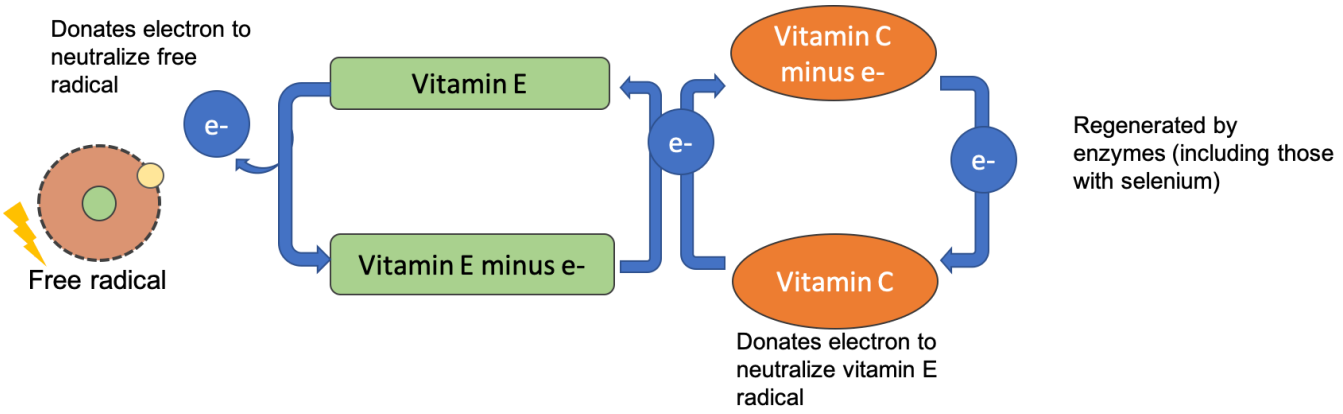


Figure 8.4.4: After vitamin E donates an electron to neutralize a free radical, it can be regenerated by an electron from vitamin C. Vitamin C is then regenerated by antioxidant enzymes. "Vitamin E/vitamin C antioxidant cycle" by Alice Callahan is licensed under CC BY 4.0.

In addition to its role as an antioxidant, vitamin C is a required part of several enzymes involved in synthesizing ***collagen***, a protein important to the strength and structure of muscles, bones, tendons, ligaments, connective tissue, and skin. Vitamin C is also required to **synthesize neurotransmitters** important for signaling in the brain, some hormones, and amino acids. It also plays a **role in immune function** and **improves the absorption of dietary iron.**

The body's vitamin C status is tightly controlled to maintain steady tissue and plasma concentrations. This means that if you consume high doses of vitamin C, you'll absorb less from the intestine and excrete more in urine to prevent excessive concentrations in the body. 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 thus can exist in the body as a functioning antioxidant for many weeks.

Food Sources of Vitamin C

Fruits and vegetables are great sources of vitamin C. Some of the best sources include bell pepper, citrus, broccoli, strawberries, Brussels sprouts, and cantaloupe.

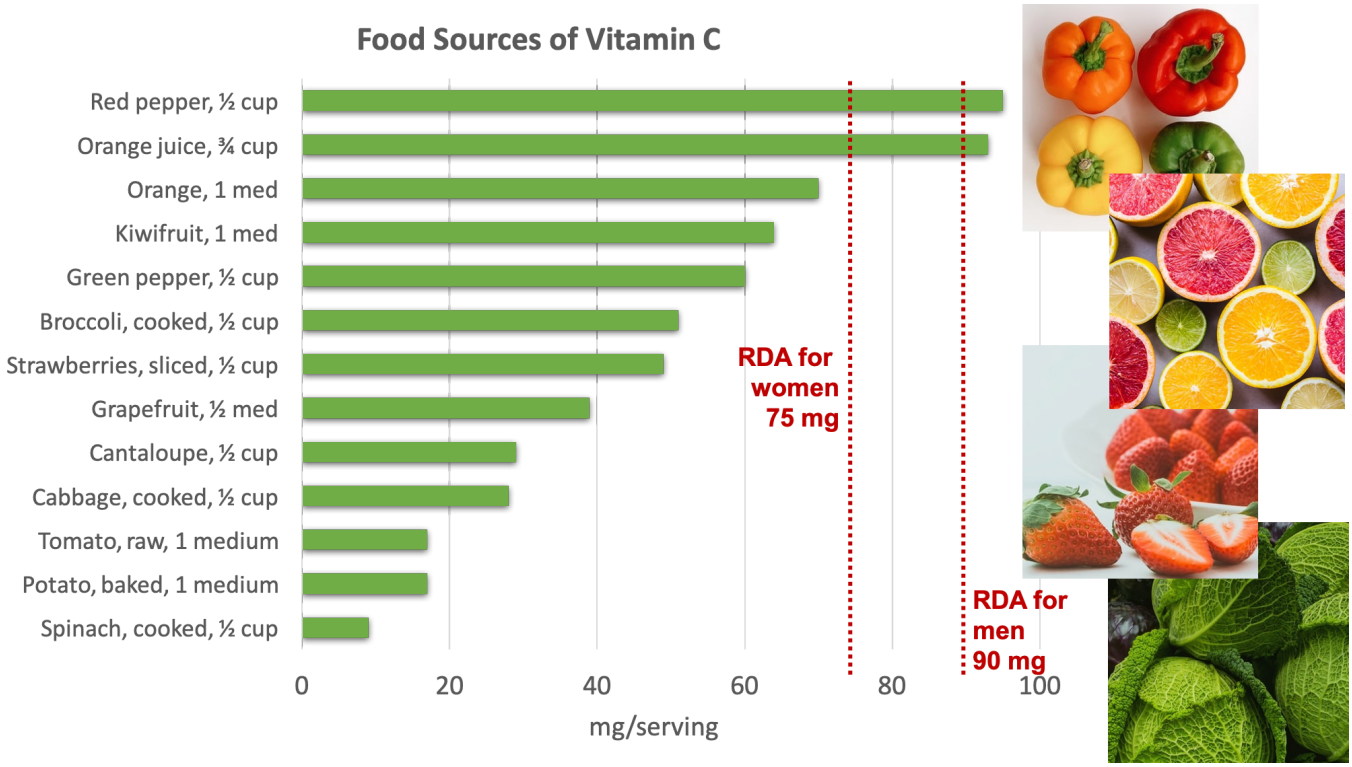


Figure 8.4.5: Dietary sources of vitamin C.[4] "Food sources of Vitamin C" by Alice Callahan is licensed under CC BY 4.0, with image credits from top to bottom as follows: "Four assorted colored bell peppers" by Irene Kredenets, "flat lay photography of sliced pomegranate, lime, and lemon" by Bruna Branco, "Strawberries in round plate" by Kyaw Tun, and "Green and white cabbage vegetable" by Forest Diver, all of which are licensed under the standard Unsplash License.

Because vitamin C is water-soluble, it leaches from foods considerably during cooking, freezing, thawing, and canning. Up to 50% of vitamin C can be boiled away. Therefore, eating fruits and vegetables raw or lightly steamed maximizes their vitamin C value.

Vitamin C Deficiency and Toxicity

The classic condition caused by vitamin C deficiency is ***scurvy***. The signs and symptoms of scurvy include skin disorders, bleeding gums, joint pain, and weakness—all of which may be related to vitamin C's role in collagen synthesis. Additional symptoms of scurvy include abnormally thickened skin, fatigue, depression, iron deficiency anemia, and increased susceptibility to infections.

In the past, scurvy was common among sailors on long ocean voyages whose diets were completely lacking in fruits and vegetables for many months. In the mid-1700s, British Navy surgeon Sir James Lind's experiments revealed that citrus fruits and juices could prevent scurvy in sailors. British sailors were often referred to as "limeys," as they carried sacks of limes onto ships to prevent scurvy. It was not until 1932 that scientists showed that vitamin C was the essential nutrient in this cure.

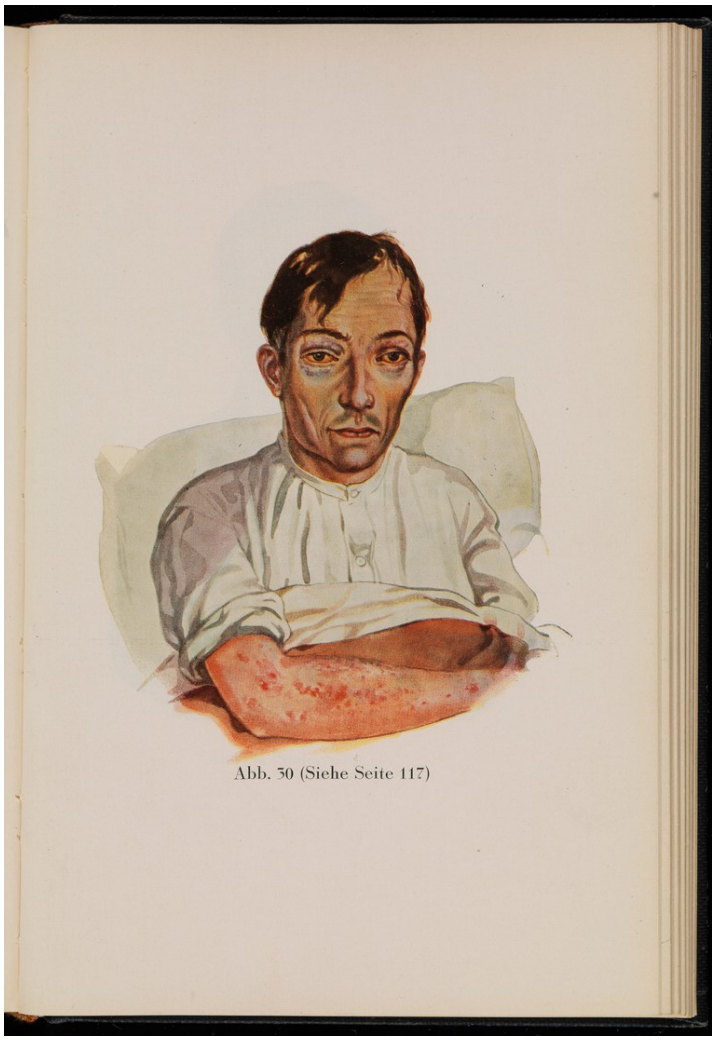


Figure 8.4.6: This drawing of a sailor with scurvy, from the 1929 edition of "Kranken-Physiognomik" by von K. H. Baumgärtner, shows common effects of the disease, including sunken eyes and skin lesions. "38-year-old man suffering from scurvy" by von K. H. Baumgärtner via the Wellcome Library is licensed under CC BY 4.0.

Scurvy is prevented by even a low intake of fruits and vegetables, and it takes at least a month of consuming very little or no vitamin C for scurvy symptoms to develop. Thus, scurvy is rare in developed countries today. Diet surveys show that most Americans meet the RDA for vitamin C. When vitamin C deficiency occurs today, it is in people who consume very limited food variety, such as those with mental illness, people who abuse alcohol or drugs, people on very restrictive diets, and impoverished people with limited fruit and vegetable access. People who smoke also require more vitamin C to counter the free radicals generated by smoking.

The risk of vitamin C toxicity from foods is essentially nonexistent because the body can adjust intestinal absorption and urinary excretion to maintain a healthy vitamin C level. However, high doses of vitamin C from supplements have been reported to cause numerous problems, including gastrointestinal upset and diarrhea. To prevent these discomforts, the Dietary Reference Intake Upper Limit for vitamin C is set at 2,000 milligrams per day for adults, more 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. There is also some evidence that taking vitamin C supplements at high doses increases the risk of developing kidney stones; however, this effect is most often observed in people who already have multiple risk factors for kidney stones.

Can Vitamin C Supplements Prevent the Common Cold?

Many people believe that taking a vitamin C supplement can prevent the common cold or decrease its symptoms. Linus Pauling popularized this idea in the 1970s, and it's continuously promoted today in the form of over-the-counter supplements such as

Emergen-C and *Airborne*. These typically contain doses in the range of 1000 mg of vitamin C, far higher than normal levels of vitamin C in the diet and enough to reach the UL of 2000 mg if a person takes two doses per day.



Figure 8.4.7: "Emergen-C" by Mike Mozart is licensed under CC BY 2.0.

Do these high-dose vitamin C supplements do anything to prevent or treat the misery of the common cold? A systematic review and meta-analysis published in 2013 by the Cochrane Collaboration summarized the results of 29 studies on this question. The review concluded that for most people, these supplements don't prevent the common cold but can reduce the duration of symptoms by 8% in adults and 14% in children—amounting to a day or two of relief—but only if they're taken consistently every day and before cold symptoms begin. If taken after the onset of symptoms, a vitamin C supplement does not seem to reduce the duration or severity of symptoms. Some research shows that vitamin C supplements may be more effective in cold prevention in athletes and those in extreme physical conditions, such as marathon runners, endurance skiers, and soldiers.[5]

Selenium

Selenium is an essential trace mineral. It is part of the structure of at least 25 proteins in the body, with functions in reproduction, thyroid hormone metabolism, DNA synthesis, and antioxidant and immune protection.[6] As part of antioxidant enzymes, selenium helps to regenerate other antioxidants, including vitamin C. These enzymes also protect lipids from free radicals and, in doing so, spare vitamin E. This reinforces how antioxidants work together to protect the body against free radical-induced damage.

Food Sources of Selenium

Organ meats, muscle meats, and seafood have the highest selenium content. Grains and some nuts contain selenium when grown in selenium-containing soils. The selenium content of the soils used to grow animal feed can also affect the selenium content of animal products.

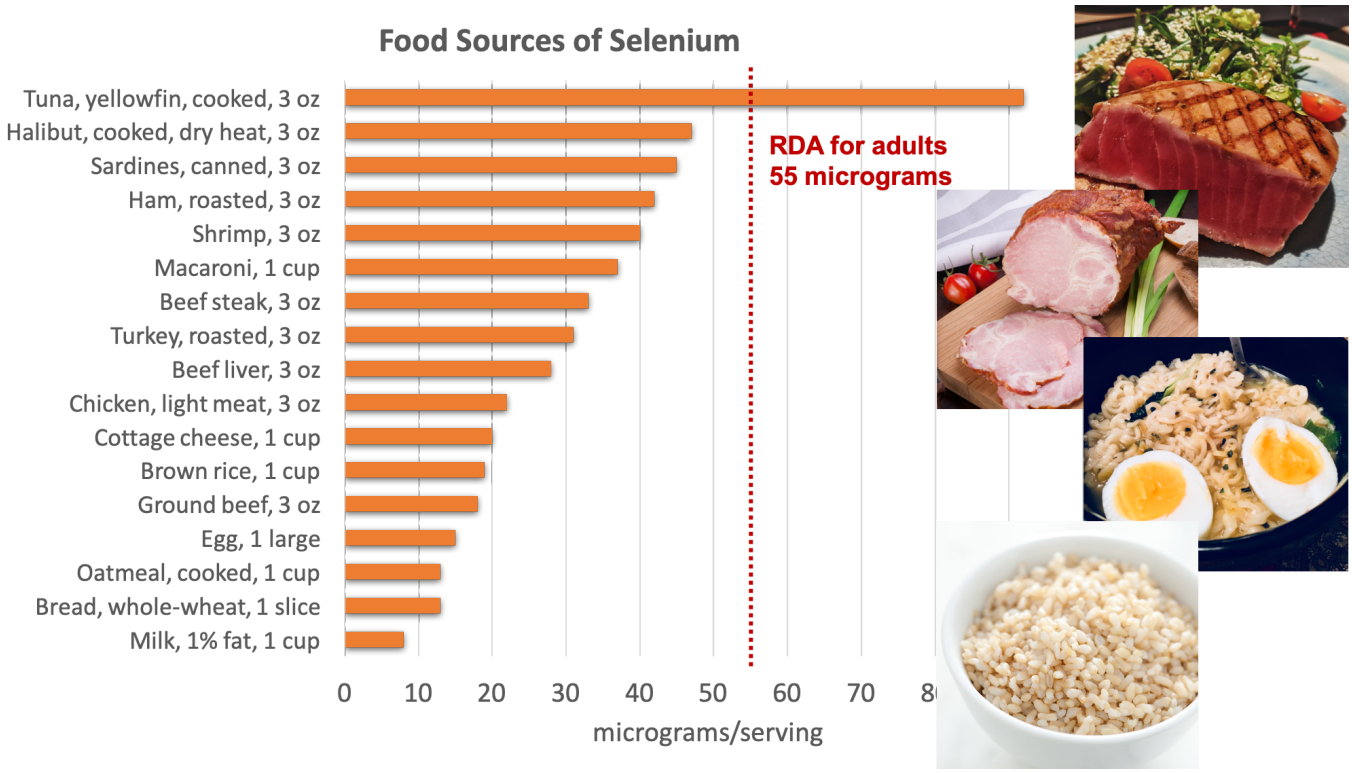


Figure 8.4.8: Dietary sources of selenium.[6] "Food sources of selenium" by Alice Callahan is licensed under CC BY 4.0, with images credits from top to bottom as follows: "Perfect tuna steak" by sunorwind, "Sliced ham" by Сергей Орловский, and "Noodle with hard-boiled eggs" by Cake Tuxedo are licensed under the standard Unsplash License; "par cooked brown rice" by jules is licensed under CC BY 2.0

Selenium Deficiency and Toxicity

Selenium deficiency is very rare in the United States and other developed countries. Worldwide, people with a primarily vegetarian diet in areas with low soil selenium levels, including parts of China and Europe, may be at risk for selenium deficiency.[6]

Chronic exposure to foods grown in soils containing high levels of selenium (above the UL of 400 micrograms per day) can cause brittle hair and nails, gastrointestinal discomfort, skin rashes, halitosis, fatigue, and irritability. Brazil nuts contain very high levels of selenium, so if eaten regularly, they could cause selenium toxicity. Selenium at doses several thousand times the RDA can cause acute toxicity, and when ingested in gram quantities, it can be fatal.

Attributions:

- Zimmerman, M., & Snow, B. Nutrients Important as Antioxidants. In *An Introduction to Nutrition* (v. 1.0). https://2012books.lardbucket.org/boo...ion/index.html, CC BY-NC-SA 3.0

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8.5: Vitamins Important for Vision

Vision is one of our five basic senses, and unless you've experienced vision loss, it's hard to imagine life without sight. Vitamin A plays a key role in vision and eye health. On this page, we'll cover the functions, food sources, and signs of deficiency and toxicity for vitamin A and carotenoids such as beta-carotene, which can be converted to vitamin A.

Vitamin A

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 it is converted in the body to the biologically active forms of vitamin A: retinal and retinoic acid. The dietary retinol in animal-derived foods is called ***preformed or active vitamin A***.

This differentiates it from ***beta-carotene*** and other ***carotenoid*** compounds, which are brightly colored yellow, orange, and red pigments synthesized by plants. These are called ***provitamin*** A carotenoids because they can be converted to vitamin A in the body. Among the carotenoids, beta-carotene is most efficiently converted to vitamin A. If you look at the beta-carotene molecule, you can see that it looks like two connected retinol molecules. Enzymes in the intestine and liver can cleave the beta-carotene molecule in half, creating two new molecules of vitamin A.

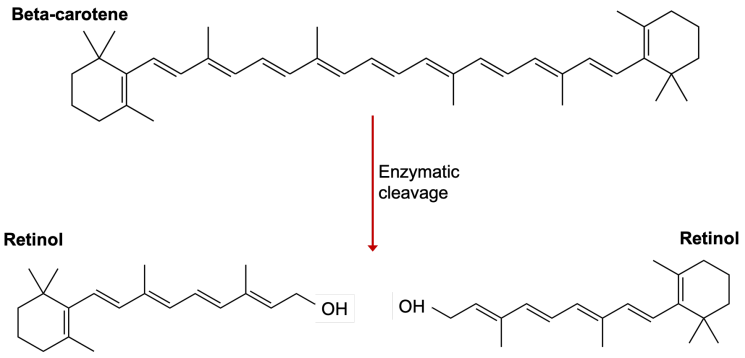


Figure 8.5.1: One molecule of beta-carotene can be enzymatically cleaved to 2 molecules of vitamin A. "Beta-carotene and vitamin A" by Alice Callahan is licensed under CC BY 4.0, using "Skeletal formula of beta-carotene" and "Chemical structure of retinol," both by NEUROtiker and in the Public Domain.

As with other fat-soluble vitamins, vitamin A is packaged into chylomicrons in the enterocytes of the small intestine and then 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. Beta-carotene can be converted into vitamin A in the intestine, or it can be absorbed intact, packaged in chylomicrons, and then transported around the body in lipoproteins. Beta-carotene and other carotenoids that aren't converted to vitamin A can also act as powerful antioxidants and have other helpful functions in the body, which may in part explain the health benefits of a diet rich in fruits and vegetables.

The retinoids are aptly named, as their most notable function is in the retina of the eye. Retinol circulating in the blood is taken up by cells in the retina, where it is converted to retinal and is used as part of the pigment ***rhodopsin***. Rhodopsin is especially important to our ability to see in low-light conditions. When light hits rhodopsin in the eye, a nerve signal is sent to the brain, allowing us to detect that light. A person who is deficient in vitamin A has less rhodopsin pigment in the eye and is, therefore, less able to detect low-level light. **This makes it more difficult to see at night, a condition referred to as *night blindness***, and this is one of the first signs that a person is deficient in vitamin A.



Figure 8.5.2: A depiction of the vision of a person suffering from night blindness, in which there is inadequate rhodopsin for detection of light. "Depiction of vision of a person suffering from night blindness " by Upchar is licensed under CC BY-SA 4.0.

Vitamin A is also required for normal ***cellular differentiation***, the process of changing from stem cells to more specialized cells with specific structure and function. Cellular differentiation is important in every tissue of the body, but if there is a shortage of vitamin A, the eye is one of the first areas to be impacted. Specialized cells in the lining of the eyes produce mucus and tears, which keep eyes moist and lubricated. When the mucus-secreting cells die, they must be replaced with new cells. If the body is deficient in vitamin A, those new cells don't differentiate normally, resulting in dry eyes, a condition called ***xerophthalmia***. Instead of producing mucus, these dysfunctional cells produce a protein called keratin. ***Keratin*** is a hard, structural protein found in nails, hair, and the outer layer of skin, and you can imagine the problems it causes when it accumulates in the eye. Instead of a moist, well-lubricated eye, keratin makes the eye hard and dry, resulting in clouded vision.



Figure 8.5.3: A child with xerophthalmia caused by vitamin A deficiency, demonstrating cloudiness on the eye's surface. "Eye with xerophthalmia" by Dr. J. Justin Older of the Centers for Disease Prevention and Control is in the Public Domain

A deficiency in vitamin A can thus impair vision in two ways:

1. Development of night blindness due to a lack of the pigment rhodopsin
2. Development of xerophthalmia, or dry eyes, caused by abnormal cellular differentiation

Night blindness is usually the first sign of a vitamin A deficiency, followed by xerophthalmia and clouded vision. If the deficiency persists, the damage from keratin in the lining of the eye can cause permanent blindness.[1]

Vitamin A's role in cellular differentiation also makes it critical to cells around the body involved in **normal growth, development, reproduction, and immune function.** All of these processes require cells to develop in specific ways at specific times, and

vitamin A helps to orchestrate these processes. For example, embryonic development requires stem cells to differentiate into specific types of cells to form new organs, and timing is critical.

Food Sources of Vitamin A and Carotenoids

Preformed vitamin A is found only in animal-derived foods. The best food sources are liver and fish oils, as vitamin A is fat-soluble and stored in fatty tissues. Smaller amounts can be found in other animal products, such as meat, eggs, and dairy products.

Provitamin A carotenoids such as beta-carotene are mostly found in fruits and vegetables. Carotenoids are brightly-colored pigments, so vibrant color is a good indicator of their presence. Top sources include orange and yellow vegetables such as carrots, sweet potatoes, pumpkins, bell peppers, fruit, leafy green vegetables, and some vegetable oils. Some carotenoids can also be found in animal-derived foods. For example, the yellow color of egg yolk comes from carotenoids absorbed from the diets of the hens.

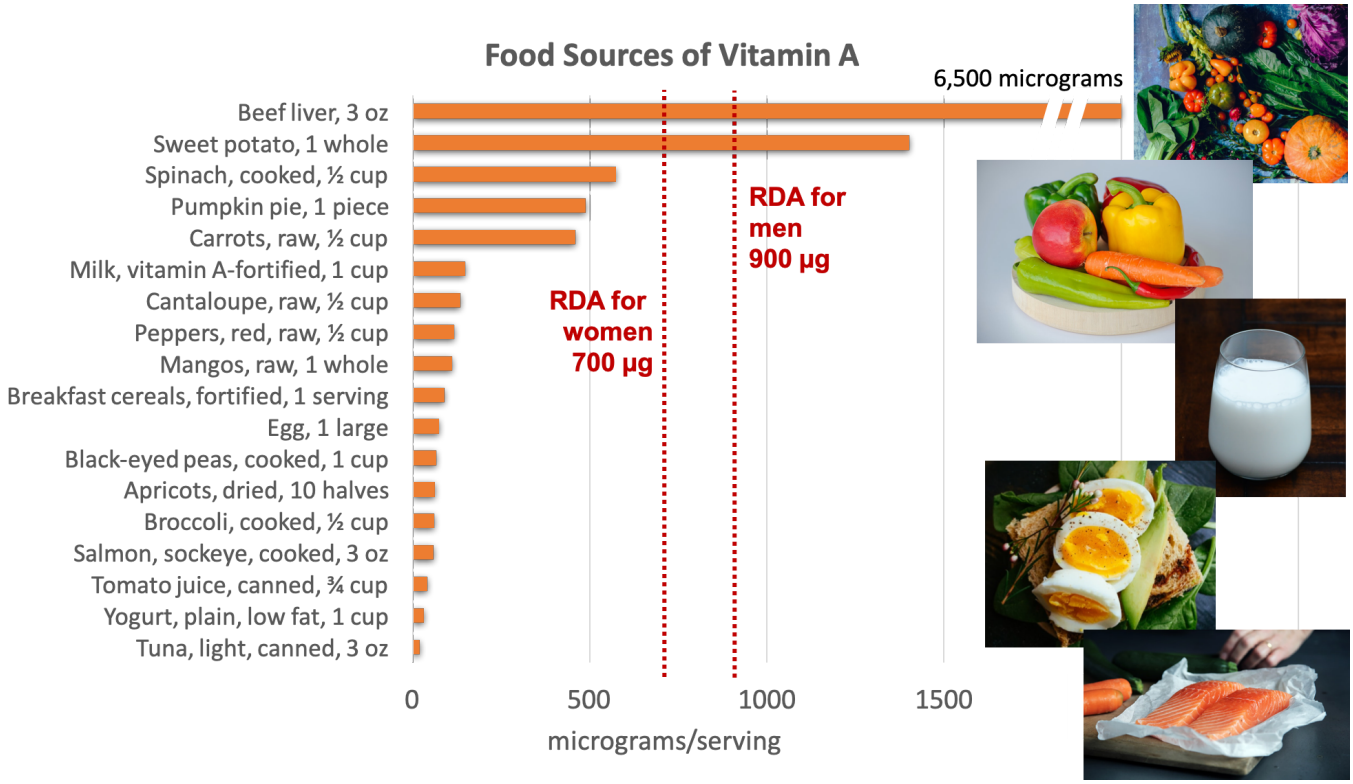


Figure 8.5.4: Food sources of vitamin A.[2] "Food sources of Vitamin A" by Alice Callahan is licensed under CC BY 4.0, with image credits from top to bottom as follows: "veggies on blue surface" by Ella Olsson, "red and green bell pepper and red apple on whilte plate" by Alexander Schimmeck, "glass of milk" by Kim Gorga, "sandwich with boiled egg" by Joseph Gonzalez, "raw fish meat on brown chopping board" by CA Creative Caroline Attwood are all licensed under the standard Unsplash License.

Deficiency and Toxicity of Vitamin A and Carotenoids

The main symptoms of vitamin A deficiency are xerophthalmia, night blindness, and increased susceptibility to infections. Another symptom is ***hyperkeratosis***, which occurs when cells in the skin overproduce the protein keratin (similar to what happens in the eye with xerophthalmia), causing the skin to become rough and irritated.

Vitamin A deficiency is rare in developed countries, but globally, it is the leading cause of preventable blindness in children. It is caused by malnutrition related to the consumption of inadequate diets predominantly based on staple grains and lacking in animal products, fruits, vegetables, and fat, which increases the absorption of vitamin A. According to the World Health Organization, an estimated 333 million children in low- and middle-income countries suffer from vitamin A deficiency. The highest prevalence is in children under the age of 5.[3]

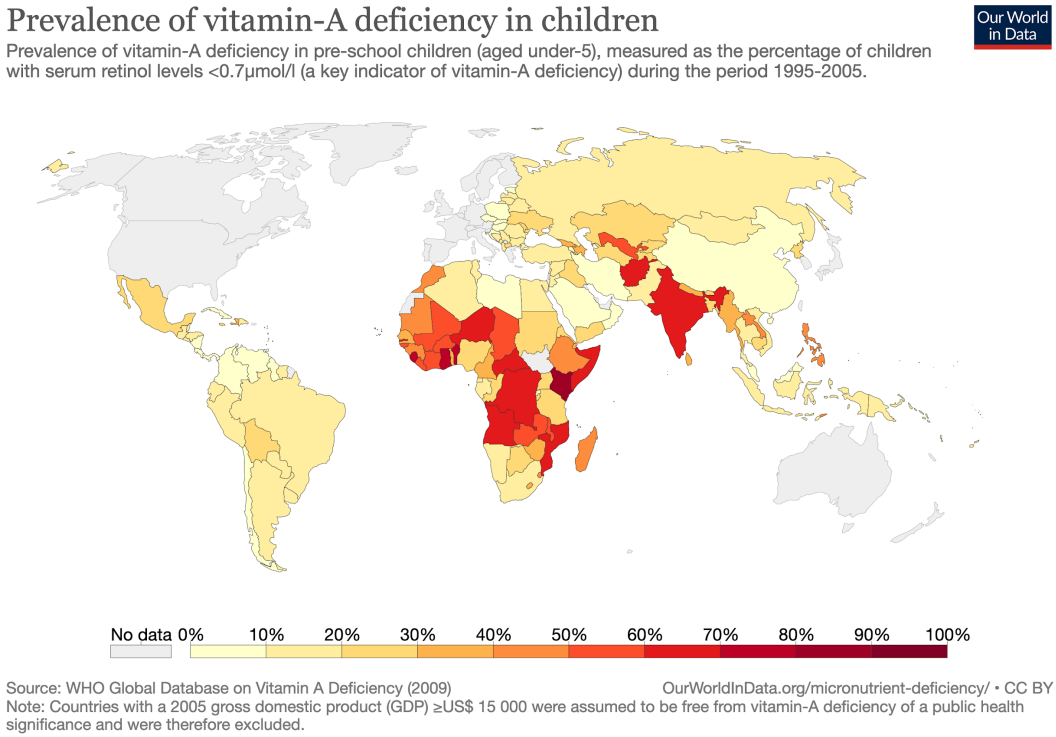


Figure 8.5.5: The worldwide prevalence of vitamin A deficiency in 1995-2005, based on World Health Organization data. "Prevalence of vitamin-A deficiency in children" by Our World in Data is licensed under CC BY 4.0.

Vitamin A toxicity causes dry, itchy skin, loss of appetite, dizziness, nausea, swelling of the brain, and joint pain. In the most severe cases, it can cause liver damage, coma, and death. Vitamin A toxicity is almost always caused by taking supplements in doses above the UL of 3,000 micrograms per day for substantial periods. These high doses would not be found in a normal diet, although vitamin A toxicity has been observed in Arctic explorers who ate large amounts of bear and seal liver.[4]

Consuming excessive amounts of vitamin A during pregnancy can also cause birth defects, so pregnant people should pay close attention to vitamin A contained in supplements. In addition, some synthetic forms of vitamin A (Retin-A and Accutane, for example) are used as acne treatments and should never be used during pregnancy due to the risk of birth defects.

Unlike preformed vitamin A, beta-carotene and other carotenoids do not seem to cause birth defects or other major toxicity effects in high doses. This is because the body doesn't convert beta-carotene to vitamin A if it already has excessive amounts of vitamin A. Because it doesn't cause toxicity, beta-carotene is usually used as the source of vitamin A in prenatal multivitamin supplements.

Beta-carotene that isn't converted to vitamin A is absorbed intact in the intestine. When high levels of beta-carotene are consumed in the diet, it can have the unusual effect of making a person's skin appear yellow or orange. The color change doesn't seem harmful, and normal skin tone returns once the person stops consuming so much beta-carotene. However, studies have shown that long-term consumption of high-dose beta-carotene supplements has been linked to increased rates of cancer and death, so it's best to get beta-carotene from food rather than supplements.

Attributions:

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8.6: Nutrients Important for Bone Health

In this section, we will discuss nutrients important for bone health. Many people are familiar with calcium as a key nutrient for maintaining bone strength and density, but several additional nutrients contribute to healthy bones.

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8.6.1: Introduction to Bone Health

The human skeleton consists of 206 bones and other connective tissues that, together, support and protect many organs, produce red and white blood cells, and act as a storage depot for minerals such as calcium, phosphorus, and magnesium. Although bones may look inactive at first glance, they are living tissues that are dynamic and in a constant state of breaking down and rebuilding to withstand mechanical forces. Bones also contain a complex network of canals, blood vessels, and nerves that allow for nutrient transport and communication with other organ systems.

Nutrition influences all body systems, and the skeletal system is no exception. Our lifestyle choices impact the health of our bones. In this section, we will look at how bone forms across the lifecycle and discuss the complex interactions of nutrients, hormones, genetics, and environmental factors that impact bone health.

What Is Bone?

Bone is a living tissue, made mostly of ***collagen***, a protein that provides a soft framework, and minerals like calcium phosphate that form tiny crystals called ***hydroxyapatite*** around the collagen fibers. These inorganic minerals harden the collagen framework and provide strength. The combination of collagen and minerals makes bone both flexible and strong, allowing it to withstand stress.

Most bones contain two types of tissue, compact and spongy, but their distribution and concentration vary based on the bone's function. ***Spongy bone,*** also known as trabecular bone, is 50 to 90% porous and appears as a lattice-like structure under a microscope. It makes up about 20% of the adult skeleton and is found at the ends of long bones, in the cores of vertebrae, and in the pelvis, as it supports shifts in weight distribution. ***Compact bone,*** also known as cortical bone, is dense to withstand compressive forces. It is only 10% porous and resembles the rings in a tree trunk, with many concentric circles sandwiched together. Compact bone tissue is approximately 80% of the adult skeleton and surrounds all spongy tissue.

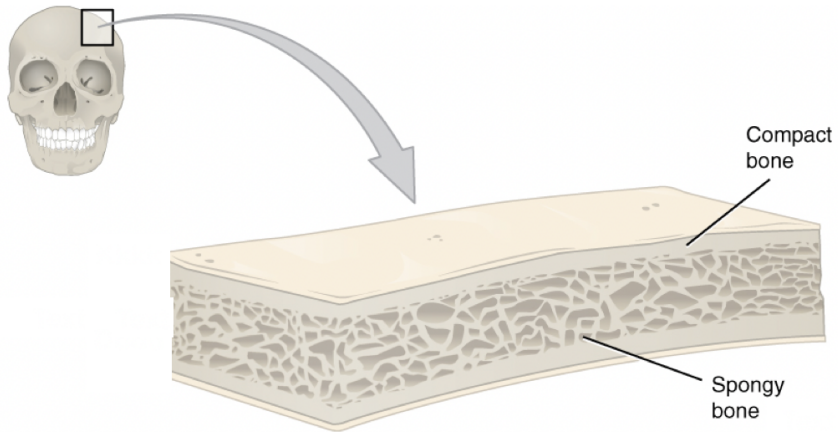


Figure 8.6.1.1: This cross-section of a flat bone from the skull shows the spongy bone lined on either side by a layer of compact bone. "Anatomy of a Flat Bone" is from Anatomy and Physiology by OpenStax and is licensed under CC BY 4.0.

Bone Growth, Modeling, and Remodeling

Bones change in shape, size, and position throughout the life cycle. During infancy, childhood, and adolescence, bones are continuously growing and changing shape through two processes: growth, or ***ossification,*** and ***modeling***. In the modeling process, bone tissue is dismantled at one site and built up at a *different* site, which influences the *shape* of the bone. During childhood and adolescence, more bone is deposited than dismantled, so bones grow in size and density, reaching 90% of peak bone mass by age 18 in girls and 20 in boys.[1] ***Peak bone mass*** is reached by age 30, at which point bones have reached their maximum strength and density. Factors affecting peak bone mass include gender, race, hormones, nutrition, physical activity, and behavioral factors like smoking. These factors will be discussed in more detail when we discuss osteoporosis.

In adulthood, our bones stop growing and modeling, but they continue to go through bone ***remodeling***, in which bone tissue is degraded and built up at the *same* location. About 10% of bone tissue is remodeled each year in adults. Bones adapt their structure

to the forces acting upon them, even in adulthood. This is why physical activity increases bone strength, especially in weight-bearing activities. For example, tennis players can have measurably higher bone mass in the arm they use for play compared with the other arm.[2] Ultimately, bones adapt their shape and size to accommodate function.

The dynamic nature of bone means that new tissue is constantly formed, and old, injured, or unnecessary bone is dissolved for repair or calcium release. The cell type responsible for bone ***resorption***, or breakdown, is the ***osteoclast***. Osteoclasts are continually breaking down old bone tissue. Another type of cells, called ***osteoblasts,*** are continually forming new bone. The ongoing balance between osteoblasts and osteoclasts is responsible for the constant but subtle reshaping of bone. The decline in bone mass after age 40 occurs because the rate of bone loss is greater than the rate of bone formation. This means that osteoclast-mediated bone degradation exceeds that of the bone-building activity of osteoblasts. How much bone is lost in adulthood depends on peak bone mass reached in early adulthood and other risk factors.

Osteoporosis

Osteoporosis is a bone disease that occurs when bone density or bone mass decreases. The bone becomes thinner and more porous and is, therefore, more susceptible to breaking. According to the National Institute of Arthritis and Musculoskeletal and Skin Diseases, more than 53 million people in the US either have osteoporosis already or are at high risk of developing it because of low bone mass.[3]

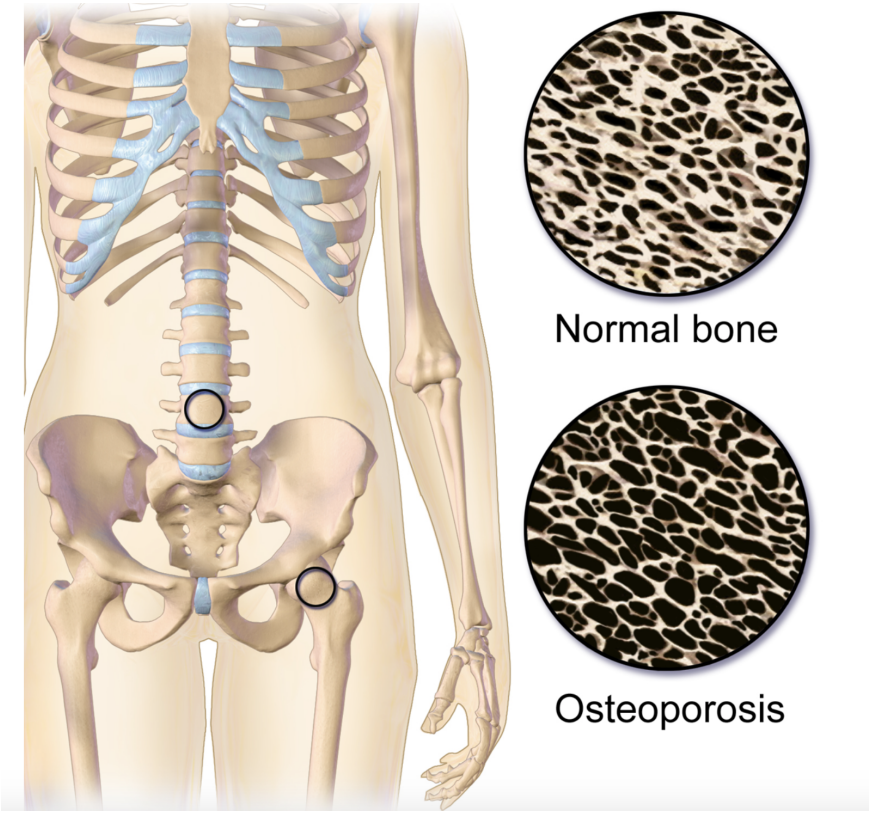


Figure 8.6.1.2: Osteoporosis. This illustration shows the difference between the structure of normal bone, which is less porous, and bone with osteoporosis, which is more porous. The two circles located on the spine and hip represent the location of the images. "Osteoporosis" by BruceBlaus is licensed under CC BY-SA 4.0.

Bone loss usually occurs without symptoms, so osteoporosis is often called a **silent disease**. It can go undetected until bones become so weak that they fracture from a sudden strain, bump, or fall.

One way to assess bone health is by measuring bone mineral density. A ***bone mineral density (BMD***) test can detect osteoporosis and predict the risk of bone fracture. The most common tool used to measure BMD is called ***dual energy X-ray absorptiometry (DXA)***. This method can measure bone density over the entire body, but most often, the DXA scan focuses on measuring BMD in the hip and the spine. These measurements are then used as indicators of overall bone strength and health. DXA is painless and non-invasive, uses low doses of radiation, and is the most accurate way to measure BMD.

An individual's chances of developing osteoporosis depend on several risk factors, some of which are controllable and some of which are not. It is thought that genetic factors (such as gender and race) may account for up to 75% of bone mass, and lifestyle factors (such as diet and exercise habits) account for the remaining 25%.[1]

Osteoporosis risk factors that are biological and cannot be controlled:

- **Body frame size.** People with small frames are at higher risk for osteoporosis.
- **Race.** Caucasian and Asian populations are at higher risk of osteoporosis than African American and Hispanic populations, which are at lower risk.[3]
- **Family history.** Having a family member with osteoporosis may increase risk, as heredity seems to play a part in the development of osteoporosis.
- **Age.** After age 40, bone mass declines because bone breakdown exceeds bone formation. Therefore, any person over the age of 40 has an increased likelihood of developing osteoporosis compared with a younger person. Starting with a higher peak bone mass in early adulthood enables you to lose more bone during the aging process and not develop osteoporosis.
- **Gender.** Females, on average, have a lower peak bone mass compared with males and a much greater risk of developing osteoporosis, in part because of hormone levels.
- **Hormones.** Both the female hormone estrogen and the male hormone testosterone help to increase peak bone mass. Estrogen is the primary female reproductive hormone, and it stimulates bone building and reduces bone breakdown. When women go through menopause (usually around age 50), they experience a natural decline in estrogen levels, which accelerates bone loss and increases the risk of developing osteoporosis. People with diseases that impact hormone levels and athletes who engage in extreme physical activity may be impacted by hormonal changes that increase osteoporosis risk.
- **Medications.** Certain medications, including some over-the-counter and prescription medications, can increase the risk of bone loss. It is a good idea to discuss any medications you take with your healthcare provider.

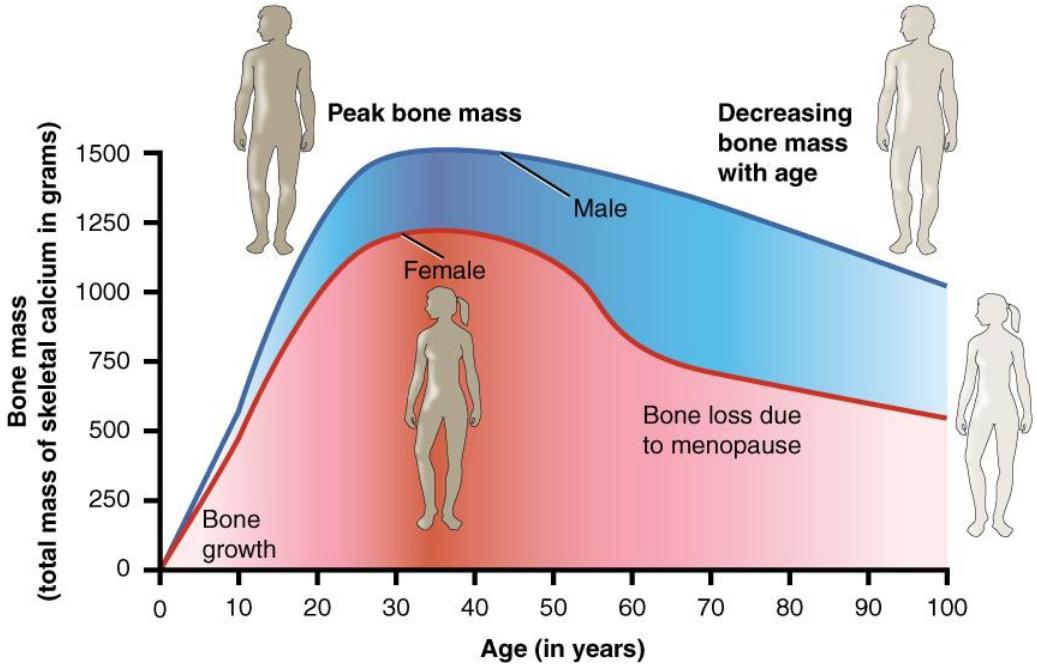


Figure 8.6.1.3: Age and bone mass. Bone density peaks at about *30 years of age, and women lose bone mass more rapidly than men, particularly around menopause. "Age and Bone Mass"* is from Anatomy and Physiology by OpenStax and is licensed under CC BY 4.0.

Risk factors that can be controlled:

- **Physical inactivity.** Physical inactivity lowers peak bone mass and decreases BMD at all ages and is linked to an increase in fracture risk, especially in the elderly. Regular exercise can help individuals achieve greater peak bone mass, prevent bone loss for women and men age 30 and older, and maintain strength and balance to help prevent falls later in life. The best activities for stimulating new bone are weight-bearing exercises, such as walking, hiking, and dancing, and resistance exercises, such as weight lifting.

- **Nutrition.** Ensuring adequate nutrition is a key component in maintaining bone health. Low dietary intakes of calcium and vitamin D are strong risk factors for developing osteoporosis. Protein is also important during childhood and adolescence for proper bone development and in older age to preserve bone mass.[4]
- **Smoking.** Smoking cigarettes has long been known to correlate to a decrease in bone mass and an increased risk of osteoporosis and fractures. However, because people who smoke are more likely to be physically inactive and have poor diets, it is difficult to determine whether smoking itself causes osteoporosis. Smoking is also linked to earlier menopause, and therefore, the increased risk of developing osteoporosis among female smokers may also be attributed, at least in part, to having reduced estrogen production at an earlier age. However, studies have also shown that tobacco smoke and nicotine can directly have a negative impact on bone metabolism.[5]
- **Alcohol intake.** Alcohol intake may also affect bone health, although this seems to depend on the amount consumed. Light to moderate alcohol intake (two drinks or less per day) has been shown in some studies to be associated with an increase in bone density and a decreased risk of developing osteoporosis. However, excessive alcohol intake is associated with decreased bone density and increased fracture risk, although this may be due in part to other lifestyle factors, such as poor diet and less physical activity.[6]
- **Being underweight**- Being underweight significantly increases the risk of developing osteoporosis because people who are underweight often have a smaller frame size and a lower peak bone mass. The most striking relationship between being underweight and bone health is seen in people with anorexia nervosa. Anorexia nervosa is strongly correlated with low peak bone mass with a threefold lifetime risk of fracture.[7]

The changeable risk factors for osteoporosis provide ways for people to improve their bone health, even though some people may be genetically predisposed to the disease. Prevention of osteoporosis begins early in life since this is a critical time of bone growth. A balanced diet that provides adequate amounts of calcium, vitamin D, and protein is important for bone health throughout the life cycle. Participating in exercise such as walking, hiking, and weight lifting, as well as refraining from risky behaviors such as smoking and excessive drinking, are all behaviors that will help protect bones.

Attributions:

- Zimmerman, M., & Snow, B. Bone Structure and Function. In *An Introduction to Nutrition* (v. 1.0). https://2012books.lardbucket.org/boo...ion/index.html, CC BY-NC-SA 3.0
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8.6.2: Calcium- Critical for Bones and Throughout the Body

Bones have two components: inorganic minerals and a protein matrix. Minerals, which make up 65% of bone tissue, are what give bones their hardness. Calcium and phosphorus together form hydroxyapatite crystals, the main mineral component of bone. Other minerals, including magnesium, fluoride, sodium, and potassium, play supporting roles. This page focuses on calcium, and we'll cover potassium, magnesium, and fluoride on the following page. (Sodium and potassium are covered in another section of this text.)

Calcium Functions and Regulation

Calcium is the most abundant mineral in the body. Most of the body's calcium—approximately 98% of it—is stored in bone, where it's important for bone strength and structure. The remaining 1% of the body's calcium is found in the blood and soft tissues, but it is here that calcium performs its most critical functions. For example, calcium is required to transmit every nerve impulse and electrical signal sent from one nerve cell to another. It's also required for every cycle of muscle contraction and relaxation. With inadequate calcium, muscles can't relax, become stiff, and contract involuntarily, a condition known as ***tetany***. Calcium also plays vital roles in blood pressure regulation, blood clotting, enzyme activation, hormone secretion, and signaling between cells.[1]

The many roles of calcium around the body are critical to daily survival, so maintaining homeostasis, or a steady state, of blood calcium levels is a high priority. The body rigorously controls blood calcium levels in a very tight range. If blood calcium drops, your body initiates several mechanisms to restore homeostasis, including drawing calcium from the bone. While the calcium stored in bone is important for the long-term strength and structure of bone, it also serves as a calcium "bank" that can be drawn upon to support the vital functions of calcium in the body should blood calcium drop too low.

Two endocrine glands are key players in regulating blood calcium concentrations: the thyroid and parathyroid glands. The ***thyroid gland*** is a small, butterfly-shaped gland located at the base of the neck. It secretes a hormone called ***calcitonin***. There are four ***parathyroid glands***, each about the size of a pea and located at the back of the thyroid gland. They secrete a hormone called ***parathyroid hormone (PTH)***.

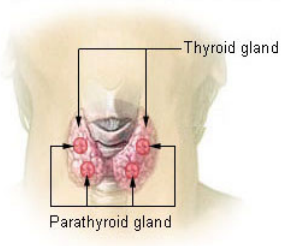


Figure 8.6.2.1: The thyroid and parathyroid glands are located at the back of the neck. "Thyroid and parathyroid glands" by National Cancer Institute is in the Public Domain.

Let's take a closer look at how the body regulates blood calcium levels. If the blood calcium concentration drops too low, the parathyroid glands release ***parathyroid hormone*** or PTH. **PTH then acts in several ways to increase blood calcium levels**:

1. PTH stimulates the activity of osteoclasts to release calcium from bone.
2. PTH acts on the kidney to reduce the amount of calcium lost in the urine, returning more to circulation.
3. PTH stimulates enzymes in the kidney that convert vitamin D to its active form, also called ***calcitriol***. This activated vitamin D acts on the intestine to increase calcium absorption. Vitamin D also works together with PTH to stimulate the release of calcium from the bone and reduce calcium loss in urine.

Once blood calcium levels are normal, PTH levels drop, turning off these mechanisms for increasing calcium.

On the other hand, **if blood calcium levels become too high**, the thyroid gland releases calcitonin, which inhibits the release of calcium from the bone and increases calcium excretion from the kidneys. These mechanisms help to restore normal blood calcium concentrations, after which calcitonin levels drop again.

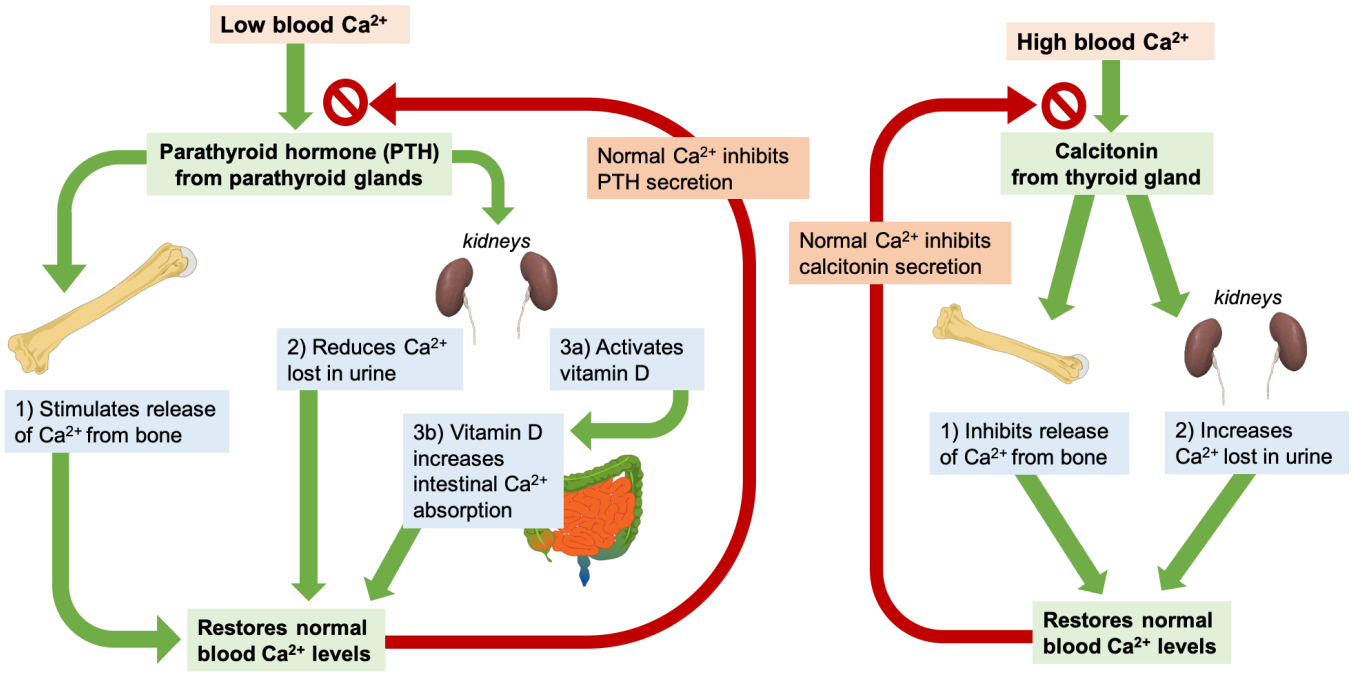


Figure 8.6.2.2: Blood calcium (Ca^{2+}) levels are tightly regulated by PTH, vitamin D, and calcitonin. "Calcium regulation" by Alice Callahan is licensed under CC BY 4.0, with kidney, bone, and intestine images by Mikael Haggstrom, which are in the Public Domain.

Through these two opposing pathways—PTH and vitamin D for raising blood calcium and calcitonin for lowering blood calcium—the body can very effectively maintain blood calcium homeostasis. This system depends on stored calcium in bone, which is sacrificed when needed to ensure adequate blood calcium. In the short term, this isn't a problem because bone remodeling allows you to replace calcium in the bone. However, in the long-term, inadequate dietary calcium means you continuously reduce the calcium stores in your bones, resulting in declining bone mineral density and increased risk of fracture.

Calcium requirements are highest for children and adolescents, who are growing and building bones, and for older adults, who are losing bone density. The RDA for calcium for children 9 to 13 and teens 14 to 18 is 1,300 milligrams daily. The RDA for adults is 1,000 mg per day but increases to 1,200 mg per day for women ages 51 and up and for men age 71 and older.[1]

Dietary Sources of Calcium

In the typical American diet, calcium is obtained mostly from dairy products. A slice of cheddar or Swiss cheese contains over 200 milligrams of calcium. One cup of milk contains approximately 300 milligrams of calcium, about a third of the RDA for calcium for most adults. Foods fortified with calcium, such as cereals, soy milk and other plant-based beverages, and orange juice also provide one-third or greater of the calcium RDA. Smaller amounts of calcium are naturally present in plant-based foods such as legumes, leafy greens, and nuts. With careful planning, adequate calcium can be obtained from non-dairy sources.

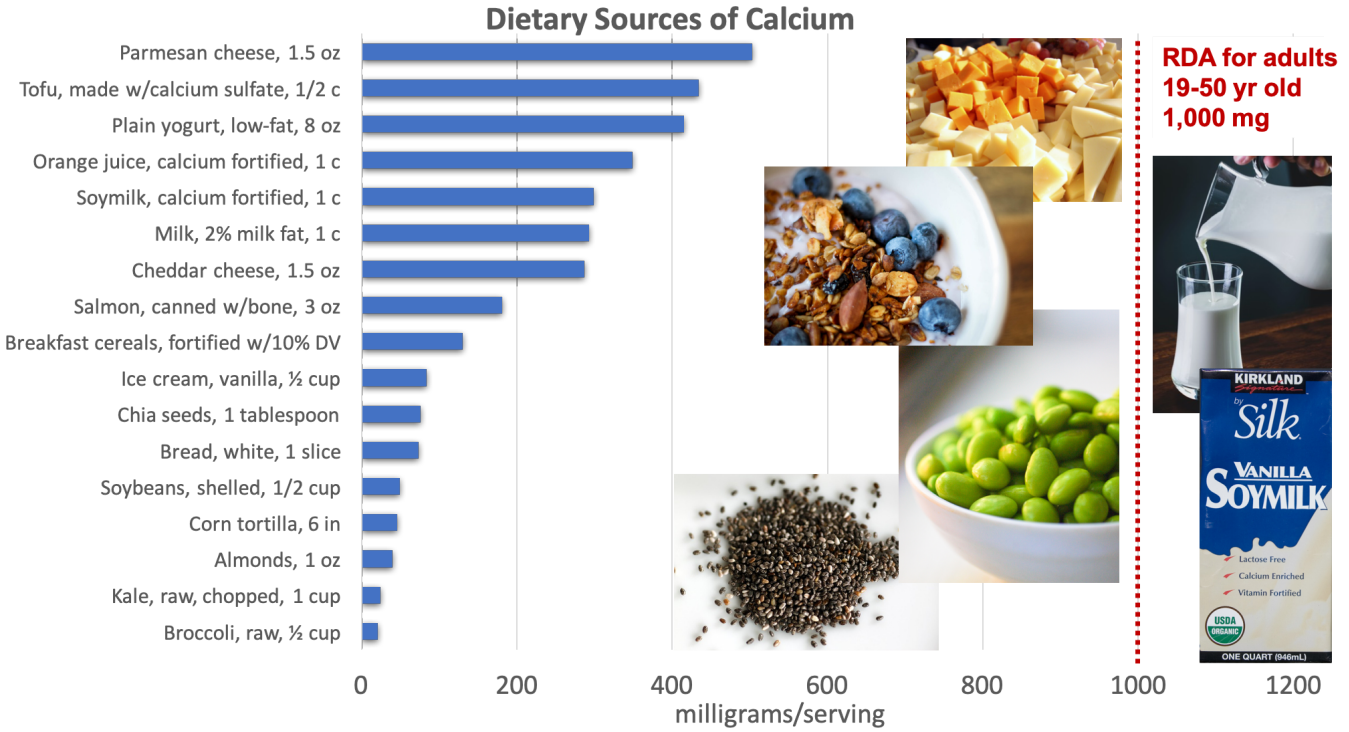


Figure 8.6.2.3: Dietary sources of calcium. Examples of good sources pictured include cheese, milk, fortified soymilk, yogurt (with almond granola), edamame, and chia seeds.[1] "Dietary sources of calcium" by Alice Callahan is licensed under CC BY 4.0, with the following images and respective attribution statements: "Cheese!" by Finite Focus is licensed under CC BY-NC 2.0; "person pours milk into a glass" by Eiliv-Sonas Aceron is licensed under the standard Unsplash License; "Bowl with blueberries, almonds and granola" by Marco Verch (Wuestenigel) is licensed under CC BY 2.0; "edamame" by Carrie T is licensed under CC BY-NC 2.0; "soymilk" by Ian Fuller is licensed under CC BY-NC 2.0; and "chia seeds" by Stacy Spensley is licensed under CC BY 2.0.

Calcium bioavailability, or the amount of dietary calcium absorbed from the intestine into the bloodstream, can vary significantly. In general, calcium absorption is highest in infants and young children—who need relatively high amounts of calcium for building bone—and declines with age. With higher calcium intake, especially from supplements, bioavailability decreases to prevent excessive calcium absorption. Some chemical components of plant foods, including phytic acid (found in whole grains, beans, seeds, soy, and nuts) and oxalic acid (found in spinach, collard greens, sweet potatoes, rhubarb, and beans), bind to calcium and reduce bioavailability. Despite reduced absorption, these foods can still provide a significant amount of calcium.[1]

Calcium Deficiency and Toxicity

In the short term, there are no obvious signs of calcium deficiency. This is because the body stores so much calcium in bones, and just 1% of total body calcium is required for daily functioning. If low blood calcium does occur, symptoms include muscle cramping, numbness and tingling in fingers, convulsions, lethargy, poor appetite, and abnormal heart rhythms. Without treatment, low blood calcium can lead to death.[1]

Much more common is a long-term calcium deficiency, resulting from a continuous draw of calcium stores from the bone. This causes ***osteopenia***, or low bone mass, which can lead to **osteoporosis** if untreated. Osteoporosis significantly increases a person's risk of fractures. Refer to the previous section of this chapter for details regarding osteoporosis risks and prevention.

Too much calcium can also cause problems, although this is rarely caused by excessive calcium intake from foods. Abnormally high activity of the parathyroid gland or a parathyroid tumor can cause high blood calcium, leading to calcification or hardening of blood vessels and soft tissue and the formation of kidney stones. High calcium intake from supplements has also been associated with an increased risk of kidney stones and, in some studies, an increased risk of cardiovascular disease. It can also cause constipation.[1]

Attributions:

- Zimmerman, M., & Snow, B. Nutrients Important for Bone Health. In *An Introduction to Nutrition* (v. 1.0). https://2012books.lardbucket.org/boo...ion/index.html, CC BY-NC-SA 3.0

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8.6.3: Other Minerals Important to Bone Health

Phosphorus

Phosphorus is the second most abundant mineral in the human body, and 85% of the body's phosphorus is housed in the skeleton. In addition, phosphorus (in the form of phosphate) is a component of the backbones of RNA and DNA, adenosine triphosphate (ATP), and phospholipids. Phosphate also plays important roles in regulating cell signaling, enzyme activity, and acid-base balance, as well as being part of creatine phosphate, an energy source for muscles during exercise.[1]

Because phosphorus is present with calcium in mineralized bone, it is somewhat regulated in parallel to calcium. PTH and activated vitamin D stimulate bone resorption, increasing not only blood calcium levels but also blood phosphate levels. However, in contrast to the effect of PTH on calcium reabsorption by the kidney, PTH stimulates the renal excretion of phosphate so that it does not accumulate to toxic levels.

Dietary Sources of Phosphorus

Compared with inadequate calcium intake, most people in the US are not at risk for inadequate phosphorus intake. Phosphorus is present in many foods, including meat, fish, dairy products, potatoes, nuts, beans, and whole grains. Phosphorus is also added to soft drinks and many processed foods because it acts as an emulsifying agent, prevents clumping, improves texture and taste, and extends shelf life.

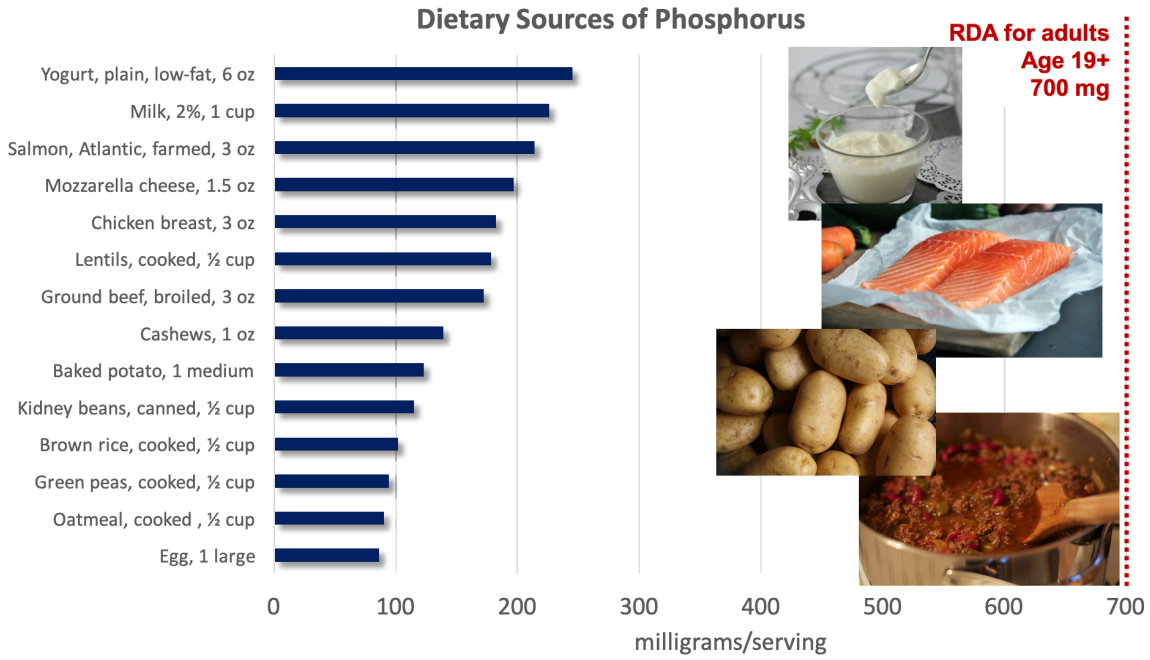


Figure 8.6.3.1: Food sources of phosphorus. Good sources pictured include yogurt, salmon, potatoes, and chili (made with ground beef and kidney beans). Source: https://ods.od.nih.gov/factsheets/Phosphorus-HealthProfessional/ "Dietary sources of phosphorus" by Alice Callahan is licensed under CC BY 4.0, with the following images and respective attribution statements: "Yogurt photo" by Sara Cervera, "raw fish meat on brown chopping board" by CA Creative, "brown potato lot" by Lars Blankers, which are licensed under the standard Unsplash License; "Superbowl Chili" by Jake Przespo is licensed under CC BY 2.0.

Phosphorus Deficiency and Toxicity

Both deficiency and toxicity of phosphorus are rare. The average phosphorus intake 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 phosphorus is 4,000 milligrams per day for adults and 3,000 milligrams per day for people over 70. Very high doses of phosphorus taken in supplement form can interfere with calcium regulation and cause calcification, or hardening, of soft tissues, especially the kidneys.[2]

Magnesium

Approximately 60% of magnesium in the human body is stored in the skeleton, making up about 1% of mineralized bone tissue. In addition to contributing to bone maintenance, magnesium has several other functions in the body. It is required in every reaction involving ATP, amounting to more than three hundred enzymatic reactions. Magnesium plays a role in synthesizing DNA and RNA, carbohydrates, and lipids, and it is essential for nerve conduction, muscle contraction, and normal heart rhythm.

Dietary Sources of Magnesium

Magnesium is part of the green pigment, chlorophyll, which is vital for photosynthesis in plants; therefore, green leafy vegetables are good dietary sources of magnesium. Magnesium is also found in high concentrations in nuts, whole grains, legumes, potatoes, dairy products, fish, and meats. Most foods high in fiber are good sources of magnesium, and it is added to some fortified foods, such as breakfast cereal. Additionally, chocolate, coffee, and hard water contain a good amount of magnesium.

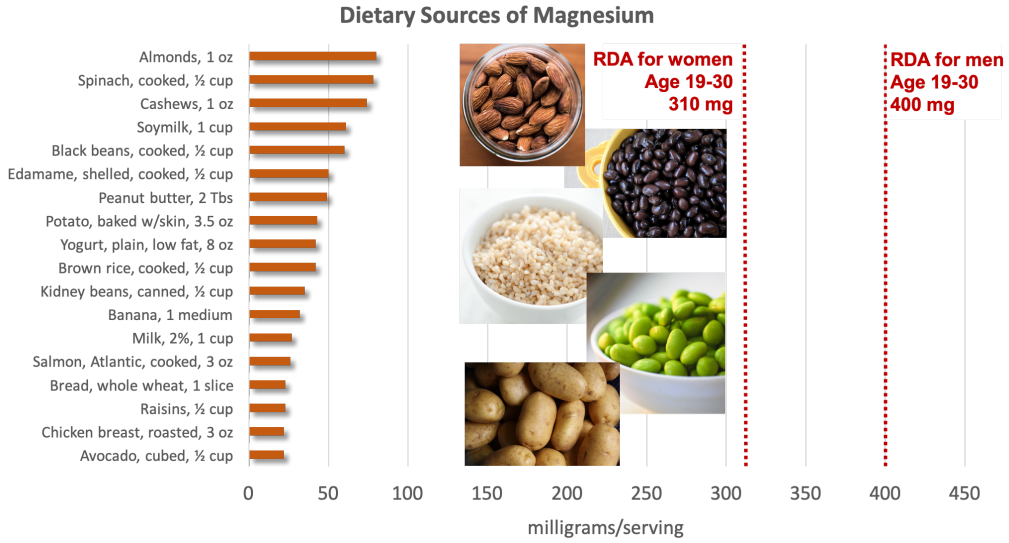


Figure 8.6.3.2: Dietary sources of magnesium. Good sources pictured include almonds, black beans, brown rice, edamame, and potatoes. Source: *NIH Office of Dietary Supplements* "Dietary sources of magnesium" by Alice Callahan is licensed under CC BY 4.0, with the following images and their respective attributions: "almonds" by Remi Yuan and "brown potato lot" by Lars Blankers, both licensed under the standard Unsplash License; "Black beans" by cookbookman17 and "par cooked brown rice" by jules are licensed under CC BY 2.0; "edamame" by Carrie T is licensed under CC BY-NC 2.0.

Magnesium Deficiency and Toxicity

Most people in the US do not meet the RDA for magnesium, and studies indicate that consuming adequate magnesium may improve health. For example, people with higher dietary intakes of magnesium tend to have lower rates of cardiovascular disease, type 2 diabetes, and osteoporosis, leading some researchers to hypothesize that low intake of magnesium may increase the risk of these chronic diseases. More studies are needed to determine whether magnesium supplements may help prevent these diseases. However, because magnesium is present in many healthful whole foods, improving magnesium intake through diet may bring multiple benefits.

Obvious magnesium deficiency due to low dietary intake is rare in healthy people because the kidneys can decrease urinary excretion of this mineral when intake is inadequate. People at greater risk of magnesium deficiency include those with type 2 diabetes, gastrointestinal diseases like Crohn's and celiac, chronic alcoholism, and older adults. A magnesium deficiency can cause decreased appetite, nausea, vomiting, fatigue, and weakness. If extreme, it can cause personality changes, muscle cramps, numbness, tingling, seizures, and an abnormal heart rhythm.[3]

Excessive intake of magnesium from foods is not a risk, as the kidneys can effectively excrete the excess. However, people should take care not to consume more than the UL for magnesium from supplements and medications.[3]

Fluoride

Fluoride is a trace mineral needed in very small amounts in the body. It is known mostly as the mineral that combats tooth decay, but it also plays a role in assisting with tooth and bone development and maintenance. Because it isn't necessary for growth or to

sustain life, fluoride is generally not considered an essential mineral. However, fluoride's role in preventing **dental caries**, or tooth decay, the most prevalent chronic disease in children and adults, underscores the importance of this mineral in the human diet.[4]

Fluoride combats tooth decay via three mechanisms:

- Blocking acid formation by bacteria
- Preventing demineralization of teeth
- Enhancing remineralization of destroyed enamel

As a natural mineral, fluoride is present in the soil and water in varying concentrations depending on geographical location. In the 1930s, researchers observed that children living in areas with naturally higher fluoride concentrations in their drinking water had a lower incidence of cavities, leading to the idea that adding fluoride to municipal water supplies could benefit public health. Fluoride was first added to drinking water in 1945 in Grand Rapids, Michigan; now, over 60% of the US population consumes drinking water that has been supplemented with fluoride to provide amounts that support dental health. The Centers for Disease Control and Prevention (CDC) has reported that water fluoridation reduces cavities by 25% in children and adults and considers water fluoridation one of the ten great public health achievements of the twentieth century.[5]

Fluoride's benefits to mineralized tissues of the teeth are well substantiated, but fluoride also plays an important role in the mineralization of bones, increasing their structural stability. 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. In general, it appears that at low doses, fluoride treatment increases bone mineral density in people with osteoporosis and is more effective in increasing bone quality when the intake of calcium and vitamin D is adequate. The Food and Drug Administration has not approved fluoride for the treatment of osteoporosis, mainly because its benefits are not sufficiently known. It also has several side effects, including frequent stomach upset and joint pain. The doses of fluoride used to treat osteoporosis are much greater than those in fluoridated water.

Dietary Sources of Fluoride

Fluoride is not widely found in the food supply. In communities with municipal water fluoridation, greater than 70% of fluoride intake comes from drinking water. In communities without fluoridated water, intake depends on how much fluoride occurs naturally in the water, but in most areas, natural levels fall below amounts recommended for cavity prevention. Other beverages with a high amount of fluoride include teas and grape juice. Solid foods do not generally contain a large amount of fluoride. However, this depends on the fluoride level of the soil and water they were grown in and whether they were cooked in fluoridated water. Canned meats and fish that contain bones do contain some fluoride. Other good non-dietary sources are fluoridated toothpaste and dental rinses.



Figure 8.6.3.3: Dietary sources of fluoride include water, tea, shellfish, and fluoridated dental products such as toothpaste. "Dietary sources of fluoride" includes the following images: "clear drinking glass filled with water" by manu schwendener, "tea" by Sarah Gualtieri, "four shrimps on top of ice" by AM FL, and "white green and blue toothbrush with blue toothpaste" by William Warby, are licensed under the standard Unsplash License.

Fluoride Deficiency and Toxicity

Because it is a nonessential mineral, there is no defined fluoride requirement, but lower levels are associated with higher rates of dental cavities in adults and children. This connection is why so many water supplies are fluoridated.

However, as with all minerals, fluoride can also be quite toxic if consumed in excessive amounts. Acute toxicity symptoms from large intakes of fluoride include nausea, vomiting, diarrhea, and convulsions. Chronic toxicity results in an irreversible condition

known as ***fluorosis***, characterized by the mottling (white speckling) and pitting of the teeth, as noted in Figure 9.10. Fluorosis is primarily a risk in children because mineralization of permanent teeth has typically occurred by age eight.[6]



Figure 8.6.3.4: A mild case of fluorosis (left) versus a severe case of fluorosis (right). "Dental fluorosis (mild)" by josconklin is licensed under CC BY-SA 3.0 and "Dental fluorosis (excessive)" by Editmore is in the Public Domain.

Because fluoridated oral care products often taste good, making them appealing to young children, it is important to ensure infants and children do not consume too much fluoride by swallowing toothpaste or other oral care products. Recommendations for managing fluoride intake in children include the following:[7-9]

- Do not use any fluoride supplement without talking to your healthcare provider.
- Consider a prescription fluoride supplement for children who live in communities without fluoridated water or rely on a well water supply that is not fluoridated.
- In infants up to age 2, use only a rice-sized amount of fluoride toothpaste as soon as the first tooth erupts.
- Use only a pea-sized amount of fluoride toothpaste in children aged 3 to 6 years.
- Encourage children to spit out toothpaste instead of swallowing it.
- Avoid fluoride mouth rinses in children younger than 6 years.

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8.6.4: Vitamin D- Important to Bone Health and Beyond

Vitamin D is unique among the vitamins because we can synthesize most of what we need in our skin. Sunlight is an essential ingredient in this process, so vitamin D is sometimes called the “sunshine vitamin.” However, the amount of vitamin D synthesized in the body is often insufficient to meet our needs, so many people also need to consume dietary sources.

Metabolism and Functions of Vitamin D

Vitamin D synthesis in the skin begins with the conversion of cholesterol to 7-dehydrocholesterol. Then, in the presence of ultraviolet (UV) rays from sunlight, 7-dehydrocholesterol is converted to vitamin D_3, also called ***cholecalciferol***, which is transported to the liver by a binding protein.

In dietary sources, vitamin D may be present in the form of vitamin D_3 from animal products or vitamin D_2, also called ***ergocalciferol***, made by plants, mushrooms, and yeast. Dietary vitamins D_2 and D_3 are transported to the liver via chylomicrons and then taken up in chylomicron remnants.

Vitamins D_2 and D_3 are both inactive until they undergo two ***hydroxylations,*** chemical reactions that add a hydroxyl (-OH) group. The first hydroxylation occurs in the liver, creating ***calcidiol***. This is the circulating form of vitamin D and the form measured in blood to assess a person’s vitamin D status. The second hydroxylation occurs in the kidneys and forms ***calcitriol,*** the biologically active form of vitamin D.

Recall from our discussion of blood calcium regulation that one of the actions of parathyroid hormone (PTH) is to stimulate enzymes in the kidney that perform this last step in the activation of vitamin D. Active vitamin D increases the absorption of both calcium and phosphorus in the intestine, as well as working with PTH to reduce calcium loss in the urine and stimulate the release of calcium and phosphorus from the bone. In these ways, vitamin D plays a critical role in maintaining blood calcium homeostasis and enhancing the supply of calcium and phosphorus for bone mineralization. Vitamin D deficiency results in poor bone mineralization, with serious consequences in both children and adults.

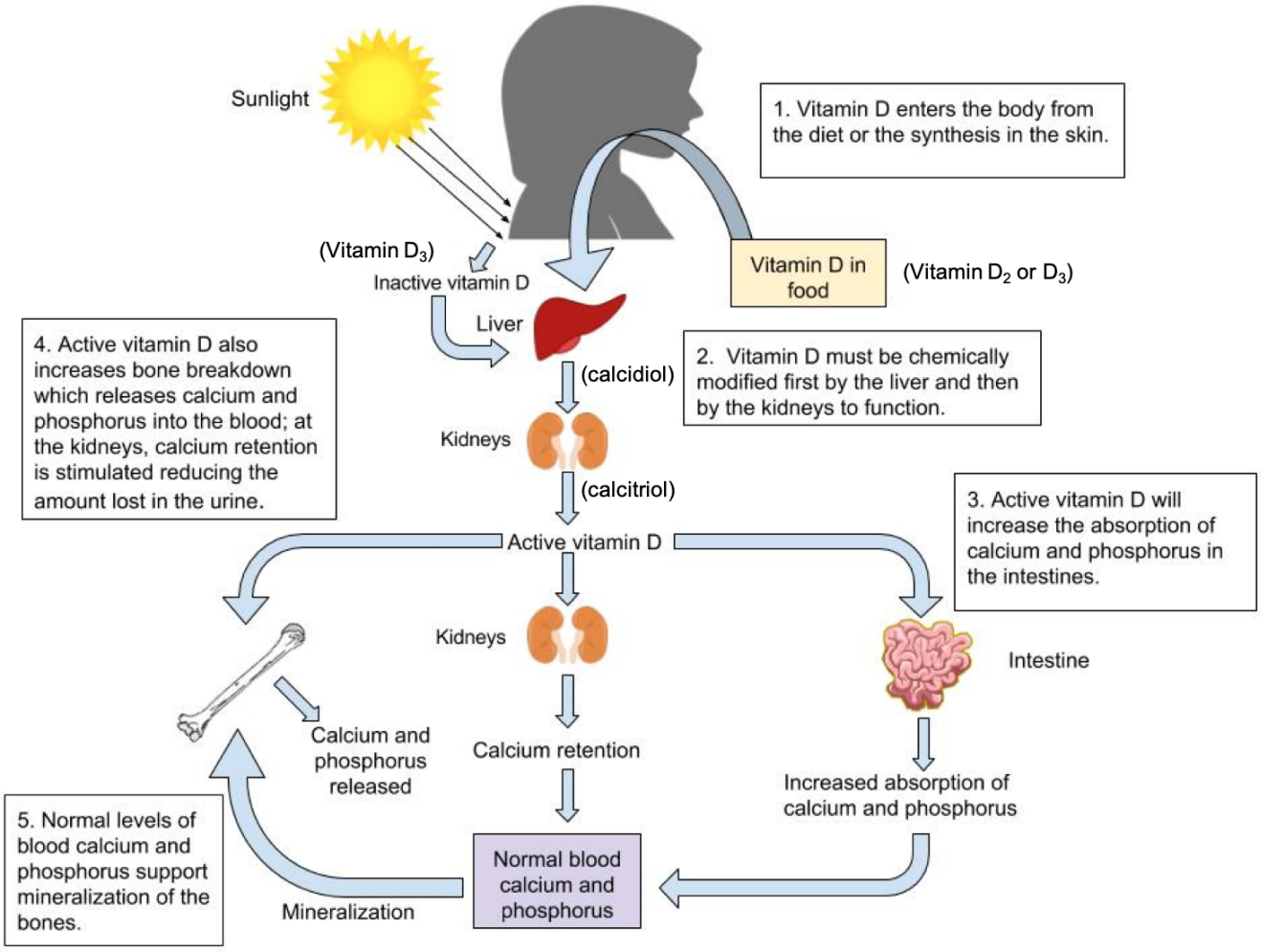


Figure 8.6.4.1: Vitamin D can be synthesized in the skin (vitamin D_3) or provided in the diet (vitamin D_2 or D_3). It is converted by reactions occurring first in the liver (making calcidiol) and then kidney (making calcitriol, the active form). Once active, vitamin D works in several ways to ensure blood calcium homeostasis and enhance the availability of calcium for bone mineralization. "The Functions of Vitamin D" by Allison Calabrese is licensed under CC BY 4.0.

Beyond its role in bone health, vitamin D has many other functions in the body. Cells throughout the body have vitamin D receptors in their nuclei, and by binding to these receptors, vitamin D is thought to regulate the expression of hundreds of genes. Specifically, vitamin D is known to play important roles in regulating cellular differentiation and growth, immunity, insulin secretion, and blood pressure. Studies have found *correlations* between low circulating vitamin D levels and increased risks of chronic diseases, including cancer, diabetes, cardiovascular disease, and multiple sclerosis. However, it has been difficult to determine if a lack of vitamin D actually contributes to the *cause* of these diseases, and research in this area is ongoing.[1]

Sunlight as a Source of Vitamin D

In most people, vitamin D synthesis in the skin provides a significant portion of their body's needs, and a little sun exposure can go a long way. Vitamin D researchers suggest that most people need between 5 and 30 minutes of sun exposure between 10 AM and 3 PM, at least twice per week, to synthesize adequate vitamin D. However, any factor that decreases exposure to UV rays can interfere with vitamin D synthesis, including the following:[2]

- **Geographic latitude and season.** Your location on Earth and the time of the year affect your exposure to UV radiation from the sun. Exposure to UV light is greatest at the equator and declines as you move further north or south. Likewise, in the summer months, the sun is directly overhead for a greater part of the day, so you have more opportunities to synthesize vitamin D. In the winter, the sun stays lower in the sky, day length is shorter, and cloud cover is more likely to block the sun's rays, all of which decrease opportunities to synthesize vitamin D. North of about 35 degrees latitude, vitamin D synthesis is inadequate

for at least a few months during the winter because the sun simply doesn't get high enough in the sky to provide enough UV radiation on earth's surface. For example, in Boston and at the California-Oregon border (42nd parallel north), vitamin D synthesis occurs only from March until October. However, in Los Angeles (34th parallel north), vitamin D synthesis occurs year-round. Ozone and air pollution also can block UV rays and decrease vitamin D synthesis.

- **Skin pigmentation.** Darker skin pigmentation, caused by greater melanin production in the skin, decreases UV light absorption. This helps to protect the skin from damage from UV radiation—a helpful adaptation for those living closer to the equator—but it also reduces synthesis of vitamin D. People with darker skin pigmentation need to spend more time in the sun to synthesize the same amount of vitamin D as lighter-skinned people.
- **Age.** The efficiency of vitamin D synthesis declines with age. In addition, older adults often spend less time outside and may thus receive less exposure to sunlight.
- **Sun-protective behavior.** While some UV light exposure is needed to synthesize vitamin D, UV radiation is also carcinogenic, and too much exposure increases the risk of skin cancer. It's wise to protect your skin from UV radiation by applying sunscreen, covering up with clothing and a hat, finding shade, and avoiding sun exposure in the middle of the day. People who are highly vigilant in these sun-protective behaviors or simply aren't able to go outside during the day (UV rays don't penetrate glass) may not get enough UV light for vitamin D synthesis.

With so many factors affecting UV radiation exposure, many people cannot synthesize enough vitamin D for at least part of the year. Because vitamin D is fat-soluble, liver and adipose storage can supply the body for a while. Beyond that, dietary sources and supplements may be needed to meet the vitamin D requirement.[2]

Dietary Sources of Vitamin D

Only a few foods are naturally good sources of vitamin D. These include fatty fish such as salmon, tuna, and mackerel, as well as cod liver oil. Smaller amounts are found in egg yolks, cheese, and beef liver. Additionally, some mushrooms grown in UV light can be a good source of vitamin D.

Most cow's milk is fortified with vitamin D in the U.S. and Canada, but other dairy products such as ice cream and cheese are not. Fortified orange juice, soymilk, and other plant-based beverages, and breakfast cereal can all contribute to dietary intake of vitamin D, although amounts added vary significantly between products.[2]

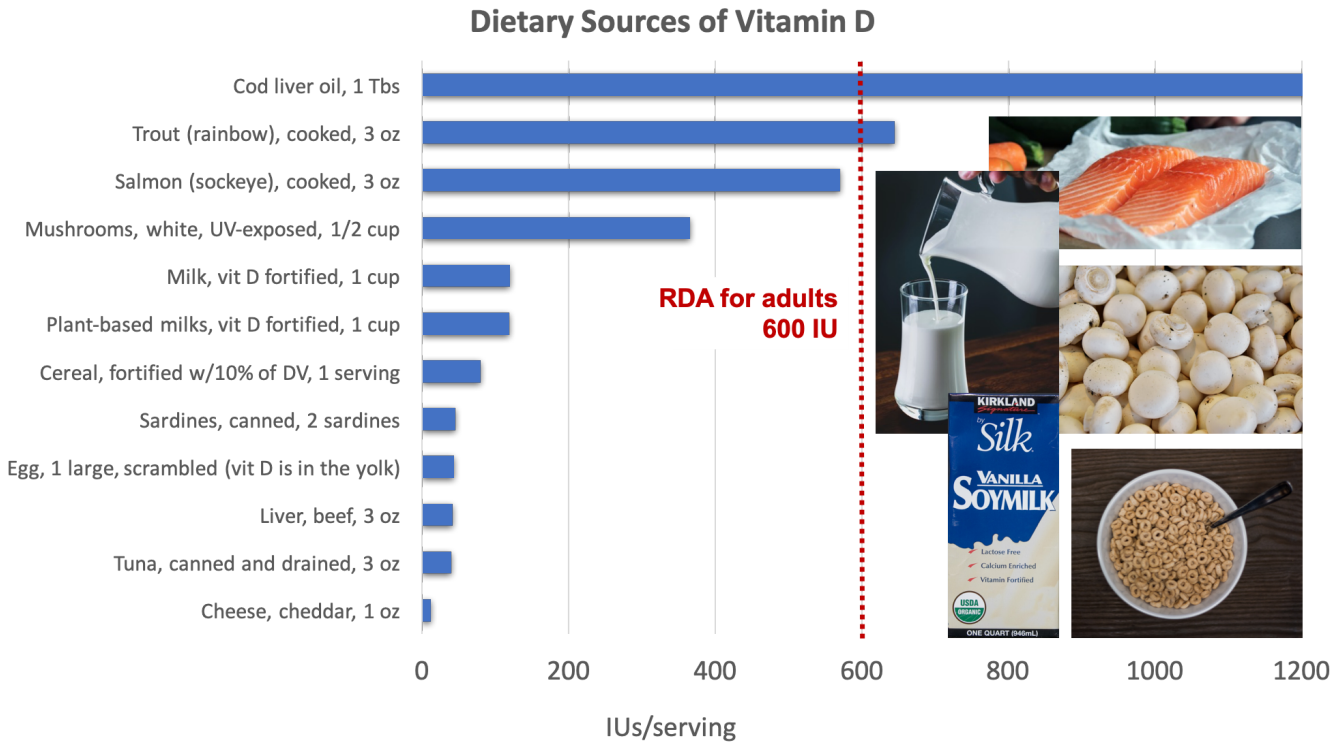


Figure 8.6.4.2: Dietary sources of vitamin D. Source: Examples of good sources pictured include salmon, milk, mushrooms, fortified soy milk, and fortified cereal. NIH Office of Dietary Supplements "Dietary sources of vitamin D" by Alice Callahan is

licensed under CC BY 4.0, with the following images: "person pours milk into a glass" by Eiliv-Sonas Aceron, "raw fish meat on brown chopping board" by CA Creative, "white mushrooms" by Waldemar Brandt, and "cereals in bowl with spoon" by John Matychuk are all licensed under the standard Unsplash License; "soymilk" by Ian Fuller is licensed under CC BY-NC 2.0.

Both vitamin D_2 and D_3 supplements are also available. Some studies have found D_3 to be more effective at raising circulating vitamin D levels, but others haven't found a difference in the efficacy of the two forms.[1,2] Vegans should be aware that vitamin D_3 is typically sourced from sheep lanolin, whereas D_2 is typically sourced from plants. Human breast milk doesn't contain adequate vitamin D, so the American Academy of Pediatrics recommends that breastfed infants receive a supplement with 400 IU of vitamin D per day until they are weaned to vitamin D-fortified formula or cow's milk. A vitamin D supplement may also be recommended for older children and adults, depending on dietary intake and sun exposure, but this should be discussed with a healthcare provider.

Vitamin D Deficiency and Toxicity

In children, vitamin D deficiency causes ***rickets***, a disease in which the bones are soft, weak, and deformed. Rickets was very common in the US until the 1930s, when milk processors were asked to add vitamin D to cow's milk. Milk fortification has virtually eliminated rickets from the US and other developed countries. However, rickets does still occur in breastfed infants and children raised on vegan diets who aren't provided with other sources of vitamin D, particularly if they have darker skin pigmentation.[1,3]



Figure 8.6.4.3: Vitamin D deficiency in children causes rickets, a disease in which inadequate vitamin D leads to soft, weak, and deformed bones. "Three children with rickets" by anonymous and digitized and shared as part of the Wellcome Collection is licensed under CC BY 4.0.

In adults, vitamin D deficiency causes ***osteomalacia***, characterized by bone softening, reduced bone mineral density, and increased risk of osteoporosis. Because bones are continuously remodeled throughout the lifespan, inadequate vitamin D limits the calcium available to rebuild bone tissue. Vitamin D deficiency can also cause bone pain, as well as muscle weakness and pain, symptoms that can increase the risk of falling and fractures, particularly in older adults.[2]

Although vitamin D toxicity is rare, taking excessive amounts of vitamin D in supplement form can lead to ***hypercalcemia*** or high blood calcium. Hypercalcemia can cause kidney damage and calcium deposits to develop in soft tissues such as the kidneys, blood vessels, or other parts of the cardiovascular system. Synthesis of vitamin D from the sun does not cause vitamin D toxicity because vitamin D synthesis is tightly regulated and decreases if the body has abundant vitamin D.

Attributions:

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8.7: Vitamins and Minerals Involved in Energy Metabolism

Have you ever heard that taking vitamins will give you more energy? Or have you bought a product that claimed it could boost your energy level because it has added vitamins? Based on the knowledge that you've learned in this course, you know that vitamins are not broken down in the body to provide energy. So, where does the idea that vitamins give you energy come from? On this page, we will provide an overview of the B vitamins and several minerals that are important to the process of energy metabolism in the body and take a closer look at two of those vitamins (folate and vitamin B12) that have some important implications in our health.

The Role of B Vitamins and Minerals in Energy Metabolism

All the B vitamins and several minerals play a role in energy metabolism; they are required as functional parts of enzymes involved in energy release and storage. Many enzymes don't work optimally or even at all unless bound to other specific helper molecules, called ***coenzymes*** or ***cofactors***. Binding to these molecules promotes optimal conformation and function for their respective enzymes.

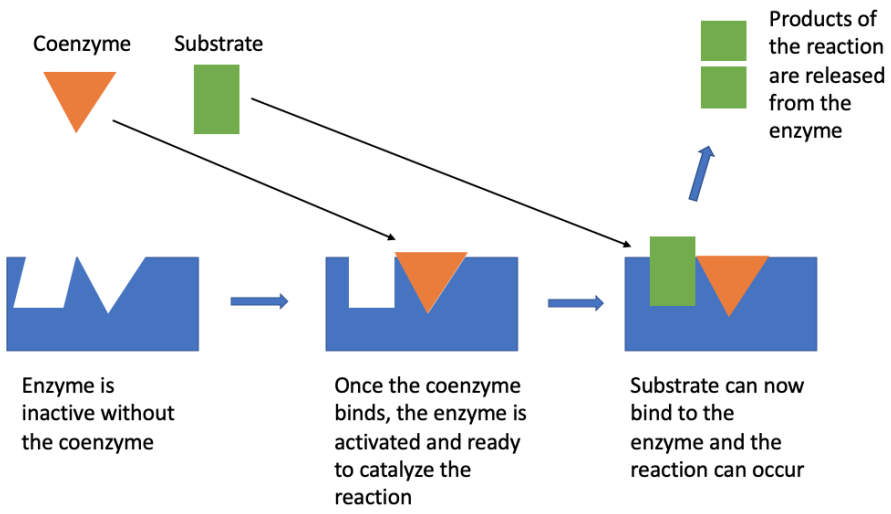


Figure 8.7.1: Role of a coenzyme assisting in an enzymatic reaction to break down a substrate. "Role of coenzyme" by Heather Leonard is licensed under CC BY 4.0.

Vitamins that bind to enzymes are referred to as **coenzymes**—*organic* molecules that enzymes require to catalyze a specific reaction. They assist in converting a substrate to an end product. **Cofactors** are the *inorganic* minerals that assist in these enzymatic reactions. Coenzymes and cofactors are essential in catabolic pathways (i.e., breaking down substances) and play a role in many anabolic pathways (i.e., building substances).

Table displays nutrients involved in energy metabolism and their key functions

Nutrients Involved in Energy Metabolism	
B Vitamins	**Role in Energy Metabolism**
Thiamin (B_1)	Assists in glucose metabolism and RNA, DNA, and ATP synthesis
Riboflavin (B_2)	Assists in carbohydrate and fat metabolism
Niacin (B_3)	Assists in glucose, fat, and protein metabolism
Pantothenic Acid (B_5)	Assists in glucose, fat, and protein metabolism, cholesterol and neurotransmitter synthesis
Pyridoxine (B_6*)	Assists in the breakdown of glycogen and synthesis of amino acids, neurotransmitters, and hemoglobin

Biotin (B_7)	Assists in amino acid synthesis and glucose, fat, and protein metabolism,
Folate (B_9)	Assists in the synthesis of amino acids, RNA, DNA, and red blood cells
Cobalamin (B_{12}*)	Protects nerve cells and assists in fat and protein catabolism, folate function, and red blood cell synthesis
Minerals	**Role in Energy Metabolism**
Iodine	Assists in metabolism, growth, development, and synthesis of thyroid hormone
Manganese	Assists in carbohydrate and cholesterol metabolism, bone formation, and the synthesis of urea
Sulfur	A component in sulfur-containing amino acids necessary in certain enzymes; a component in thiamin and biotin
Chromium	Assists in carbohydrate, lipid, and protein metabolism, DNA and RNA synthesis
Molybdenum	Assists in the metabolism of sulfur-containing amino acids and synthesis of DNA and RNA

*Normally used instead of common names

Table 8.7.1: Vitamins and minerals involved in energy metabolism and the role they each play. “Vitamins and minerals involved in energy metabolism” by Heather Leonard is licensed under CC BY 4.0.

Do B Vitamins Give You Energy?

Because B vitamins play so many important roles in energy metabolism, it is common to see marketing claims that B vitamins boost energy and performance. This is a myth that is not backed by science. The “feeling” of more energy from energy-boosting supplements stems more from the high amount of added sugars, caffeine, and other herbal stimulants accompanying the high doses of B vitamins in these products. 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. And because B vitamins are water-soluble, they are not stored in the body, and any excess will be excreted, essentially flushing out the added expense of the supplements.

Deficiency and Toxicity

The B vitamins important for energy metabolism are naturally present in numerous foods, and many other foods are enriched with them; therefore, B vitamin deficiencies are rare. Similarly, most of the minerals involved in energy metabolism and listed above are trace minerals that are not frequently deficient in the diet. However, when a deficiency of one of these vitamins or minerals does occur, symptoms can be seen throughout the body because of their relationship to energy metabolism, which happens in all cells of the body. A lack of these vitamins and minerals typically impairs blood health and the conversion of macronutrients into usable energy, known as ATP. Deficiency can also lead to increased susceptibility to infections, tiredness, lack of energy, and decreased concentration. Groups most at risk for a deficiency in any of these micronutrients are people on Calorie-limited diets, people with imbalanced or insufficient nutrition, people with eating disorders, and people experiencing extensive levels of physical or emotional stress.[1]

Because of their water-solubility, toxicities of most of these nutrients are also uncommon, as excess intake is often excreted from the body. That doesn’t mean taking high doses comes without risks. Large quantities, particularly through supplements, can lead to adverse side effects or cause interactions with medications. For example, too much niacin can cause skin flushing or dangerous drops in blood pressure, and a high intake of B_6 can lead to **neuropathy**, described as pain, numbness or tingling in the body

from nerve damage. When taking vitamin or mineral supplements, always pay attention to the Recommended Dietary Allowance (RDA) and avoid exceeding the Tolerable Upper Intake Level (UL).

Folate

Folate, or vitamin B_9, is a required coenzyme for the synthesis of several amino acids 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 anemia***. Macrocytic means "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 that are less efficient at carrying oxygen to 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.

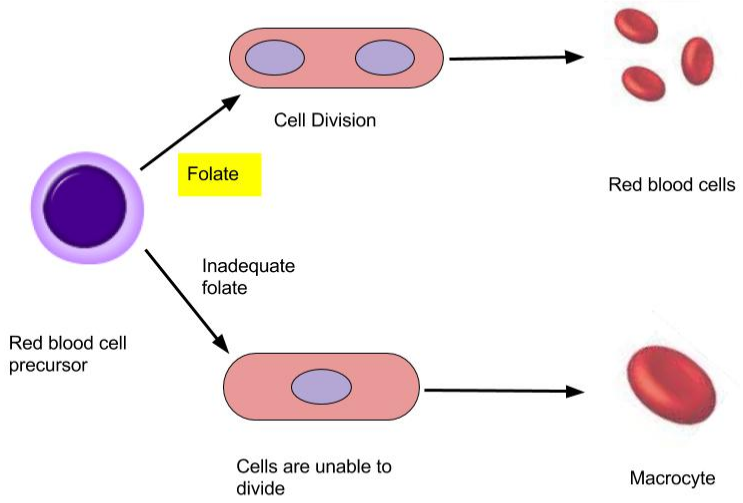


Figure 8.7.2: Folate and the formation of macrocytic anemia. "Folate and the formation of macrocytic anemia" by Allison Calabrese is licensed under CC BY 4.0.

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 in a developing fetus when the spine does not completely enclose the spinal cord. Spina bifida can lead to many physical and mental disabilities. In 1998, the US Food and Drug Administration (FDA) began requiring manufacturers to enrich breads, cereals, flours, and cornmeal with ***folic acid*** (a synthetic form of folate) to increase the consumption of folate in the American diet and reduce the risk of neural tube defects. Observational studies show that the prevalence of neural tube defects decreased after the fortification of enriched cereal and grain products with folate compared with before these products were fortified.

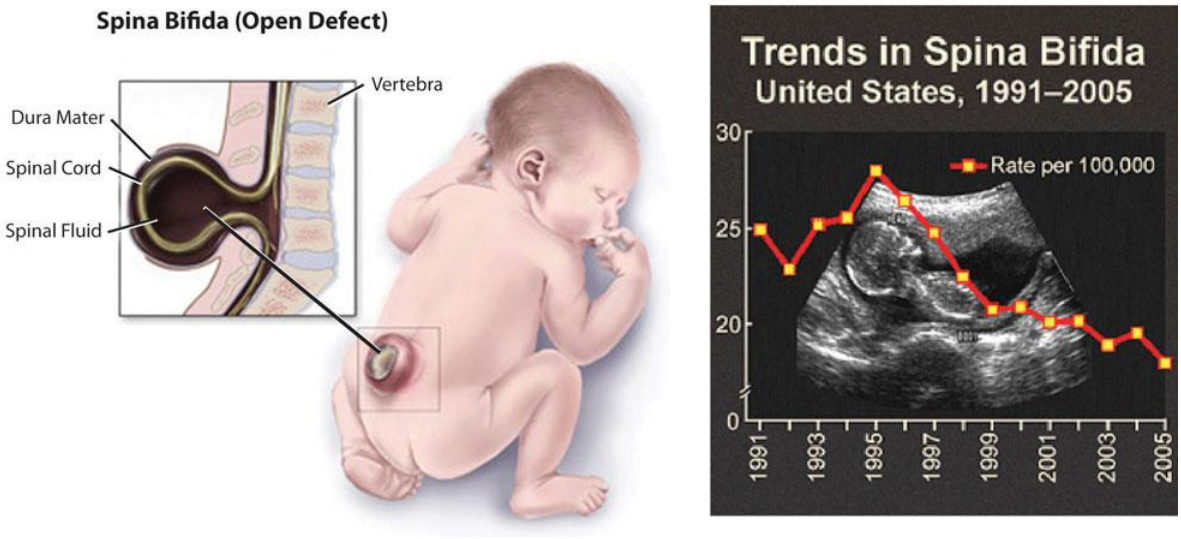


Figure 8.7.3: Spina bifida (left) is a neural tube defect that can have serious health consequences. The prevalence of cases of spina bifida has decreased significantly with the enrichment of cereal and grain products in the United States beginning in 1998. "Spina bifida in infants" by Centers for Disease Control and Prevention is in the Public Domain.

Additionally, clinical trials have demonstrated that neural tube defects are significantly decreased in the offspring of mothers who began taking folic acid supplements one month before becoming pregnant and throughout pregnancy. In response to the scientific evidence, the Food and Nutrition Board at the National Academies of Sciences, Engineering, and Medicine raised the RDA for folate to 600 micrograms per day for pregnant women.

Dietary Sources of Folate

Folate is found naturally in a wide variety of foods, including vegetables (particularly dark leafy greens), fruits, nuts, beans, legumes, meat, poultry, eggs, and grains. As mentioned, folic acid (the synthetic form of folate) is also found in enriched foods such as grains.

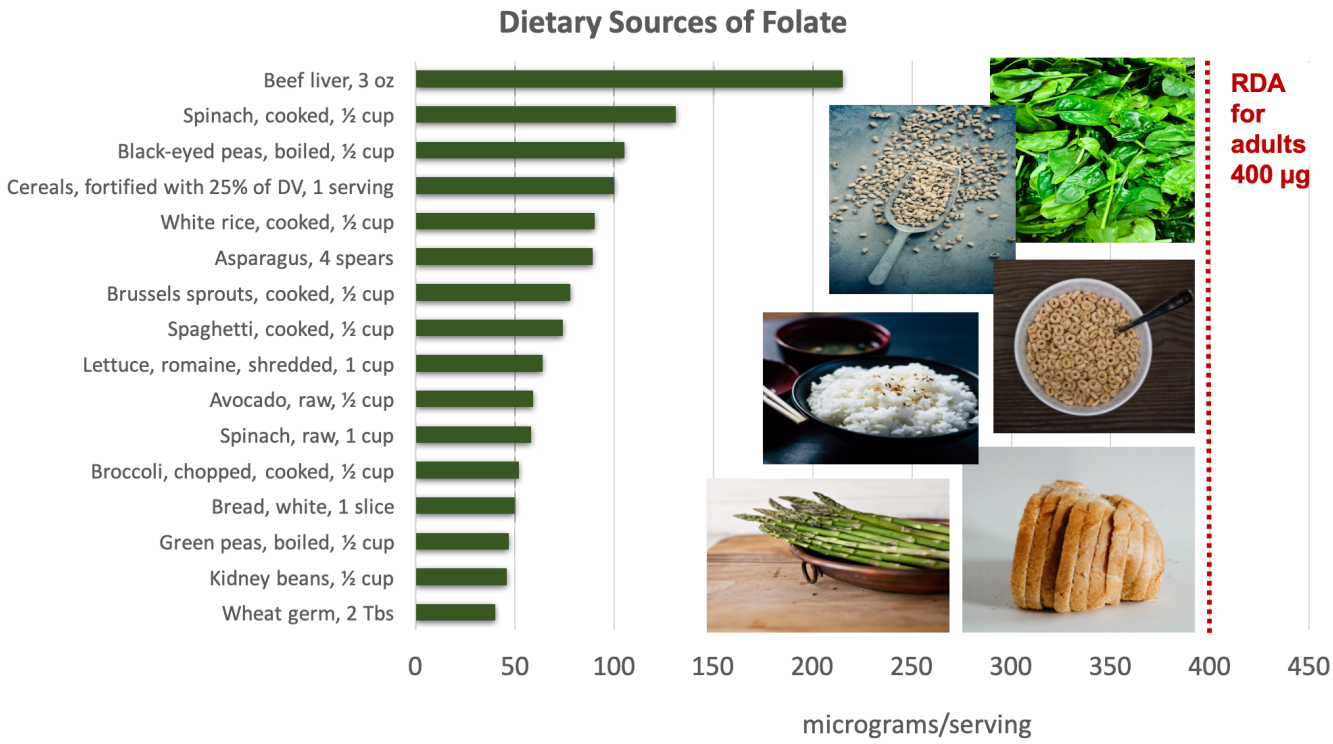


Figure 8.7.4: Dietary sources of folate. Examples of good sources pictured include spinach, black-eyed peas, enriched cereal, rice, bread, and asparagus. Source: NIH *Office of Dietary Supplements*. "Dietary sources of folate" by Alice Callahan is licensed

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Folate Deficiency and Toxicity

Folate deficiency is typically due to an inadequate dietary intake; however, smoking and heavy, chronic alcohol intake can also decrease absorption, leading to a folate deficiency.[2] The primary sign of a folate deficiency is **macrocytic anemia**, characterized by large, abnormal red blood cells, which can lead to fatigue, weakness, poor concentration, headache, irritability, and shortness of breath. Other symptoms of folate deficiency include mouth sores, gastrointestinal distress, and changes in the skin, hair, and nails. Women with insufficient folate intakes are at increased risk of giving birth to infants with neural tube defects and low intake during pregnancy has been associated with preterm delivery, low birth weight, and fetal growth retardation.[3]

The toxicity of folate from excess consumption in foods is not typically seen. However, there is concern regarding a high intake of folic acid from supplements because it could mask a deficiency in vitamin B_{12}. Because folate and vitamin B_{12} deficiencies manifest similar anemias, if a person with vitamin B_{12} deficiency is taking a high dose of folic acid, the macrocytic anemia would be corrected, while the underlying B_{12} deficiency went undetected, which could result in significant neurological damage. Thus, a tolerable upper intake level (UL) has been established for folate to prevent irreversible neurological damage due to high folic acid intake, masking a B_{12} deficiency.[2]

Vitamin B12 (Cobalamin)

Vitamin B_{12} is a unique vitamin because it contains an element (cobalt) and is found almost exclusively in animal products. Neither plants nor animals can synthesize vitamin B_{12}; only bacteria can synthesize it. The vitamin B_{12} found in animal-derived foods was produced by microorganisms within the animals. Animals consume the microorganisms in soil, or microorganisms in the GI tract of animals produce vitamin B_{12} that can then be absorbed.

Vitamin B_{12} helps to prevent the breakdown of the ***myelin sheath,*** a cover that surrounds and protects nerve cells. It is also an essential part of coenzymes. It is necessary for fat and protein catabolism, folate coenzyme function, and hemoglobin synthesis. A folate-dependent enzyme needs an enzyme requiring vitamin B12 to synthesize DNA. Thus, a deficiency in vitamin B_{12} has similar consequences to health as a 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.

For the human body to absorb vitamin B_{12}, the stomach, pancreas, and small intestine must function 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 caused either 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 older adults, who may have impaired functioning of digestive organs, a normal consequence of aging. Some metabolic surgeries, such as bariatric surgery, also increase Vitamin B12 deficiency risk because of changes in the stomach and/or small intestines that limit secretion and absorption.

Vitamin B_{12} and folate play key roles in converting ***homocysteine***, an amino acid found in the blood, to the amino acid methionine. High levels of homocysteine in the blood increase the risk for heart disease. Low levels of vitamin B_{12}, folate, or vitamin B_6 will increase homocysteine levels, thereby increasing the risk of heart disease.

Dietary Sources of Vitamin B12

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}. Because vitamin B_{12} is only found primarily in animal products, it is important for strict vegetarians who consume no animal products (vegans) to get vitamin B_{12} either through fortified products like cereals and milk alternatives, nutritional yeast, or supplements. Recent research suggests some plant-based sources like edible algae, mushrooms, and fermented vegetables may contain substantial amounts of vitamin B_{12} as well.[2]

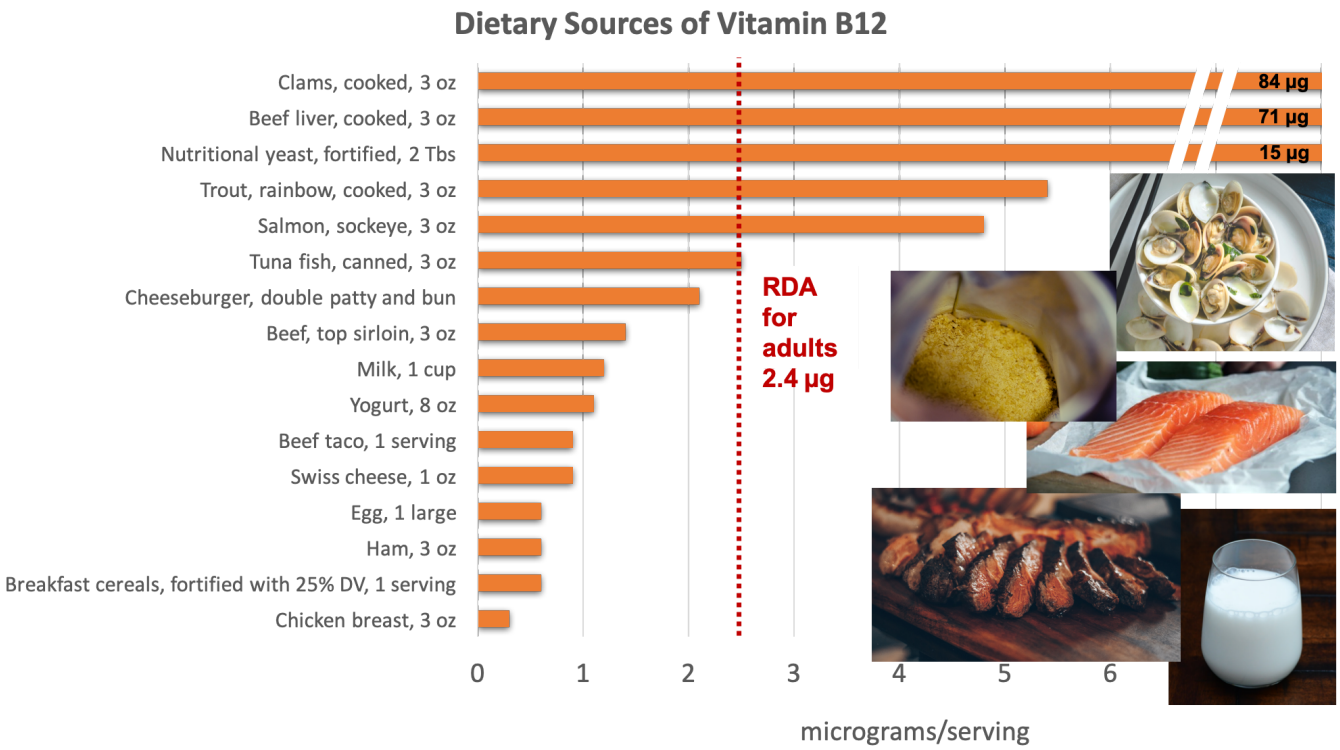


Figure 8.7.5: Dietary sources of vitamin B $_{12}$. Examples of good sources pictured include clams, salmon, nutritional yeast, red meat, and milk. Source: NIH Office of Dietary Supplements, www.bragg.com. “Dietary sources of vitamin B12” by Alice Callahan is licensed under CC BY 4.0, with the following images: "Clams" by Eiliv-Sonas Aceron, "raw fish meat on brown chopping board" by CA Creative, "cooked, sliced red meat"by Emerson Vieira, "glass of milk" by Kim Gorga, are licensed under the standard Unsplash License; "Nutritional yeast in bag" by Tony Webster is licensed under CC BY 2.0.

Vitamin B12 Deficiency and Toxicity

A vitamin B_{12} deficiency prevents the conversion of inactive folate (from food) to active folate in the body for the synthesis of DNA. However, folic acid from supplements or fortified foods can 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. Vitamin B_{12} deficiency also results in nerve degeneration and abnormalities that can often precede the development of anemia. These include a decline in mental function and burning, tingling, and numbness of the legs. These symptoms can continue to worsen, and deficiency can be fatal.[4]

The most common cause of vitamin B_{12} deficiency is the condition of inadequate intrinsic factor production that leads to poor vitamin B_{12} absorption, resulting in pernicious anemia. This condition is common in people over the age of 50 because the production of intrinsic factors decreases with age. Pernicious anemia is treated by large oral doses of vitamin B_{12} or by putting the vitamin under the tongue (sublingual), 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.

Because vitamin B_{12} is found primarily in foods of animal origin, a vegan diet can result in cases of vitamin B_{12} deficiency. Therefore, careful dietary planning to include fortified sources or supplements of vitamin B_{12} is important to prevent deficiency in this population.

No toxicity of vitamin B_{12} has been reported. Because of the low risk for toxicity, a tolerable upper intake level (UL) has not been established for vitamin B_{12}.[4]

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8.8: Vitamins and Minerals Involved in Blood Health

Blood is essential to life. It transports absorbed nutrients and oxygen to cells, removes metabolic waste products for excretion, and carries molecules, such as hormones, to allow for communication between organs.

Blood is a connective tissue of the circulatory system, made up of four components forming a matrix:

- ***red blood cells,*** erythrocytes, which transport oxygen to cells
- ***white blood cells,*** leukocytes, which are part of the immune system and help destroy foreign invaders
- ***platelets,*** which are fragments of cells that circulate to assist in blood clotting
- ***plasma,*** which is the fluid portion of the blood and contains proteins that help transport nutrients and aid in blood clotting.

Maintaining healthy blood, including its continuous renewal, is essential to support its vital functions. Blood health is acutely sensitive to deficiencies in some vitamins and minerals,especially iron and vitamin K.

Iron

Iron is a trace mineral. It is a necessary component of many proteins in the body responsible for functions such as the transport of oxygen energy metabolism, immune function, and antioxidant defense. Iron is also important in brain development and function.

Iron is essential for oxygen transport because of its role in ***hemoglobin***, a protein in red blood cells that transports oxygen to cells and gives red blood cells their color. Hemoglobin is composed of four globular peptides, each with an iron-containing heme complex in the center (Figure 8.8.1).

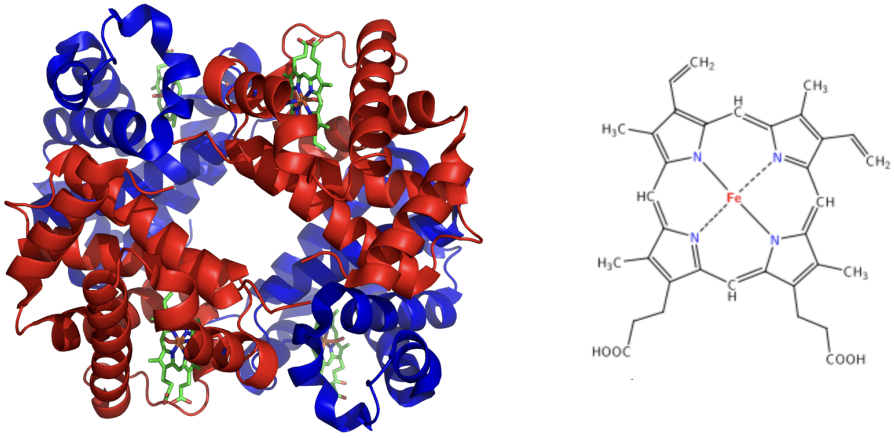


Figure 8.8.1: The structure of hemoglobin and the heme complex. On the left, the structure of hemoglobin includes four globular peptides (shown in blue and red) and the iron-containing heme groups (shown in green). On the right is a closer view of the heme complex. "Structure of Hemoglobin" by Zephyris is licensed under CC BY-SA 3.0 and "Heme" by Lennert B is in the Public Domain.

The iron in hemoglobin is what binds to oxygen, allowing for transportation to cells. If iron levels are low, hemoglobin is not synthesized in sufficient amounts, and the oxygen-carrying capacity of red blood cells is reduced, resulting in ***anemia***. Iron is also an important part of ***myoglobin***, a protein similar to hemoglobin but found in muscles.

Dietary Sources of Iron

There are two types of iron found in foods:***heme iron*** and ***non-heme iron***.

- **Heme iron** is part of the proteins hemoglobin and myoglobin, so it is found only in foods of animal origin, such as meat, poultry, and fish. Heme iron is the most bioavailable form of iron. About 40% of the iron in animal foods is heme iron, and 60% is non-heme iron.
- **Non-heme iron** is the mineral by itself and is not a part of hemoglobin or myoglobin. Non-heme iron can be found in foods from both plants, including nuts, beans, vegetables, and fortified and whole grains, as well as animals. It is **less bioavailable** than heme iron. Consuming vitamin C, meat, poultry, and seafood with non-heme iron increases its bioavailability. For example, eating an orange, a good source of vitamin C, along with your bowl of vegetarian chili will help you to absorb more of

the iron from the beans and vegetables. On the other hand, chemicals such as phytates found in beans and grains and plant polyphenols found in fruits, vegetables, some cereals, legumes, tea, coffee, and wine decrease bioavailability due to binding with iron.[1]

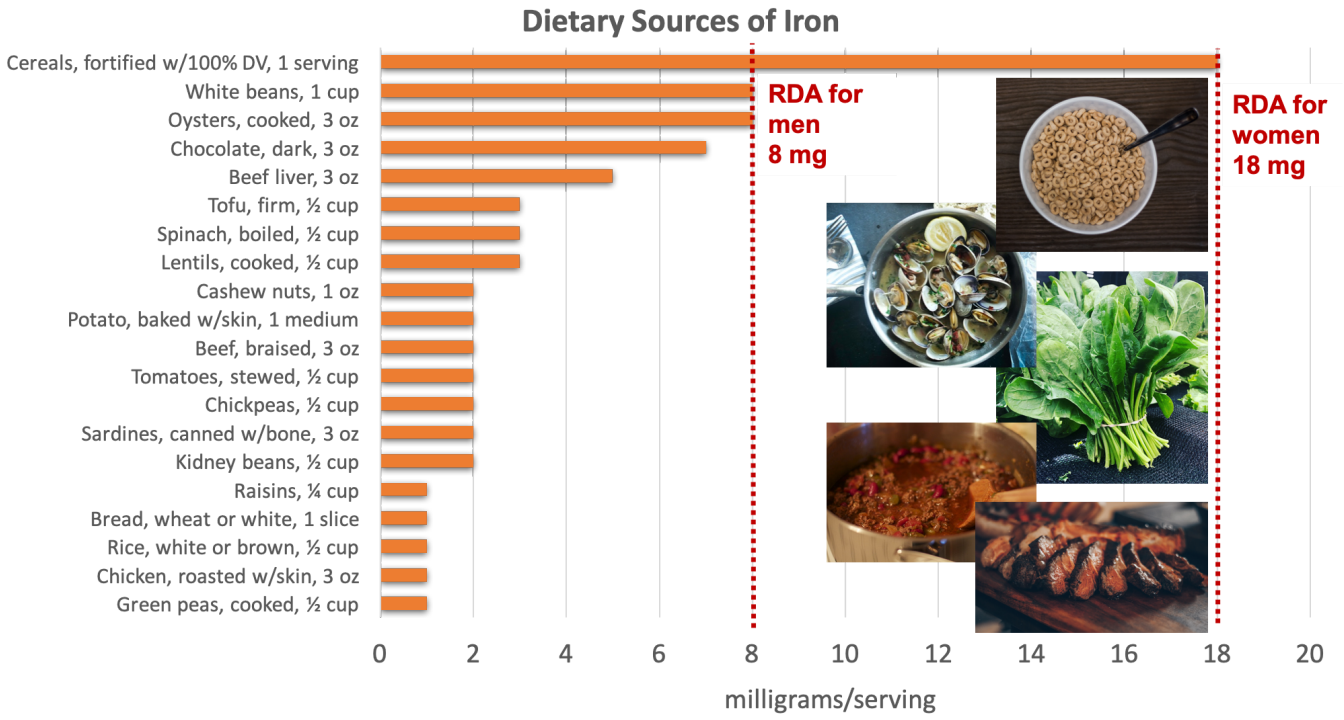


Figure 8.8.2: Dietary sources of iron. Good sources pictured include fortified cereal, clams, spinach, lentils, and red meat. Source: NIH Office of Dietary Supplements “Dietary sources of iron” by Alice Callahan is licensed under CC BY 4.0, with the following images: "cereals in bowl with spoon" by John Matychuk, "seafood boil" by WikiSleep App, "Spinach in the Farmer's Market" by Elianna Friedman, "cooked, sliced red meat" by Emerson Vieira, are licensed under the standard Unsplash License; “Superbowl Chili” by Jake Przespo is licensed under CC BY 2.0.

The bioavailability of iron is approximately 14% to 18% from mixed diets and 5% to 12% from vegetarian diets.[2] Bioavailability is influenced by the dietary factors previously mentioned, as well as iron status. The body has no physiological mechanism to excrete iron; therefore, iron balance is tightly regulated by absorption.[2] When iron stores are low, more dietary iron will be absorbed.

Most of the body’s iron needs are not met by dietary sources but rather by recycling iron within the body, referred to as ***endogenous*** sources. Ninety percent of daily iron needs are met by recycling iron released from the breakdown of aging cells, mostly red blood cells.[2]

Iron Deficiency and Toxicity

Iron deficiency is one of the most common nutrient deficiencies, affecting more than a third of the world’s population.[3] ***Iron-deficiency anemia*** is a condition that develops from having insufficient iron levels in the body, resulting in fewer and smaller red blood cells that contain less hemoglobin. As a result, blood carries less oxygen from the lungs to cells. 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

Infants, children, adolescents, and women are the populations most at risk worldwide for iron-deficiency anemia.[4] Infants who are premature, have low birthweight, or have a mother with iron deficiency are at risk for iron deficiency because they are born with low iron stores relative to the amount needed for growth and development. Young children and adolescent girls are at risk for iron deficiency due to rapid growth, low dietary intake of iron, as well as heavy menstruation for adolescent girls. In these populations, iron-deficiency anemia can also cause the following signs and symptoms: ***pica*** (an intense craving for and ingestion of non-food items such as paper, dirt, or clay), 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, are also at risk for iron inadequacy due to their increased requirements for iron.

To give you a better understanding of these risks, it is helpful to look at how much higher the RDA is for women of reproductive age and pregnant women compared with men (Table 8.8.1).[1] To put this in perspective, 3 ounces of beef contains about 3 milligrams of iron, making it challenging for some women to meet their daily iron requirement.

Table displays the Recommended Daily Allowance of Iron for 3 population groups

Population Group	**RDA for Iron**
Women of reproductive age, 19-50 years	18 mg/day
Pregnancy, 19- 50 years	27 mg/day
Men, 19-50 years	8 mg/day

Table 8.8.1: A comparison of the RDAs for adult women of reproductive age, pregnancy, and adult men. "A comparison of the RDAs" by Tamberly Powell is licensed under CC BY 4.0 with data from National Institutes of Health Office of Dietary Supplements. *Iron – Health Professional Fact Sheet.* Retrieved April 29, 2020 from https://ods.od.nih.gov/factsheets/Iron-HealthProfessional/#en4

Additionally, those who frequently donate blood, as well as people with cancer, heart failure, or gastrointestinal diseases such as Crohn's, are at greater risk for iron inadequacy.

Iron deficiency progresses through three stages:

1. **Mild depletion of iron stores:** No physical symptoms will be present because hemoglobin levels are not affected, but there will be a decrease in ***ferritin,*** a storage form of iron.
2. **Iron-deficient erythropoiesis,** erythrocyte, or red blood cell production: Iron stores are depleted, and iron transport is decreased due to a decrease in ***transferrin,*** the transport protein for iron, but hemoglobin levels are usually within the normal range.
3. **Iron-deficiency anemia:** Iron stores are exhausted and hemoglobin levels are reduced, resulting in ***microcytic anemia*** (small red blood cells) and ***hypochromic anemia*** (low color red blood cells).

Healthy adults are at little risk of iron overload from foods, but too much iron from supplements can result in gastric upset, constipation, nausea, vomiting, and abdominal pain. The body excretes little iron; therefore, the potential for toxicity from supplements is a concern. In children, death has occurred from ingesting as little as 200 mg of iron, so it is critical to keep iron supplements out of children's reach. The tolerable upper intake for iron is 45 mg daily for adults, based on the amount that causes gastrointestinal distress.[1]

Vitamin K

Vitamin K refers to a group of fat-soluble vitamins that are similar in chemical structure. They act as coenzymes and have long been known to play an essential role in blood ***coagulation*** or clotting. Vitamin K is also required for maintaining bone health, as it modifies a protein that is involved in the bone remodeling process.

Dietary Sources of Vitamin K

Vitamin K is found in the highest concentrations in green vegetables, such as collard and turnip greens, kale, broccoli, and spinach. Soybean and canola oil are also common sources of vitamin K in the US diet.[5] Additionally, vitamin K can be synthesized by bacteria in the large intestine, but the bioavailability of bacterial vitamin K is unclear.

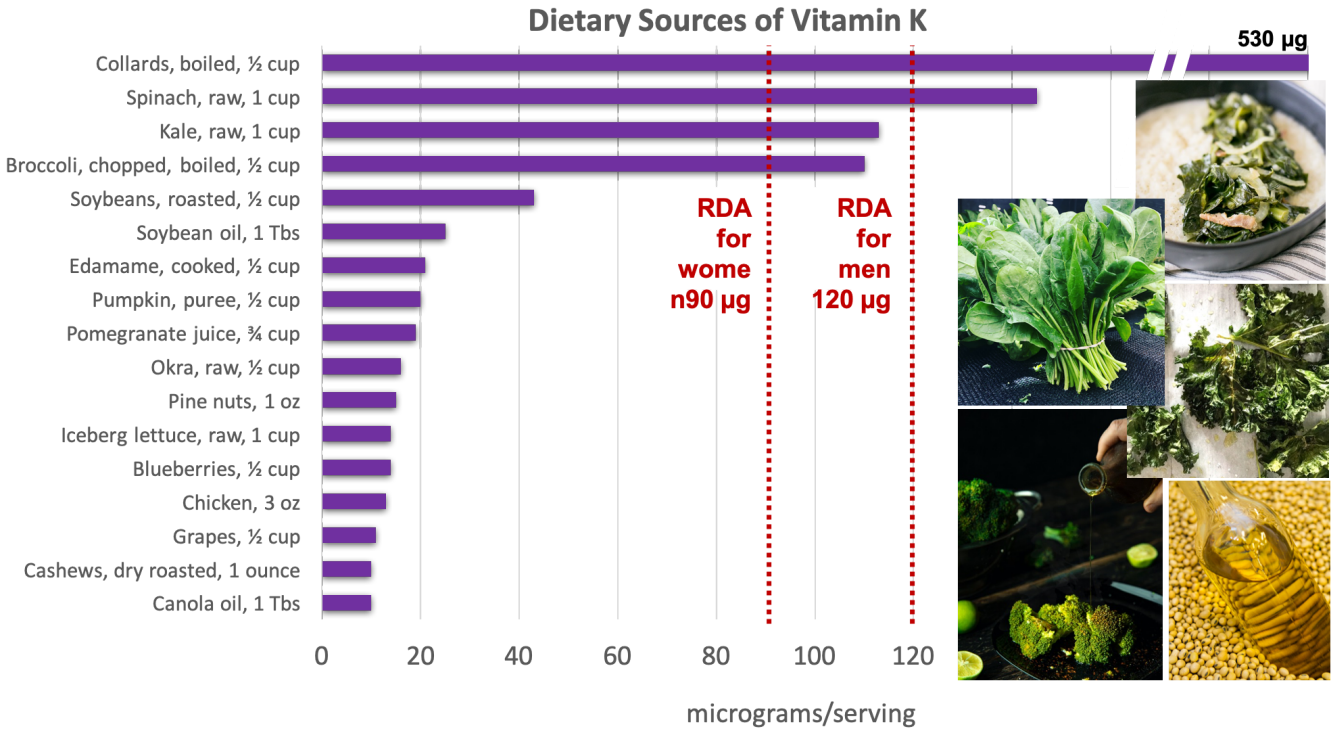


Figure 8.8.3: Dietary sources of vitamin K. Good sources pictured include chard, spinach, kale, broccoli, and soybean oil. Source: NIH Office of Dietary Supplements "Dietary sources of vitamin K" by Alice Callahan is licensed under CC BY 4.0, with the following images: "collard greens" by Kim Daniels, "Spinach in the Farmer's Market" by Elianna Friedman, "kale" by Ronit Shaked, "broccoli" by Sam Hojati, are licensed under the standard Unsplash License; "High oleic acid soybean oil_0030" by Mizzou CAFNR is licensed under CC BY-NC 2.0.

Vitamin K Deficiency and Toxicity

Vitamin K deficiency is rare, as most US diets are adequate in vitamin K.[5] A deficiency in vitamin K causes excessive bleeding, or ***hemorrhage***. When there is damage to a blood vessel that results in bleeding, like a small tear, the body can stop this bleeding through a cascade of reactions. Without adequate vitamin K, blood does not clot properly, and this small bleed can turn into a larger problem, causing excessive bleeding or hemorrhage. People at risk are those who have malabsorption and other gastrointestinal disorders such as celiac disease. Newborns are also at risk for vitamin K deficiency during the first few months of life, as there is poor transfer of vitamin K across the placenta, and breast milk is also low in vitamin K. Therefore, it has become a routine practice to inject newborns with a single intramuscular dose of vitamin K to prevent hemorrhaging, as bleeding within the skull is especially life-threatening.

The Food and Nutrition Board (FNB) has not established a UL for vitamin K because it has a low potential for toxicity. Some medications taken to reduce blood clotting risk require dietary adjustments so that Vitamin K intake does not interfere with the medication's intent. Anyone taking medications should talk to their healthcare provider about potential nutrient-medication interactions.

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8.9: Dietary Supplements

By now you know that a balanced, nutritious diet is important for good health. But you may also wonder if your diet is adequate, or if you could benefit from taking a vitamin or mineral supplement. You may also be curious about other supplements that claim to help you lose weight, build muscle, ease joint pain, or help build good bacteria in your gut.



Figure 8.9.1: "Woman holding probiotic capsule" photo by Daily Nouri is licensed under the standard Unsplash License.

According to the Centers for Disease Control and Prevention, 56% of US adults reported using supplements in 2017-2018.[1] With over half of Americans reporting dietary supplement use, it's important to have a conversation about the safety and efficacy of these products. Are dietary supplements safe? Are they effective? Do Americans need a multivitamin/mineral supplement? If so, what are the guidelines and recommendations for choosing a supplement? We will explore these important questions in this section.

Regulation of Dietary Supplements

A ***dietary supplement*** is defined as a product that:[2]

- is intended to supplement the diet
- contains one or more dietary ingredients (e.g., vitamins, minerals, herbs or other botanicals, amino acids, and enzymes)
- can be taken by mouth as a pill, capsule, tablet, or liquid
- is labeled as being a dietary supplement

The Food and Drug Administration (FDA) regulates dietary supplements, but under a different set of regulations than foods, pharmaceuticals, and over-the-counter drugs. In 1994, the Dietary Supplement Health and Education Act (DSHEA) created new regulations for the labeling and safety of dietary supplements. Under these rules, the **"FDA is not authorized to review dietary supplement products for safety and effectiveness before they are marketed**."[3] Therefore, the responsibility falls on the manufacturers and distributors of dietary supplements to ensure their products are safe before they go to consumers. **The FDA has to prove that the product is unsafe to remove it from the market.** This is a big contrast to pharmaceuticals, which must obtain approval from the FDA, showing substantial evidence that their drugs are safe and effective *before* reaching the marketplace.

The FDA issued Good Manufacturing Practices (GMPs) for dietary supplements in 2007. GMPs are a set of requirements and expectations by which dietary supplements must be manufactured, prepared, and stored to ensure quality. Manufacturers are expected to guarantee the identity, purity, strength, and composition of their dietary supplements.[4]

Once a dietary supplement is on the market, the FDA tracks side effects reported by consumers, supplement companies, and others. If the FDA finds a product unsafe, it can take legal action against the manufacturer or distributor and may issue a warning or require that the product be removed from the marketplace. However, the FDA says it can't test all products marketed as dietary supplements that may have potentially harmful hidden ingredients.

Safety of Dietary Supplements

Under current regulations, the safety of dietary supplements is the manufacturers' responsibility. Unfortunately, manufacturers don't always have the public's best interest in mind, especially when profit is at stake.



Figure 8.9.2: "Supplement display" by Angel Sinigersky is licensed under the standard Unsplash License.

According to the FDA website, the "FDA has found that manufacturing problems have been associated with dietary supplements. Products have been recalled because of microbiological, pesticide, and heavy metal contamination and because they do not contain the dietary ingredients they are represented to contain or they contain more or less than the amount of the dietary ingredient claimed on the label."[1]

What this means for consumers is that they should use caution when considering whether to use a dietary supplement. Keep in mind the following information from the Center for Complementary and Integrative Health at the National Institutes of Health:[2]

- **What's on the label may not be what is in the product.** For example, the FDA has found prescription drugs, including anticoagulants and anticonvulsants, in products being sold as dietary supplements. You can see a list of some of those products on the FDA's Tainted Supplements webpage.
- **Supplement labels may make illegal claims** to make their product more appealing. A 2012 Government study of 127 dietary supplements marketed for weight loss or to support the immune system found that 20 percent made illegal claims.
- **Dietary supplements can interact with other medications and cause harm**. For example, the herbal supplement St. John's wort makes many medications less effective.
- **The term natural does not always mean safe.** Ephedra, an evergreen plant native to central Asia, is associated with heart problems and risk of death. In 2004, the FDA banned the sale of ephedrine in dietary supplements for these reasons. Supplements can contain natural herbs and other plant-based ingredients that have not been adequately studied. We don't know if supplement ingredients are dangerous until people end up very sick or even die from consuming them. Dietary supplements result in an estimated 23,000 emergency room visits every year in the United States, according to a 2015 study. Many of the patients are young adults having heart problems from weight-loss or energy products and older adults having swallowing problems from taking large vitamin pills.
- **The term"standardized," "verified," or "certified" on a supplement does not always guarantee product quality or safety.** Manufacturers use these terms to sell their product, but they have not been legally defined.

You can report safety concerns about a dietary supplement through the U.S. Health and Human Services Safety Reporting Portal. For more information on contaminants in dietary supplements, visit the FDA's Dietary Supplement Products & Ingredients webpage.

Efficacy of Dietary Supplements

The amount of scientific evidence on dietary supplements varies widely—there is a lot of information on some and very little on others. The Center for Complementary and Integrative Health at the National Institutes of Health offers these key points about the efficacy of dietary supplements:[2]

- Dietary supplements can't be marketed with claims that they can diagnose, treat, cure, mitigate, or prevent any disease; such claims would require the product to be approved by the FDA as a pharmaceutical. Instead, dietary supplements are marketed with health claims or structure/function claims, similar to claims on food labels. Recall from an earlier chapter that structure/function claims, such as "builds strong bones" or "boosts immunity", are intentionally vague and require no evidence to support them. Supplements are often labeled with claims that have little to no scientific basis.
- Studies have found that some dietary supplements may have benefits, such as melatonin for jet lag. Others may have little or no benefit, such as ginkgo for dementia. Many dietary supplements haven't been studied at all in humans.
- Studies of many supplements haven't supported claims made about them. For example, in several studies, echinacea didn't help cure colds and Ginkgo biloba wasn't useful for dementia—but you can still find Ginkgo biloba supplements with claims that they improve memory and echinacea supplements with claims of providing "immune support." Often, the research on dietary supplements is conflicting, such as whether the supplements glucosamine and chondroitin improve symptoms of osteoarthritis. Research design and interpretation can also be biased when funded by the supplement industry.
- Most research shows that taking multivitamin/mineral supplements doesn't result in living longer, slowing cognitive decline, or lowering the chance of getting cancer, heart disease, or diabetes. However, taking a multivitamin is unlikely to pose health risks, provided you follow the guidelines below for choosing supplements.

Guidelines for Choosing Supplements

Throughout this text, we have discussed the importance of whole foods. As you might suspect, supplements can not replace real, whole food. Marion Nestle, professor emerita at New York University and author of many books about nutrition, wrote eloquently about the benefits of getting nutrients from food instead of supplements in a blog post:

> Unless you have been diagnosed with a vitamin or mineral deficiency and need to replenish that nutrient in a great big hurry, it is always better to get nutrients from foods—the way nature intended. I can think of three benefits of whole foods as compared to supplements:
>
> (1) you get the full variety of nutrients—vitamins, minerals, antioxidants, etc–in that food, not just the one nutrient in the supplement;
>
> (2) the amounts of the various nutrients are balanced so they don't interfere with each other's digestion, absorption, or metabolism; and
>
> (3) there is no possibility of harm from taking nutrients from foods (OK. Polar bear liver is an exception; its level of vitamin A is toxic).
>
> In contrast, high doses of single nutrients not only fail to improve health but also can make things worse, as has been shown in some clinical trials of the effects of beta-carotene, vitamin E, and folic acid, for example, on heart disease or cancer. And foods taste a whole lot better, of course.[5]

However, certain populations may be at risk for developing nutrient deficiencies, and they may benefit from a multivitamin supplements or specific nutrients. These groups include the elderly, vegans, people restricting their caloric intake, pregnant women, or individuals with food insecurity.[6]

If you choose to take supplements, keep moderation in mind and use the following guidelines to help you choose a supplement.

1. **Don't substitute for whole foods.** The Dietary Guidelines for Americans supports supplementation only when nutrient-dense foods don't meet nutritent requirements, particularly in pregnant women, infants, and older adults.[7] Whole foods are complex and not only contain essential vitamins and minerals but also dietary fiber and phytochemicals that may have positive health benefits. Supplements should never act as a replacement for whole foods but rather to fill in some nutritional gaps.

2. **Check the dose carefully.** Because dietary supplements are not regulated before they hit the market, it is not uncommon to find nutrient levels that exceed the upper intake level (UL). A good rule of thumb is to choose a supplement that keeps the dose close to 100% of the Daily Value (unless advised by a doctor to help correct a deficiency) and definitely no more than the UL.

3. **If getting supplements from multiple sources, make sure you add together the doses**. Supplements come not only in pill form but also in powder and liquid form. Vitamin water, protein powder, and other products like Emergen-C are often fortified with large amounts of vitamins and minerals.

4. **Be skeptical of product claims.** Remember that supplement manufacturers promote their products with structure/function claims, and they don't have to provide any evidence that the product actually does what it claims to do. If something sounds too good to be true, it probably is.

5. **Look for third-party testing when purchasing a supplement.** ConsumerLab.com, NSF International, US Pharmacopeia (USP), and UL are all companies that do third-party testing on dietary supplements.[8] If you see these companies' stamps (see Figure 8.5) on a supplement bottle, it means that the product is periodically tested to check that it

- Contains the ingredients listed on the label, in the declared potency and amounts.
- Does not contain harmful levels of specified contaminants (e.g., heavy metals and pesticides).
- Will break down and release into the body within a specified amount of time. (If a supplement does not break down properly to allow its ingredients to be available for absorption in the body, the consumer will not get the full benefit of its contents).

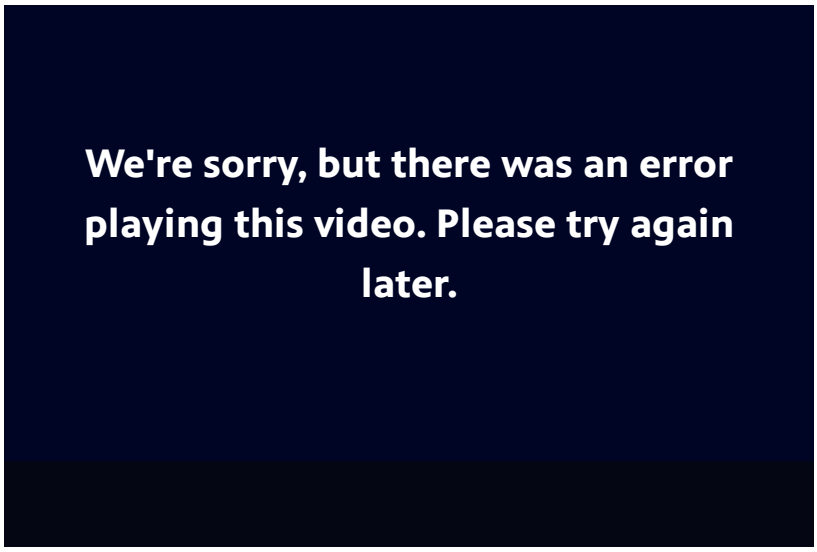


Figure 8.9.3: The US Pharmacopeia (USP) verification mark. USP is a nonprofit organization that does third-party testing on dietary supplements. This mark helps assure consumers that the product has been tested for quality, purity, potency, performance, and consistency.[9] "USP Verification Mark" by USP is used with permission.

6. **Choose a multivitamin mineral (MVM) supplement tailored to your age, gender, and other characteristics, such as pregnancy.** This is important because different populations have different nutrient needs. MVMs for seniors typically provide more calcium and vitamin D for bone health than MVMs for younger adults. MVMs for women contain more iron than MVMs for men. Prenatal supplements generally provide no vitamin A as retinol, and most children's MVMs provide age-appropriate nutrients amounts.[10]

7. **Check with your healthcare provider to ensure the supplement you are considering is safe for you.** Supplements can interact with both prescription medications and over-the-counter medications, potentially causing life-threatening complications.

Video 8.9.1: "Supplements and Safety" by Frontline, PBS.org (January 19, 2016, 54:11 minutes) provides an extensive look at the supplement industry.[11] "An investigation into the hidden dangers of vitamins and supplements, a multibillion-dollar industry with limited FDA oversight. Frontline, *The New York Times* and the Canadian Broadcasting Corporation examine the marketing and regulation of supplements, and cases of contamination and serious health problems." https://www.pbs.org/video/frontline-supplements-and-safety/



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CHAPTER OVERVIEW

9: Hydration

9.1: Introduction
9.2: Water’s Importance to Vitality
9.3: Water Balance in the Body
9.4: Overview of Fluid And Electrolyte Balance
9.5: Electrolytes Important for Fluid Balance
9.6: Consequences of Deficiency or Excess
9.7: Popular Beverages- Caffeine, Alcohol, Sports Drinks

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9.1: Introduction



Learning Objectives

1. Explain why water intake is important in the body.
2. Predict the outcomes of osmosis and osmoregulation.
3. Explain the role of electrolytes (sodium and potassium) in water balance in cells and the body.
4. Describe how the dietary recommended intake for water for males and females can be met from both fluid and foods.
5. State the recommended dietary intake for sodium and potassium and food sources for each.
6. Describe factors (exercise, diet, age, or disease) that can influence a person's hydration level.
7. Distinguish between dehydration, water intoxication, heat stroke, and hypertension.
8. Distinguish between the benefits and consequences of drinking coffee and tea.
9. Differentiate the impacts of acute and chronic alcohol intake on overall health.
10. Identify components of sports drinks that affect a person's hydration.

Water is the most critical macronutrient because we can only survive a few days without it. Even though the exact amount of water our bodies need can depend on a variety of factors, we are all mostly made of water. Water has several functions in the body that make it a critical component for life. Because of these critical functions, water levels in the body and cells are tightly controlled to achieve the proper water balance or hydration level. We can achieve proper water balance by taking in and excreting water, but electrolytes are truly the drivers that help achieve water balance throughout our tissues and cells. Drinks like coffee or tea, alcohol, and sports drinks will impact hydration levels through different mechanisms.

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9.2: Water's Importance to Vitality

Water is Essential for Life

You get up in the morning, flush waste 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, and prepare dinner. Add all the ways you use water every day, and you will still 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. In fact, your body is mostly water. The average adult person contains 60-70% total body water, but the amount of water or **hydration** in the human body varies depending on age, sex, and body composition. In this chapter, we will discuss how our bodies use and regulate the amount of water in our cells and tissues. We begin with the functions of water in the human body.



Figure 9.2.1: Water is the foundation of all life—the surface of the earth is 70% water; the volume of water in humans is about 60%. "The Blue Marble" is a famous photograph of the Earth taken on December 7, 1972 by the crew of the Apollo 17 spacecraft en route to the Moon. (Public Domain; NASA)

Water As a Transportation Vehicle

Water is called the "universal solvent" because more substances dissolve in it than any other fluid. It is helpful to imagine mixing up a glass of salt water. When you add a teaspoon of salt to water, the salt will eventually dissolve into the water. When this happens, we call the salt molecules **solute** and water the **solvent**. Molecules like salt and sugar dissolve in water because of water's ability to loosely bond with other molecules. Water molecules consist of oxygen and two hydrogen atoms, H_2O, that readily surround solute molecules to dissolve them. The solvent action of water allows for substances to be more readily transported. A pile of undissolved salt crystals 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% water. Dissolved substances or solutes in the blood include proteins, lipoproteins, glucose, electrolytes, and metabolic waste products, such as carbon dioxide and urea, all of which are either dissolved in the surrounding blood to be transported to cells to support basic functions or are removed from cells to prevent waste buildup and toxicity. Blood is not just the primary vehicle of transport in the body. Blood also acts as a fluid tissue that structurally supports blood vessels, which would collapse without water. Similarly, the brain is 75% water, with the water in the brain providing structure.

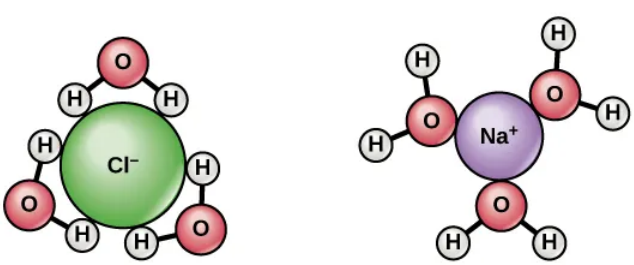


Figure 9.2.2: Water is the universal solvent. Water molecules, shown in red and white, can surround and dissolve many molecules, such as chloride (green) and sodium (purple) ions. In this case, water is the solvent, and the salt ions are solutes. "Water is the universal solvent" from *Biology, 2e* by OpenStax is licensed under CC BY 4.0.

Water As a Medium for Chemical Reactions

Water is required for even the most basic **chemical reactions**. Previously, you learned that enzymes are proteins, and proteins fold into their functional shape based on how their amino-acid sequences react with water. Once 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, including those in chemical digestion. Water acts as an agent to break chemical bonds or is removed from other molecules to form chemical 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 cannot occur without water. Mucus, which is not only essential to discharge nasal irritants but also required for breathing, transportation of nutrients along the gastrointestinal tract, and elimination of waste materials through the rectum, is composed of more than 90 percent water. Mucus is 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 the main component of the lubricating fluid between joints and eases the movement of articulated bones.

The aqueous and vitreous humors, which 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 environmental changes. 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**, balances heat gain with heat loss. Water in the body plays an important role in accomplishing this. Like blood glucose levels, our body temperature is tightly regulated. Human life is supported within a narrow range of temperatures, with the temperature set point or homeostasis of the body being 98.6°F (37°C). Too low or too high 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. The hypothalamus in the brain regulates body temperature in several ways. In response to cold temperatures, the hypothalamus signals to smooth muscle tissue surrounding blood vessels, causing them to constrict and reduce blood flow. This reduces heat lost to the environment. When body temperature rises, as occurs during exercise, the hypothalamus sends a signal to the smooth muscle of blood vessels, causing them to dilate, which can cause flushed skin as the blood vessels get larger. This also supports water loss in the form of sweat, which cools the body temperature back to its set point.

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9.3: Water Balance in the Body

Osmoregulation: Achieving water balance

As you eat a bite of food, the salivary glands secrete saliva. As the food enters your stomach, gastric juice is secreted. As it enters the small intestine, pancreatic juice is secreted. Each of these fluids contains a great deal of water. How is that water replaced in these organs? What happens to the water now in the intestines? The processes that control the exchange of water in cells and tissues is referred to as **osmoregulation**. Osmoregulation involves complex communication between the brain, kidneys, and endocrine system to achieve a balance in water intake, primarily through the diet, and water loss through excretion. Through osmoregulation, a stable set point or **homeostasis** for water balance is achieved.

Regulation of Daily Water Input

Each day, the average person puts out approximately 2.5 liters of water through their breath, sweat, urine, and feces. This must be balanced with water input so that the body does not lose water or gain water over the day (Figure 9.3.1). Our tissues produce around 0.3 liters of water per day through metabolic processes. The remaining water output must be balanced by drinking fluids and eating solid foods. The average daily fluid consumption is 1.5 liters, and water gained from solid foods approximates 0.7 liters.[1]

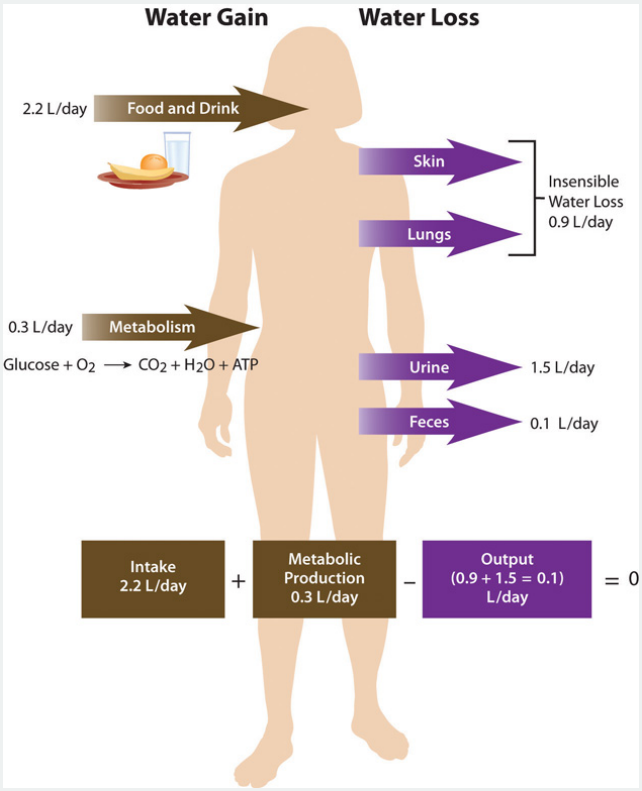


Figure 9.3.1: Water balance in the body. Water output or loss through the skin, lungs, and excretion must be balanced by water inputs from food, drink, and metabolism. "Water balance in the body" from An Introduction to Nutrition (Zimmerman) is licensed under CC BY-NC-SA 3.0.

Recommendations for Water Intake

The **Adequate Intake (AI)** for water is a recommendation based on the average water intake observed in a survey of Americans. It will prevent detrimental effects of **dehydration**, or the state of having too little water in the body. For adult males, the AI for water is 3.7 liters (15.6 cups), and adult females should consume 2.7 liters (11 cups).[1] It is important to note that the AI for **total water intake** includes water from *all dietary sources:* that is, water coming from food as well as beverages. In America, approximately 20 percent of dietary water comes from solid foods. See Table 9.3.1 for the range of water contents for selected food items.

Table 9.3.1: Water Content in Foods

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

Source: USDA Agricultural Research Service FoodData Central. https://fdc.nal.usda.gov/

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. The amount of hydration a person needs actually varies based on the climate a person lives in, as well as their age, physical activity level, and kidney function. Situations such as fevers, diarrhea, skin burns, increased physical activity, and breastfeeding will increase water needs. Because our bodies can efficiently excrete excess water and maintain water balance in most cases, there is no recommended upper limit for water intake.

Thirst Mechanism: Why Do We Drink?

When we get dehydrated and need to increase water intake, the thirst mechanism kicks in. **Thirst** is a part of osmoregulation that aims to increase water input. The thirst mechanism is activated in response to changes in water volume in the blood (Figure 9.3.2). When blood volume decreases, blood pressure drops and hormones such as angiotensin signal the brain that a person is thirsty. The thirst mechanism is also triggered by changes in the concentration of molecules dissolved in the blood, known as **blood osmolality**. Blood osmolality is primarily driven by the concentration of sodium in the blood. Specific proteins called **osmoreceptors** sense blood osmolality in the **hypothalamus**, a portion of the brain that lies just above the brain stem. The hypothalamus is ultimately responsible for stimulating the thirst you feel when you are dehydrated. In older people, the thirst mechanism is not as responsive, and as we age, there is a higher risk for dehydration.

The physiological control of thirst is the backup mechanism to increase water input. Fluid intake occurs primarily through conscious eating and drinking habits dependent on social and cultural influences, as well as other dimensions of wellness. 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. Most American adolescents have a daily habit of soft drink consumption. Demographics, access to soft drinks, social impacts, and personal behavior all influence soft drink consumption.

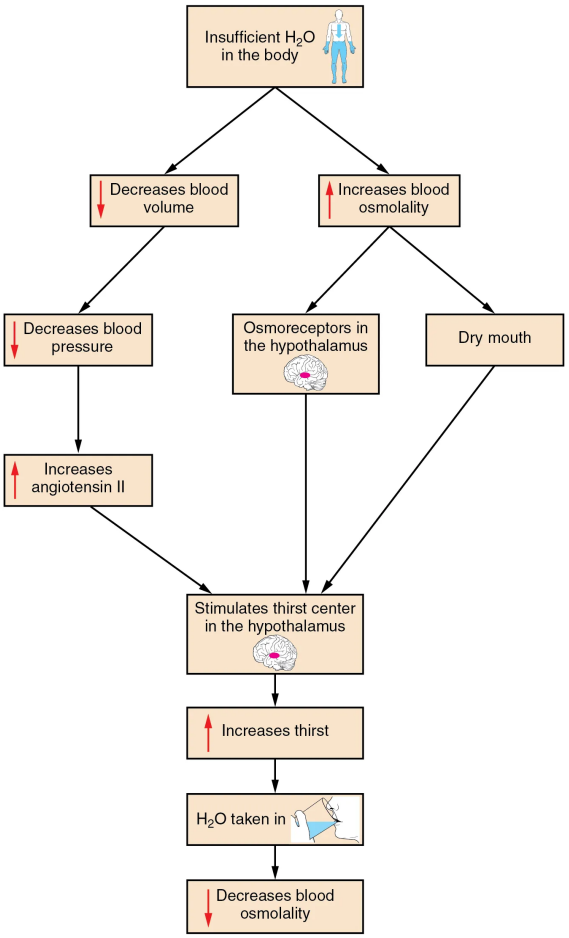


Figure 9.3.2: Thirst mechanism. When hydration levels drop, there is a decrease in blood volume and an increase in blood osmolality. This triggers a response in the brain's hypothalamus to increase thirst and promote water input. "Thirst mechanism" from *Anatomy & Physiology, 2e* by OpenStax is licensed under CC BY 4.0.

Regulation of Daily Water Output

As mentioned previously, there is no upper limit for total water intake because our bodies can efficiently excrete excess water in most cases. There are two types of water outputs: insensible water loss and sensible water loss. **Insensible water loss** is not easily measured and occurs primarily through the skin and breath. In most cases, this water output accounts for about 40-50% of the total water output daily. The body loses about 0.25 liters of water through exhalation each day, but this output will increase if a person is breathing more rapidly because of increased physical activity, for example. Another 0.5 liters is lost through our skin, but increased temperatures will increase this output. The remaining water output occurs through **sensible water loss**, which includes urine and feces. Urine accounts for about 1.5 liters of water output, and feces account for roughly 0.1 liters of water output. Regulating urine output is a primary function of the kidneys and involves communication with the brain and endocrine system.

The Kidneys and Hypothalamus Regulate Water Output

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. On average, the kidneys filter about 190 liters of blood and produce 1.5 liters of urine per day. **Urine** is mostly water, but it also contains electrolytes and waste products, such as urea. The color of urine can be an indicator for hydration status (Figure 9.3.3). The amount of water filtered from the blood and excreted as urine depends on the water input and electrolyte levels 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 that activates the 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. In response to high sodium levels that occur during dehydration, the hypothalamus activates the thirst mechanism, as discussed above. The hypothalamus can also limit urine output by stimulating the release of **antidiuretic hormone,** which signals the kidneys to decrease water output.

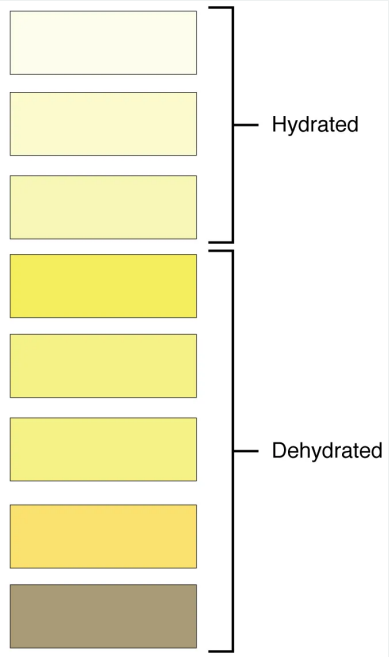


Figure 9.3.3: Urine color and hydration status. Urine is a primary output of water and is produced when the kidneys filter the blood. The color of urine can indicate hydration status. "Urine Color and Hydration Status" from *Anatomy & Physiology, 2e* by OpenStax is licensed under CC BY 4.0.

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1. Stallings VA, Quirk M, Oria M, eds. *Dietary Reference Intakes for Sodium and Potassium: A Consensus Study Report of The National Academies of Sciences, Engineering, Medicine*. Washington, DC: The National Academies Press; 2019. https://nap.nationalacademies.org/re...5353/chapter/1. Accessed October 2, 2023.

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9.4: Overview of Fluid And Electrolyte Balance

Water Distribution and Composition

As previously discussed, water is an important vehicle helps move a diverse array of molecules throughout the body. In the human body, water is distributed into two compartments: inside cells, called **intracellular fluid or ICF**, and outside cells, called **extracellular fluid or ECF**. Extracellular fluid includes both the fluid component of the blood, known as **plasma,** and the **interstitial fluid or IF** that surrounds all cells not in the blood (Figure 9.4.1).

Although water makes up the largest percentage of body volume, it is not actually pure water but rather a mixture of dissolved substances, collectively called **solutes**, that are critical for osmoregulation and water balance. These solutes include **electrolytes**, substances that dissociate into charged ions when dissolved in water. For example, table salt or sodium chloride contains electrolytes in the form of sodium (Na^+) and chloride (Cl^-) in water. In extracellular fluid, sodium is the major positively-charged electrolyte, or **cation**, and chloride (Cl^-) is the major negatively-charged electrolyte, or **anion**. Inside cells in the intracellular fluid, potassium (K^+) is the major cation. Together, these electrolytes are involved in many body functions, including water balance and acid-base balance, and they assist in transmitting electrical impulses along cell membranes in nerves and muscles.

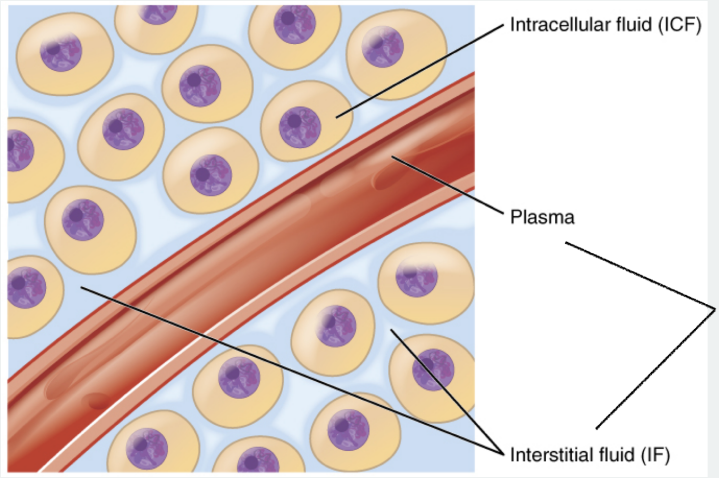


Figure 9.4.1: Fluid compartments in the human body. The intracellular fluid (ICF) is the fluid within cells. The extracellular fluid (ECF) includes both the blood plasma and the interstitial fluid (IF) between the cells. Source: "Fluid Compartments in the Human Body" from *Anatomy & Physiology, 2e* by OpenStax is licensed under CC BY 4.0.

Fluid and Electrolyte Balance

One of the essential homeostatic functions of the body is to maintain fluid and electrolyte balance within cells and their surrounding environment. Cell membranes are **selectively permeable**: Water can move freely through the cell membrane, while other substances, such as electrolytes, require special transport proteins, channels, and often energy. The movement of water between the intracellular and extracellular fluid happens by **osmosis**, which is simply the movement of water through a selectively permeable membrane from an area where solutes are less concentrated to an area where solutes are more concentrated (Figure 9.4.2).

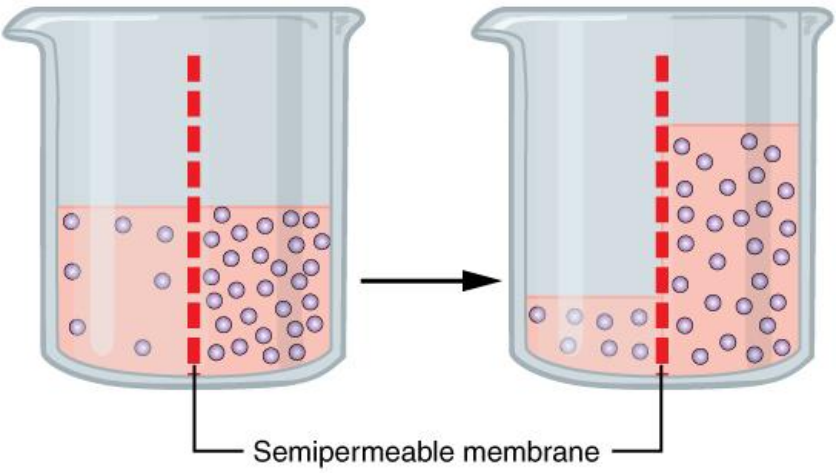


Figure 9.4.2: Osmosis is the diffusion of water through a semipermeable membrane towards higher solute concentration. If a membrane is permeable to water but not a solute, water will equalize its own concentration by diffusing to the side of lower water concentration (and thus the side of higher solute concentration). In the beaker on the left, the solution on the right side of the membrane is more concentrated with solutes; therefore, water diffuses to the right side of the beaker to equalize its concentration. Source: "Osmosis" by OpenStax is licensed under CC BY 4.0.

To maintain water and electrolyte balance, cells control the movement of electrolytes across their membranes, and water follows the electrolytes by osmosis. The health of the cell depends on proper fluid and electrolyte balance. If the body's fluid and electrolyte levels change too rapidly, cells can struggle to correct the imbalance quickly enough. For example, consider a person exercising strenuously, losing water and electrolytes in the form of sweat, and drinking excessive amounts of water. The excess water dilutes the sodium in the blood, leading to **hyponatremia**, or low blood sodium concentrations. Sodium levels within the cells are now more concentrated, leading water to enter the cells by osmosis. As a result, the cells swell with water and can burst if the imbalance is severe and prolonged.

In contrast, the opposite situation can occur in a person exercising strenuously for a long duration with inadequate fluid intake. This can lead to dehydration and **hypernatremia**, or elevated blood sodium levels. The high concentration of sodium in the extracellular fluid causes water to leave cells by osmosis, making them shrink (Figure 9.4.3). This scenario can also occur anytime a person is dehydrated because of significant fluid loss, such as from diarrhea and/or vomiting caused by illness.

Recall that the thirst response is triggered when solutes like sodium become too concentrated in the blood during dehydration. Sensory receptors in the thirst center in the hypothalamus monitor the concentration of solutes in the blood. If blood solutes (like sodium) increase above ideal levels, the hypothalamus transmits signals that result in a conscious awareness of thirst. The hypothalamus also communicates to the kidneys to decrease water output through the urine.

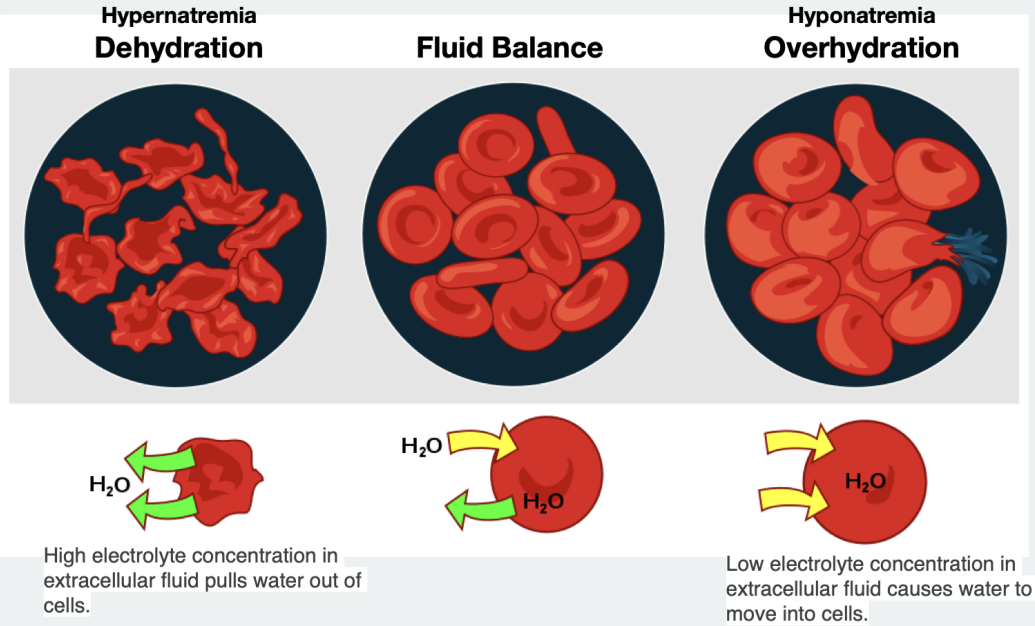


Figure 9.4.3: Effect of fluid imbalance on cells. With dehydration, the concentration of electrolytes becomes greater outside of cells, leading to water leaving cells and making them shrink. In fluid balance, electrolyte concentrations are balanced inside and outside cells, so water is in balance, too. During overhydration, electrolyte concentrations are low outside the cell relative to inside the cell (as in hyponatremia), so water moves into the cells, making them swell. Source: "Fluid Balance Effects on Cells" by Tamberly Powell is licensed under CC BY 4.0; edited from "Osmotic pressure on blood cells diagram" by LadyofHats is in the Public Domain.

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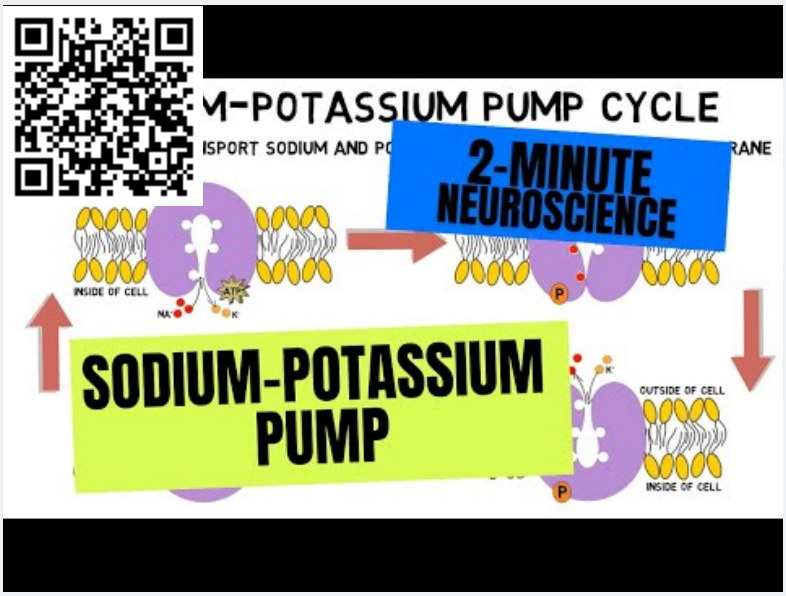
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9.5: Electrolytes Important for Fluid Balance

Moving Electrolytes Across Membranes

Cells constantly transport nutrients in and waste out, but this constant movement of molecules could cause too much water to move in or out of the cells. So, how is the concentration of solutes maintained to achieve water balance? To maintain homeostasis, the cell creates proteins that transport molecules, particularly the electrolytes sodium, chlorine, and potassium.

For example, the **sodium-potassium pump,** a protein found in a variety of human cells, uses energy to pump sodium ions out of the cell while moving potassium ions into the cell. The constant work of the sodium-potassium pump maintains the solute equilibrium and, consequently, water distribution between intracellular and extracellular fluids. The sodium-potassium pump is also critical for the function of nerve and muscle cells. The unequal movement of the positively charged sodium (Na^+) and potassium (K^+) ions makes intracellular fluid more negatively charged than the extracellular fluid. This charge gradient is another source of energy that a cell uses to perform work and is essential for nerve conduction and muscle contraction. However, the sodium-potassium pump uses energy to pump electrolytes, and nearly half of the brain's energy is spent on maintaining the sodium-potassium pump. In this section, we will further explore the sources and functions of sodium, chlorine, and potassium.



Video 9.5.1: The sodium-potassium pump is the primary mechanism for cells to maintain water balance between themselves and their surrounding environment.[1] Source: https://www.youtube.com/watch?v=AkiaMiGnPuQ

Sodium

Functions of Sodium in the Body

You have probably heard that most Americans eat too much sodium. As a component of table salt, sodium can be abundant in the diet because it is an effective preservative and flavor enhancer. Although excess sodium is linked to health problems, sodium is an essential nutrient that functions in water balance, nerve signaling, and muscle contraction. Sodium is also essential for nutrient absorption in the small intestine and nutrient reabsorption in the kidney. Amino acids, glucose, and water must go 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 moves sodium out of the cell and creates a higher sodium concentration outside the cell.

Sodium Requirements and Recommendations

In contrast to many minerals, sodium absorption in the small intestine is extremely efficient. In a healthy individual, 90-95% of sodium is excreted by the kidneys, and the remainder is lost in feces and sweat. The kidneys actively reabsorb sodium, so ultimately, dietary sodium is only needed in small amounts. The Food and Nutrition Board of the National Academies of Science, Engineering, and Medicine set an Adequate Intake (AI) level for sodium for healthy adults between the ages of nineteen and fifty at 1.5 grams (1,500 milligrams) per day. 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. There is no tolerable upper intake level established for sodium because there is not enough evidence demonstrating toxic effects of sodium, other than chronic diseases such as hyptertension.[2]

The Food and Nutrition Board more recently established a **Chronic Disease Risk Reduction (CDRR) Intake** level for sodium based on many studies focused on determining the association between reduced sodium intake and cardiovascular disease and high blood pressure, also known as **hypertension**. Based on the evidence, the CDRR intake for sodium is set to 2.3 grams (2300 milligrams) per day for adults. Reducing sodium intake below the CDDR will likely lower the risk of chronic diseases in the general population.[2] Table salt is approximately 40 percent sodium and 60 percent chloride, and one teaspoon of salt contains approximately 2.3 grams (2300 milligrams) of sodium (Figure 9.5.1). The average American consumes 3.4 grams (3400 milligrams) of sodium each day, which is much more than the recommended amounts.[3]



Figure 9.5.1: Table salt. One teaspoon of table salt provides the Chronic Disease Risk Reduction daily limit for sodium. Exceeding this amount of salt may lead to health consequences like hypertension and cardiovascular disease. Source: "Salt and spoon" by Bill HR is licensed under CC BY 2.0.

Food Sources of Sodium

Most sodium in the typical American diet comes from processed and prepared foods (Figure 9.5.2). 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, 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. Soft water replaces calcium with sodium, which contributes to the sodium content of one's diet. Soy sauce and monosodium glutamate are also sources of sodium.[3]



Figure 9.5.2: Dietary Sources of Sodium. Most sodium is consumed in processed foods and prepared foods. "Sodium Chart" by the Centers for Disease Control and Prevention is in the Public Domain.

Sodium Excess and Deficiency

In the United States, sodium deficiency is rare because table salt is commonly and abundantly added to foods. In certain circumstances, however, low blood sodium levels can occur. This condition, known as **hyponatremia**, can occur when taking

certain medications that affect kidney function or when water balance is disrupted due to vomiting, diarrhea, or even excessive water consumption. Symptoms of hyponatremia include nausea, headache, confusion, and seizures, depending on the severity of the condition.[4]

Health complications due to excessive sodium intake are much more common. If there is excessive sodium in the diet, the kidneys cannot efficiently remove sodium from the blood. Extremely high levels of sodium in the blood lead to **hypernatremia**. Symptoms include excessive thirst, fatigue, and confusion. When sodium levels increase in the blood, water moves out of cells into the blood plasma and interstitial fluid. This increases the pressure in the blood, a condition called **hypertension**, and requires more energy from the heart to continue pumping blood through the body. This extra work and pressure on the blood vessels can lead to heart attacks or strokes.

Many studies have shown that reducing sodium intake can help prevent hypertension and possible cardiovascular disease. For example, a large 8-year study called the Trials of Hypertension Prevention found that reduced sodium intake was associated with reductions in blood pressure throughout the study. After 10-15 years, individuals who reduced sodium intake were 25% less likely to have a heart attack, stroke, bypass surgery, or have died from heart disease.[5,6] Although the direct connection between sodium intake and cardiovascular disease needs more research, hypertension is a leading cause of cardiovascular disease.[7]

Tools for Change: Hypertension and the DASH Diet

The Dietary Approaches to Stop Hypertension (DASH) diet was first described in 1997 as a way to reduce hypertension. In the first study of the diet, 456 people were randomly assigned to one of three diets: 1) the average American diet with red meat, sugars, and low fiber; 2) a similar diet with fruits and vegetables; and 3) a DASH diet consisting of mostly fruits, vegetables, and low-fat dairy with limited sugars, red meat, and saturated fats.[8] After 8 weeks, the individuals on the DASH diet had the greatest reduction in blood pressure. Later studies showed that a low-sodium DASH diet had an even greater effect.[9] Even more recently, a review of multiple studies reaffirmed the value of the DASH diet on lowering blood pressure, as well as with weight loss and reducing the risk of Type 2 diabetes.[10] The image below summarizes the DASH diet components, and you can find information to help follow the DASH diet at the National Heart, Lung, and Blood Institute's DASH Eating Plan.

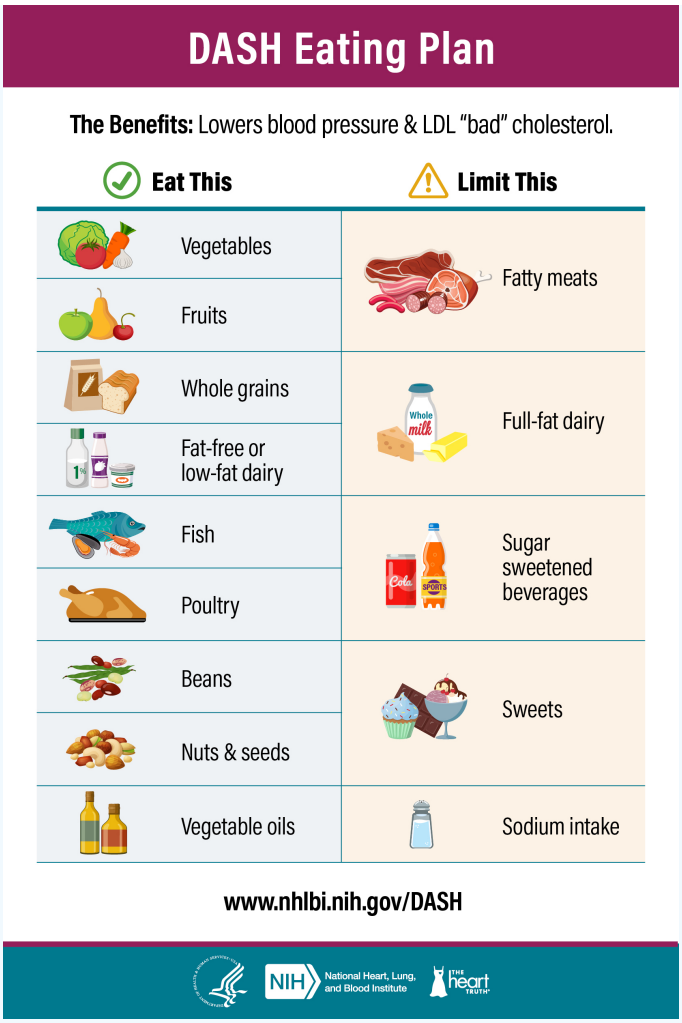


Figure 9.5.2: DASH Eating Plan from the National Heart, Lungs, and Blood Institute. Source[11]: https://nhlbi.nih.gov/education/dash-eating-plan "Dash Eating Plan" by the National Heart, Lungs, and Blood Institute is in the Public Domain.

Salt Sensitivity

High dietary intake of sodium is one risk factor for hypertension and contributes to high blood pressure in many people. However, studies have shown that not everyone's blood pressure is affected by lowering sodium intake. About a third of the population is salt-sensitive, meaning their blood pressure is affected by salt intake.[12] Genetics, race, sex, weight, and physical activity level are determinants of salt sensitivity. African Americans, women, and overweight individuals are more salt-sensitive than others. Also, if hypertension runs in a person's family, that person is more likely to be salt-sensitive.

Chloride

Functions of Chloride in the Body

Chloride is the primary negatively charged electrolyte or anion in extracellular fluid. Chloride plays a role in fluid balance as it moves across membranes following sodium and potassium gradients. Chloride also has its own protein channels that reside in cell membranes. These protein channels are especially abundant in the gastrointestinal tract, pancreas, and lungs. Chloride is the major anion in sweat and vomit. It is the anion of **stomach acid**, which is hydrochloric acid.

Chloride channels play a role in regulating **fluid secretion**, such as pancreatic juice into the small intestine and the flow of water into mucus. The importance of chloride movement in the body is exemplified in the signs and symptoms of a genetic disease called **cystic fibrosis**. This condition is caused by a mutation in a protein that transports chloride ions out of the cell. Signs and symptoms of this condition include salty skin, poor digestion and absorption, sticky mucus accumulation in the lungs, and liver damage. The

digestive process is impaired because chloride is not transported properly, resulting in sticky mucus that blocks ducts in the pancreas, thereby preventing pancreatic juices from reaching the digestive tract.

Chloride Requirements and Recommendations

Table salt is 60% chloride, so most chloride in the diet comes from salt. A teaspoon of salt equals 5.6 grams, with each teaspoon of salt containing 3.4 grams of chloride and 2.2 grams of sodium. The **Adequate Intake (AI)** level of chloride AI for adults is 2.3 grams.[13] Therefore, just ⅔ teaspoon of table salt per day is sufficient for chloride, as well as sodium.

Food 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.

Chloride Excess and Deficiencies

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.

Potassium

Functions of Potassium in the Body

Potassium is the most abundant positively charged electrolyte inside 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. When potassium levels in the blood increase, the adrenal glands release a hormone that stimulates an increase in the number of sodium-potassium pumps in the kidneys. 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. So, one of potassium's important functions is fluid and electrolyte balance. Potassium is also required for nerve signaling, protein synthesis, and energy metabolism and acts as a buffer in blood, playing a role in acid-base balance.

Potassium Requirements and Recommendations

According to the U.S. Dietary Reference Intakes, there is not enough evidence to establish a Recommended Dietary Allowance (RDA) for potassium. However, the National Academy of Medicine has established an Adequate Intake (AI) for potassium based on the levels associated with a decrease in blood pressure, a reduction in salt sensitivity, and a minimal risk of kidney stones. For adult male and females above the age of nineteen, the adequate intake for potassium is 3.4 grams (3400 milligrams) and 2.6 grams (2600 milligrams) per day, respectively. Unlike sodium, the Food and Nutrition Board did not find sufficient evidence to recommend a CDRR value for potassium.[2] Most Americans do not consume enough potassium in the diet, and potassium is considered a nutrient of public health concern according to the Dietary Guidelines for Americans.[12] Based on survey data, the average daily potassium intake from foods is 3,016 mg for men and 2,320 mg for women aged 20 and older. Because of this, potassium is now listed of food nutrition labels to help consumers improve potassium intake. Health concerns associated with insufficient potassium intakes include increased blood pressure, risk for kidney stones, bone turnover, urinary calcium excretion, and salt sensitivity.

✔ Tools for Change: Potassium

Many foods contain potassium, but it is important to have a varied diet to achieve the recommended potassium intake. Take some time to find one vegetable, fruit, dairy, and protein-rich food that contains potassium using the Dietary Guidelines for Americans Potassium Food Sources page.[14]

Imbalances of Potassium

Insufficient potassium levels in the body, known as **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**, is toxic and also affects the heart. It is a silent condition as it often displays no signs or symptoms. Extremely high potassium levels 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.

Groups at risk of developing hypokalemia are individuals with renal and large intestine issues such as urine and diarrhea losses; people with uncontrolled diabetes, which causes diabetic acidosis and urine losses; dehydration; prolonged diarrhea or emesis; and certain drugs like diuretics, steroids, or laxatives. These deficiencies are due to excessive loss and not a dietary deficiency.

Attributions

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9.6: Consequences of Deficiency or Excess

Hydration and Health

Like 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 changes in hydration and electrolytes that compromise health.

High-Hydration Status: Water Intoxication/Hyponatremia

Water intoxication is extremely rare, primarily because healthy kidneys are capable of excreting up to one liter of excess water per hour. However, over-hydration can occur if urinary excretion does not compensate for water input. This was unfortunately demonstrated in 2007 by Jennifer Strange, who drank six liters of water in three hours without going to the bathroom while competing in a “Hold Your Wee for a Wii” radio contest. Afterward, she complained of a headache, vomited, and died. Water intoxication can also affect athletes who over-hydrate. Excessive water intake dilutes the concentration of sodium and other electrolytes.

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, lack of concentration, low blood pressure, fatigue, low (dark-colored urine) to no urine output, inability to regulate body temperature, weakness, and lethargy, and, in extreme cases, loss of consciousness and death. It is important to remember that the thirst mechanism is activated after dehydration occurs, so you are already dehydrated by the time you feel thirsty.[1] If a person is dehydrated for an extended period, the kidneys may not function properly. There is evidence that low-hydration status increases the risk of kidney stones and may be associated with chronic kidney disease.[2]

There are several risk factors for dehydration. Infants, athletes, and individuals with diabetes or alcoholism are more likely to experience dehydration. In addition, older people often suffer from chronic dehydration as their thirst mechanism is no longer as sensitive as it used to be.[3]

A person engaged in intense physical performance, especially in the heat or if heavy attire such as uniforms are involved, are at risk of dehydration if a good hydration plan is not in place. Examples of physical performance include military personnel, firefighters, or people who work in labor-intensive jobs. Research on athletic performance and dehydration supports the value of an athlete having a good hydration plan. Avoiding weight loss during an extended training session or event of no more than 2 to 3% of body weight may help the athlete avoid declining performance. Dehydration can impact both the physical and psychological aspects of sports performance. Tracking body weight change by weighing before and after an extended training session or event can serve as a good gauge of how well the athlete’s hydration plan is working. In addition to using weight as an indicator of hydration, athletes are encouraged to monitor their urine color, as shown in Section 9.3, and their thirst.[4]



Figure 9.6.1: Hydration and activity. Hydration status can be affected by physical activity, and without a good hydration plan, factors such as heavy uniforms and heat can lead to dehydration. "NLA, Lausanne HC vs. Rapperswil-Jona Lakers, 11th November 2014 03" by Fabien Perissinotto is licensed under CC BY-SA 4.0. https://commons.wikimedia.org/w/inde...curid=36740195

Heat Stroke

Dehydration can also contribute to abnormal temperature regulation in the body. **Heat stroke** is a life-threatening condition that occurs when the body temperature is greater than 105.1°F (40.6°C). It results from the body being unable to cool itself sufficiently 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.

Attributions

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9.7: Popular Beverages- Caffeine, Alcohol, Sports Drinks

Beverages that Affect Hydration

In this last section, we will discuss three beverage types that affect hydration: caffeinated drinks, alcohol, and sports drinks. We will examine the effects of these beverages on fluid levels and nutrition within the body so that you will be better able to make wise decisions about your beverage choices.

Caffeinated Drinks

Caffeine is a chemical found in the seeds, leaves, and fruit of many plants, where it acts as a natural pesticide. Coffee, tea, and chocolate are the most common natural sources of caffeine found in the diet, but sodas and other beverages can have caffeine added during processing. Caffeine is the most widely consumed psychoactive drug and is such an important part of many people's lives that they might not even think of it as a drug. A **psychoactive drug** is any substance that crosses the blood-brain barrier, primarily affecting the functioning of the brain, be it altering mood, thinking, memory, motor control, or behavior.

Typical Doses and Dietary Sources

Up to 90 percent of adults around the world use caffeine daily, and the average adult in America consumes about 135 mg of caffeine each day.[1] According to the FDA, caffeine can be part of a healthy diet. Up to 400 mg of caffeine, or 3 to 4 cups of coffee, each day is not generally associated with negative health outcomes.[2] However, much higher doses of caffeine can have adverse health effects such as anxiety, restlessness, and insomnia. If high doses greater than 10,000 milligrams are consumed in a short amount of time, caffeine can be fatal.[1] It would take 75-100 cups of standard coffee to reach this dose, and cases of caffeine fatalities have been primarily reported in individuals who consume caffeine supplements or energy drinks with high caffeine content.

Pure caffeine has a bitter taste, which adds to the flavor of many caffeinated drinks. In a survey of Americans age 35-49 years of age, coffee accounted for 65% of total caffeine intake. Tea and soft drinks were equally popular, each contributing to about 16% of total caffeine intake.[3] Some individuals who consume caffeine regularly can develop a tolerance to the effects of caffeine, so one cup of coffee may no longer provide a boost of energy. On the other hand, some individuals are more sensitive to the effects of caffeine and may feel anxiety and restlessness after a small dose of caffeine.[1]

Just how much caffeine is in a cup of coffee? It varies. The caffeine content of an average cup of coffee can range from 80-100 milligrams, and the range for tea is 30-50 milligrams. Table 9.7.1 provides the range of caffeine found in common beverages.[2]

When estimating your total caffeine consumption, remember it's not only in beverages but also in some foods and medicines.

Table 9.7.1: Caffeine Content in Various Beverages and Foods

Beverage/Food	Caffeine (milligrams)
12 oz. Soft Drinks (12 oz.)	30-40 mg
Green or Black Tea (8 oz.)	30-50 mg
Coffee (8 oz.)	80-100 mg
Energy Drink (8 oz.)	40-250 mg

Source: https://www.fda.gov/consumers/consum...feine-too-much

Coffee and hydration status

A diuretic refers to any substance that elevates the normal urine output above that of drinking water. Caffeinated beverages are commonly believed to be dehydrating due to their diuretic effect, and there is evidence that acute doses of highly caffeinated coffee increase urine output.[4] However, drinking coffee does not seem to increase the risk of dehydration. In a cross-over study, individuals who regularly consumed both water and caffeinated coffee showed the same hydration level as determined by urine analysis and body weight.[5] Overall, a systematic review of the scientific studies concluded that coffee with high amounts of

caffeine has an acute diuretic effect, but tolerance is developed if individuals regularly consume coffee.[6] Coffee and teas are, therefore, often considered a source of hydration rather than a diuretic that can contribute to dehydration.

Health Benefits

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

Many studies have aimed at determining the health consequences of consuming caffeine, but the results of these studies have several limitations. Because caffeine tolerance can build up over time, it can be difficult to conclude long-term health effects from short studies. Second, drawing conclusions about the health effects of caffeine can be difficult because people may engage in other behaviors, such as smoking, while participating in studies. Third, many studies of caffeine intake focus on coffee and tea, both of which contain phytochemicals called polyphenols. These compounds can have strong antioxidant properties that may impact health. It is also important to consider that many caffeinated drinks contain excess sugars, which can have negative health consequences.

Despite these challenges, some consistent health benefits have been observed. A recent review in the *New England Journal of Medicine* reports that caffeine intake may be associated with lower long-term weight gain, reduced risk of liver damage, and a lower risk of Parkinson's disease.[1] Parkinson's disease is an illness of the central nervous system causing many movement disorders. One study demonstrated that men who did not consume coffee had a five times more likely chance of Parkinson's disease than men who consumed more than 3 cups of coffee daily. In this study, other caffeine sources, such as soft drinks and tea, were also associated with a reduced risk of Parkinson's disease.[7]

Health Consequences

The acute adverse health effects of caffeine ingestion are anxiety, shakiness, and sleep deprivation. On a more chronic basis, some scientific reports suggest that higher caffeine intake is linked to negative effects on heart health and increased cardiovascular disease, although at this point, most data suggest caffeine does not significantly increase either. A comprehensive review published in the *American Journal of Clinical Nutrition* reports that caffeine induces a modest increase in blood pressure lasting less than three hours in people with hypertension, but there is no evidence that habitual coffee consumption increases blood pressure long-term or increases the risk for cardiovascular disease.[8] There is limited evidence that chronic caffeine exposure increases blood pressure chronically in people without hypertension.

Alcohol

Alcohol is both a beverage providing some sustenance and a drug. For thousands of years, alcohol has been consumed in a medicinal, celebratory, and ritualistic manner. In America, it is estimated that more than half of adults consumed an alcoholic drink in the past 30 days.[9] Like caffeine, alcohol is a psychoactive drug. Alcohols in chemistry refer to a group of similar organic compounds, but in beverages, the only alcohol consumed is **ethanol**, a simple molecule consisting of two carbons, one oxygen, and six hydrogen atoms.

Typical Doses

Chronic alcohol use occurs when individuals consume alcohol regularly over an extended period. The health consequences of chronic alcohol use are dependent on the amount of alcohol consumed or the **dose**. Alcohol doses vary depending on the type of alcoholic drink. Some alcoholic drinks, such as beer and wine, have less alcohol content per drink, so standard drink sizes have been established to help define the actual alcohol intake. According to the 2020-2025 Dietary Guidelines for Americans, one **alcoholic drink equivalent** is defined as containing 14 grams or 0.6 fluid ounces of pure alcohol. Based on this definition, 12 fluid ounces of regular beer containing 5% alcohol, 5 fluid ounces of wine containing 12% alcohol, or 1.5 fluid ounces of 80-proof distilled spirits containing 40% alcohol are all standard drink equivalents. The 2020-2025 Dietary Guidelines for Americans recommend no more than one alcoholic drink per day for women and no more than two alcoholic drinks per day for men to avoid the negative health effects of alcohol.[10] The 2025-2030 Dietary Guidelines have less specific guidance and recommend individuals to "consume less alcohol for overall health."[11] It is important to note that women who are pregnant and individuals who are under

the age of 21 or have a history of certain medical conditions, including substance abuse, should avoid drinking alcohol altogether.[10,11]

Alcohol Absorption and Metabolism

Alcohol is a hydrophilic or water-loving molecule that is easily absorbed into the bloodstream and distributed throughout the body. The higher the concentration of alcohol in the small intestines, the faster the absorption. so drinks with high alcohol content will cause more rapid absorption. Food in the stomach can slow down alcohol absorption because it slows down the release of stomach contents into the small intestines, where most of the alcohol is absorbed.

More than 90 percent of ingested alcohol is metabolized in the liver. The remaining amount stays in the blood and is eventually excreted through the breath, urine, saliva, and sweat. **Blood alcohol concentration, or BAC**, measures the amount of alcohol present in the blood and is associated with mental and physical intoxication effects of alcohol (Table 9.7.2). BAC values, measured in milligrams percent, can be determined using breath tests or breathalyzers, which compare units of alcohol to units of blood. BAC is a measurement used legally to assess intoxication and the impairment and ability to perform certain activities, such as driving a car.

Table 9.7.2: Mental and Physical Effects of Different BAC Levels

BAC Percent	Typical Effects
0.02	Some loss of judgment, altered mood, relaxation, increased body warmth
0.05	Exaggerated behavior, impaired judgment, some loss of muscle control (focusing eyes), feeling of well-being, lowered alertness, release of inhibition
0.08	Poor muscle coordination (balance, speech, vision, reaction time), difficulty detecting danger, and impaired judgment, self-control, reasoning, and memory
0.10	Clear deterioration of muscle control and reaction time, slurred speech, poor coordination, slowed thinking
0.15	Far less muscle control than normal, major loss of balance, vomiting

As a general rule, the liver can metabolize one standard drink per hour. Drinking more than this, or more quickly, will cause BAC to rise to potentially unsafe levels. Giving the liver enough time to metabolize the ingested alcohol fully is the only effective way to avoid alcohol toxicity. Drinking coffee or taking a shower will not help. The legal limit for intoxication in many states is a BAC of 0.08. Taking into account the rate at which the liver metabolizes alcohol after drinking stops and the alcohol excretion rate, it takes at least five hours for a legally intoxicated person to achieve sobriety. In addition to the one-drink-per-hour guideline, the rate at which an individual's BAC rises is affected by the following factors:

- **Sex**: BAC levels rise faster in women than men who have consumed the same amount of alcohol.
- **Weight**: BAC levels rise faster in individuals with lower weights.
- **Genetics**: Some individuals may not metabolize alcohol quickly, which leads to higher BAC levels.
- **Length of time as a heavy drinker**: Individuals who are heavy chronic drinkers may metabolize alcohol faster.
- **Type of alcohol consumed**: Higher alcohol content will lead to faster absorption.
- **Amount of alcohol consumed**: More alcohol increases BAC levels faster.
- **Consumption rate**: Fast consumption increases BAC levels faster.
- **Consumption before or after a meal**: Food in the stomach slows down absorption.
- **Mixture**: Carbonated drinks can increase absorption.
- **Medications**: Some medications may affect the absorption and metabolism of alcohol.



Figure 9.7.1. Alcohol and food. Drinking alcohol with food will slow the absorption of the alcohol. Source: "Beer and chicken wings" by Leonid Mamchenkov is licensed under CC BY 2.0.

Health Benefits

Moderate alcohol intake has been shown to provide some health benefits, but it is important to remember that these findings may not apply if an individual has a risk of substance abuse or other underlying health conditions. Studies have consistently shown that moderate alcohol intake reduces the risk of heart disease in middle-aged and older people. A review of twenty-nine studies concluded that moderate alcohol intake reduces the risk of coronary heart disease by about 30% in comparison with those who do not consume alcohol.[12] Several other studies demonstrate that moderate alcohol consumption reduces the incidences of stroke, heart attack, and death caused by cardiovascular and heart disease. The drop in risk for these adverse events ranges between percent. Moreover, there is some scientific evidence that moderate alcohol intake reduces the risk of metabolic syndrome, type 2 diabetes, and gallstones.[13] It has not been clearly demonstrated that moderate alcohol consumption benefits younger populations, and the risks of any alcohol consumption do not outweigh the benefits for pregnant women, those who are taking medications that interact with alcohol, and those who are unable to drink in moderation. According to the Dietary Guidelines for Americans, individuals who do not drink alcohol should not start drinking. Drinking less is healthier than drinking more.

Health Consequences

Alcohol consumption can lead to a variety of health problems if consumed in excess. According to the CDC, **excessive alcohol use** is the leading cause of preventable death in the United States.[14] Several patterns of drinking are considered excessive alcohol use. First, any alcohol consumption during pregnancy or under the age of 18 is considered excessive. Second, **binge drinking** is defined as consuming 4 or more drinks on an occasion for a woman or 5 or more drinks on an occasion for a man. According to the National Survey on Drug Use and Health, approximately 10-30% of adults over the age of 18 reported binge drinking in the past 30 days.[9] Finally, **heavy drinking** is defined as 8 or more drinks per week for a woman or 15 or more drinks per week for a man. Any form of excessive alcohol use can increase the risk for several chronic diseases.

Because alcohol provides calories, excessive alcohol consumption has been suspected of causing weight gain. One alcoholic drink equivalent contains 100-150 calories, so even moderate drinking can substantially increase calorie intake. Distilled spirits have exceptionally few nutrients, but adding sugary mixers will increase the calorie content of the drink. Beer and wine do provide some nutrients, vitamins, minerals, and beneficial phytochemicals along with calories. Research studies have not consistently shown an association between alcohol consumption and weight gain. For example, a prospective study of nearly 15,000 men showed a slightly increased risk of weight gain with higher alcohol intake.[15] However, light-to-moderate consumption of wine has been associated with less weight gain in some studies.[16] The contradictory results of these studies may be partly because alcohol contributes calories to the diet, but when drunk in excess, it reduces the secretion of pancreatic juice and damages the lining of the gastrointestinal system, impairing nutrient digestion and absorption. Alcohol is also a **diuretic**, a substance that increases urine output. Heavy alcohol consumption results in **dehydration** because alcohol suppresses the release of antidiuretic hormone and decreases the kidneys' water reabsorption. Drinking alcohol in excess can lead to a “hangover,” the majority of whose symptoms are the direct result of dehydration.

Effects of Alcohol Abuse on the Brain

Alcohol can adversely affect nearly every area of the brain. When BAC rises, the central nervous system is depressed. Alcohol disrupts the way nerve cells communicate with each other by interfering with receptors on certain cells. The immediate impact of alcohol on the brain can be seen in the awkwardly displayed symptoms of confusion, blurred vision, slurred speech, and other signs of intoxication. These symptoms will go away once drinking stops, but abusive alcohol consumption over time can lead to long-lasting damage to the brain and nervous system. This is because alcohol and its metabolic byproducts kill brain cells. Excessive alcohol intake has the following effects on specific areas of the brain:

1. **Medulla.** This area controls automatic functions, such as heart rate. When alcohol first limits its functioning, people feel sleepy. With greater BAC levels, unconsciousness, comas, and death can result.
2. **Cerebellum.** This is where conscious movement is coordinated. With too much alcohol, balance and motor skills are impaired.
3. **Cerebral cortex.** Senses and thoughts are processed here, and this is where action is initiated. When BAC levels increase, the ability to think, exercise good judgment, and feel pain decreases.
4. **Hypothalamus and pituitary gland.** Alcohol increases sexual desire but decreases sexual performance. It also prompts signals that increase urine production.
5. **Limbic system.** When alcohol affects this area, individuals may become very emotional and lose memory function.

Effects of Alcohol Abuse on the Liver

The liver is one of the body's main filtering organs and is severely stressed by alcohol abuse. The term **alcoholic liver disease, or ALD**, is used to describe liver problems linked to excessive alcohol intake. ALD can be progressive, with individuals first suffering from a fatty liver and going on to develop cirrhosis. It is also possible to have different forms of ALD simultaneously.

The three most common forms of ALD are

- **Fatty liver.** A rather benign disorder that develops after excessive alcohol consumption; however, it can progress to more fatal diseases. Fatty liver is reversible if alcohol use is brought under control.
- **Alcoholic hepatitis.** The symptoms of this alcohol-induced liver inflammation are a swollen liver, abdominal pain, nausea, fever, jaundice, and vomiting. Although linked to alcohol use, even people who drink moderately can sometimes develop this condition, and not all alcohol abusers do. If a person stops drinking alcohol, the liver damage can be reversed. But if they continue, cirrhosis may develop, and death can result.
- **Cirrhosis.** This serious and sometimes fatal form of ALD develops when liver cells die and form scar tissue, which blocks blood flow and causes wastes and toxins to build up in the system. Strictly speaking, cirrhosis cannot be cured. It can, however, be stopped with medical treatment; and complications can be managed if the individual stops drinking, and many do survive. Not all cases of cirrhosis are strictly due to alcoholism, and not all alcoholics develop the disease. Symptoms of cirrhosis include the buildup of abdominal fluid (ascites), abdominal pain, fever, thirst, confusion, and fatigue.

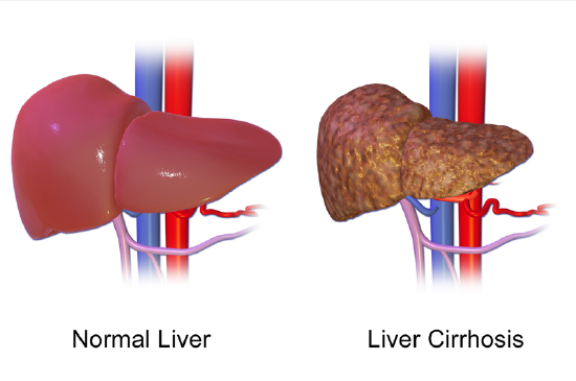


Figure 9.7.2: Liver cirrhosis. Excessive alcohol consumption destroys liver cells. In an attempt to repair itself, the liver initiates an inflammatory and reparation process, causing scar tissue to form. In the liver's attempt to replace the dead cells, surviving liver cells multiply. The result is clusters of newly formed liver cells, also called regenerative nodules, within the scar tissue. This state is called cirrhosis of the liver. Source: "Liver Cirrhosis" by BruceBlaus is licensed under CC BY-SA 4.0.

Sports Drinks

Sports drinks contain carbohydrate and electrolytes such as sodium and potassium with the goal of replenishing hydration during exercise to enhance performance. Some studies support these claims, but these findings are not consistent.[17] The primary source of water loss during intense physical activity is sweat. Perspiration rates are variable and dependent on many factors including body composition, humidity, temperature, and type of exercise. The hydration goal for obtaining optimal endurance and performance is to replace what is lost. Individuals can replenish lost fluids, energy and electrolytes used during exercise by drinking plain water and eating a sports bar or snack that contains carbohydrates, protein, and electrolytes. If solid food is not tolerated before or during exercise, sports drinks can serve as a convenient was to refuel. Athletes or persons involved in physical activity over an extended period of time, in the heat, or at a frequency in which they can't make up a fuel deficit such as in tournament play, may value from using a sports drink.[18] However, casual exercisers are not likely to need a standard electrolyte-replacing, fuel-providing sports drink.

Although sports drinks are often advertised and perceived as healthy sources of hydration, unnecessary use of sports drinks can lead to weight gain due to excess added sugars and calories, especially in children. In a 7-year study of over 7,000 adolescents, individuals who consumed more sports drinks were more likely to experience weight gain and obesity.[19] It is important to note that excess weight gain is associated with several chronic diseases, including diabetes and cardiovascular disease. Ultimately, the best source of hydration for most people is water.

Attributions

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CHAPTER OVERVIEW

10: Weight Management

10.1: Introduction
10.2: Introduction to Energy Balance
10.3: Energy Balance- Energy In, Energy Out—Yet Not As Simple As It Seems
10.4: Indicators of Health- BMI, Body Composition, and Metabolic Health
10.5: Overweight and Underweight—What are the Risks?
10.6: Obesity Epidemic - Causes and Solutions
10.7: Best Practices For Weight Management

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10.1: Introduction



Learning Objectives

1. Compare and contrast the indicators of health (body mass index, fat content, fat distribution).
2. Describe limitations for each indicator of health.
3. Estimate and interpret the body mass index for a given height and weight.
4. Compare the use of body mass index, fat content, and fat distribution to predict disease.
5. Calculate the estimated energy requirement of an individual.
6. Predict changes in total energy expenditure given changes in basal metabolism, digestion, and physical activity.
7. Describe factors that affect energy intake and energy use.
8. Describe the relationship between energy balance and weight control.
9. Describe health risks associated with overweight and obese status.
10. Distinguish the health risks of eating disorders.
11. Describe how the dimensions of wellness are related to pursuing a healthy weight.
12. Identify evidence-based nutrition, behavioral and physical fitness strategies for healthy weight management.

Cover Art: "Apple and measuring tape on white. Dieting and healthy lifestyle concept" by wuestenigel is licensed under CC BY 2.0.

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10.2: Introduction to Energy Balance

On December 26, 2018, 33-year-old Colin O'Brady of Portland, Oregon, became the first person to cross the landmass of Antarctica solo, unassisted, and without any resupply shipments. Others had crossed the continent with the help of a wind sail to propel them over the ice or with resupply drops along the way—both ways of saving precious energy—but O'Brady completed the 926-mile trek only on skis, pulling a sled packed with food, fuel, and supplies the entire way. Speed was important because he was racing another man, Louis Rudd, a 49-year-old British Army captain. And, of course, he didn't want to run out of food hundreds of miles from the finish. Rudd finished the Antarctica crossing just two days after O'Brady.



Figure 10.2.1 Endurance athlete Colin O'Brady, photographed in March 2016. "Colin O'Brady 2016" by Colin O'Brady is licensed under CC BY 3.0.

To prepare for the expedition, O'Brady and his team had to make careful calculations to estimate his nutrient and caloric needs. He'd be skiing all day for about two months, in below-zero temperatures and against constant wind. O'Brady estimated that he'd burn about 10,000 calories per day on his journey, and he knew that if he didn't pack enough food, he wouldn't have the strength to complete this epic test of endurance in extreme conditions. Previous explorers had died in the Antarctic because they hadn't packed enough food.

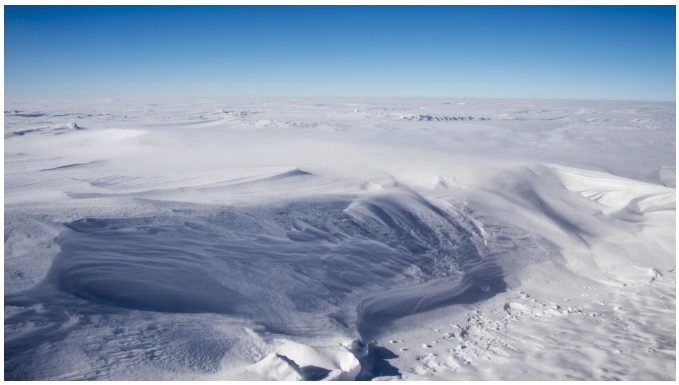


Figure 10.2.2. O'Brady and Rudd raced across a landscape similar to that shown in this photo from Antarctica—a polar desert and the coldest, windiest, driest continent on earth. "Snow Landscape at the South Pole" by Christopher Michel is licensed under CC BY 2.0.

But O'Brady also knew that the more food he packed, the heavier his sled would be—ironically making him burn more calories, as well as slowing him down and prolonging his trip. So he focused on making his food calorie- and nutrient-dense but lightweight: oatmeal with added oil and protein powder; freeze-dried dinners reconstituted with melted snow; and 4,500-calorie slabs of a custom-made "Colin bar" made from coconut oil, nuts, seeds, and dried fruit.

At the start of his journey, O'Brady's sled weighed 375 pounds and contained enough food to provide him with 8,000 calories per day. That was a bit short of the 10,000 calories he estimated he'd burn every day, so to build up some additional energy stores, he gained 15 pounds before his trip. In the end, after 54 days of skiing through ice and snow, he lost 25 pounds during his Antarctic crossing. He was successful, and while his fitness level and determination surely played a part, the trip would have been impossible without an adequate supply of calories.[1-3]

In our daily lives, we need far fewer calories than an Antarctic explorer, and we don't need to schlep a two-month supply of food on our backs wherever we go. And thankfully, we get to enjoy fresher and more interesting food options, too! But each of us, every day, whether we're aware of it or not, is attempting to balance the calories we consume with the calories we burn, just like Colin O'Brady. This is the concept of ***energy balance***—one we'll explore throughout this chapter. If adults eat roughly the same number of calories as they burn each day, their body weight will generally stay very constant. If they burn more calories than they eat, like O'Brady was on his expedition, they'll lose weight. If they consume more calories than they burn, they'll gain weight.

Energy balance may seem like a simple concept, but in practice, how many calories a person eats and expends each day is influenced by so many different factors that it can be frustratingly difficult to apply. Still, it's a vitally important concept to understand. We live in a world where food is easily available, and we're constantly bombarded with marketing messages telling us to eat more of it. Not surprisingly, the prevalence of obesity is rising around the globe, and the health effects of carrying too much weight are a concern at both the population and personal levels. On the other hand, being underweight or overly focused on body weight also carries health risks. In this unit, we'll explore these concepts and concerns and seek some answers.

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10.3: Energy Balance- Energy In, Energy Out—Yet Not As Simple As It Seems

The concept of energy balance seems simple on paper. Balance the calories you consume with the calories you expend. But many factors play a role in energy intake and energy expenditure. Some of these factors are under our control, and others are not. In this section, we will define energy balance, look at the different components of energy expenditure, and discuss the factors that influence energy expenditure. We'll also consider some of the factors that affect energy intake and consider why energy balance is more complex than it seems.

Energy Balance

Our body weight is influenced by our energy intake (calories we consume) and our energy output (energy we expend during rest and physical activity).[1] This relationship is defined by the ***energy balance equation***: Energy Balance = energy intake – energy expenditure.

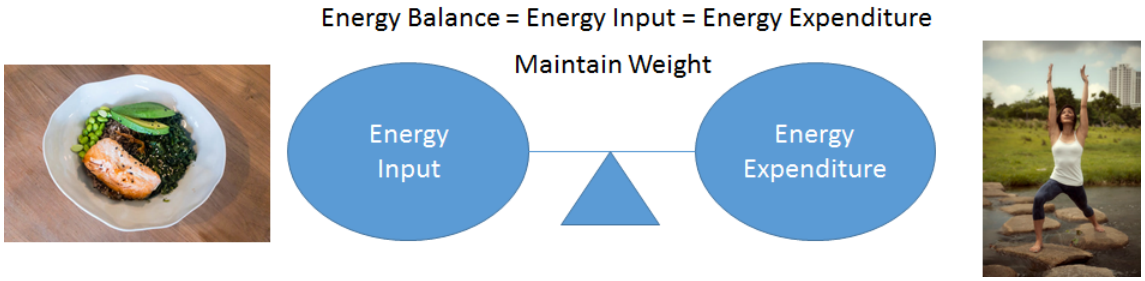


Figure 10.3.1: When an individual is in ***energy balance***, energy intake equals energy expenditure, and weight should remain stable. "Energy balance" by Tamberly Powell is licensed under CC BY-NC-SA 2.0 with the following images with their respective attribution statements: "Salmon, whole grain wild rice, sesame-spinach, avocado, edamame, home-made teriyaki sauce" by Marco Verch by is licensed under CC BY 2.0 and "Yoga" by Matt Madd is licensed under CC BY-NC-ND 2.0.

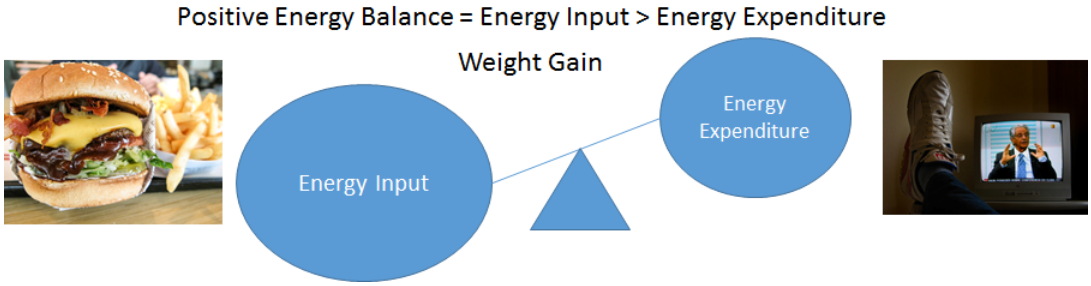


Figure 10.3.2: ***Positive energy balance*** occurs when energy intake exceeds energy expenditure, usually resulting in weight gain. "Positive energy balance" by Tamberly Powell is licensed under CC BY-NC-SA 2.0 with the following images: "The Habit: Bacon Cheeseburger" by Person-with-No Name and "Watching Gabeira" by Carlos Ebert are licensed under CC BY 2.0.

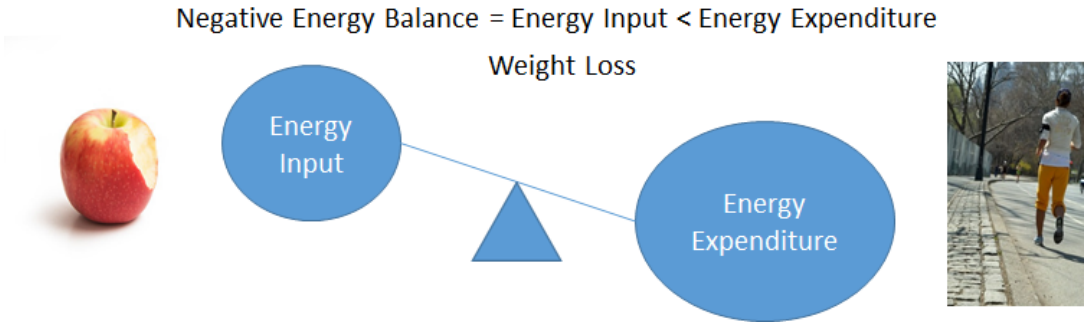


Figure 10.3.3: ***Negative energy balance*** occurs when energy intake is less than expenditure, usually resulting in weight loss. "Negative energy balance" by Tamberly Powell is licensed under with the following images: "Bitten Apple" by DLG Images is licensed under CC BY 2.0 and "Exercise" by Andy Cross is licensed under CC BY-NC 2.0.

Energy intake comprises the calories we consume from food and beverages. These calories come from the macronutrients (carbohydrates, proteins, and fats) and alcohol. Remember that when the body has a surplus of energy, this energy can be stored as fat. *In theory*, if you consume 3,500 more calories than your body needs, you could potentially gain about one pound because a

pound of fat is equal to about 3,500 calories. If you expend 3,500 more calories than you take in, you could lose about a pound, as your body turns to this stored energy to compensate for the energy deficit. However, in practice, how individuals respond to an excess or deficit of 3500 calories can be quite variable. Over time, the body adapts to these conditions and resists changes in body weight.

Energy balance is complex, dynamic, and variable between individuals—something we'll explore later on this page—but it is still a vital concept in understanding body weight. Next, let's look at the energy expenditure side of the energy balance equation to see the components that make up energy expenditure and the factors that influence them.

Components of Energy Expenditure

The sum of caloric expenditure is called total energy expenditure (TEE). There are three main components of TEE:

1. Basal metabolic rate (BMR)
2. Thermic effect of food (TEF)
3. Physical activity

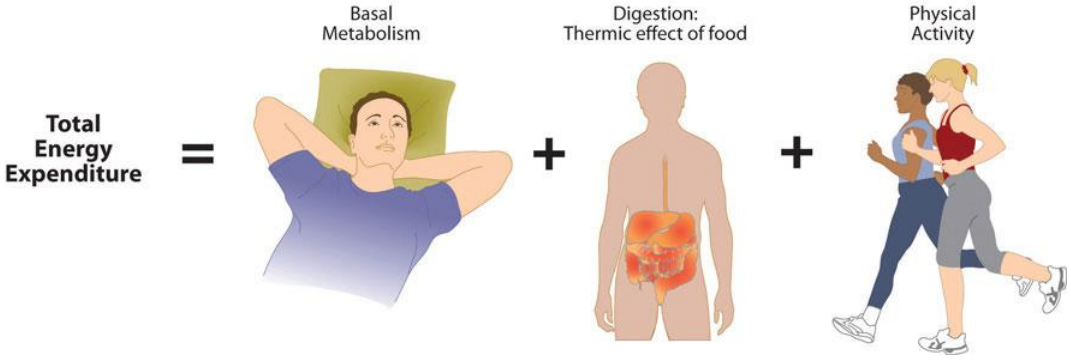


Figure 10.3.4: Components of total energy expenditure include basal metabolism, the thermic effect of food, and physical activity. "Components of total energy expenditure" from *An Introduction to Nutrition (v. 1.0)* is licensed under CC BY-NC-SA 3.0.

1. Basal Metabolic Rate (BMR)

BMR is the energy expended by the body when at rest. These are the behind-the-scenes activities that are required to sustain life. Examples include:

- respiration
- circulation
- nervous system activity
- protein synthesis
- temperature regulation

Basal metabolic rate does not include the energy required for digestion or physical activity.

If a person is sedentary or moderately active, BMR is the largest component of energy expenditure, making up about 60 to 75% of total energy output. For example, a sedentary person might need about 1800 calories in a day, with about 1200 of them being for BMR.

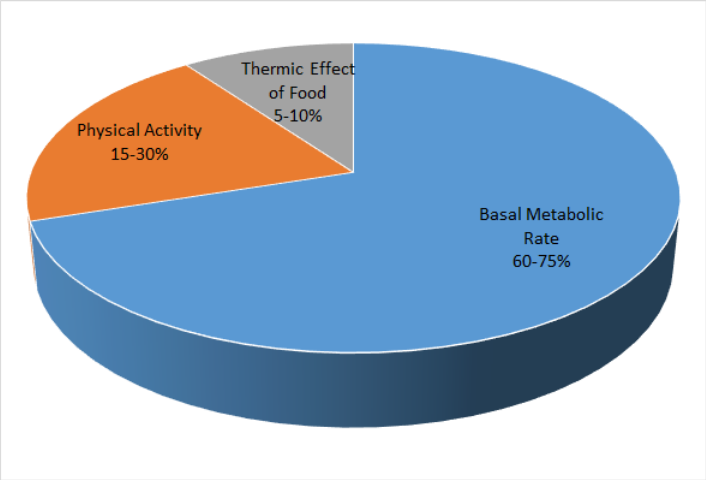


Figure 10.3.5: Components of energy expenditure and their percent contribution to the total in sedentary to moderately active people. "Components of energy expenditure" by Tamberly Powell is licensed under CC BY-NC-SA 2.0.

BMR can vary widely among individuals. An individual's lean body mass—made up of organs, bone, and muscle—is the biggest determinant of BMR, because lean body tissue is more metabolically active than fat tissue. This means that a muscular person expends more energy than a person of similar weight with more body fat. Likewise, increasing your muscle mass can cause an increase in your BMR. However, skeletal muscle at rest only accounts for about 18 percent of the total energy expended by lean mass. Most is used to meet the energy needs of vital organs. The liver and brain, for example, together account for nearly half of the energy expenditure by lean mass.

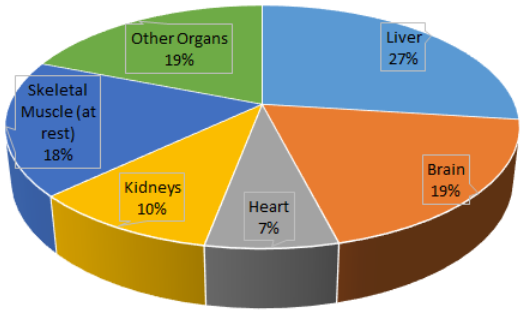


Figure 10.3.6: Energy expenditure of organs. "Energy expenditure of organs" by Tamberly Powell is licensed under CC BY-NC-SA 2.0.

BMR depends not only on body composition but also on body size, gender, age, nutritional status, genetics, body temperature, and hormones (Table 9.1). People with a larger frame size have a higher BMR simply because they have more mass. On average, women have a lower BMR than men because they typically have a smaller frame size and less muscle mass. As we get older, muscle mass declines, and therefore BMR declines as well.

Nutritional status also affects basal metabolism. If someone is fasting, starving, or even just cutting their caloric intake for a diet, their BMR will decrease. This is because the body attempts to maintain homeostasis and adapts by slowing down its basic functions (BMR) to help preserve energy and balance the decrease in energy intake. This is a protective mechanism during food shortages, but it also makes intentional weight loss more difficult.

Table 10.1. Factors that Impact Basal Metabolic Rate by Tamberly Powell is licensed under CC BY-NC-SA 2.0.

Table displays the factors that increase BMR and the factors that decrease BMR

Factors That Increase BMR	Factors That Decrease BMR
Higher lean body mass	Lower lean body mass
Larger frame size	Smaller frame size
Younger age	Older age

Male gender	Female gender
Stress, fever, illness	Starvation or fasting
Elevated levels of thyroid hormone	Lower levels of thyroid hormone
Pregnancy or lactation	
Stimulants such as caffeine and tobacco	

2. Thermic Effect of Food (TEF)

This is the energy needed to digest, absorb, and store the nutrients in foods. It accounts for 5 to 10 percent of total energy expenditure and does not vary greatly amongst individuals.

3. Physical activity

Physical activity is another important way the body expends energy. Physical activity usually contributes anywhere from 15 to 30 percent of energy expenditure and can be further divided into two parts:

- exercise-related activity thermogenesis (EAT)
- non-exercise activity thermogenesis (NEAT)

EAT is planned, structured, and repetitive physical activity with the objective of improving health (participating in a sport like soccer or strength training at the gym, for example).

NEAT is the energy expenditure for unstructured and unplanned activities. This includes daily living activities such as cleaning the house, yard work, shopping, and occupational activities. NEAT also includes the energy required to maintain posture and spontaneous movements such as fidgeting and pacing.[2]

NEAT can vary by up to 2,000 calories a day for two people of similar size, according to Dr. James Levine, the Mayo Clinic researcher who first coined the term. NEAT may be an important component of obesity and is currently an area of research.[3]

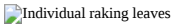


Figure 10.3.7: Man raking leaves. "raking leaves109/365" by Eric Ray is licensed under CC BY 2.0.

Factors Affecting Energy Intake

Given the importance of energy's role in sustaining life, it's not surprising that energy balance is tightly regulated by complex physiological processes. The brain, specifically the hypothalamus, is the main control center for hunger and satiety. There is a constant dialogue between our brains and gastrointestinal tracts through hormonal and neural signals, determining whether we feel hungry or full. Nutrients themselves also play a role in influencing food intake because the hypothalamus senses nutrient levels in the blood. When nutrient levels are low, the hunger center is stimulated. Conversely, when nutrient levels are high, the satiety center is stimulated.

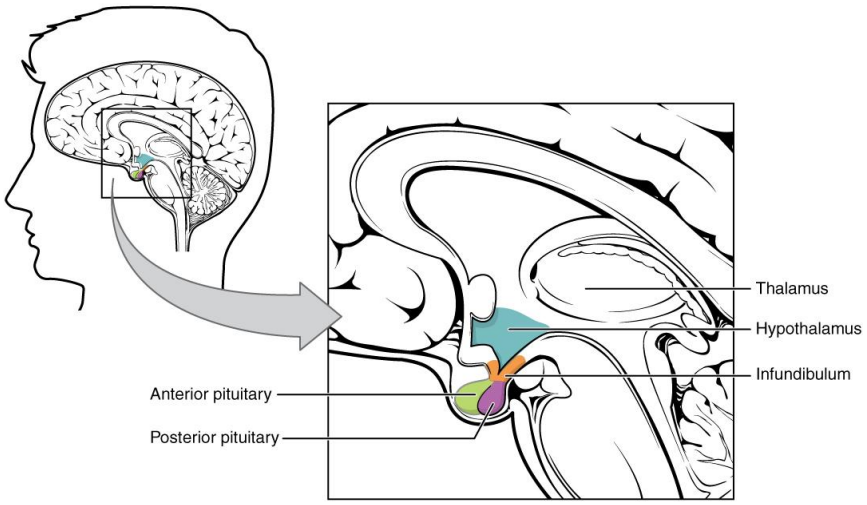


Figure 10.3.8: The hypothalamus, shown in blue-green, is about the size of an almond and serves as the hunger center of the brain, receiving signals from the gastrointestinal tract, adipose tissue, and blood and signaling hunger and satiety. "The Hypothalamus-Pituitary Complex" from *Anatomy & Physiology* by OpenStax is licensed under CC BY-SA 3.0.

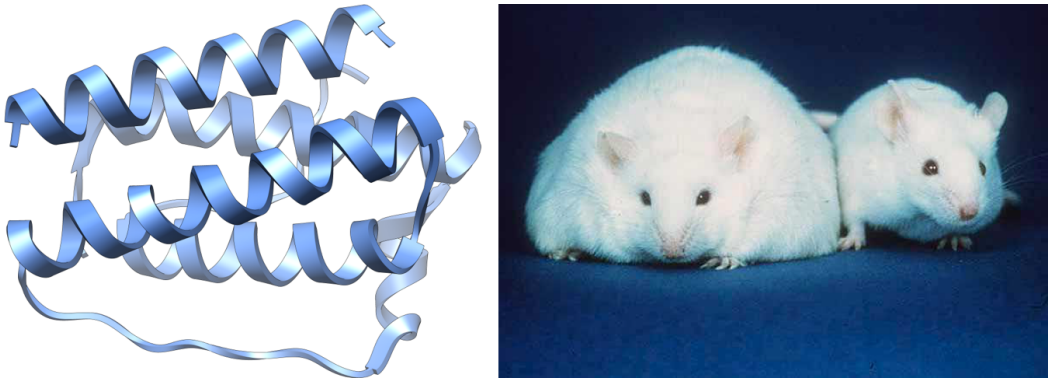


Figure 10.3.9: The structure of the hormone leptin (left), is primarily produced by adipose tissue. The obese mouse in the photo has a gene mutation that makes it unable to produce leptin, resulting in constant hunger, lethargy, and severe obesity. For comparison, a mouse with normal leptin production is also shown. Such gene mutations are rare, but they serve as a dramatic illustration of the importance of the hormone in signaling energy balance. "Leptin" by Vossman is licensed under CC BY-SA 3.0; Fatmouse by the US Department of Energy Human Genome Project is in the Public Domain.

Hunger is the **physiological** need to eat. When the stomach is empty, it contracts and starts to grumble and growl. The stomach's mechanical movements relay neural signals to the hypothalamus. Of course, the stomach also contracts when it's full and hard at work digesting food, but we can't hear these movements as well because the stomach's contents muffle the noise. The stomach is also the main organ that produces and secretes the "hunger hormone," ***ghrelin***, the only gut hormone found to increase hunger. Ghrelin levels are high before a meal and fall quickly once nutrients are absorbed.[4]

Appetite is the **psychological** desire to eat. ***Satiety*** is the sensation of feeling full. 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. Many hormones are associated with satiety, and various organs secrete these hormones, including the gastrointestinal tract, pancreas, and adipose tissue. ***Cholecystokinin (CCK)*** is an example of one of these satiety hormones and is secreted in response to nutrients in the gut, especially fat and protein. In addition to inhibiting food intake, CCK stimulates pancreatic secretions, gall bladder contractions, and intestinal motility—all of which aid in the digestion of nutrients.[4]

Fat tissue also plays a role in regulating food intake. Fat tissue is the primary organ that produces the hormone ***leptin***, and as fat stores increase, more leptin is produced. Higher levels of leptin communicate to the satiety center in the hypothalamus that the body is in positive energy balance. Leptin acts on the brain to suppress hunger and increase energy expenditure. 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. 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. Therefore, when you administer leptin to an overweight or obese person, there is generally no sustained effect on food intake.[5]

The Complexity of Energy Balance

Energy balance seems like it should be a simple math problem, and in fact, it is based on a fundamental truth in physics—the first law of thermodynamics. This law states that energy can't be created or destroyed; it can only change form. That is, calories that are consumed must go somewhere, and if they aren't metabolized, which converts caloric energy to heat and work energy, they must be stored, usually in the form of adipose tissue. What makes energy balance challenging is the reality that both energy intake and energy expenditure are dynamic variables that are constantly changing, including in response to each other.[6,7]

Let's first look at the energy intake side. As we've already discussed, how much food we eat each day is not just a matter of willpower or self-control. It's the result of powerful physiological and psychological forces that tell us if we need to eat or if we've had enough. Our brains are hard-wired to seek food if we're in negative energy balance, an instinct required for survival. This means that if you start to exercise more—increasing your energy expenditure—you will also feel hungrier because your body needs more fuel to support the increase in physical activity. If you eat fewer calories, perhaps in an effort to lose weight, your stomach will produce more ghrelin, and your adipose tissue will produce less leptin. These shifting hormone levels work together to increase hunger and make you focus on obtaining more calories. People who try to gain weight run into the opposite problem. Their leptin levels increase, suppressing hunger. It's also uncomfortable to eat beyond satiety, and food doesn't taste as good.

Even measuring how much energy is consumed is not as simple as you might think. We can measure the caloric content of food from a chemical standpoint, but we can only *estimate* how much energy a person will absorb from that food. This will depend on how well the food is digested and how well the macronutrients are absorbed—factors that vary depending on the food itself, the digestion efficiency of the person eating it, and even the microbes living in their gut. Two people may eat the exact same meal, yet not absorb the same number of calories.

Energy expenditure is also dynamic and changes under different conditions, including increased or decreased caloric intake. Decreased caloric intake and going into negative energy balance cause a drop in BMR to conserve energy. Muscles also become more efficient, requiring less energy to work, and without realizing it, people in negative energy balance often decrease their NEAT activity level. These adaptations help to conserve body weight and make it more difficult to stay in negative energy balance. People may still be able to lose weight despite their bodies working to prevent it, but maintaining a new, lower weight requires constant vigilance, and weight regain is common.

Research has also shown that people respond differently to positive energy balance. When a group of people are overfed, the amount of weight gained among study participants varies widely. In a study of identical twins who were given an extra 1,000 calories per day for 100 days, weight gain varied between 10 and 30 pounds among participants. Weight gain between twins was more similar (though not exactly the same), which may be attributed to genetic factors.[8] People gain and lose weight differently; we don't necessarily follow formulas.

When people say that the answer to the obesity epidemic is to eat less and move more, they're not wrong. But this is also an oversimplified answer because of all the complexities underlying energy intake and expenditure.

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10.4: Indicators of Health- BMI, Body Composition, and Metabolic Health

Determining Your Healthy Size

Many metrics are used to assess body composition, but none give a complete picture of an individual's health. That requires a truly individual assessment of a person's overall health and well-being in the context of family history and lifestyle, not just numbers on the scale.

Here's how the authors of the text "Sport Nutrition for Health and Performance"[1] describe a healthy body weight:

- *A weight that is appropriate for your age and physical development*
- *A weight you can achieve and sustain without severely curtailing your food intake and constantly dieting*
- *A weight that is compatible with normal blood pressure, lipid levels, and glucose tolerance*
- *A weight that is based on your genetic background and family history of body shape and weight*
- *A weight that promotes good eating habits and allows you to participate in regular physical activity*
- *A weight that is acceptable to you*

Overall, a healthy size should not be dictated by a formula, the latest fad, or societal expectations. People come in all shapes and sizes, and you must determine what a healthy size is for you. Yet it's also worth understanding some of the measures used to estimate body composition, how they can be linked to health, and their limitations.

Body Mass Index

Body mass index (BMI) is an inexpensive screening tool used in clinical and research settings to assess body weight relative to height. Because it takes height into account, it is more predictive of how much body fat a person has than weight alone. However, BMI is not a direct measure of body fat, so it shouldn't be used on its own to diagnose obesity or the health of an individual.[2]

BMI calculations and categories

BMI is calculated using the following equations:

$$\text{BMI} = [\text{weight (kg)}/\text{height (m}^2\text{)}]$$

OR

$$\text{BMI} = [\text{weight (lb)}/\text{height (in}^2\text{)}] \times 703$$

Think of BMI as a "score," usually with a two-digit outcome. A lower score correlates with lower health risk.

> The Centers for Disease Control and Prevention provide a BMI calculator on their website. [3]

For adults, BMI ranges are divided into four categories, which are associated with different levels of health risk. BMI values are interpreted differently for children because body fatness changes with age, growth, and development, and can be different between boys and girls.

- **Underweight –** BMI < 18.5
- **Normal weight –** BMI from 18.5-24.9
- **Overweight –** BMI from 25-29.9
- **Obese –** BMI from 30 or higher

Obesity is frequently subdivided into categories based on BMI:

- **Class 1 obesity:** BMI of 30 to < 35
- **Class 2 obesity:** BMI of 35 to < 40
- **Class 3 obesity**: BMI of 40 or higher

In general, BMI in the "normal" range is associated with better health compared with both underweight and overweight or obese values, because there are risks of carrying both too little and too much body fat. When researchers have looked at BMI and health in large groups of people, they generally find that the lowest risk of disease and of dying younger is in the range of BMI of 20 to 25. As BMI values increase into the overweight and obese ranges, the risk of developing type 2 diabetes, cardiovascular

disease and stroke, and even cancer increases, as well as other complications of obesity, such as osteoarthritis.[4,5,6] Carrying extra weight not only puts a mechanical strain on the body but also negatively impacts metabolic health and increases inflammation.[7]

Limitations of BMI

The advantage of BMI is that it's simple and easy to calculate, but it also has several important limitations. Because it's based only on weight and height, it doesn't distinguish between muscle mass and adipose tissue. It's not unusual for muscular athletes to be classified as overweight based on BMI, but this can be misleading, because they may have little to no excess body fat. On the flip side, BMI can underestimate body fatness in someone with very low muscle mass, such as a person who is elderly and frail. In addition, BMI can't tell us where body fat is located in the body, and as we'll learn, this is a major factor determining the impact of body fat on health.

BMI's accuracy in predicting body fatness is also affected by biological sex and race—not surprising, given the natural diversity in shape and size of human bodies. At the same BMI, women tend to carry more body fat than men. Also, at the same BMI, a Black person tends to have less body fat and an Asian person tends to have more body fat compared with a white person. This means that a high BMI may overestimate health risk in a Black person and underestimate health risk in an Asian person. BMI is also not useful for estimating body fatness in a pregnant woman because pregnancy weight gain includes placental and fetal tissues.[8]

All of this means that BMI is not particularly useful for comparing one individual to another or even one population to another because this one number simply doesn't account for all of the underlying diversity in factors like body type, muscle mass, biological gender, and race. And for an individual, one BMI measurement at a single point in time may not be all that meaningful—other measurements and clinical assessments are needed to diagnose obesity and more accurately assess disease risk, as we'll discuss in a moment.

BMI is perhaps most useful for tracking *changes* in body composition over time, whether of a population or an individual. For example, the data on average BMI in the US show a clear increase over the last several decades, and the most likely explanation for that is not that people in the US are all gaining several pounds of muscle each year but that we're putting on more fat. On the other hand, someone may have a BMI classified as overweight, but if they've been at that BMI their entire adult life and are active and metabolically healthy, that may just be the natural size and shape of their body.

Measuring Body Composition

A person's body mass is made up of water, lean body mass (including organs, bone, and muscle), fat, and other components like minerals. The weight on the scale does not distinguish between these different components, but body composition measurements can.

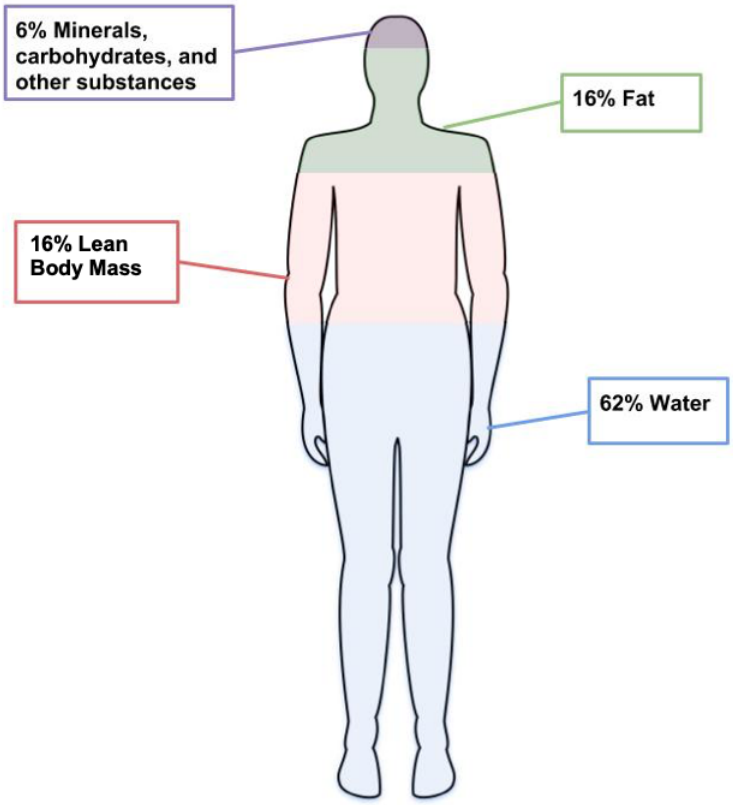


Figure 10.4.2. *The four main components of body weight are water, fat, lean body mass and other components like minerals* . "Components of weight" by Allison Calabrese is licensed under CC BY 4.0.

Individuals and researchers use body composition to determine how much of a person's weight is made up of body fat and lean body mass. An individual might use body composition measurements to track their progress in building muscle with a new strength training program. Since increased body fat is often a risk factor for diseases like cardiovascular diseases and diabetes, researchers are often interested in this type of data. There are several different methods used to measure body composition, each with advantages and limitations.[9]

- **Skinfold test**. This is a simple, non-invasive, and low-cost way to assess fat mass. Calipers are used to measure the thickness of skin on three to seven different parts of the body, and these numbers are then entered into a conversion equation. Keep in mind that the accuracy of the skinfold test depends on the skill of the person taking the measurements, the accuracy of the calipers, and the appropriateness of the conversion equations. Best practice is for the same person to take repeated measurements if using them to monitor changes over time. Repeated measurements by different technicians, using different calipers, and different conversion equations will yield very different results.

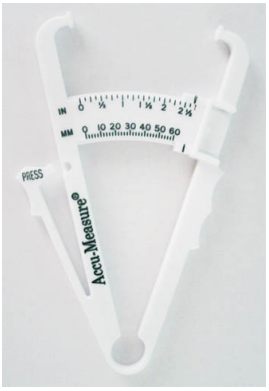


Figure 10.4.3. Calipers used to assess body fat during skinfold testing. "Body Fat Caliper" by Jks111 is licensed under CC BY-SA 3.0.

- **Bioelectric Impedance Analysis (BIA)**. This is a simple, non-invasive, quick tool that does not require extensive training. BIA estimates body composition by sending a small amount of electricity through the body. Since water is a good conductor of electricity, and lean body mass contains more water than fat, the rate at which the current travels can be used to estimate percent body fat. Body fluid levels must be normal with BIA, which is a limitation because exercise, alcohol, and menstrual cycles can impact hydration.



Figure 10.4.4. BIA hand device. "101005-M-3215R-001" by the United States Marine Corps is in the Public Domain.

- **Air displacement plethysmography (ADP)** – This is a non-invasive, quick tool that does not take extensive training. It's more accurate but also more expensive than BIA. While a person sits inside an enclosed chamber (usually called a Bod Pod), changes in air pressure are used to determine the amount of air displaced in the test chamber, which can determine body volume. These measurements are then translated into percent body fat. Hydration status can affect the accuracy of this test. This test must also be conducted in a facility with a Bod Pod, so it is not as accessible as the skinfold test or the BIA.



Figure 10.4.5. Body composition measurement with whole-body air displacement plethysmography (ADP) technology or BodPod "Adult body composition through air displacement plethysmography" by COSMED is licensed under CC BY-SA 3.0.

- **Dual-energy X-ray absorptiometry (DXA)**. This method directs two low-dose X-ray beams through the body and determines the amount of 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 and bone density can be accurately estimated. Although this is one of the most accurate methods of measuring fat mass, it is expensive and mostly used in research. It also requires low doses of radiation to the subject being tested and is not appropriate for pregnant women.



Figure 10.4.6. Dual-Energy X-ray Absorptiometry (DXA) "DEXA scanner in use ALSPAC" by Nick Smith Photography is licensed under CC BY-SA 3.0.

Keep in mind that body composition can be hard to measure accurately when using inexpensive and accessible techniques like skinfold testing and BIA. Your best bet is to pick one method and use that method over time to compare numbers and see how they change. Just don't get too hung up on the actual number, as the accuracy will be questionable depending on the method chosen.

Measuring Fat Distribution

Total body fat is one predictor of health; another is how the fat is distributed in the body. The location of fat is important because people who store fat more centrally (apple-shaped) have a higher risk for chronic disease—like cardiovascular disease and type 2 diabetes—compared with people who store fat in the hips, thighs, and buttocks (pear-shaped). This is because visceral fat that surrounds vital organs, which is common in central obesity or apple-shaped fat patterning, is more metabolically active, releasing more hormones and inflammatory factors thought to contribute to disease risk compared with subcutaneous fat. Subcutaneous fat stored just below the skin, common in pear-shaped fat patterning, does not seem to increase the risk for chronic disease significantly.

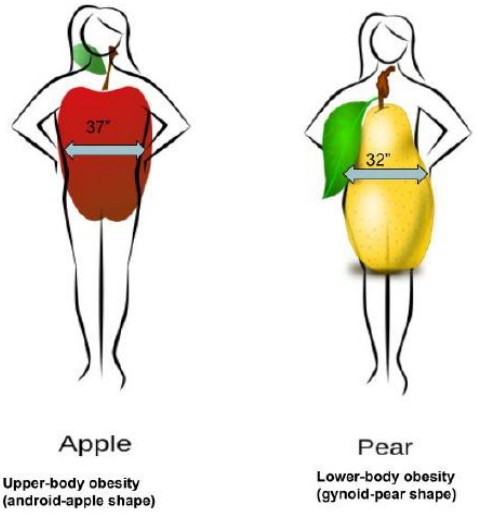


Figure 10.4.7. Fat can be located in the abdominal region (apple shape) or hips, thighs, and buttocks (pear shape). "Fat Distribution" by Allison Calabrese is licensed under CC BY 4.0.

Body fat distribution can be measured by waist circumference and waist-to-hip ratio, both of which only require a measuring tape.

- **Waist circumference** is measured just above the hip bone, level with your 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.
- **Waist-to-hip ratio** is calculated by measuring waist circumference and hip circumference (at its widest part) and dividing the two values. Abdominal obesity is defined as a waist-to-hip ratio above 0.90 for males and above 0.85 for females.

Indicators of Metabolic Health

Metabolic health refers to the body's ability to maintain normal homeostasis and effectively regulate measures like blood pressure, blood lipids, and blood glucose. It is assumed that when an individual is classified as overweight and obese, based on measurements of BMI and body fat composition and distribution, metabolic health is negatively impacted. However, some individuals who meet the criteria for obesity do not experience an increased risk of metabolic health.[10] These individuals are known as "***metabolically healthy obese***" ***(MHO).*** Metabolically healthy can be described as an absence of insulin resistance, type 2 diabetes, dyslipidemia, and hypertension.

In contrast, some individuals are classified as a healthy weight (BMI < 25) but show an increased metabolic risk. These individuals are known as ***metabolically obese normal weight (MONW).***

These variations challenge the assumptions we hold about body fatness. It can not always be assumed that thinness equals healthy, and fatness equals unhealthy.

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10.5: Overweight and Underweight—What are the Risks?

As the previous section illustrated, many factors influence energy balance. Whether an individual is in positive or negative energy balance ultimately influences the overall trend in whether that individual is normal weight, overweight, or underweight. While much of the focus in society is placed on concerns with being overweight or obese, both ends of the weight spectrum are associated with health risks, and being underweight can negatively impact health just as being overweight can. In fact, **research has shown a J-shaped association between mortality risk and BMI**, with greater risk for dying in underweight and obese populations and the lowest risk occurring in the normal BMI range.[1]

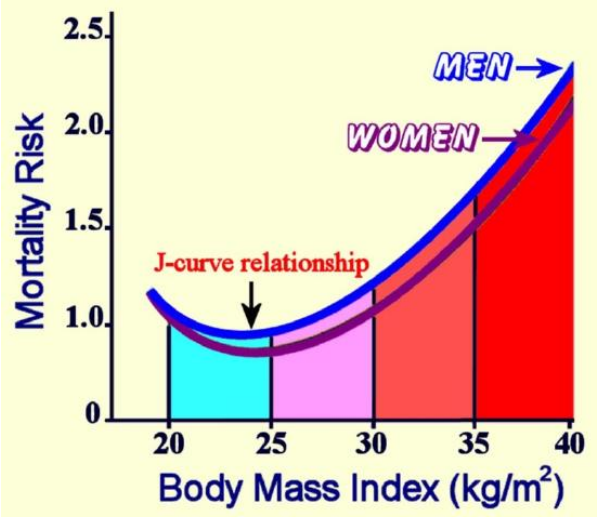


Figure 10.5.1: The relationship between body mass index and mortality forms a J-shaped curve, demonstrating higher rates of death associated with underweight and overweight/obese, with the lowest rates of death associated with normal weight.

"Relationship Between Body Mass Index (BMI) and Mortality" from *Clinical Problems Caused by Obesity* is licensed under CC BY-NC-ND 2.0.

Health Risks of Being Overweight or Obese

The health consequences of having too much body fat are numerous. Fat cells are not lifeless storage tanks—they're dynamic, metabolically active tissue that secretes a number of different hormones and hormone-like messengers. These hormones cause low-grade inflammation that's believed to contribute to chronic disease development, such as type 2 diabetes, cardiovascular disease, and some types of cancer.

According to the World Health Organization (WHO), there are more people worldwide who are overweight or obese than underweight, and an estimated 2.8 million adults die annually as a result of being overweight or obese.[2] As BMI increases over 25, the risks increase for several health conditions,[3] including:

- Heart disease
- Type 2 diabetes
- Hypertension
- Stroke
- Osteoarthritis
- Sleep apnea
- Some cancers (endometrial, breast, colon, kidney, gallbladder, liver)
- Depression and anxiety
- Difficulty with physical movement
- Lower quality of life

Childhood obesity is also a global health concern. In 2016, more than 340 million children and adolescents and 41 million preschool children were overweight or obese. And obese children are more likely to become obese adults, develop diabetes and cardiovascular disease at younger ages, and have an increased risk of premature death.[2]

Like other public health organizations, the WHO states that the main causes of the global obesity epidemic are increased intake of energy-dense foods and decreased physical activity 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.[2]

Economic and Societal Costs of Being Overweight and Obese

The economic burden of overweight and obesity has skyrocketed as obesity rates in the United States continue to climb. According to a recent report, direct health care costs due to overweight and obesity (money directly paid to treat the illness) exceed $480 billion, and indirect health care costs (lost economic productivity due to absenteeism, lost wages, and reduced productivity) have surpassed $1.2 trillion.[4] On the individual level, people who are obese spend $3,429 more per year for medical care than people of healthy weight.[5]

The social and emotional consequences of being overweight or obese are no less real than economic costs. Individuals with obesity often face discrimination, lower wages, depression, anxiety, and lower quality of life.[3,6] Weight bias and discrimination are of particular concern for those who are overweight or obese. ***Weight bias*** is defined as "negative weight-related attitudes, beliefs, assumptions and judgments toward individuals who are overweight and obese," though this bias does extend to those who are underweight as well.[7]

The Incidence of weight discrimination has increased by 66% since 1995 and occurs at rates similar to that of racial discrimination.[8] According to Rebecca Puhl, PhD, deputy director of the Rudd Center for Food Policy & Obesity at the University of Connecticut, "Bias, stigma, and discrimination due to weight are frequent experiences for many individuals with obesity, which have serious consequences for their personal and social well being and overall health."[9] Puhl has also noted that "about 40% of the general population reports that it has experienced some type of weight stigma—whether it be weight-based teasing, unfair treatment, or discrimination."[10] Individuals who are obese are often blamed for their disease and viewed as being lazy, stupid, ugly, and lacking in self-control or motivation.[11] This bias toward people with obesity is seen in many aspects of life, including the workplace, health care, social environments, and even the individual's own family.[12]

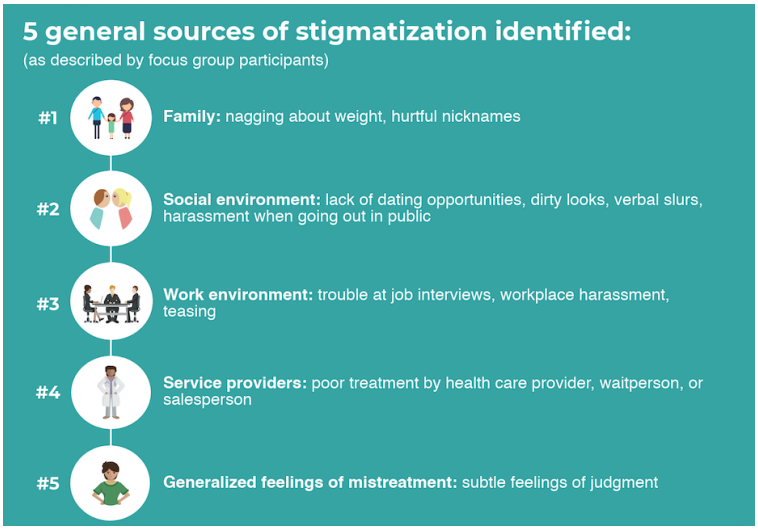


Figure 10.5.2: Common sources of weight stigmatization identified by individuals who are overweight or obese include families, social environments, work environments, and service providers, as well as generalized feelings of judgment from others.[14] "Sources of Stigmatization" by Heather Leonard is licensed under CC BY 4.0.

Combating weight bias and discrimination will require change on many levels. Governments can include weight as a category covered in anti-discrimination laws. Anti-bullying efforts at the school level should include policies on harassment and bullying related to weight. Health care should include reimbursement for obesity treatment, and weight bias training should be required for health care providers. And education and awareness about weight bias on an individual level will help change negative attitudes toward overweight and obesity.[9,13]



Video 10.5.1: " Weight of the Nation: Stigma—The Human Cost of Obesity." This is an excellent video to help increase awareness of weight stigma, humanizing the pain and damage caused by weight bias and discrimination. (Time 18.54).[14]

Health Risks of Being Underweight

The 2017-2018 National Health and Nutrition Examination Survey (NHANES) estimated that 1.6% of adults and 4.1% of children and adolescents in the United States are underweight.[15,16] Underweight individuals represent a small portion of Americans, yet the health risks associated with being underweight are an important part of the discussion on nutrition and health.

Being underweight is linked to nutritional deficiencies, especially iron-deficiency anemia, and to other problems such as delayed wound healing, hormonal abnormalities, increased susceptibility to infection, and increased risk of some chronic diseases such as osteoporosis. In children, being underweight can stunt growth. The most common underlying cause of underweight in America is inadequate nutrition. Other causes are wasting diseases (cancer, multiple sclerosis, tuberculosis) and eating disorders. People with wasting diseases are encouraged to seek nutritional counseling, as a healthy diet greatly affects survival and improves responses to disease treatments.

Eating Disorders

The National Institute of Mental Health (NIMH) defines eating disorders as " serious and sometimes fatal illnesses that cause severe disturbances to a person's eating behaviors."[17] People with eating disorders often experience a preoccupation with food choices and body weight, and they frequently have a distorted body image, believing that self-worth is tied to body size and shape.[18]



Figure 10.5.3: Woman on scale. Preoccupation with body weight is a common experience for a person with an eating disorder. "woman on scale" by Luxstorm is licensed under the standard Pixabay License.

It is estimated that 28.8 million people in the US will suffer from an eating disorder in their lifetime. An eating disorder can occur at any age, any race, any sexual orientation and any gender.[19] Prevention and proper treatment of eating disorders must involve a multi-faceted approach, including physical, emotional, and social issues related to each individual's needs.[20]

Anorexia Nervosa

Anorexia nervosa, more often referred to as "anorexia," is a psychiatric illness in which a person obsesses about their weight and about the food that they eat. Anorexia results in extreme nutrient inadequacy and, eventually, organ malfunction. It is an extreme example of how an unbalanced diet can affect health.

Anorexia frequently manifests during adolescence, although it may emerge much later in adulthood as well. People with anorexia consume, on average, fewer than 1,000 calories per day and exercise excessively. They are in a tremendous caloric imbalance. Moreover, some may participate in binge eating, self-induced vomiting, and purging with laxatives or enemas. The exact causes of anorexia are not completely known, but many things contribute to its development, including economic status, as it is more prevalent in high-income families. It is a genetic disease and is often passed from one generation to the next. Complications during fetal development and abnormalities in the brain, endocrine system, and immune system may all contribute to the development of this illness.

The primary signs of anorexia are fear of being overweight, extreme dieting, an unusual perception of body image, and depression. The secondary signs and symptoms of anorexia are all related to the caloric and nutrient deficiencies of the unbalanced diet and include excessive weight loss, a multitude of skin abnormalities, diarrhea, cavities and tooth loss, osteoporosis, and liver, kidney, and heart failure. There is no physical test that can be used to diagnose anorexia and distinguish it from other mental illnesses. Therefore, a correct diagnosis involves eliminating other mental illnesses, hormonal imbalances, and nervous system abnormalities. Treatment of any mental illness involves not only the individual but also family, friends, and a psychiatric counselor. Treating anorexia often involves a registered dietitian, who helps to provide dietary solutions that are adjusted over time. The goals of treatment for anorexia are to restore a healthy body weight and significantly reduce the weight obsession and behaviors associated with the eating disorder. Relapse to an unbalanced diet is high. Many people do recover from anorexia; however, most continue to have a lower-than-normal body weight for the rest of their lives.

Bulimia

Bulimia, like anorexia, is a psychiatric illness that can have severe health consequences. Bulimia is characterized by episodes of eating large amounts of food followed by purging, which is accomplished by vomiting and with the use of laxatives and diuretics. Unlike people with anorexia, those with bulimia often have a normal weight, making the disorder more difficult to detect and diagnose. Bulimia is characterized by signs similar to anorexia, such as fear of being overweight, extreme dieting, and bouts of excessive exercise. Secondary signs and symptoms include gastric reflux, severe erosion of tooth enamel, dehydration, electrolyte imbalances, lacerations in the mouth from vomiting, and peptic ulcers. Repeated damage to the esophagus puts people with bulimia at an increased risk for esophageal cancer. The disorder is also highly genetic, is linked to depression and anxiety disorders, and most commonly occurs in adolescent girls and young women. Treatment often involves antidepressant medications and, like

anorexia, has better results when both the family and the individual with the disorder participate in nutritional and psychiatric counseling.



Figure 10.5.4: This photo shows the erosion on the lower teeth caused by bulimia. For comparison, the upper teeth were restored with porcelain veneers. "Oral Manifestation of Bulimia" by Jeffrey Dorfman is licensed under CC BY-SA 3.0.

Binge-Eating Disorder

Similar to those who experience anorexia and bulimia, people with binge-eating disorder have lost control over their eating. Binge-eating disorder was only recently classified as a distinct psychiatric illness, becoming formally recognized as a diagnosable eating disorder in 2013. People with ***binge-eating disorder*** will periodically overeat to the extreme, but their loss of control over eating is not followed by fasting, purging, or compulsive exercise. As a result, people with this disorder are often overweight or obese, and their chronic disease risks are those linked to having an abnormally high body weight, such as hypertension, cardiovascular disease, and type 2 diabetes. Additionally, they often experience guilt, shame, and depression. Binge-eating disorder is commonly associated with depression and anxiety disorders. Treatment often involves antidepressant medication as well as nutritional and psychiatric counseling.

Orthorexia

Orthorexia is a disordered eating behavior defined as an unhealthy obsession with healthy eating. The term “orthorexia” was first defined in 1998, but it has yet to be formally classified as an eating disorder, making it difficult to determine how prevalent it is. Research suggests it may be identified as a form of obsessive-compulsive disorder.[21] Although focusing on a healthy diet isn’t inherently a bad thing, in situations of orthorexia, the individual takes the emphasis of healthy eating, or “clean” eating, to the extreme, so much so that it becomes a fixation, putting their health at risk.

Signs of orthorexia include compulsively reading food labels, cutting several food groups out of the diet, spending an unusual amount of time focusing on what foods may be available at upcoming events, and experiencing a high level of stress when healthy foods are not available. The obsession with healthfulness comes with a high social cost, as it is often difficult to enjoy eating out or sharing meals with friends and family.

There is no formal treatment plan for orthorexia, but many eating disorder experts treat it similarly to anorexia and obsessive-compulsive disorder.

Eating Disorder Resources

If you think you or someone close to you might have an eating disorder and you want to learn more or find resources for help, check out these organizations and links.

National Eating Disorders Association

ANAD Eating Disorders Helpline

Eating Disorder Hope

Eating Recovery Center

Attributions:

- University of Hawai‘i at Mānoa Food Science and Human Nutrition Program, “ Undernutrition, Overnutrition, and Malnutrition ,” CC BY-NC 4.0

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- **7.4: Risks of Too Little and Too Much Body Fat** by Alice Callahan, Heather Leonard, and Tamberly Powell is licensed CC BY-NC-SA 4.0.

10.6: Obesity Epidemic - Causes and Solutions

Obesity Trends

Obesity in the United States continues to escalate, as seen in these maps from the Centers for Disease Control and Prevention. The methods used by the CDC to collect the data changed in 2011, so we can't directly compare between the periods before and after that change, but the trend has continued. Every year, more and more people in the U.S. are obese.

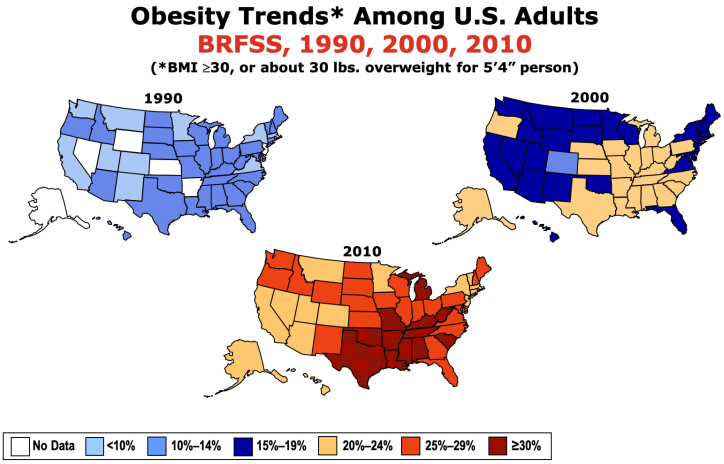


Figure 10.6.1: Each year since 1990, the CDC has published maps of the United States in which states are color-coded based on the percentage of their population estimated to be obese. The maps show a clear increase in the prevalence of obesity between 1990 and 2010. "Obesity Trends Among US Adults, BRFSS, 1990-2010" by the Centers for Disease Control & Prevention Division of Nutrition, Physical Activity, and Obesity is in the Public Domain.

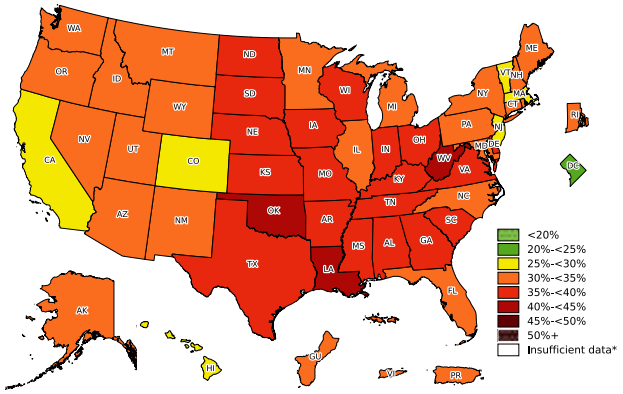


Figure 10.6.2:

2022 Prevalence of obesity based on self-reported weight and height among US adults by state and territory. "Prevalence of Obesity Based on Self-Reported Weight and Height Among U.S. Adults by State and Territory, BRFSS, 2022" by the Centers for Disease Control & Prevention Division of Nutrition, Physical Activity, and Obesity is in the Public Domain.

These trends are unmistakable, and they're not occurring only in adults. **Childhood obesity** has seen similar increases over the last few decades—perhaps an even greater concern as the metabolic and health effects of carrying too much weight can be compounded over a person's entire lifetime.

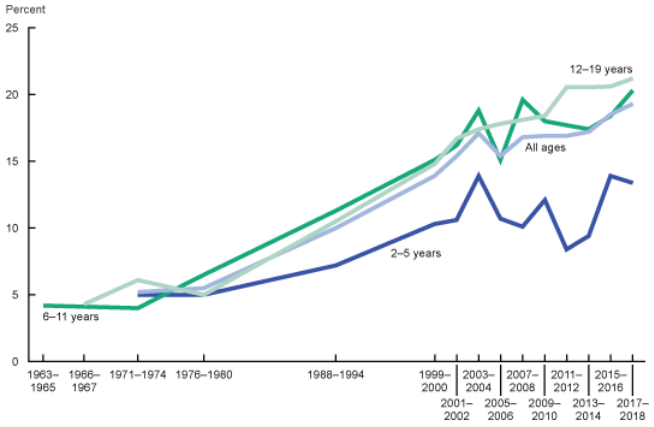


Figure 10.6.3: Since the 1970s, the prevalence of obesity in both children and teens has risen steadily. "Trends in obesity among children and adolescents aged 2–19 years, by age: United States, 1963–1965 through 2017–2018" by the Centers for Disease Control & Prevention Division of Nutrition, Physical Activity, and Obesity is in the Public Domain.

Although obesity is a problem across the United States, it affects some groups of people more than others. Based on reports in 2021, obesity rates are higher among Hispanic (45.6%) and Black adults (49.9%) compared with white adults (41.4%). Non-Hispanic Asians have the lowest obesity rate (16.1%). And overall, people who are college-educated and have a higher income are less likely to be obese.[1] These health disparities point to the importance of looking at social context when examining causes and solutions. Not everyone has the same opportunity for good health or an equal ability to make changes to their circumstances because of factors such as poverty and longstanding inequities in how resources are invested in communities. These factors are called "***social determinants of health.***"[2]

The obesity epidemic is also not unique to the United States. Obesity is rising around the globe and it is estimated to affect 2 billion people worldwide, making it one of the largest factors affecting poor health in most countries.[3] Globally, among children aged 5 to 19 years old, the rate of overweight increased from 10.3% in 2000 to 18.4% in 2018. Previously, overweight and obesity mainly affected high-income countries, but some of the most dramatic increases in childhood overweight over the last decade have been in low-income countries such as those in Africa and South Asia, corresponding to greater availability of inexpensive, processed foods.[4]

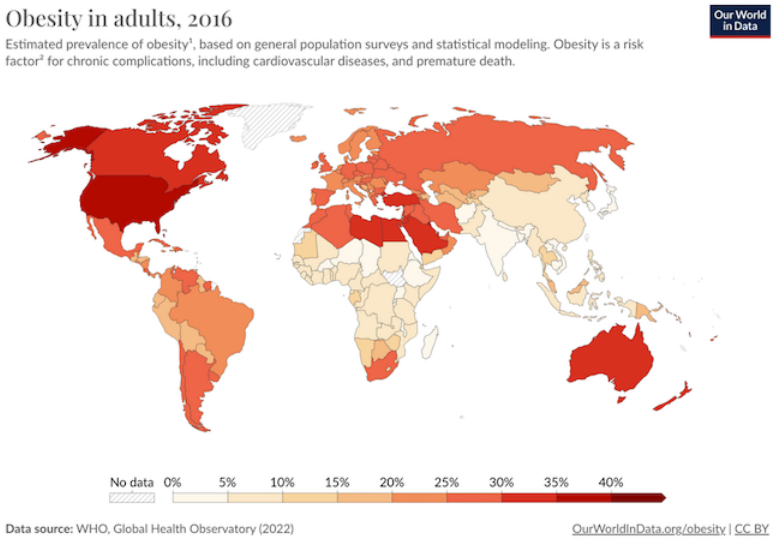


Figure 10.6.4: Obesity rates worldwide have been associated with prosperity.[5] "Obesity in adults, 2016" by Our World in Data is licensed under CC BY 4.0.

Despite the gravity of the problem, no country has yet been able to implement policies that have reversed the trend and brought about a decrease in obesity. This represents "one of the biggest population health failures of our time," wrote an international group of researchers in the journal The Lancet in 2019.[6] The World Health Organization has set a target of stopping the rise of obesity by

2025. Doing so requires understanding what is causing the obesity epidemic; it is only when these causes are addressed that change can start to occur.

Causes of the Obesity Epidemic

If obesity were an infectious disease sweeping the globe, affecting billions of people's health, longevity, and productivity, we surely would have addressed it by now. Researchers and pharmaceutical companies would have worked furiously to develop vaccines and medicines to prevent and cure this disease. But the causes of obesity are much more complex than a single bacteria or virus, and solving this problem means recognizing and addressing a multitude of factors that lead to weight gain in a population.

Behavior

At its core, rising obesity is caused by a chronic shift towards positive energy balance—consuming more energy or calories than one expends each day, leading to an often gradual but persistent increase in body weight. People often assume that this is an individual problem, that those who weigh more need simply to change their behavior to eat less and exercise more, and if this doesn't work, it must be because of a personal failing, such as a lack of self-control or motivation. While behavior patterns such as diet and exercise can certainly impact a person's risk of developing obesity, the environments where we live also have a big impact on our behavior and can make it much harder to maintain energy balance.

Environment

Many of us live in what researchers and public health experts call "***obesogenic environments.***" That is, the ways in which our neighborhoods are built and our lives are structured influence our physical activity and food intake to encourage weight gain.[7] Human physiology and metabolism evolved in a world where obtaining enough food for survival required significant energy investment in hunting or gathering—very different from today's world, where more people earn their living in sedentary occupations. From household chores to workplace productivity to daily transportation, getting things done requires fewer calories than it did in past generations.



Figure 10.6.5: Some elements of our environment that may make it easier to gain weight include sedentary jobs, easy access to inexpensive calories, and cities built more for car travel than for physical activity. "wocintech (microsoft) - 229" by WOCinTechChat is licensed under CC BY 2.0; "Vending Machines" by Purchase College Library is licensed under CC BY-NC 2.0; "assorted cars on asphalt road under overpass" by Tamara Menzi is licensed under the standard Unsplash License.

Our jobs have become increasingly sedentary, with fewer opportunities for non-exercise thermogenesis (NEAT) throughout the day. There's less time in the school day for recess and physical activity, and fears about neighborhood safety limit kids' ability to get out and play after the school day is over. Our towns and cities are built more for cars than for walking or biking. We can't turn back the clock on human progress, and finding a way to stay healthy in obesogenic environments is a significant challenge.

> ### Calculate your Walk Score
>
> Check out how your neighborhood rates for commuting, public transportation, and bike access at https://www.walkscore.com/score/

Our environments can also impact our food choices. We're surrounded by vending machines, fast food restaurants, coffee shops, and convenience stores that offer quick and inexpensive access to calories. These foods are also heavily advertised, and especially when people are stretched thin by working long hours or multiple jobs, they can be a welcome convenience. However, they tend to be calorie-dense (and less nutrient-dense) and more heavily processed, with amounts of sugar, fat, and salt optimized to make us want to eat more, compared with home-cooked food. In addition, portion sizes at restaurants, especially fast food chains, have increased over the decades, and people are eating at restaurants more and cooking at home less.

Poverty and Food Insecurity

Living in poverty usually means living in a more obesogenic environment. Consider the fact that some of the poorest neighborhoods in the United States—with some of the highest rates of obesity—are often not safe or pleasant places to walk, play, or exercise. They may have busy traffic and polluted air, and they may lack sidewalks, green spaces, and playgrounds. A person living in this type of neighborhood will find it much more challenging to get adequate physical activity compared with someone living in a neighborhood where it's safe to walk to school or work, play at a park, ride a bike, or go for a run.

In addition, poor neighborhoods often lack a grocery store where people can purchase fresh fruits and vegetables and basic ingredients necessary for cooking at home. Such areas are called "***food deserts***"—where healthy foods simply aren't available or easily accessible.

Another concept useful in discussions of obesity risk is "food insecurity." ***Food security*** means "access by all people at all times to enough food for an active, healthy life."[8] ***Food insecurity*** means an inability to consistently obtain adequate food. It may seem counter-intuitive, but in the United States, food insecurity is linked to obesity. That is, people who have difficulty obtaining enough food are more likely to become obese and suffer from diabetes and hypertension. This is likely related to the fact that inexpensive foods tend to be high in calories but low in nutrients. When these foods form the foundation of a person's diet, they can cause both obesity and nutrient deficiencies.

Genetics

What about genetics? While it's true that our genes can influence our susceptibility to becoming obese, researchers say they can't be a cause of the obesity epidemic. Genes take many generations to evolve, and the obesity epidemic has occurred over just the last 40 to 50 years—only a few generations. When our grandparents were children, they were much less likely to become obese than our own children. That's not because their genes were different but rather because they grew up in a different environment. However, it is true that a person's genes can influence their susceptibility to becoming obese in this obesogenic environment, and obesity is more prevalent in some families. A person's genetic make-up can make it more difficult to maintain energy balance in an obesogenic environment because certain genes may make you feel more hungry or slow your energy expenditure.[1]

Solutions to the Obesity Epidemic

Given the multiple causes of obesity, solving this problem will also require many solutions at different levels. Because obesity affects people over the lifespan and is difficult to reverse, the focus of many of these efforts is prevention, starting as early as the first years of life. We'll discuss individual weight management strategies later in this chapter. Here, we'll review some strategies happening in schools, communities, and at the state and federal levels.

Support Healthy Dietary Patterns

Interventions that support healthy dietary patterns, especially among people more vulnerable because of food insecurity or poverty, may reduce obesity. In some cases, studies have shown that they have an impact, and in other cases, it's too soon to know. Here are some examples:

- Implement and support better nutrition standards for childcare, schools, hospitals, and worksites.[9]
- Limit marketing of processed foods, especially ads targeted towards children.
- Provide incentives for supermarkets or farmer's markets to establish businesses in underserved areas.[9]



Figure 10.6.6: Farmer's markets can expand healthy food options for neighborhoods and build connections between consumers and local farmers.

"group of people standing near vegetables" by Megan Bucknall is licensed under the standard Unsplash License; "Veggies at Corvallis Farmers Market" by Friends of Family Farmers is licensed under CC BY-ND 2.0.

- Place nutrition and calorie content on restaurant and fast food menus to raise awareness of food choices.[10] Beginning in 2018, as part of the Affordable Care Act, chain restaurants with more than 20 locations were required to add calorie information to their menus, and some had already done so voluntarily. There isn't yet enough research to say whether having this information improves customers' choices; some studies show an effect, and others don't.[11] Many factors influence people's decisions, and the type of restaurant, customer needs, and menu presentation all likely matter. For example, some studies show that health-conscious consumers choose lower calorie menu items when presented with nutrition information, but people with food insecurity may understandably choose higher calorie items to get more "bang for their buck".[12] Research has also shown that adding interpretative images—like a stoplight image labeling menu choices as green or red as shorthand for high or low nutrient density—can help. A 2018 study found that when calorie counts are on the left side of English-language menus, people order lower-calorie menu items. Putting calorie counts on the right side of the menu (as is more common) doesn't have this effect, likely because the English language is read from left to right.[13] Some studies have also found that restaurants that implement menu labeling offer lower-calorie and more nutrient-dense options, indicating that menu labeling may push restaurants to look more closely at the food they serve.[11,14]



Figure 10.6.7: As of 2018, restaurant chains and some other food vendors are required to list calorie counts on their menus. Would these make you pause before ordering? "Ballpark Calorie Counting" by Kevin Harber is licensed under CC BY-NC-ND 2.0.

- Increase access to food assistance programs and align them with nutrition recommendations. For example, in 2009, the U.S. Department of Agriculture revised the food packages for the Women, Infants, and Children (WIC) program to better align with the Dietary Guidelines for Americans. The new packages emphasized more fruits, vegetables, whole grains, and low-fat dairy and decreased the availability of juice. After this change, there was a decrease in the obesity rate of children in the WIC

program. Similar progress may be made by increasing access to the Supplemental Nutrition Assistance Program (SNAP) to reduce food insecurity. Many farmers' markets now accept SNAP benefits for the purchase of fresh fruit and vegetables.[2]

- Tax sugary drinks, such as soda and sports drinks, which contribute significant empty calories to the U.S. diet and are associated with childhood obesity. Local taxes on soda and other sugary drinks are often controversial, and soda companies lobby to prevent them from passing. However, early research in U.S. cities with soda taxes show that they do work to decrease soda consumption.[2] In the US, soda has only been taxed at the local level, and the tax has been paid by consumers. The United Kingdom has taken a different approach: They started taxing soft drink manufacturers for the sugar content of the products they sell. Between 2015 and 2018, the average sugar content of soda sold in the UK dropped by 29%.[14]

Support Greater Physical Activity

Increasing physical activity increases energy expended during the day. This can help maintain energy balance, thus preventing weight gain. It may also help to shift a person into negative energy balance and facilitate weight loss if needed. But simply adding an exercise session—a run or a trip to the gym, say—often doesn't shift energy balance (though it's certainly good for health). Why? Exercise can increase hunger, and there are only so many calories a person can burn in 30 or 60 minutes. That's why it's also important to look for opportunities for non-exercise activity thermogenesis (NEAT): that is, find ways to increase movement throughout the day.

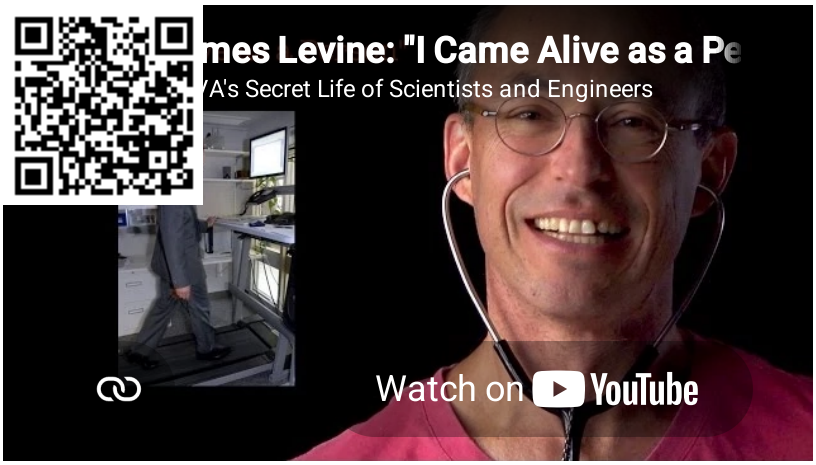
- Prioritize physical education and recess time in schools. In addition to helping kids stay healthy, movement also helps them learn.
- Make neighborhoods safer and more accessible for walking, cycling, and playing.
- When safe, encourage kids to walk or bike to school.
- Build family and community activities around physical activity, such as trips to the park, walks together, and community walking and exercise groups.
- Facilitate more movement in the workday by encouraging walking meetings, movement breaks, and treadmill desks.
- Find ways to move that are enjoyable to you and fit your life. Yard work, walking your dog, playing tag with your kids, and going out dancing all count!



Figure 10.6.8: There are lots of ways to increase physical activity, including walking to work, playing with friends, and going for a bike ride.

"Early Bird" by Jorge Vasconez, "boy running to the future" by Rafaela Biazi, and "people riding bicycles in side bicycle lane beside skyscraper" by Steinar Engeland are all licensed under the standard Unsplash License.

To wrap up this chapter, stand up and watch a quick video on NEAT.



Video 10.6.1: YouTube VIDEO (3.04 minutes). James Levine: 'I Came Alive as a Person'. [15] This short video explains some of the research on NEAT and efforts to increase it in our lives

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10.7: Best Practices For Weight Management

With over 70% of Americans currently overweight or obese, it isn't surprising that many individuals report engaging in weight management efforts.[1] In fact, a 2019 report from a national survey on current trends in weight loss attempts and strategies found that 42% of adults in the United States had recently attempted to lose weight, primarily through reduced food consumption and exercise.[2] In this unit we examine the best practices for weight management based on the body of evidence from many years of scientific research.



Figure 10.7.1: Adults enjoying a walk outside. "20150429-45[1]" by Obesity Canada is licensed under CC BY-NC-ND 2.0.

Biology Behind the Challenge of Weight Loss

We have just considered the gravity of the obesity problem in the US and worldwide. How is the US 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% of their body weight and keeping it off for at least one year.[3] Results from some lifestyle intervention studies suggest that most individuals are not successful at long-term weight loss. Yet an evaluation of successful weight loss involving more than fourteen thousand participants published in the International Journal of Obesity estimated that more than one in six Americans, or 17%, who were overweight or obese were successful at both achieving and maintaining a significant level of weight loss.[4] While this estimate is more promising than other studies suggest, it still raises the question: Why is achieving long-term weight loss so difficult? Much of the explanation lies in understanding the biology of weight loss.

Weight loss has often been viewed as a simple formula: energy in versus energy out. If you consume more calories than you expend, you gain weight. If you expend more calories than you consume, you lose weight. This is the general principle of energy balance, as discussed earlier in this chapter, and this principle gives foundation to the basic premise of weight management.

However, the body is more complex than a simple formula. And much like many functions within the body, weight is tightly regulated. To prevent perpetual weight loss or weight gain every time environmental or behavioral factors change, mechanisms within the body adjust to help normalize weight at a steady point.[5] But our obesogenic environment often promotes behaviors that encourage excessive caloric intake and lower energy expenditure, leading to a higher steady weight over time. When an individual focuses on losing weight, active weight-loss efforts often yield initial weight loss. But those same mechanisms that work to maintain a steady weight also kick in during periods of weight loss to help the body defend the original weight.[5] The body recognizes weight loss as a threat to survival, lowering basal metabolic rate to preserve calories and protect against starvation. Additionally, as someone loses weight, there is less physical mass to the body that has to be moved from place to place throughout the day, resulting in fewer calories burned through physical movement and activity and less metabolically active tissue using calories for fuel throughout the day.

Biological differences in individual metabolism may also impact weight loss success. Researchers have found that some individuals have a "thrifty" metabolism, meaning that they have a lower metabolic rate and expend significantly fewer calories when in a fasting (or calorie-restricted) state, common in weight loss efforts. This results in a lower level of weight loss. In contrast, individuals with a "spendthrift" metabolism tend to have a higher metabolic rate in a fasting state, burning more calories and thus yielding bigger weight loss results.[6] According to researcher Martin Reinhardt, M.D., "The results corroborate the idea that some people who are obese may have to work harder to lose weight due to metabolic differences."[7]

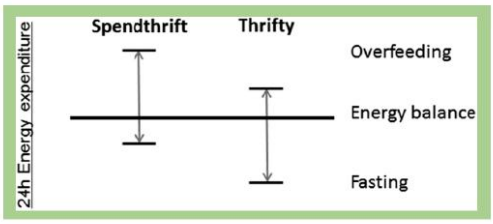


Figure 10.7.2: Illustration of the concept of spendthrift and thrifty metabolisms, characterized by their response to overfeeding and fasting.[6]

To add to the challenge of metabolic differences, research also suggests that changes in hormone levels due to weight loss may impact the body's ability to maintain a lower weight. Decreases in thyroid hormones that regulate metabolism, as well as changes in hormones such as leptin and insulin that affect satiety levels, contribute to the challenge of maintaining a lower weight after initial weight loss occurs.[5,8] In individuals maintaining a 10% or greater weight loss, all of these changes combine to account for an estimated decrease of 300-400 calories in energy expenditure per day beyond what is expected due to the change in body composition alone.[8] These biological factors and their influence on weight are discussed further in the following video.



Video 10.7.1: The Quest to Understand the Biology of Weight Loss.[9] (22:52 minutes)

Evidence-Based Approaches to Weight Loss

Despite the challenges imposed by biological processes in the body, there is significant evidence to suggest that successful weight loss and maintenance is possible. There are many approaches when considering options for weight loss, and no single treatment is right for everyone. In fact, while following a lower-calorie healthy eating plan is often the first approach to weight loss, research shows that there is no single dietary strategy that is superior to others. [10,11] For example, **a recent trial, called the DIETFITS study, followed participants on either a low-fat or low-carbohydrate diet for one year and found no significant difference in weight loss between study groups.** And both dietary strategies produced a range of weight loss results, with some participants losing over 60 pounds and others gaining 20 pounds over the course of the year, suggesting that what works for one individual may produce varying results in others.[1]

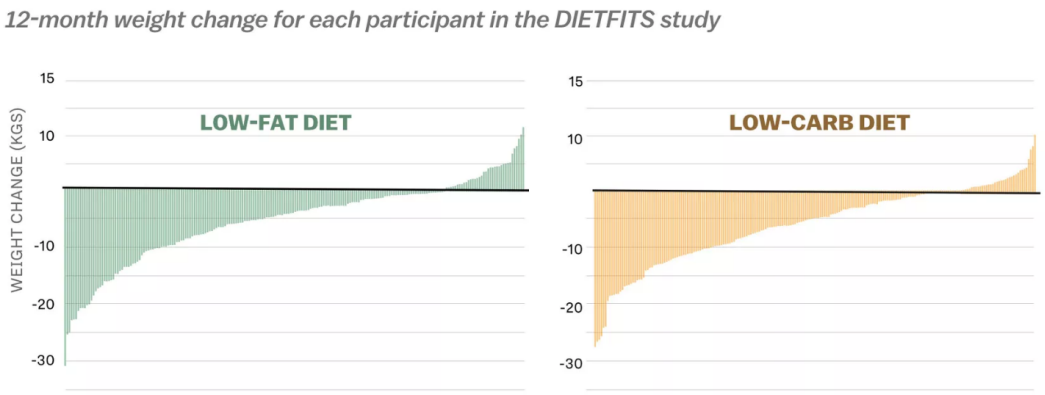


Figure 10.7.3: Results from the DIETFITS study show that, regardless of the type of diet followed, participants experienced a similar wide range of changes in weight.[11]

To learn more about the DIETFITS study, check out the following video.



Video 10.7.2: Stanford's Christopher Gardner Tackles the Low-Carb vs. Low-Fat Question.[12] by Stanford Medicine. (4:08 minutes).

The National Weight Control Registry (NWCR) has tracked 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 show that 98% of participants in the registry modified their food intake, and 94% increased their physical activity, mainly by walking.[9]

Although NWCR members took a great variety of approaches to achieve successful weight loss, most have reported 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.[13] In most scientific studies, successful weight loss is accomplished only by changing the diet and increasing physical activity together. Doing one without the other limits the amount of weight lost and the length of time that weight loss is sustained.[14]

Evidence-Based Dietary Recommendations

The 2020-2025 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.[15] These recommendations include following a healthy eating pattern that accounts for all foods and beverages within an appropriate calorie level, including the following:

- A variety of vegetables from all of the subgroups—dark green, red, and orange, legumes (beans and peas), and starchy
- 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 and yogurts
- A variety of protein foods, including seafood, lean meats and poultry, eggs, legumes (beans and peas), nuts, seeds, and soy products

- Oils, including vegetable oils, and oils from nuts, seeds, and seafood

A healthy eating pattern limits the following:

- Saturated fats and trans fats
- Added sugars
- Sodium
- Alcohol. If alcohol is consumed, it should be limited—no more than one drink or less per day for women and two drinks per day or fewer for men—and only by adults of legal drinking age. Pregnant women should not drink alcohol.

The 2025-2030 Dietary Guidelines for Americans continue to emphasize similar healthy eating patterns while emphasizing the importance of portion size and appropriate calorie intake for individual needs.[16] While the guidelines establish basic recommendations for dietary intake across all food groups, most Americans fall short of achieving these recommendations. Figure 10.7.4 shows how Americans are falling short of meeting the Dietary Guidelines.

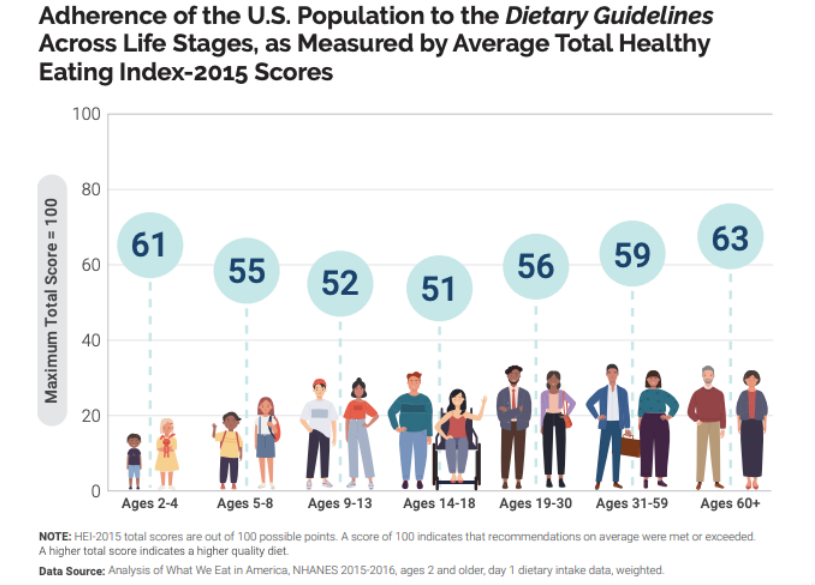


Figure 10.7.4: The Healthy Eating Index is based on 100 points. American scores per age group range from 51 to 61.[15] "Adherence of the US Population to the Dietary Guidelines Across Life Stages, as Measured by Average Total Healthy Eating Index-2015 Scores" from *Dietary Guidelines for Americans, 2020-2025* by the US Department of Agriculture is in the Public Domain.

Evidence-Based Physical Activity Recommendations

The other part of the energy balance equation is physical activity. The Dietary Guidelines are complemented by the 2018 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. These guidelines provide recommendations to Americans aged three and older about how to improve health and reduce chronic disease risk through physical activity. Increased physical activity has been found 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.[17]

The key guidelines for adults include the following:

- Adults should move more and sit less throughout the day. Some physical activity is better than none. Adults who sit less and do any amount of moderate-to-vigorous physical activity gain some health benefits.
- For substantial health benefits, adults should do at least 150 minutes (2 hours and 30 minutes) to 300 minutes (5 hours) per week of moderate-intensity aerobic activity, or 75 minutes (1 hour and 15 minutes) to 150 minutes (2 hours and 30 minutes) per week of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity aerobic activity .
- Preferably, aerobic activity should be spread throughout the week.

- Engaging in physical activity beyond the equivalent of 300 minutes (5 hours) of moderate-intensity physical activity per week can result in additional health benefits and may help with weight loss and weight loss maintenance.
- Adults should also do muscle-strengthening activities of at least moderate intensity that involve all major muscle groups on 2 or more days per week, as these activities provide additional health benefits. Exercises such as push-ups, sit-ups, squats, and lifting weights are all examples of muscle-strengthening activities.

The 2018 Physical Activity Guidelines broadly classify moderate physical activities as those when you "can talk, but not sing, during the activity" and vigorous activities as those when you "cannot say more than a few words without pausing for a breath." [17] Despite the indisputable benefits of regular physical activity, a 2018 report from the American Heart Association estimates that 8 out of 10 Americans do not meet these guidelines.[2]

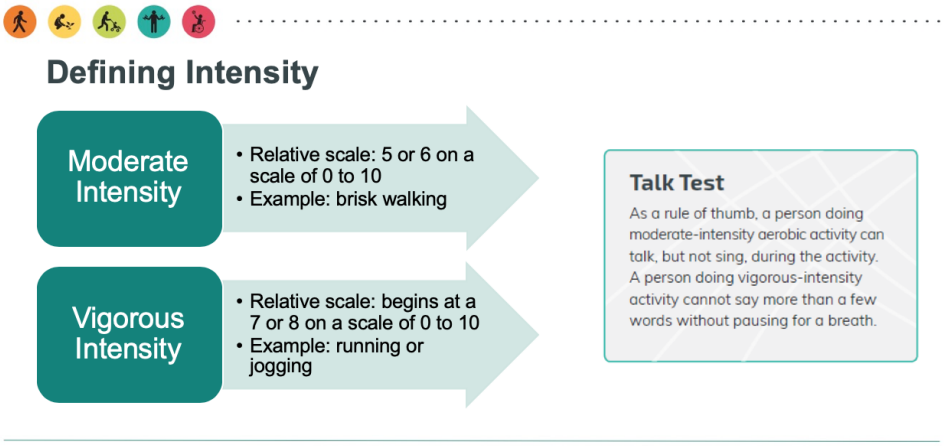


Figure 10.7.5: The 2018 Physical Activity Guidelines' definition of moderate-intensity and vigorous-intensity exercise.[17]

Given the number of Americans who are falling short on both nutrition and physical activity recommendations, it is easy to see that these two areas of behavior are of primary interest in improving the health and weight of our nation.

Evidence-Based Behavioral Recommendations

Behavioral weight loss interventions have been described as approaches "used to help individuals develop a set of skills to achieve a healthier weight. It is more than helping people to decide what to change; it is helping them identify how to change." [18] Cornerstones for these interventions typically include self-monitoring through daily recording of food intake and exercise, nutrition education and dietary changes, physical activity goals, and behavior modification.[19] Research shows that these types of interventions can result in weight loss and a lower risk for type 2 diabetes, and similar maintenance strategies lead to less weight regained later.[20]

Behavioral interventions have been shown to help individuals achieve and maintain weight loss of at least 5% from baseline weight. The Food and Drug Administration (FDA) considers a 5% weight loss to be clinically significant, as this level of weight loss has been shown to improve cardiometabolic risk factors such as blood lipid levels and insulin sensitivity.[19,20] The behavioral intervention team often includes primary care clinicians, dietitians, psychologists, behavioral therapists, exercise physiologists, and lifestyle coaches. These programs may include a variety of delivery methods, often through group classes of 10-20 participants both in-person and online, and may use print-based or technology-based materials and resources. The interventions usually span one to two years, with more frequent contact in the initial months (weekly to bi-monthly) followed by less frequent contact (monthly) in the latter months or maintenance phase.[20] A variety of behavioral topics are covered throughout the program and range from nutrition education and goal-setting to problem-solving and assertiveness. Relapse prevention is included as participants move into the maintenance phase.[21]



Figure 10.7.6: Common topics included in behavioral interventions for weight loss. "Behavioral Weight-Loss Treatment Topics" by Heather Leonard is licensed under CC BY 4.0.

Pharmacotherapy and Bariatric Surgery

In some situations, lifestyle changes in diet, exercise, and behavior modification are not enough to produce meaningful levels of weight loss, and the use of medications may be considered to improve weight loss outcomes. The use of medications is recommended in conjunction with, and not in place of, lifestyle changes. Medications are typically considered for individuals with a BMI over 30, or BMI over 27 with at least one coexisting condition, such as heart disease, type 2 diabetes, or hypertension. Only medications approved by the FDA for weight loss should be used.[22] Over-the-counter weight loss supplements are not monitored by the FDA and are not recommended because of safety concerns.

Surgical interventions may be appropriate for individuals with a BMI over 40 or BMI over 35 with obesity-related coexisting conditions if behavioral interventions (with or without medication) have not been effective. Potential candidates for surgery should be referred to an experienced bariatric surgeon for consultation and evaluation.[22]

Non-Diet Approaches

In addition to weight management approaches that focus on the energy balance equation through dietary changes, physical activity programs, and behavioral interventions, there is a growing movement for non-diet approaches for a healthier mentality toward weight, food, and body image. These approaches focus on establishing healthier relationships with food and more body acceptance and positivity regardless of shape and size. Many of these programs seek to normalize relationships with food, make eating an enjoyable experience focused on well-being rather than dieting, do away with shame or guilt often associated with failed weight loss efforts, and promote respect and inclusivity for all people regardless of weight or size. Mindful eating or intuitive eating are common components of these approaches.



Figure 10.7.7: Body positivity activities can support a healthier perspective on body image. "Stop Bullying" by Lucky Lynda is licensed under CC BY 2.0.

One of these approaches, the ***Satter Eating Competence Model***, is based on four components: eating attitudes, food acceptance, regulation of food intake and body weight, and management of the eating context. According to Ellyn Satter, a registered dietitian and family therapist and the founder of the model, competent eaters are "confident, comfortable, and flexible with eating and are matter-of-fact and reliable about getting enough to eat of enjoyable and nourishing food." [22] This approach enhances "the importance of eating by making it positive, joyful, and intrinsically rewarding." [23] This model emphasizes that by developing a healthier relationship with food, individuals will yield the following benefits:[24]

- Have better diets
- Feel more positive about food and eating
- Have better overall health
- Have the same or lower BMI
- Sleep better
- Be more active
- Have better physical self-acceptance
- Be more trusting of themselves and others

Health at Every Size (HAES) is another movement started by the Association for Size Diversity and Health organization as an alternative to weight-centered health models. HAES aims to decrease our culture's obsession with body size and weight, decrease weight discrimination and stigma, and instead promote size acceptance and inclusivity.[25] Key principles of the HAES approach include:

- Acceptance and respect for the inherent diversity of body shapes and sizes
- Health enhancement through policies and services that promote well-being in all aspects of health, including physical, economic, social, emotional, and spiritual needs
- Respectful care and elimination of weight bias and discrimination through proper education and training
- Eating behaviors driven by hunger, satiety, nutritional needs, and pleasure instead of external regulation by diets and eating plans
- Physical activity through life-enhancing movement for all sizes and abilities

In summary, managing the energy balance equation is complicated but not impossible. Take some time to consider the many behaviors to prioritize steps toward a healthier body. Considering how each of the Dimensions of Wellness contributes to your current behaviors is a great place to start!

Attributions:

- University of Hawai'i at Mānoa Food Science and Human Nutrition Program, "Dietary, Behavioral, and Physical Activity Recommendations for Weight Management," CC BY-NC 4.0

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CHAPTER OVERVIEW

11: Life Cycle Nutrition

11.1: Introduction
11.2: Nutrition in Pregnancy and Lactation
11.3: Nutrition in Early Infancy
11.4: Raising Healthy Eaters
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11.1: Introduction



Learning Objectives

- Describe the stages of the human lifespan.
- Justify the dietary recommendations during pregnancy, infancy, youth, adult, and elderly stages of the human lifespan.
- Compare community resources related to food insecurity for various stages of the human lifespan.
- Describe common food-borne illnesses and identify sensitive populations for each.
- List the requirements for safe food production, distribution, cooking, and storage.

Our nutritional needs change as we develop from infancy to older age. Dietary recommendations for each stage in the human lifespan are based on these nutritional needs, and community nutrition programs have been developed to help individuals at each life stage accomplish a healthy diet. In this chapter, you will learn about specific nutritional considerations for pregnancy, infancy, youth, adult, and elderly life stages. Safe food practices will also be discussed because some life stages, such as infancy, may be more sensitive to common food-borne illnesses.

Cover Art: "Grandfather and grandaughter shaking hands" by wuestenigel is licensed under CC BY 2.0.

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11.2: Nutrition in Pregnancy and Lactation

Becoming a parent is a huge commitment, and for all its many rewards, it's also costly to have a baby. And that cost comes not just in time and money. For mothers, having a baby also represents a nutritional and metabolic investment. Throughout pregnancy and infancy, a new human grows and develops, and this feat is made possible in large part because of the nutrients that the mother provides. Nutrient requirements are greater in pregnancy and lactation to support maternal health, the healthy growth and development of the fetus, and the production of milk to nourish the infant.

Physiology of Pregnancy



Figure 11.2.1: Pregnant woman by Omar Lopez is licensed under the standard Unsplash License.

Human pregnancy lasts for approximately 40 weeks (when counted from the first day of a woman's last menstrual period) and is roughly divided into thirds, or trimesters. Dramatic changes occur throughout pregnancy, including in the earliest days, sometimes before women realize they're pregnant. Therefore, adequate nutrition is vital for women who are trying to conceive or may become pregnant. In addition, women who are either underweight or obese before becoming pregnant can find it more difficult to get pregnant and face greater risks of pregnancy complications. Therefore, it's recommended to establish healthy eating and exercise habits and work towards a healthy weight before pregnancy.[1] Nutrition before conception is also important for fathers; studies have shown that sperm quality is better in fathers who have a healthy body weight, consume adequate amounts of folate and omega-3 fatty acids, and follow a healthy dietary pattern, such as a Mediterranean diet emphasizing seafood, poultry, whole grains, legumes, and fruits and vegetables.[2]

Pregnancy begins when the sperm fertilizes the egg, and the single cell formed from this union begins to divide and differentiate. During the first few weeks of development, the cells of the uterine lining provide nutrients to the developing embryo. Between the 4th and 12th weeks, the developing ***placenta*** gradually takes over the role of feeding the embryo, which is called a fetus beginning in the 9th week of pregnancy. **T**he placenta forms from tissues deriving from both the fetus and the mother, and this new organ becomes the interface between the two. The placenta provides nutrition and respiration, handles waste from the fetus, and produces hormones important to maintaining the pregnancy. The blood of the fetus and mother do not mix in the placenta, but they come close enough that nutrients (including glucose, amino acids, fatty acids, vitamins, and minerals) and oxygen can pass from the mother's blood to the fetus, and carbon dioxide and waste products can be passed from the fetus to the mother.[3]

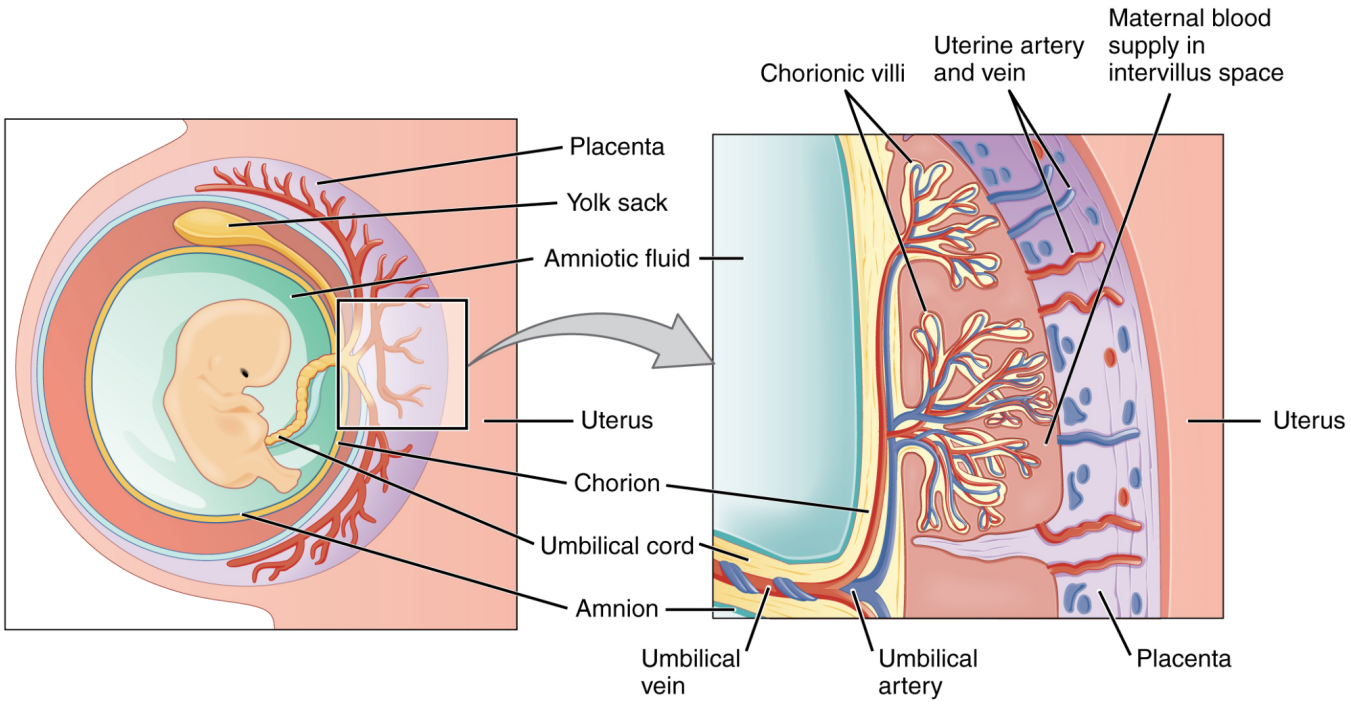


Figure 11.2.2. Cross-section of the placenta. In the placenta, the maternal and fetal bloodstreams do not mix, but nutrients, gasses, and waste products can diffuse between them. "Cross-Section of the Placenta" from *Anatomy & Physiology* by OpenStax is licensed under CC BY 4.0.

The first trimester is a key period for the formation of embryonic and fetal organs. During the second and third trimesters, the fetus continues to grow and develop, with the final development of organs such as the brain, lungs, and liver continuing in the last few weeks of pregnancy. Infants born before 37 weeks of pregnancy are considered preterm, and because they have not completed fetal development, are at increased risk for a range of health problems. Advances in neonatal care have greatly improved outcomes for these babies born too soon, but in most cases, the best scenario is for the fetus to have the full term of pregnancy to develop in the protective environment of the uterus, receiving nutrients through the placenta.[4]

Nutrient Requirements During Pregnancy

Pregnant women need more calories, macronutrients, and micronutrients than before pregnancy. However, the increase in nutrient requirements is relatively greater than the increase in caloric needs, emphasizing the importance of a nutrient-dense diet. A dietary pattern focused on vegetables, fruits, whole grains, nuts, legumes, fish, and vegetable oils, and lower in red and processed meats, refined grains, and added sugars is associated with a reduced risk of pregnancy complications such as gestational diabetes and hypertension.[5] There is nothing revolutionary about this dietary pattern—it's what is recommended for everyone! However, it's even more beneficial during pregnancy, as it promotes both maternal and fetal health.

Energy Intake and Weight Gain

During the first trimester, energy requirements are generally not increased, so women should consume about the same number of calories as they did before pregnancy. As fetal growth ramps up, energy requirements increase by about 340 calories per day in the second trimester and 450 calories per day in the third trimester. This is just an average; individual energy requirements vary depending on factors such as activity level and body weight before pregnancy .[6-7]

Weight gain is a normal part of pregnancy. The growth of the fetus accounts for about 6 to 8 pounds of weight gain by the end of the pregnancy. Much of the rest comes from the development and expansion of tissues and fluids to support the pregnancy, including the placenta, uterus, breasts, amniotic fluid, blood, and maternal body fluids. In addition, women starting pregnancy at a normal weight should gain about 8 to 10 pounds of body fat and protein during pregnancy, in part to prepare for lactation.[3]

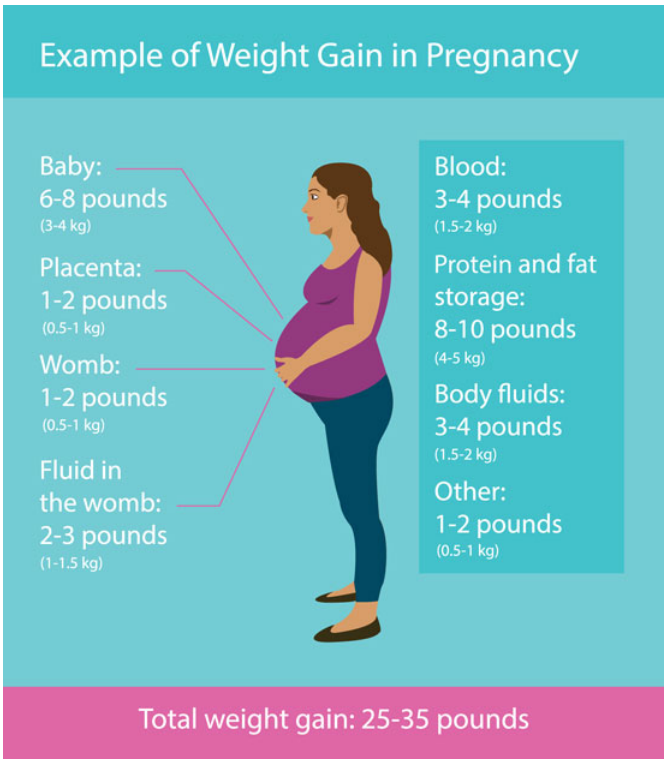


Figure 11.2.3. Components of weight gain in healthy pregnant women with normal BMI before pregnancy. Weight gain comes not just from the baby, but from many different body systems changing to support the pregnancy. "Components of weight gain in healthy pregnant women with normal BMI before pregnancy." by Adrian Mercado and Suzanne Phelan, as published online in Frontiers for Young Minds is licensed under CC BY 4.0.

The National Academy of Medicine recommends different amounts of weight gain in pregnancy depending on pre-pregnancy BMI. Women who were underweight before pregnancy need to gain more, and those who were overweight or obese before pregnancy need to gain less. Gaining too little weight in pregnancy can compromise fetal growth, leading to the baby being born too small, which can cause increased risk of illness, difficulty feeding, and developmental delays. Gaining too much weight in pregnancy can cause the baby to be too big at birth, leading to birth complications and increasing the risk of needing a cesarean birth. It can also make it more difficult to lose weight after pregnancy.[8]

Table displays the recommended weight gain by weight category and body mass index

Prepregnancy Weight Category	**Body Mass Index (BMI)**	**Recommended Range of Total Weight Gain (lb)**	**Recommended Rates of Weight Gain in the 2nd and 3rd Trimesters (lb/wk)**
Underweight	Less than 18.8	28-40	1 (1-1.3)
Normal weight	18.5-24.9	25-35	1 (0.8-1)
Overweight	25-29.9	15-25	0.6 (0.5-0.7)
Obese	30 and greater	11-20	0.5 (0.4-0.6)

Table 11.2.1. Recommended weight gain during pregnancy depends on prepregnancy BMI.[7]

Exercising during pregnancy can promote the health of both the mother and the baby. According to the American College of Obstetricians and Gynecologists, regular exercise in pregnancy can reduce back pain, ease constipation, promote healthy weight gain, improve overall fitness, and help with weight loss after the baby is born. It may also decrease the risk of gestational diabetes, preeclampsia, and cesarean delivery. ACOG recommends that pregnant women get at least 150 minutes of moderate-intensity aerobic activity each week. Most forms of exercise are safe in pregnancy; women should consult their healthcare provider for individualized advice about exercising while pregnant.[9]

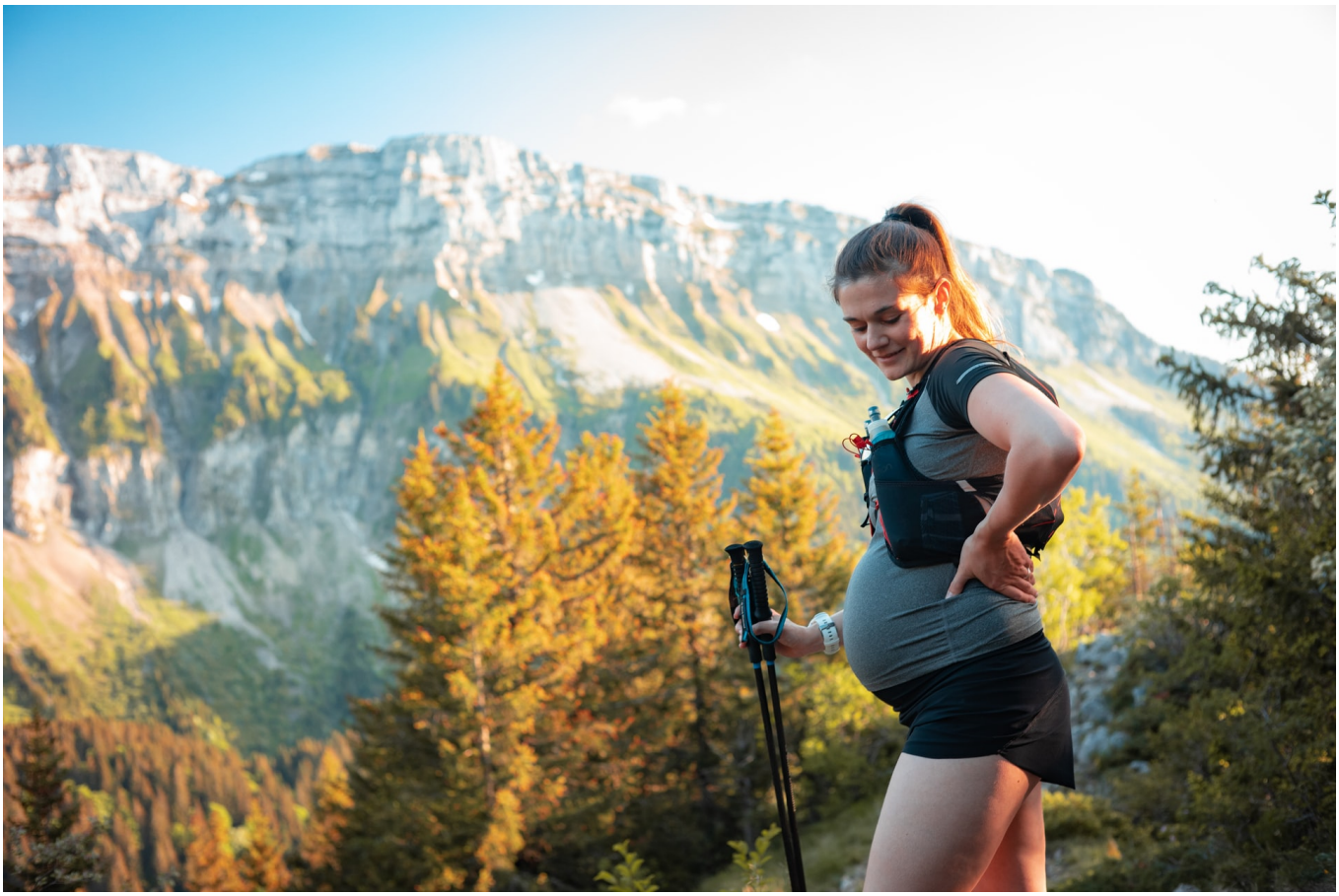


Figure 11.2.4. "Sunset hike with my wife" by Lucas Favre is licensed under the standard Unsplash License.

Macronutrient Requirements

The Acceptable Macronutrient Distributions Ranges (AMDR) for macronutrients are the same for all healthy adults, pregnant or not, with about 45 to 65% of calories coming from carbohydrates, 20 to 35% from fats, and 10 to 35% from protein. As energy intake increases, a pregnant woman needs more of each of these macronutrients.

The RDA for carbohydrates increases from 130 grams per day for non-pregnant adults to 175 grams per day for pregnant women. This level of carbohydrate intake provides energy for fetal development and ensures adequate glucose for both the mother's and the fetus's brain. The recommended fiber intake in pregnancy, expressed as an AI, is the same as for all adults: 14 grams of fiber per 1,000 calories consumed. As caloric intake increases during pregnancy, so should fiber intake, emphasizing the importance of choosing whole food sources of carbohydrates.

Additional protein is also needed during pregnancy. Protein builds muscle and other tissues, enzymes, antibodies, and hormones in both the mother and the fetus, as well as supporting increased blood volume and the production of amniotic fluid. The RDA for protein during pregnancy is 1.1 grams per kg body weight per day, coming to about 71 grams per day for an average woman—roughly 25 grams more than needed before pregnancy.[1]

There is not a specific RDA for fat during pregnancy. Fats should continue to make up 25 to 35% of daily caloric intake, providing energy and essential fatty acids (linoleic acid and alpha-linolenic acid), as well as helping with fat-soluble vitamin absorption. The omega-3 polyunsaturated fatty acids DHA and EPA become more important during pregnancy and lactation, because they are essential for brain and eye development of the fetus and infant. The 2020-2025 Dietary Guidelines for Americans recommend that pregnant women consume 8 to 12 ounces of seafood each week, in part to provide omega-3 fatty acids. Fish with high levels of mercury should be avoided; these include king mackerel, marlin, orange roughy, shark, swordfish, tilefish, and bigeye tuna.[11-12]



Figure 11.2.5. Advice from the EPA and FDA about choosing safe fish to consume during pregnancy and breastfeeding. "Advice about eating fish" by the US FDA and EPA is in the Public Domain.

Consider the following recommendations for healthy eating during pregnancy, as summarized in the My Pregnancy Plate graphic:

- Choose large portions of a variety of non-starchy vegetables such as leafy greens, broccoli, carrots, bell peppers, tomatoes, mushrooms, and cabbage.
- Choose a variety of whole fruits, limiting juice and dried fruit.
- Aim for 2 to 3 servings of nonfat or 1% milk or yogurt (unsweetened or slightly sweetened).
- Choose protein sources like poultry, beans, nuts, eggs, tofu, and cheese. Aim for 8 to 12 ounces of low-mercury seafood each week.
- Choose fiber-rich sources of carbohydrates, including whole grains, legumes, and starchy vegetables such as sweet potatoes and squash.
- Drink mainly water, decaf coffee, or tea. (Caffeine is discussed below).

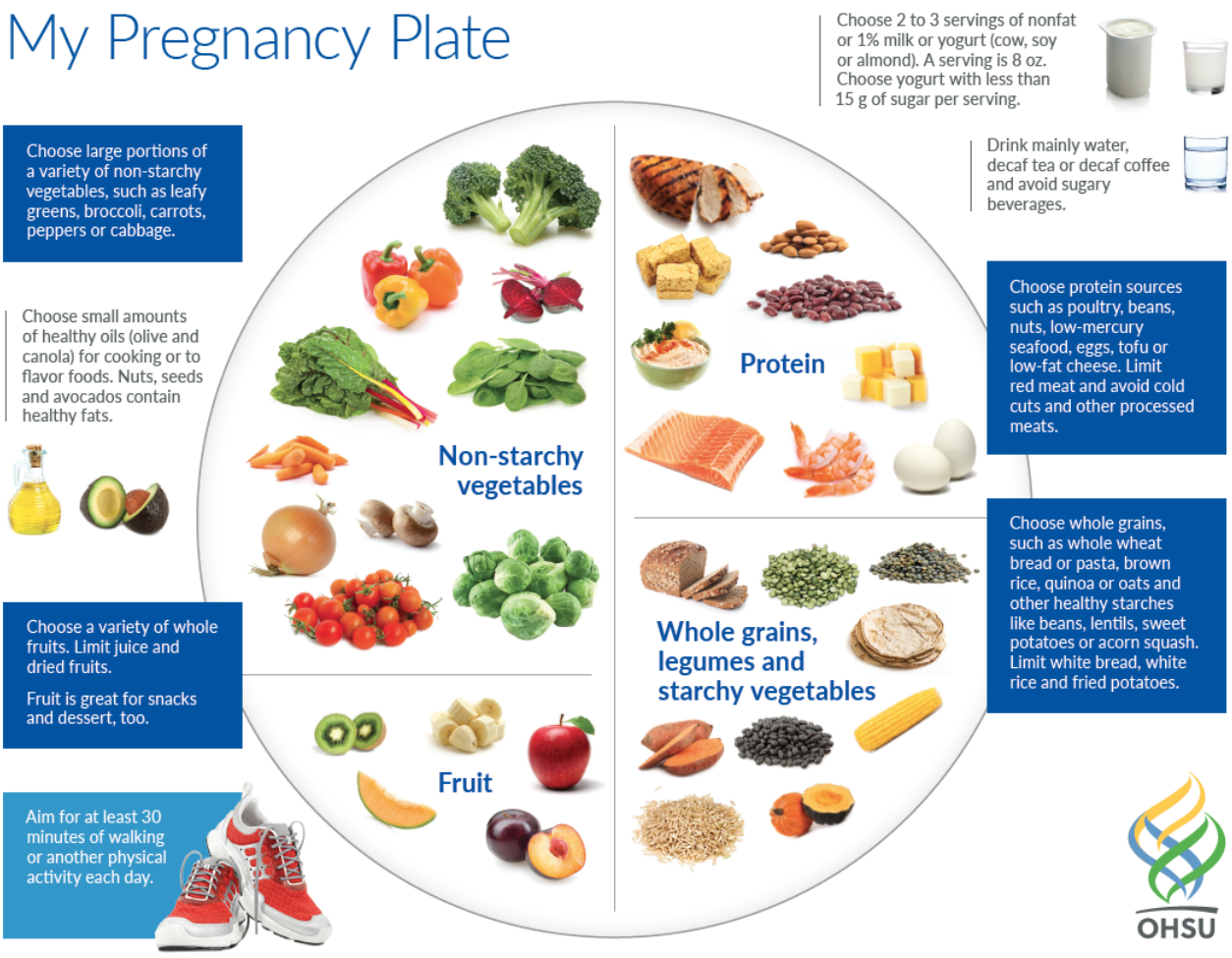


Figure 11.2.6. The My Pregnancy Plate graphic summarizes dietary recommendations for pregnancy. Source: Created by Christie Naze, RD, CDE, ©Oregon Health & Science University, used with permission. *"My Pregnancy Plate" by Christy Naze, RD, CDE, ©Oregon Health & Science University, is used with permission.*

Vitamin and Mineral Requirements

The physiological demands of pregnancy increase the requirement for many vitamins and minerals. These requirements can be met from food sources, but obstetricians also generally recommend that women take a prenatal supplement while trying to conceive and during pregnancy. This ensures that nutrient requirements are met while also providing a little peace of mind if pregnancy-related nausea and vomiting limit dietary variety and quality.[1]

The following table compares the recommended intake levels of some vitamins and minerals to the levels needed in pregnancy.

Table of the Recommended Daily Allowance of nutrients for both non-pregnant and pregnant women and its importance.

Nutrient	**RDA/AI,** Nonpregnant Adult Women	**RDA/AI,** Pregnant Adult	**Importance**
Vitamin A	700 mcg	770 mcg	*Forms healthy skin and eyesight; helps with bone growth*

Vitamin B6	1.3 mg	1.9 mg	*Helps form red blood cells; helps the body metabolize macronutrients*
Vitamin B12	2.4 mcg	2.6 mcg	*Maintains nervous system; helps form red blood cells*
Vitamin C	75 mg	85 mg	*Promotes healthy gums, teeth, and bones*
Vitamin D	600 IU	600 IU	*Builds fetal bones and teeth; promotes healthy eyesight and skin*
Folate	400	600	*Helps prevent neural tube defects; supports growth and development of fetus and placenta*
Calcium	1,000 mg	1,000 mg	*Builds strong bones and teeth*
Iron	18 mg	27 mg	*Helps red blood cells deliver oxygen to fetus*
Iodine	150 mcg	220 mg	*Essential for healthy brain development*
Choline	425 mg	450 mg	*Important for development of fetal brain and spinal cord*

Table 11.2.2. Recommended Micronutrient intakes during pregnancy. Sources: The American College of Obstetricians and Gynecologists and the NIH Office of Dietary Supplements.

Among the micronutrients, folate, iron, and iodine deserve a special mention. Folate is essential for the growth and specialization of cells of the central nervous system. Mothers who are folate-deficient during pregnancy have a higher risk of having a baby with a neural tube birth defect such as spina bifida. Folic acid fortification of grains in the US has helped to raise folate intake in the general population and has reduced the incidence of neural tube defects. However, dietary intake is often not adequate to meet the requirement of 600 mg folate per day in pregnancy, and the American College of Obstetricians and Gynecologists recommends that pregnant women take an additional 400 mg of folic acid each day, an amount usually included in prenatal supplements.[13] The neural tube closes by day 28 of pregnancy, before a woman may realize she is pregnant, so it's important to consume adequate folate while trying to conceive. Because about 45% of pregnancies in the US are unplanned, a folic acid supplement is a good idea for anyone who may become pregnant.[14]

Iron intake is important because of the increase in blood volume during pregnancy. Iron is an essential component of hemoglobin, the protein responsible for oxygen transport in blood, so adequate iron intake supports oxygen delivery to both maternal and fetal tissues. Good dietary sources of iron include meat, poultry, seafood, nuts, legumes, and fortified or whole grain cereals. Iron should also be included in a prenatal supplement or taken separately.

Iodine is essential for fetal brain development, but recent data suggests that many pregnant women in the US do not consume enough iodine to meet their increased requirement.[15] Much of the iodine in the typical American diet comes from dairy products and iodized salt. However, iodine intake in the US has declined in recent decades as more people watch their intake of table salt and/or switch to kosher or sea salt, which aren't iodized. In addition, processed foods are generally made with non-iodized salt, and the intake of processed foods has increased. Meanwhile, the popularity of dairy products has declined. Most people in the US still consume enough iodine to meet their requirement, but pregnant women may be at risk for iodine deficiency because of their increased need for this mineral. Iodine deficiency during pregnancy can cause miscarriage, stillbirth, and major neurodevelopmental deficits and growth retardation in the fetus.[16] Unfortunately, many prenatal vitamins do not contain iodine, so it's worth checking the label to ensure that iodine is included.[17]

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 nonpregnant women, many women do not typically consume adequate amounts and should make an extra effort to meet those needs.

As always, it's important to read supplement labels carefully, with the aim of choosing a prenatal supplement that contains close to the RDA or AI for micronutrients and avoiding those that exceed the UL, unless under the specific direction of a healthcare provider. In particular, both vitamin A and zinc consumed in excessive amounts can cause birth defects. Beta-carotene is typically used as the vitamin A source in prenatal supplements, because unlike vitamin A, it doesn't cause birth defects.

Foods and Other Substances to Avoid

It's not just nutrients that can cross the placenta. Other substances such as alcohol, nicotine, cannabinoids (from cannabis), and both prescription and recreational drugs can also pass from mother to fetus. Exposure to these substances can have lasting and detrimental effects on the health of the fetus. For this reason, pregnant women are advised to avoid using alcohol, tobacco, cannabis, and recreational drugs during pregnancy. Medical providers can help pregnant women quit using these substances and advise them on the safety of specific medications needed during pregnancy.[18]

Some substances 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 (Figure 11.2.7) . Alcohol enters the fetus's bloodstream 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. There is no known safe amount of alcohol in pregnancy.

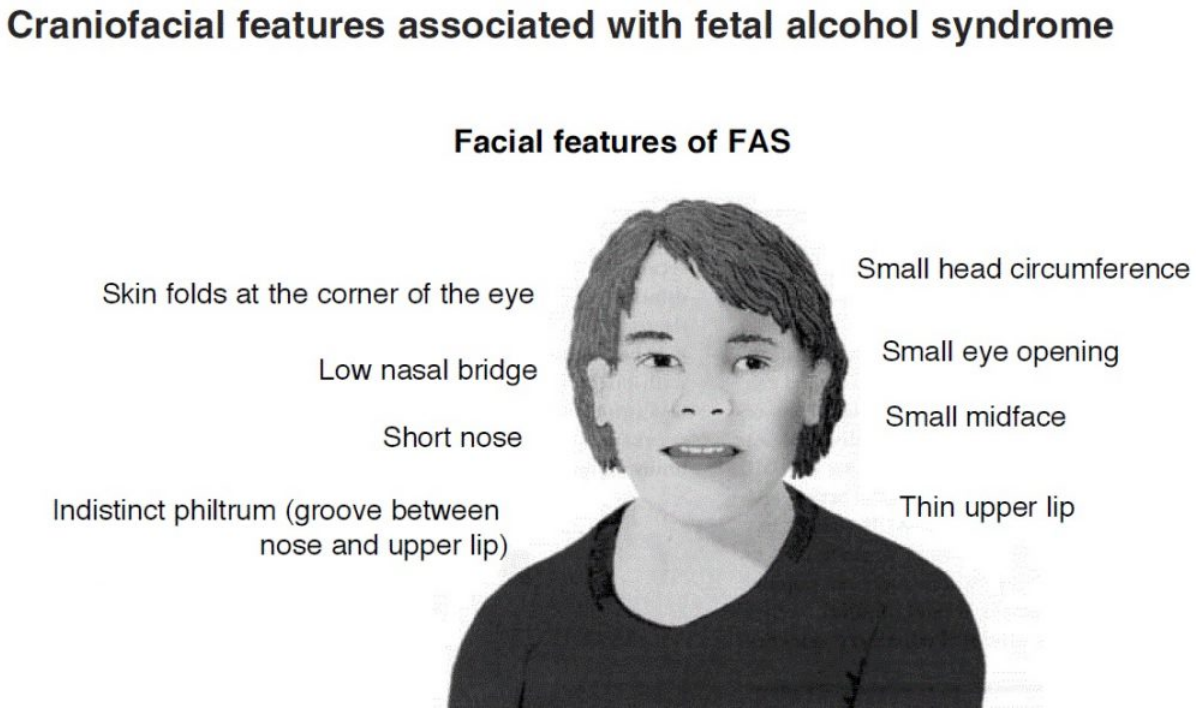


Figure 11.2.7. Craniofacial features associated with fetal alcohol syndrome. "Craniofacial features associated with fetal alcohol syndrome" by the NIH/National Institute on Alcohol Abuse and Alcoholism is in the Public Domain.

Caffeine use should be limited to less than 200 milligrams per day, or the equivalent of about two cups of coffee. Consumption of greater amounts is linked to miscarriage and preterm birth. Keep in mind that caffeine is also found in other sources such as chocolate, energy drinks, soda, tea, and some over-the-counter pain and headache medications.[18]

It's also important to pay special attention to avoiding food-borne illness during pregnancy, as it can cause major health problems for both the mother and the developing fetus. For example, the food-borne illness caused by the bacteria Listeria monocytogenes, called listeriosis, can cause miscarriage, stillbirth, and fetal or newborn meningitis. According to the CDC, pregnant women are ten times more likely to become ill with this disease than nonpregnant adults, likely because they have a dampened immune

response.[19] Other common food-borne illnesses, such as those caused by Salmonella and E. coli , can also be very serious in pregnant women.

Foods more likely to be contaminated with food-borne pathogens should be avoided by pregnant women to decrease their chances of infection. These include the following:[20]

- Unpasteurized dairy products such as soft cheeses
- Raw or smoked seafood
- Hot dogs and deli meats (or heat to 165° before eating)
- Paté and other meat spreads
- Undercooked or raw meat, poultry, and eggs
- Raw sprouts
- Raw dough
- Unpasteurized juice and cider

Following standard food safety practices can also go a long way towards preventing food-borne illness, during pregnancy or anytime. The CDC offers this summary of food safety tips:

- **COOK**. Use a food thermometer to ensure that foods are cooked to a safe internal temperature: 145°F for whole beef, pork, lamb, and veal (allowing the meat to rest for 3 minutes before carving or consuming), 165°F for ground meats, and 165°F for all poultry, including ground chicken and turkey.
- **CLEAN**. Wash your hands after touching raw meat, poultry, and seafood. Also, wash your work surfaces, cutting boards, utensils, and grill before and after cooking.
- **CHILL**. Keep your refrigerator below 40°F and refrigerate foods within 2 hours of cooking (1 hour during the summer heat).
- **SEPARATE**. Germs from raw meat, poultry, seafood, and eggs can spread to produce and ready-to-eat foods unless you keep them separate. Use different cutting boards to prepare raw meats and any food that will be eaten without cooking.



Figure 11.2.8: Woman slicing purple vegetable by Heather Ford is licensed under the standard Unsplash License.

Maternal Health During Pregnancy

Especially during the first trimester, it's very common for women to feel nauseous, often leading to vomiting, and to be very sensitive to smells. This so-called "morning sickness" is misnamed because it can make women feel awful any time of day—morning, noon, and night. Nausea and vomiting during pregnancy affect as many as four out of five pregnancies. Symptoms can range from mild nausea to a much more severe illness called ***hyperemesis gravidarum*** , which causes relentless vomiting and affects between 0.3 and 3% of all pregnancies. Most women find that their nausea and vomiting subsides by the end of the first trimester, but in rare and unfortunate cases, it can continue until the baby is born.[21]

Dietary changes can help alleviate nausea and vomiting. Here are some suggestions:[22]

- **Choose foods that are low in fat and easily digestible**, such as those in the BRATT diet (bananas, rice, applesauce, toast, and tea). The goal is simply to find foods that can be tolerated. It is reassuring to remember that pregnancy does not require extra calories during the first trimester, and a prenatal supplement can help meet micronutrient needs.

- **An empty stomach can worsen feelings of nausea**, so try eating a few crackers or dry toast before getting out of bed in the morning to avoid moving around with an empty stomach. It may also help to eat five or six small meals per day and to eat small snacks such as crackers, fruits, and nuts throughout the day.
- Many pregnant women experiencing nausea and vomiting find meat unappetizing. **Try other sources of protein** such as dairy foods (e.g., milk, yogurt, ice cream), nuts and seeds (as well as nut butters), and protein powders and shakes.
- **Ginger can help settle your stomach;** it's available in capsule, candy, and tea form. Ginger ale, if made with real ginger, might also be helpful.

If nausea and vomiting remain unmanageable after making these dietary changes, medications may be necessary. Hyperemesis gravidarum, though rare, can be very serious. Constant vomiting can lead to malnutrition, weight loss, dehydration, and electrolyte imbalance. Hospitalization may be required so that women can receive fluids and electrolytes through an intravenous line, and sometimes, a feeding tube is necessary. Getting help for this condition can be a frustrating process of trial and error, and unfortunately, there are still many unknowns about its causes and effective treatment options.[23]

As pregnancy progresses, another common complaint is heartburn, caused by gastroesophageal reflux.This is caused by the upward, constrictive pressure of the growing uterus on the stomach and decreased peristalsis in the GI tract.

About 6%of pregnancies in the US are affected by gestational diabetes.[24] This is a type of diabetes that develops during pregnancy in women who didn't previously have diabetes. Gestational diabetes is managed by monitoring blood glucose levels, eating a healthy diet, and exercising regularly. Sometimes, insulin injections are needed. If blood glucose levels aren't well controlled in the mother, the fetus will also have high blood glucose levels. This can cause the baby to grow too big, leading to a greater chance of birth complications and an increased likelihood of needing a cesarean birth.[25]

Community Resources for Nutrition in Pregnancy

Food insecurity can be an issue for growing families, and women who are pregnant may need additional support in the face of increased medical expenses and increased nutritional needs. In addition to food pantries and local resources to help individuals facing food insecurity, the **Special Supplemental Nutrition Program for Women, Infants, and Children (WIC)** is a federal program aimed at supporting women during pregnancy and children in the first five years of life. In addition, the **Supplemental Nutrition Assistance Program (SNAP)** provides support for families with children and may become an option for new mothers after the baby is born. **Feeding America** in a non-profit organization that operates throughout the United States and helps individuals find local food pantries, including drive-through food pantries, and supports individuals applying for federal programs like WIC and SNAP.

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11.3: Nutrition in Early Infancy

Infancy is a time of dramatic change and development. In the first year of life, babies triple their body weight and develop from tiny bundles whose daily activities involve eating, sleeping, and creating dirty diapers to toddlers well on their way to walking, talking, and feeding themselves. The first 1,000 days of life, beginning at conception and continuing through toddlerhood, also represent the most active period of brain development in the lifespan, laying the foundation and establishing neural networks to support cognitive, motor, and social-emotional skills throughout life. All of these critical developmental processes are supported through sensitive caregiving, a safe home environment, and of course, a healthy diet.[1] Nutrient requirements on a per-kilogram body weight basis are higher during infancy than in any other stage in the lifespan.

Early Infancy: Meeting Nutrient Needs Through Milk



Figure 11.3.1: Father and baby photo by Lawrence Crayton is licensed under the standard Unsplash License.

At birth and continuing through the first 4 to 6 months of life, breast milk, infant formula, or some combination of the two should be the sole source of infant nutrition. This is because young infants' gastrointestinal tracts aren't yet ready to process more complex foods, and they lack the oral motor skills to swallow solid foods safely. Breast milk is uniquely adapted to meet the nutrient needs of young infants, and infant formula is also designed and regulated to ensure that it is safe and provides adequate nutrition. Any other substitute, including cow's milk, goat's milk, plant-based beverages such as soy milk, homemade infant formula, or watered-down formula, should be avoided. These do not provide the right balance of nutrients to meet infants' requirements and can cause serious problems such as damage to the intestines or kidneys.[2]

Choosing breastfeeding or formula-feeding

The World Health Organization and the American Academy of Pediatrics, as well as many other health organizations, recommend that infants receive only breast milk, with no formula or other foods, for about the first 6 months of life. Breast milk is considered the optimal source of infant nutrition, but it also contains many other bioactive molecules, including immunoglobulins or antibodies, hormones, enzymes, growth factors, and protective proteins.[3] In addition, breast milk contains special carbohydrates, called human milk oligosaccharides, that help to establish a healthy gut microbiome by serving as a food source for friendly bacteria and binding up harmful bacteria.[4]

Breastfeeding is beneficial to babies in many ways; it reduces a baby's risk of gastrointestinal, respiratory, and ear infections, and it may also protect babies from sudden infant death syndrome (SIDS), eczema, and asthma. It is also associated with a small increase in IQ and a reduced risk of obesity later in childhood. In addition, breastfeeding benefits the health of mothers; it's associated with a reduced risk of hypertension, type 2 diabetes, and breast and ovarian cancer.[3] However, it's important to note that most of the data on the benefits of breastfeeding come from observational studies, and these studies have many confounding factors. Women who breastfeed tend to have higher incomes, be more educated, be older, and be white compared with those who don't breastfeed. This means breastfed babies are often born with more advantages beyond how they are fed, so it can be difficult to separate correlation from causation in studies of infant feeding outcomes.[5]



Figure 11.3.2: Family with breastfeeding baby by Jonathon Borba is licensed under the standard Unsplash License.

Despite the challenges in breastfeeding research, breastfeeding has many well-established benefits, and most mothers intend to breastfeed. In 2017, 84% of babies born in the US were breastfed at birth, but just 58% were still breastfeeding at 6 months of age, and 26% were exclusively breastfed through 6 months.[6] These statistics represent the many challenges women face with breastfeeding. Although breastfeeding is natural, it doesn't always come naturally or easily. Breastfeeding challenges can often be addressed with the help of an experienced professional, such as a lactation consultant, but this support is not easy for all women to access. Women may also find it hard to establish and continue breastfeeding if they have to return to work just a few weeks or months postpartum, a scenario common in the US, the only developed country that has no national policy for paid parental leave.[7,8]

There are also a few circumstances in which babies should not or can not be breastfed. In the US, it's recommended that women infected with HIV do not breastfeed because the virus can pass to infants in milk. Infants born with rare metabolic disorders may not be able to metabolize breast milk and need to receive special formulas. There are also some medications that, if taken by the mother, are not safe for breastfeeding infants. In these cases, mothers may be advised to formula-feed.[3]

Many women find breastfeeding enjoyable and a wonderful way to bond with their babies. For others, breastfeeding can be a struggle for one or more of the reasons discussed above, and that struggle can overshadow a mother's relationship with her baby. For all of these reasons, the choice to breastfeed or formula-feed, or to feed some of both, is complex and individual. Parents should be supported whatever their decision, and they can be confident that infant formula is a safe, nutritionally adequate option.

Nutrient Composition of Breast Milk

The first milk, called **colostrum**, is produced immediately after birth and continues for the first two to five days after the baby's arrival. Colostrum is yellowish, thicker than mature breast milk, and produced in small quantities. It is low in fat and easily digestible, yet rich in protein, fat-soluble vitamins, and minerals. Colostrum is also a concentrated source of immunoglobulins that pass from the mother to the baby and provide immune protection to the newborn. The stomach capacity of newborns is small, so they only consume a teaspoon or two of colostrum per feeding in the first few days of life, but they need to feed often. Frequent, on-demand feeding (whenever the baby is hungry, not on a schedule) helps to promote full milk production.[5]

After a couple of days, colostrum is replaced by **transitional milk**, which is produced in much greater volume and lasts through 7 to 14 days postpartum. Compared with colostrum, transitional milk has more fat and lactose, and less protein and immunoglobulins, and it is also more calorie-dense. Finally, women begin to produce **mature milk** and will continue to make this type of milk through the end of lactation. Mature milk contains about 87% water, 4% fat, 1% protein, and 7% lactose. Together, these meet infants' macronutrient and caloric requirements.[9]

However, there is variability even within mature milk. In a given feeding, the milk secreted at the beginning of the feeding, known as foremilk, is thinner and higher in lactose than the milk at the end of the feeding, known as hindmilk. The higher levels of fat in the hindmilk helps to ensure the baby's energy needs are met.[9] Milk can also vary from day to night; nighttime milk is higher in fat and the sleep-promoting hormone melatonin.[10] As breastfeeding continues beyond 6 or 7 months, the levels of some vitamins and

minerals begin to decline. This is around the time that babies begin to eat some solid foods, so foods can help to fill in nutritional gaps, while breast milk continues to be an important source of nutrients.[5]

Breast milk provides enough of all of the micronutrients that young infants need with two main exceptions: vitamin K and vitamin D. For this reason, newborns should receive a vitamin K shot soon after birth; otherwise, vitamin K deficiency can lead to serious bleeding disorders such as hemorrhage. The American Academy of Pediatrics also recommends that breastfed newborns be given a vitamin D supplement beginning in the first few days of life and continuing until they are weaned to formula or cow's milk, both of which are fortified with adequate vitamin D. Cow's milk can be given beginning at 12 months of age.[11]

Breast milk is also low in iron, although what little is there is absorbed very efficiently. Newborns are born with a certain amount of iron absorbed from their mothers during pregnancy, and they utilize this stored iron—in addition to that provided in breast milk—to meet their iron requirement in early infancy. However, stored iron is depleted by around 4 months of age, so the American Academy of Pediatrics recommends that exclusively breastfed infants begin taking an iron supplement at this age and continue until they are eating substantial amounts of iron-rich solid foods, such as meat or iron-fortified cereals. Iron deficiency remains a significant problem, with 11% of 1-year-olds in the US estimated to be iron-deficient.[11] Iron is essential for brain development, and iron deficiency may cause lasting developmental deficits.[12]

Nutrition for Breastfeeding Mothers

Breastfeeding mothers have nutrient requirements similar to women in the third trimester of pregnancy. After all, they're continuing to provide nutrients for their babies through their milk, and milk production requires energy, macronutrients, micronutrients, and water. Breastfeeding women have a remarkable ability to make enough milk to meet their babies' nutrient needs even without an optimal diet, but eating well supports maternal health and energy levels during this demanding time.



Figure 11.3.3: "Newborn breastfeeding" by Amy Bundy is licensed under CC BY-NC 2.0.

Breastfeeding increases energy requirements by about 450 to 500 calories per day, part of which can be supplied by using adipose stored in pregnancy and part of which should be supplied from greater caloric intake. In general, breastfeeding mothers can eat a wide variety of foods, and they don't usually need to avoid or restrict any specific foods. However, as in pregnancy, they should continue to avoid high-mercury fish. Consuming low-mercury fish 2 to 3 times per week provides the omega-3 fatty acids DHA and EPA, which pass into breast milk and support brain and eye development for the breastfeeding infant.[13] There is no need to avoid common food allergens, such as peanut or dairy; avoiding these foods while breastfeeding has not been shown to reduce babies' chances of developing food allergies.[14] Sometimes, women find that certain foods, such as garlic or spicy foods, are associated with fussiness or gas in their infants, and they may experiment with avoiding those foods. However, most infants don't have a problem tolerating these foods. In fact, flavors from the mother's diet pass into breast milk, so researchers hypothesize that when mothers eat a wide variety of foods and flavors while breastfeeding, their children grow up to be more adventurous eaters.[15]

In addition to consuming a nutrient-dense diet, obstetricians sometimes recommend that breastfeeding mothers continue taking a prenatal supplement to ensure that their micronutrient needs are met. Breastfeeding mothers should also be sure to drink plenty of fluids to support milk production.[13]



Figure 11.3.4: "Breastfeeding mother and baby" by Centers for Disease Control and Prevention is in the Public Domain.

Similar to pregnancy, substances consumed by the breastfeeding mother can pass to the infant in her milk. However, how much passes into the milk depends on the type of substance and the timing of consumption relative to breastfeeding. For example, it's considered safe for a breastfeeding mother to have an alcoholic drink so long as she waits at least two hours before breastfeeding because, by that point, most of the alcohol will have cleared her bloodstream and will not pass into her milk. Caffeine lasts longer in the blood but is considered safe in moderation, with a limit of about 300 milligrams per day.[13] Cannabinoids, the chemicals found in cannabis, are fat-soluble and remain in a mother's bloodstream and body tissues for much longer. Tetrahydrocannabinol (THC), the main psychoactive chemical in cannabis, has been detected in breast milk as much as 6 weeks after a mother used cannabis.[16] Although it's not clear how these chemicals affect babies when consumed in breast milk, medical organizations agree it's best to avoid using cannabis while breastfeeding.

> The National Institutes of Health's LactMed database is a great resource for information about the safety of drugs, medications, and supplements during breastfeeding.

Nutrient Composition of Infant Formula

To a certain extent, the nutrient composition of infant formula is modeled after that of human milk, and although it by no means duplicates breast milk, it is a safe and effective substitute. Formula is made from ingredients such as cow's milk, soy, vegetable oils, and corn syrup. These may be combined in ways to mimic the overall macronutrient composition of breast milk, but the content of individual amino acids, fatty acids, and sugars can vary somewhat. In addition, some of these nutrients are less digestible, so to compensate, formulas tend to have higher levels of some nutrients, such as protein, than breast milk. Formula contains more of some micronutrients such as iron, vitamin D, and vitamin K, so deficiencies of these vitamins and minerals are more common in breastfed infants if they don't receive appropriate supplementation or solid foods when the time comes.[17]

Infant formula also does not contain most of the bioactive molecules found in breast milk, although formula companies are beginning to add versions of some of these molecules. For example, many formulas now include some type of indigestible sugar molecule intended to act as a prebiotic to feed healthy gut bacteria, similar to human milk oligosaccharides. At this point, however, the evidence that such ingredients are beneficial to infants is not very convincing. However, novel ingredients like these are often used as marketing tools, with labels touting vague structure-function claims such as "brain-boosting" and "immune-supporting." Consumers should know that there is often little evidence that "designer ingredients" in infant formula make them healthier for babies. All infant formulas are required by law to be safe and meet the nutrient requirements of infants, and in most cases, basic store brand formulas cost less and are just as good as other products on the shelf. It may be true that infant formula can't replicate the complexity of breast milk, but it has a very strong track record of safety, and infants can grow and thrive with formula-feeding.[17]



Figure 11.3.5: "Baby bottle feeding" by Bradley Johnson is licensed under CC BY 2.0.

Attributions:

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11.4: Raising Healthy Eaters

"Raising a healthy eater takes years. Children learn bite by bite, food by food, meal by meal. The goal of raising a healthy eater is to help your child grow up with positive eating attitudes and behaviors; it is not to get him to eat his peas for tonight's supper."

Ellyn Satter, MS, MSSW, RDN



Figure 11.4.1: "20210805-FNS-UNC-0018" by USDAgov is marked with Public Domain Mark 1.0.

As we discussed previously, what we feed kids is important to ensure that they are meeting their nutrient requirements. But, just as important as WHAT we feed kids, is HOW we feed kids. The structure and environment that parents provide when feeding not only impacts nutrition, but it can also affect weight and behavioral problems. Families who regularly eat together have children who eat more fruits and vegetables, have healthier weights, and are less likely to use drugs, alcohol, or tobacco when they are older.[1]

Family meals have many nutritional, social, and emotional benefits. In this section, we will discuss best practices for providing family meals and raising healthy eaters.

The Division of Responsibility

The gold standard for feeding children is Ellyn Satter's Division of Responsibility (sDOR). Ellyn Satter is a dietitian, family therapist, and internationally recognized authority on eating and feeding. ***The Division of Responsibility*** outlines the optimal relationship between parent and child when it comes to feeding: the parent determines the *what, where, and when* of feeding, and the child chooses *how much* to eat and *whether* to eat from the foods provided.[2]

The parents' jobs with feeding:

- Provide structured, sit-down meals and snacks at predictable times
- Decide what foods will be offered at meals and snacks
- Make mealtimes pleasant
- Teach table manners
- Only offer water between meal and snack times; no other foods or beverages
- Be considerate of food preferences, but don't cater to likes and dislikes
- Trust your child knows how much food to eat and will grow into the body right for them

The child's jobs with feeding:

- Eat the amount of food he or she needs
- Learn to eat a variety of foods that are offered at family meals
- Have good table manners
- Grow into the body that is right for him or her



Video 11.4.1: "FEAST: Division of Responsibility" by United Way for Southeastern Michigan.[3] YouTube (January 23, 2019), 4:22

The division of responsibility is built on the trust that children know when they are hungry and full, that they want to eat, and that they want to learn to eat grown-up foods. Parents can best support their child's eating by providing the structure of family sit-down meals and snacks and modeling relaxed, enjoyable eating. The division of responsibility is an authoritative approach, providing structure and limits but allowing the child autonomy within those limits. At meals and snack times, parents promote children's independence by allowing them to pick and choose foods from what has been made available and decide how much of each to eat.

As your child learns to eat grown-up foods, every day will look slightly different— some days eating a lot and others eating very little. Don't cross the division of responsibility and pressure your child to eat more or less of something; this kind of pressure backfires. Pressure can be positive: praise, rewards, bribing, making special food, playing games, or talking about nutrition to encourage kids to eat more of nutritious foods or less of "bad" foods. Pressure can also be negative: restricting, threatening, punishing, shaming, or withholding dessert or fun activities. Instead of pressure, follow the division of responsibility in feeding.

Eating Competence

Eating competence is an evidence-based model that defines the interrelated spectrum of eating attitudes and behaviors.[4] The model is based on the principle that internal cues of hunger, appetite, and satiety are reliable and can be used to inform food selection and guide energy balance and body weight. Satter breaks eating competence down into 4 basic components: (1) eating attitudes, (2) food acceptance attitudes and skills, (3) internal regulation attitudes and skills, and (4) contextual attitudes and skills for providing family meals.

According to Ellyn Satter, "Eating competence is being positive, comfortable, and flexible with eating as well as matter-of-fact and reliable about getting enough to eat of enjoyable food. Even though they don't worry about what and how much to eat, competent eaters do better nutritionally, are more active, sleep better, and have better lab tests. They are more self-aware and self-accepting, not only with food, but in all ways. To be a competent eater, be relaxed, self-trusting, and joyful about eating, and take good care of yourself with food."[5]



Figure 11.4.2: "Girl Biting a Large Croissant" by Gustavo Fring is licensed under the standard Pexels License.

Current nutrition advice often focuses on food avoidance and reliance on outside indicators, such as diet plans, to guide eating. Eating competence is the opposite. It encourages us to seek food that is enjoyable and to let internal processes such as hunger and satiety guide eating.

Eating competence comprises both *permission* and *discipline*.[6]

- ***Permission*** is choosing foods that are enjoyable and eating those foods in amounts that are satisfying based on hunger, appetite, and satiety.
- ***Discipline*** is providing the structure of regular meals and sit-down snacks and paying attention to internal regulators while eating.

In "Secrets of Feeding a Healthy Family: How to Eat, How to Raise Good Eaters, How to Cook," Satter discusses how the eating competence model is built on trust: "Trust in our love of food and good eating; trust in following our inclinations to eat the food we like in amounts that are satisfying; trust that taking time to enjoy eating is time well-spent; trust that taking pleasure in eating supports being healthy; trust that behaving in such a self-respecting way is legitimate."

Today's nutrition advice is often based on control—the opposite of trust. Control is looking to outside instruction for *what* and *how much* to eat. It is sticking to a strict macro or calorie count; it is eating food because it is good for you (even though it is not appealing); it is eating a defined amount of food unrelated to hunger and satiety; and it is restricting food. Control often means restrained eating, and restrained eaters actually consume *more* food when exposed to forbidden foods.[7] Also, when food choices are externally dictated, especially when promoting negative energy balance, the body's physiological and psychological defense mechanisms are activated, which can lead to gaining excess weight and accumulating excess fat after food restriction.[8]

Parents should consider their own eating competence as they work to build eating competence in their children. Do you feel positive about eating and about food? Do you enjoy eating a variety of foods and trying new foods? Do you trust your internal regulators of hunger, appetite, and satiety to guide how much you eat? Do you have structured meals and snacks? It's much more difficult to raise eating-competent children if the adults in the family do not model a healthy relationship with food. Many new parents find that having children inspires them to work towards greater eating competence for themselves.

Meal planning is a good place to start when building eating competence. Tips for meal planning:[9]

- Start with what your family is currently eating, and cluster those foods into meals and snacks.
- Try to provide food from each of the food groups for meals and from 2 to 3 groups for snacks (dairy, fruit, vegetable, protein, and grain). Make sure they are foods you like and enjoy.

- Include bread or similar food like rice at every meal. Bread is always an easy-to-like food that family members can choose when they aren't excited about other options. Pair familiar foods with unfamiliar foods and favorite foods with not-so-favorite foods.
- Include fat in food preparation to make foods enjoyable. For meals to be sustainable, they must be satisfying.
- Let everyone choose what tastes good to them from what is provided on the table.

The Picky Eater

All young children can be picky when it comes to food and refuse to try new foods; this is normal behavior. It is only a concern when children get stuck with being picky. Follow the division of responsibility and adjust your expectations. Steer clear of the following traps that can limit food acceptance:

- Catering the menu to only child-friendly foods or favorite foods
- Making a separate meal when your child complains about what is offered
- Asking your child what they want to eat
- Pressuring your child to eat
- Offering food outside of scheduled meal and snack time

The biggest goal with a finicky eater is to not make eating an issue and to have mealtime be pleasant. Provide the structure of scheduled meals and snacks, and give permission for your child to choose from what is offered with no pressure.

> For more information on how to raise a healthy eater check out the following resources:
>
> - Satter, E. *Secrets of Feeding a Healthy Family: How To Eat, How To Raise Good Eaters, How to Cook.* Kelcy Press; 2008.
> - Satter, E. *Child of Mine: Feeding with Love and Good Sense*. Bull Publishing Company; 2000.

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11.5: Nutrition in Later Infancy and Toddlerhood

In early infancy, nutrition choices are relatively simple, though not necessarily easy! When the baby is hungry, it's time to breastfeed or prepare a bottle. But in later infancy and toddlerhood, a baby's food horizons expand. This is an exciting period of learning about foods and how to eat with the rest of the family.

Introducing Solid Foods

The World Health Organization recommends that babies begin eating some solid foods at 6 months while continuing to breastfeed. Other health organizations offer more flexible advice, recommending that solid foods be introduced sometime between 4 and 6 months, depending on the baby's development, interest in eating solids, and family preferences. Regardless, most babies aren't ready to eat solid foods before 4 months, and starting too soon may increase the risk of obesity. Yet it's also important not to start solids too late, as beyond 6 months, breast milk alone can't support a baby's nutrient requirements.[1]

However, as babies begin to eat solids, breast milk or formula continues to be the nutritional foundation of the diet. This period is also called ***complementary feeding***, because solid foods are meant to complement the nutrients provided by breast milk or formula. Between 6 and 12 months, babies gradually eat more solid foods and less milk so that by 12 months, formula is no longer needed. A breastfeeding mother may choose to wean at 12 months or continue breastfeeding as long as she and the baby like.

Babies should be developmentally ready to eat solids before trying their first foods. A baby ready for solids should be able to do the following:[1]

- Sit up without support (e.g., in a high chair or lap)
- Open mouth for a spoonful of food and swallow it without gagging or pushing it back out
- Reach for and grasp food or toys and bring them to his or her mouth



Figure 11.5.1: "Baby eating egg" by hui sang is licensed under the standard Unsplash License.

The American Academy of Pediatrics recommends beginning with iron-rich foods such as pureed meat or iron-fortified cereal (e.g., rice cereal, oatmeal), as iron is usually the most limiting nutrient at this age, particularly for exclusively breastfed babies. Once these foods are introduced, others can gradually be added to the diet, introducing one at a time to keep an eye out for allergic reactions. Work up to a variety of foods from all of the food groups, as babies are willing to try just about anything at this stage, and this is an opportunity for them to learn about different flavors. You can also gradually increase texture, from pureed to mashed food, then lumpy foods to soft finger foods. By 12 months, most babies can eat most of the foods at the family table, with some modifications to avoid choking hazards.[1,2]

When choosing good complementary foods, there are three main goals: (1) to meet nutrient requirements, (2) to introduce potentially allergenic foods, and (3) to support your baby in learning to eat many different flavors and textures. Parents should be sure to include the following:[1,2]

- **Good sources of iron and zinc**, as both minerals can be limiting for breastfed infants. Good sources include meat, poultry, fish, and iron-fortified cereal. Beans, whole grains, and green vegetables add smaller amounts of iron.

- **Adequate fat** to support babies' rapid growth and brain development. Good sources include whole-fat yogurt, avocado, nut butters, and olive oil for cooking vegetables. Fish is also a great food for babies because it provides both iron and fat, and it's a good source of omega-3 fatty acids like DHA and EPA, which support brain development.
- **A variety of vegetables, fruits, and whole grains,** so your baby learns to like many different tastes and textures. It may take babies and toddlers 8 to 10 exposures to a new food before they learn to like it, so don't be discouraged if your baby doesn't like some foods right away.

There is no need to avoid giving your baby common food allergens, such as peanut, egg, dairy, fish, shellfish, wheat, soy, or tree nuts. In fact, studies indicate that introducing at least some of these foods during the first year can prevent food allergies from developing. The evidence is strongest for peanut allergy. A randomized controlled trial published in 2015, called the Learning Early About Peanut Allergy or LEAP study, showed that in infants considered high-risk for food allergies, feeding peanut products beginning between 4 and 11 months reduced peanut allergy by 81%, compared with waiting to give peanuts until age 5.[3] Similarly, early introduction of egg seems to protect children from developing an egg allergy.[4,5] With any new food, keep an eye out for symptoms of an allergic reaction, such as hives, vomiting, wheezing, and difficulty breathing.[6]

Foods to Avoid in the First Year:

- **Cow's milk** can't match the nutrition provided by breast milk or formula and can cause intestinal bleeding in infants. However, dairy products such as yogurt and cheese are good choices for babies who have started solids. Babies can eat other dairy products, like yogurt and cheese, and cow's milk can be added to the diet at 12 months.
- **Plant-based beverages** such as soy and rice milk aren't formulated for infants, lack key nutrients, and often have added sugar.
- **Juice and sugar-sweetened beverages** have too much sugar. Whole fruit in a developmentally appropriate form (pureed, mashed, chopped, etc.) is a better choice.
- **Honey** may contain botulism, which can make infants very ill.
- **Unpasteurized dairy products or juices and raw or undercooked meats or eggs**, which can be contaminated with harmful foodborne pathogens.
- **Added sugar and salt** should be kept to a minimum so your baby learns to like many different flavors and doesn't develop preferences for very sweet or salty foods.
- **Choking hazards** such as whole nuts, grapes, popcorn, hot dogs, and hard candies should be avoided.

Responsive Feeding and Infant Growth

Regardless of whether infants are fed breast milk or formula, and continuing when they start solid foods, it's important that caregivers use a ***responsive feeding*** approach. Responsive feeding is grounded in 3 steps:[2]

- **The child signals hunger and satiety.** This may occur through vocalizations (e.g., crying, talking), actions (e.g., pointing at food or turning away when full), and facial expressions.
- **The caregiver recognizes the cues and responds promptly and appropriately.** For example, if the baby seems hungry, he or she is offered food promptly. If the baby turns his or her head or pushes away the breast, bottle, or an offered bite of food, the caregiver does not pressure the baby to eat more.
- **The child experiences a predictable response to his or her signals.**



Figure 11.5.2: "Mimi feeding 2" by Philippe Put is licensed under CC BY 2.0.

With breastfeeding, responsive feeding simply means feeding the baby when he or she signals hunger, and the baby usually turns away, spits out the nipple, or falls asleep when full. With bottle feeding, whether feeding breast milk or formula in a bottle, it's a little trickier. It's human nature to want the baby to finish the bottle that you've prepared, but a responsive feeding approach means that you let the baby decide when he or she has had enough. Pressure to eat more can cause the baby to grow too fast in infancy, which is correlated with becoming overweight or obese later in childhood. When feeding solid foods, the same responsive feeding principles apply, although solids should be offered at predictable meal- and snack times to avoid constant grazing throughout the day. If babies are offered appropriate, nutrient-dense foods and fed responsively, parents generally don't need to worry about serving sizes or amounts eaten. They can trust that their babies will eat what they need.[2]

The best way to determine if children are getting enough food to eat is to track their growth. Pediatricians and other healthcare providers do this by measuring a child's weight, length, and head circumference at each check-up and plotting their measurements periodically on growth charts from the World Health Organization. Growth charts allow you to compare your child's growth to a population of other healthy children. Sometimes, parents worry that if their child is in the 15th percentile for weight, that means she's not growing well, but this isn't the case. Children come in different shapes and sizes, and some grow faster than others. Thus, a child in the 15th percentile for weight may be a bit smaller than average, but when it comes to body size, the goal is not to be average or above average. The goal is to grow steadily and predictably in a way that is healthy for that individual child. If a child previously in the 15th percentile was suddenly measured at the 5th or 50th percentile, that might indicate a health or nutrition problem that warrants further evaluation.[7]

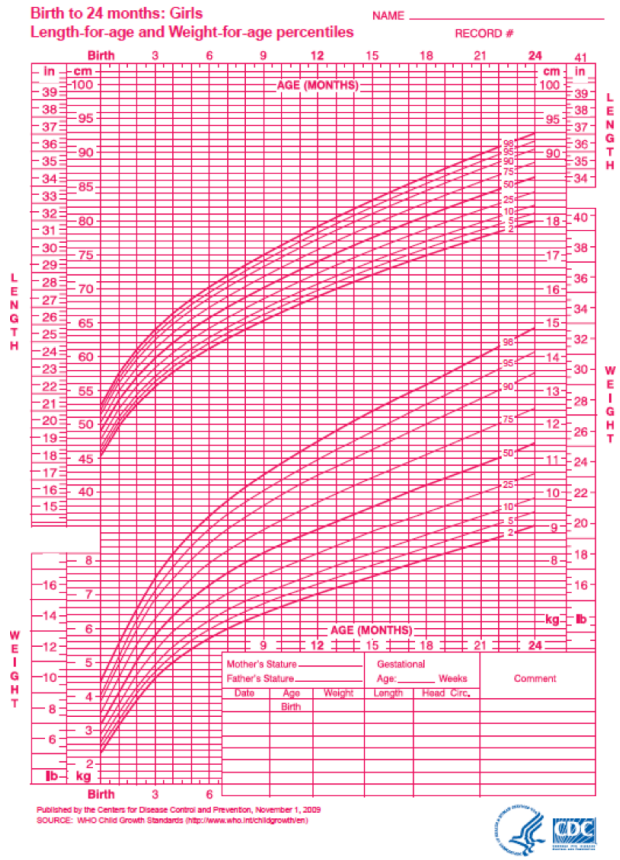


Figure 11.5.3. WHO growth chart for girls from birth to 24 months. "Girls length-for-age and weight-for-age percentiles" by Centers for Disease Control and Prevention is in the Public Domain.

Feeding Toddlers

Toddlerhood represents a stage of growing independence for children. They gain the physical ability to feed themselves confidently, and their growing language skills mean they can verbalize food preferences more clearly. Gradually, through exposure and experience, they learn to eat foods more and more like the rest of their family.[8]

In the toddler years, it's important to shift from a mindset of feeding "on demand," which is appropriate for infants, to one of predictable structure, with sit-down meals and snacks (usually three meals and two to three snacks each day). This prevents constant grazing and means that children come to the table hungry, ready to enjoy a nourishing meal. As much as you can, sit down to meals together so that your toddler learns that part of the joy of eating is enjoying time with loved ones.[2,8]

The AMDRs for children ages 1 to 3 recommend that 45 to 65%of calories come from carbohydrates, 30 to 40% from fat, and 5 to 20% from protein. Compared with older children and adults, this balance of macronutrients includes a higher level of fat to support young children's energy demands for growth and development. Therefore, fat or cholesterol generally should not be restricted in toddlers, although the focus should be on nutrient-dense sources of fat. Pediatricians usually recommend that toddlers ages 1 to 2 drink 2 to 3 cups of whole cow's milk per day to provide fat, protein, and micronutrients, including calcium and vitamin D. At age 2, parents can switch to low-fat or nonfat milk to reduce fat intake. For toddlers with a family history or other risk factors for obesity, pediatricians may recommend switching to low-fat milk sooner. It is important for toddlers to not over-consume cow's milk, as filling up on milk will reduce the consumption of other healthful foods. In particular, toddlers who drink too much cow's milk have a greater risk of iron deficiency and iron deficiency anemia, which is a common nutrient for this age group and can cause deficits in brain development.[8]

As for adults, MyPlate can be helpful for planning balanced meals for children 2 and up, with appropriate serving sizes. A ballpark recommendation for serving sizes for children ages 2 to 6 is about 1 tablespoon per year of age for each food, with additional food provided based on appetite.[8]

Other recommendations for feeding toddlers include the following:[2,8,9]

- Continuing to offer a variety of foods from all of the food groups, including a mix of vegetables and fruits of different colors, tastes, and textures.
- Include whole grains and protein sources such as poultry, fish, meats, tofu, or legumes in most meals and snacks.
- Limit salty foods and sugary snacks for health reasons, and so that your child doesn't come to expect these tastes in foods.
- By 12 to 15 months, wean toddlers from a bottle, transitioning to giving milk at meals in a cup. Prolonged bottle use tends to promote overconsumption of milk and can cause dental caries, particularly when toddlers fall asleep with a bottle.
- Continue to take care with choking hazards, as many choking incidents happen in children younger than 4. Common choking hazards include hot dogs, hard candy, nuts, seeds, whole grapes, raw carrots, apples, popcorn, marshmallows, chewing gum, sausages, and globs of peanut butter. Ensuring that children are sitting down when eating can help to prevent choking accidents.
- Stick to cow's milk and water as main beverage choices. Juice can be enjoyed occasionally in small servings (<0.5 cups/day) but is high in sugar, and whole fruit provides more nutrition. Plant-based beverages such as soy milk can be used in the case of a dairy allergy, lactose intolerance, or strong dietary preference, but be aware that these can be high in sugar and may not offer the same nutrients as cow's milk, so check labels carefully. Flavored cow's milk, soda, sports drinks, energy drinks, and caffeinated beverages should be avoided.
- Most children can get all of the nutrients they need from their diet, even if it seems that their intake is variable and they are somewhat picky about their choices. Pediatricians may prescribe a fluoride supplement for children living in areas with low fluoride levels in drinking water. They may also recommend a vitamin D supplement for children who do not consume adequate levels in their diet.

Attributions:

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11.6: Nutrition in Adolescence

Puberty marks the beginning of adolescence, the time between childhood and young adulthood. The DRI recommendations divide adolescence into two age groups: 9 through 13 years and 14 through 18 years. The onset of puberty brings many changes, including the development of the reproductive organs, the onset of menstruation in females, growth spurts, and changing body composition. Fat usually assumes a larger percentage of change in body weight in girls, while teenage boys experience greater muscle and bone development. All of these changes should be supported with sound nutrition.



Figure 11.6.1: "RDECOM presents STEM opportunities at Edgewood High School" by U.S. Army Combat Capabilities Development Command is licensed under CC BY 2.0.

Nutrient Needs in Adolescence

Energy and Macronutrients

Adequate energy intake is necessary to support the dramatic growth that takes place during adolescence. For ages 9 to 13, girls should consume about 1,400 to 2,200 calories per day, and boys should consume 1,600 to 2,600 calories per day. For ages 14 to 18, girls should consume about 1,800 to 2,400 calories per day, and boys should consume about 2,000 to 3,200 calories per day. Calorie needs vary based on activity level. The extra energy required for physical development during the teenage years should be obtained primarily from nutrient-dense foods instead of empty-calorie foods to support adequate nutrient intake and healthy body weight.

For children and adolescents ages 4 through 18, the AMDR for carbohydrates is 45 to 65% of daily calories, and most of these calories should come from high-fiber foods such as whole grains, whole fruits and vegetables. The AMDR for protein is 10 to 30% of daily calories, and lean proteins, such as meat, poultry, fish, beans, nuts, and seeds are excellent ways to meet protein needs. The AMDR for fat is 25 to 35% of daily calories. The focus should be on unsaturated plant fats to prevent chronic diseases.

Micronutrients

Micronutrient recommendations for adolescents are mostly the same as for adults, though children this age need more of certain minerals. The most important micronutrients for adolescents are calcium, vitamin D, vitamin A, and iron.

- **Calcium** levels increase to 1,300 mg/day during adolescence to support bone growth and prevent osteoporosis later in life. Low-fat dairy products and foods fortified with calcium, such as breakfast cereals and orange juice, are excellent sources of calcium.
- Adolescent girls' need for i**ron** increases with the onset of menstruation (8 mg/day for ages 9 to 13 and 15 mg/day for ages 14 to 18). Adolescent boys also need additional iron to develop lean body mass (8 mg/day for ages 9 to 13 and 11 mg/day for ages 14 to 18).

- **Vitamin A** is critical to support the rapid development and growth that happens during adolescence. Adequate fruit and vegetable intake meets vitamin A needs.

Common Nutrition-Related Health Concerns in Adolescence

Disordered Eating

Eating disorders involve extreme behaviors related to food and exercise. They encompass a group of conditions marked by under-eating or overeating, as discussed in an earlier chapter. Eating disorders stem from stress, low self-esteem, and other psychological and emotional issues. They are most prevalent among adolescent girls but have been increasing among adolescent boys in recent years. Because eating disorders often lead to malnourishment, adolescents with eating disorders are deprived of the crucial nutrients their still-growing bodies need. Girls with anorexia experience nutritional and hormonal problems that negatively influence peak bone density, and therefore may be at increased risk for osteoporosis and fracture throughout life.[1] 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.

Obesity

Children need adequate caloric intake for growth, and it is important not to impose very restrictive diets. However, exceeding caloric requirements regularly can lead to childhood obesity, which has become a major problem worldwide. According to a national survey of children's health in 2021-2022, the prevalence of obesity was 17% for youth ages 10 to 17.[2]

Several factors may contribute to this problem, including:

- early life factors, such as lack of breastfeeding support
- larger portion sizes
- limited access to nutrient-rich foods
- increased access to fast food and vending machines
- 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 levels. Even more importantly, it is a major risk factor for several diseases later in life, including cardiovascular disease, Type 2 diabetes, stroke, hypertension, and certain cancers.[3]

One major contributing factor to childhood obesity is the consumption of added sugars, especially in the form of sugar-sweetened beverages.[4] Added sugars include not only sugar added to food at the table but also ingredients in items such as bread, cookies, cakes, pies, jams, and soft drinks. 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 362 calories per day from added sugars, or about 16% of daily calories, 10% more than the Dietary Guidelines for Americans recommends.[5] Adolescent boys (ages 12 to 19 years) have the greatest added sugar intake, averaging 442 calories. The primary offenders are processed and packaged foods, along with soda and other beverages. These foods are not only high in sugar, but they are also light in terms of nutrients and often take the place of healthier options.



Figure 11.6.2: Photo of child eating frozen treat by Sharon McCutcheon is licensed under the standard Unsplash License.

If a child gains weight inappropriate for growth, parents and caregivers should nurture eating competence and follow the division of responsibility as previously discussed in this unit. 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.

Nutritionally Vulnerable

One of the psychological and emotional changes during this life stage includes the desire for independence as adolescents develop individual identities apart from their families. 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. Too many poor choices can make young people nutritionally vulnerable.

At this life stage, young people still need the structure of family meals. Evidence shows that eating family meals is associated with nutritional benefits, including eating a diet with more fruits, vegetables, fiber, and micronutrients, and less fried food, soda, and saturated and trans fat.[6]

Community Resources for Childhood Nutrition

Food insecurity can be a problem for school-aged children. Several federal programs support healthy nutrition in children who attend school. These programs are managed by the United States Department of Agriculture, who distributes funding to different state programs that organize the programs locally. The National School Lunch Program (NSLP) and the School Breakfast Program (SBP) provide meals to students for free or at a reduced price, depending on income level. The **Summer Food Service (SFS) Program** provides meals at summer sites in low-income communities to ensure year-round access to healthy foods. For eligible children not yet at school age, the **Child and Adult Care Food Program (CACFP)** provides funding for healthy meals at participating childcare centers or daycare homes. In addition to federal programs, local food banks help address food insecurity faced by families and children nationwide. You can find your local food bank and additional programs at Feeding America, a non-profit organization fighting hunger in America.

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11.7: Nutrition in Older Adults

The senior years are the period from age 51 until the end of life. Several physiological and emotional changes take place during this life stage, and as they age, older adults can face a variety of health challenges. Blood pressure rises, and the immune system may have more difficulty battling invaders and infections. The skin becomes thinner and more wrinkled and may take longer to heal after injury. Older adults may gradually lose an inch or two in height. And short-term memory might not be as keen as it once was. However, many older adults remain in relatively good health and continue to be active into their golden years. Good nutrition is important 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.

Dietary Reference Intakes (DRIs) vary based on age. Beginning at age 51, nutrient requirements for adults change to fit the nutritional issues and health challenges that older people face. Because the process of aging affects nutrient needs, some requirements for nutrients decrease as a person ages, while requirements for other nutrients increase. On this page, we will take a look at the changing nutrient requirements for older adults as well as some special concerns for the aging population.

Nutrient Needs in Older Adults

Energy and Macronutrients

Due to reductions in lean body mass and metabolic rate, older adults have lower calorie needs than younger adults. The energy requirements for people ages 51 and older 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 typical of older adults also influences nutrition requirements. The AMDRs for carbohydrates, protein, and fat remain unchanged from middle age into old age. Older adults should substitute more unrefined carbohydrates, such as whole grains, for refined ones. Fiber is especially important in preventing constipation and diverticulitis, which is more common as people age, and it may also reduce the risk of colon cancer. Protein should be lean, and healthy fats, such as omega-3 fatty acids, are a part of any good diet.



Figure 11.7.1:Photo of man kissing woman by Esther Ann on Unsplash (license information)

Micronutrients

The recommended intake levels of several micronutrients are increased in older adulthood, whereas others are decreased. A few nutrient changes to note include the following:

- To slow bone loss, the recommendations for **calcium** increase from 1,000 milligrams per day to 1,200 milligrams per day for women ages 51-70 and increases to 1,200 milligrams per day for men aged 70 and older.
- Also, to help protect bones, **vitamin D** recommendations increase from 600 IU to 800 IU per day for men and women after age 70.
- **Vitamin B_6** recommendations rise after age 70 to 1.7 milligrams per day for men and 1.5 milligrams per day for women to help lower homocysteine levels and protect against cardiovascular disease.
- Due to a decrease in stomach acid production, which can lead to an overgrowth of bacteria in the small intestine and decrease absorption of **vitamin B_{12}**, older adults need 2.4 micrograms per day of B_{12}. This increase starts at age 14.
- Higher **iron** levels are no longer needed post-menopause, and recommendations decrease from 18 milligrams per day to 8 milligrams per day starting at age 51.



Figure 11.7.2: "Woman in yellow" by the Centers for Disease Control and Prevention (CDC) is licensed under the standard Unsplash License.

Common Health Concerns in Older Adults

Older adults may face serious health challenges in their later years, many of which have ties to nutrition.

- Increased occurrence of cancer, heart disease, and diabetes
- Loss of hormone production, bone density, muscle mass, and strength, as well as changes in body composition, including increase of fat deposits in the abdominal area, increasing the risk for type 2 diabetes and cardiovascular disease
- Increased occurrence of dementia, resulting in memory loss, agitation, and delusions
- Decreased kidney function, becoming less effective in excreting metabolic products such as sodium, acid, and potassium, which can alter water balance and hydration status
- Decreased immune function, resulting in more susceptibility to illness
- Increased risk for neurological disorders and psychological conditions (e.g., depression), influencing attitudes toward food, along with the ability to prepare or ingest food
- Dental problems can lead to difficulties with chewing and swallowing, which in turn can make it hard to maintain a healthy diet
- Lower efficiency in the absorption of vitamins and minerals
- Being either underweight or overweight

Nutrition 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 levels. Figure 11.7.3 shows some nutrition recommendations for elderly adults that can help address some of the concerns described below.

Sensory Issues

At about age 60, taste buds begin to decrease in size and number. As a result, the taste threshold is 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 appetite. 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 digestion because the taste and smell of food stimulates the secretion of digestive enzymes in the mouth, stomach, and pancreas.

Dysphagia

Some older adults have difficulty getting adequate nutrition because of the disorder **dysphagia**, which impairs the ability to swallow. Stroke, which can damage the parts of the brain that control swallowing, is a common cause of dysphagia. 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 for more successful and safe swallowing. 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 60 are more likely to be obese than young or middle-aged adults. Reduced muscle mass and physical activity mean that older adults need fewer calories per day to maintain a normal weight. Being overweight or obese increases the risk for potentially fatal conditions that can afflict older adults, particularly cardiovascular disease and type 2 diabetes. Obesity is also a contributing factor for several 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 and 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 healthcare 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. Healthcare providers need to examine the causes of anorexia aging, which can vary from one individual to another. Understanding why some elderly people eat less as they age can help healthcare professionals assess the risk factors associated with this condition. Decreased intake may be due to disability or the lack of 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.

Nutrition interventions for the anorexia of aging should focus primarily on a healthy diet. Remedies can include increasing the frequency and variety of meals and adding healthy, high-calorie foods (such as nuts, potatoes, whole-grain pasta, and avocados) to the diet. The use of flavor enhancements with meals and oral nutrition supplements between meals may help to improve caloric intake.[1] Healthcare professionals should consider a patient's habits and preferences when developing a nutrition treatment plan. After a plan is in place, patients should be weighed weekly until they show improvement.

Vision Problems

Many older people suffer from vision loss and other vision problems. Age-related macular degeneration is the leading cause of blindness in Americans over sixty.[2] This disorder can make food planning and preparation extremely difficult, and people who suffer from it often depend on caregivers for their meals. Self-feeding also may be difficult if an elderly person cannot see their 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 also help to prevent macular degeneration. Consuming colorful fruits and vegetables increases the intake of lutein and zeaxanthin, two antioxidants that provide protection for the eyes.

Longevity and Nutrition

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. Therefore, it is best to start making healthy choices from a young age and maintain them as you mature. However, research suggests that adopting good nutritional choices later in life, during the 40s, 50s, and even the 60s, may still help to reduce the risk of chronic disease as you grow older.[3]

Even if past nutrition and lifestyle choices were not aligned with dietary guidelines, older adults can still do a great deal to reduce their risk of disability and chronic disease. There are a number of changes middle-aged adults can implement, even after years of unhealthy choices. Choices include eating more dark, green, leafy vegetables, choosing lean sources of protein such as lean meats, poultry, fish, beans, and nuts, and engaging in moderate physical activity for at least thirty minutes per day, several days per week. The resulting improvements will go a long way toward providing greater protection against falls and fractures and helping to ward off cardiovascular disease and hypertension, among other chronic conditions.[3]

Food Insecurity

Although food insecurity can affect any life stage, approximately 1 in 14 or about 7% of elderly adults in America experience food insecurity.[4] Factors like low income, race and ethnicity, living with a disability, and caring for other family members increase the risk for food insecurity in Americans over the age of 60. Food insecurity is almost three times higher in elderly individuals who are divorced or never married, suggesting that social factors contribute to the risk of food insecurity in elderly individuals.

There are many community resources aimed at addressing food insecurity in elderly individuals:

- The **Commodity Supplemental Food Program (CSFP)** is a federal program that provides monthly food boxes to people 60 years and older.
- **Senior food pantries** let individuals shop for free groceries. Many food banks and food pantries have special hours for elderly individuals and may provide monthly food boxes that include a variety of healthy foods.
- **Home food delivery** may be available from food banks, food pantries, or the local Meals on Wheels program. Individuals may need to meet specific income or lifestyle requirements to qualify.
- **Senior farmer's markets** help elderly individuals access fresh fruits and vegetables from local farmer's markets. These programs may host a farmer's market or give out vouchers.
- **Senior mobile pantries** bring food to senior centers or other locations in a community.
- The **Child and Adult Care Food Program (CACFP)** is a federal program that provides reimbursements for meals provided to adults who are over 60 or living with a disability and enrolled in day care facilities.
- The **Supplemental Nutrition Assistance Program (SNAP)** provides extra money each month to buy groceries at grocery stores or some farmer's markets.

Visit Feeding America to find local resources for elderly nutrition in your area.



Nutrition Strategies for Older Adults

What can make it harder for me to eat healthy as I age?

Some changes that can happen as you age can make it harder for you to eat healthy. These include changes in your

- Home life, such as suddenly living alone or having trouble getting around
- Health, which can make it harder for you to cook or feed yourself
- Medicines, which can change how food tastes, make your mouth dry, or take away your appetite
- Income, which means that you may not have as much money for food
- Sense of smell and taste
- Problems chewing or swallowing your food

What can I do if I am having trouble eating healthy?

Sometimes health issues or other problems can make it hard to eat healthy. Here are some tips that might help:

- If you are **tired of eating alone**, try organizing some potluck meals or cooking with a friend. You can also look into having some meals at a nearby senior center, community center, or religious facility.
- If you are **having trouble chewing**, see your dentist to check for problems
- If you are **having trouble swallowing**, try drinking plenty of liquids with your meal. If that does not help, check with your health care provider. A health condition or medicine could be causing the problem.
- If you're **having trouble smelling and tasting** your food, try adding color and texture to make your food more interesting
- If you **aren't eating enough**, add some healthy snacks throughout the day to help you get more nutrients and calories
- If an **illness is making it harder for you to cook or feed yourself**, check with your health care provider. He or she may recommend an occupational therapist, who can help you find ways to make it easier.

[4]U.S. National Library of Medicine (2020, June 23). *Nutrition for Older Adults*. MedlinePlus. Retrieved August 18, 2020, from https://medlineplus.gov/nutritionforolderadults.html

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11.8: Foodborne Illness and Food Safety

Foodborne Illnesses

Foodborne illness is another serious threat to health. Sometimes called "food poisoning," foodborne illness is a common public health problem resulting 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, or packaging or during distribution, though meat and poultry are the most common sources of foodborne illness. For all kinds of food, contamination also can occur during preparation and cooking in a home kitchen or a restaurant. 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.[1] 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 of developing severe complications of 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.

The Major Types of Foodborne Illness

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 those 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 has eaten. 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.[2] Most 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. The CDC is now using whole genome sequencing to better track foodborne outbreak locations with the goal of solving outbreaks while they are still small and getting the word out to the communities at risk.[3]

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, which is called the danger zone, bacteria grow rapidly.
- **Time.** More than two hours in the danger zone increases risk of bacterial growth.
- **Water.** High moisture content helps bacterial growth. 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 for bacterial growth, since most microorganisms grow best around 7.0 pH and not many will grow below 4.0 pH. Examples of higher pH foods include 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.[4] 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.

The Causes of Food Contamination

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 and examine common microbes, toxins, chemicals, and other substances that can cause food infections and intoxications. 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.

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.

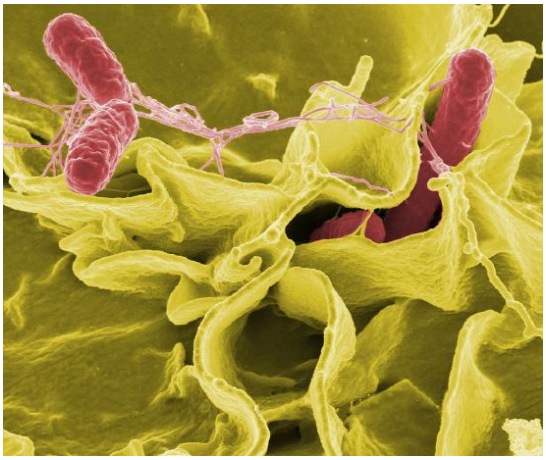


Figure 11.8.1: Salmonella was first identified in 1885 and many types of this kind of bacteria exist. The incidence of Salmonella infections has risen dramatically in the past few decades. Color-enhanced scanning electron micrograph showing Salmonella Typhimurium (red) invading cultured human cells. "Salmonella" by the Rocky Mountain Laboratories, NIAID, NIH is in the Public Domain.

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.[5]

The bacterium *Listeria monocytogenes* is found in soft cheeses, unpasteurized milk, 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 *E. coli* is caused by *Escherichia coli*. Sources include 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 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.[6]

Viruses

Viruses are another type of pathogen that can lead to food infections, however they are less predominant than bacteria. **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. Centers for Disease Control and Prevention.[7]

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.[8]

Mold Toxins

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.



Figure 11.8.2: Mold can grow on fruits, vegetables, grains, meats, poultry, and dairy products, and typically appears as gray or green "fur." Moldy nectarines that were in a refrigerator. The nectarine with black mold is also affecting the nectarine underneath. "Moldy nectarines" by Roger McLassus 1951 is licensed under CC BY-SA 3.0 Unported.

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% 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.[9]

Poisonous Mushrooms

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.[9]

Pesticides

Pesticides are important in food production to control diseases, weeds, 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.[10] 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 nonfood 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 lower risk 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.[11]

PCBs, or polychlorinated biphenyls, are man-made organic compounds that are used commercially. Like methyl mercury, higher concentrations of this contaminant are found in predatory fish. Health effects include 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.[12]

Protecting the Public Health

Most foodborne infections go unreported and undiagnosed. However, the CDC estimates that about forty-eight 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, the USDA, and Health Canada, 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. 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 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. Also, the Environmental Protection Agency (EPA) regulates public drinking water.

Government agencies also monitor 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.

Efforts within the Food Industry

The Hazard Analysis Critical Control Points (HACCP) is a system 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 hazards could occur. Those companies or retailers must then take measures 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.[13]

Efforts on the Consumer Level: What You Can Do

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).
2. **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.
3. **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.
4. **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.



Figure 11.8.3:The CDC provides an quick system for food safety, focusing on four key topics: clean, separate, cook and chill. The CDC website offers details for each topic. "Four Steps to Food Safety" by the Centers for Disease Control & Prevention is in the Public Domain.

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.



Video 11.8.1: Start at the Store: Prevent Foodborne Illness. This video provides tips to follow when selecting and purchasing food at the supermarket to help to prevent foodborne illness and protect your health (click to see video).[14]

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. 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 or microwave or in a watertight 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 a 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, fish beef, lamb and pork should be cooked to an internal temperature of 145°F, ground meat 160°F, poultry, including ground chicken and turkey to 165°F, and leftovers and casseroles to 165°F. When microwaving, rotate the dish and stir contents several times to ensure even cooking. Here is a link to the Safe Minimum Internal Temperatures for meat from the USDA.[15]

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.

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