INTRODUCTION TO NUTRITION (2E)



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Introduction to Nutrition (2e)

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This text was compiled on 08/26/2026

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1: FOUNDATIONAL CONCEPTS

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1.1: Defining Nutrition, Health, and Disease

Learning Objectives

- Explain the terms nutrition, health, health promotion, and disease prevention.
- Describe factors that influence food choices.

We are bombarded with images and messages about food everywhere we go. We see supermodels eating giant burgers, chefs battling to prepare meals, and influencers telling us how to follow the latest diet on various social media platforms. How do you use the information from entertainers and influencers to build a nutritious meal? Hopefully...you don't...at least, not before knowing whether they have the background to be a nutrition expert.

The construction of a nutritious meal requires learning about which foods are healthy and which foods are not-so-healthy, how foods and nutrients function in your body, and how to use scientific resources to make healthful choices for you and those you care about. This text is designed to provide you with the information necessary to make sound nutritional choices that will optimize health and help prevent disease.

Nutrition, Health and Disease

Nutrition science is the investigation of how an organism is nourished. It includes the study of how nourishment affects personal health, population health, and planetary health. Nutrition science involves a wide spectrum of disciplines such as biology, physiology, immunology, biochemistry, education, psychology, sustainability, and sociology. Nutrition is a relatively new discipline of science. As seen below, early research in nutrition focused on nutrient discovery and deficiencies. More recently, research has focused on supporting health and wellness, preventing and treating chronic diseases, and nutrigenomics (the interactions between genes, the environment, and nutrition).

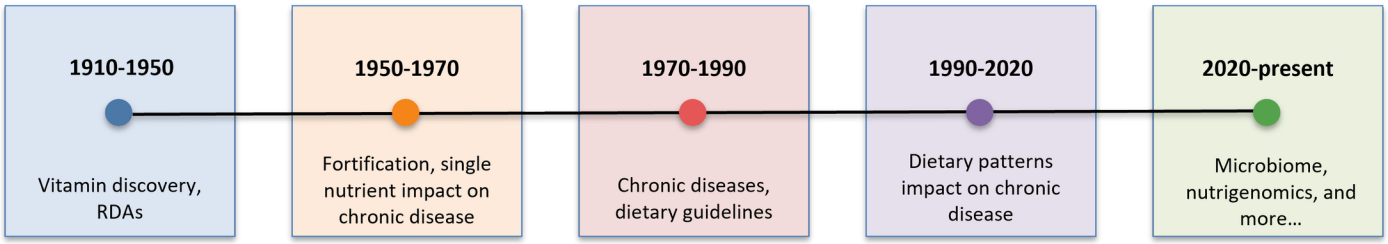


Figure 1.1.1: Timeline of Nutrition Research. (CC BY 4.0; Adapted from *BMJ* 2018;361:k2392)

Dietitians are nutrition professionals who integrate their knowledge of nutrition science into helping people achieve a healthy diet and develop good dietary habits. The Academy of Nutrition and Dietetics is the largest organization of nutrition professionals worldwide and dietitians registered with the Academy are committed to helping Americans eat well and live healthier lives. To learn more about dietitians, other nutrition professionals and the reliable nutrition advice they provide, visit www.eatright.org.

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

Without adequate nutrition the human body does not function optimally, and severe nutritional inadequacy can lead to disease and even death. Disease is defined as any abnormal condition affecting the health of an organism and is characterized by specific signs and symptoms. Signs are objective findings that can be seen or measured; some examples of signs include swelling, weight loss, or fever. Symptoms are subjective 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), nutrient deficiencies, genetics, and physiological dysfunction. Diseases that primarily affect physical health are those that impair body structure (as is the case with osteoporosis), or functioning (as is the case with cardiovascular disease).

The foods we eat affect all three aspects of our health (physical, mental, and social well-being). For example, a teen with Type 2 diabetes (a disease often brought on by poor diet) is first diagnosed by physical signs and symptoms such as increased urination, thirstiness, and unexplained weight loss. But research has also found that teens with Type 2 diabetes have impaired thinking and do not interact well with others in school, thereby affecting mental and social well-being. Type 2 diabetes is just one example of a physiological disease that affects all aspects of health.

Public Health and Disease Prevention

In 1894, the first congressional funds were appropriated to the US Department of Agriculture (USDA) for the study of the relationship between nutrition and human health. Dr. Wilbur Olin Atwater was appointed as the Chief of Nutrition Investigations and is regarded as the "Father of Nutrition Science" in America. Under his guidance, the USDA released the first bulletin to the American public that contained information on the amounts of fat, carbohydrates, proteins, and energy (calories) in various foods. Nutritional science advanced considerably in these early years, but it took until 1980 for the USDA and the US Department of Health and Human Services (HHS) to jointly release the first edition of *Nutrition and Your Health: Dietary Guidelines for Americans*.

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

In the latter part of the twentieth century, nutrition scientists, public health organizations, and the American public increasingly recognized that poor diet increases the risk of certain chronic diseases. Diet-related conditions and diseases include hypertension (high blood pressure), obesity, Type 2 diabetes, cardiovascular disease, some cancers, and osteoporosis. Dietary risks (e.g., consuming too much sodium, sugar-sweetened beverages, processed meats; not eating enough fiber, fruits, vegetables, whole grains) affect health. Collectively, dietary risks were the fifth-leading risk factor for early death in 2023; over 12% of all deaths in 2023 were associated with poor diet, with cardiovascular disease being the leading cause of death associated with diet.[2] The Dietary Guidelines for Americans,[3] which are published every 5 years, aim to promote health and prevent chronic diseases. These guidelines outline ways to improve your overall eating patterns; you'll read more about these guidelines in Chapter 2.

Factors that Influence Food Choices

Knowledge of nutrition and dietary guidelines may influence the food choices you make, but there are a number of other factors that affect the dietary choices individuals make, including:

- **Hunger vs. appetite.** Hunger is the biological urge to eat; appetite is the psychological desire to eat specific foods.
- **Sensory data.** Cues that stimulate our five senses (sight, taste, hearing, touch, smell) can influence foods we choose.
- **Taste, texture, and appearance.** Individuals have a wide range of tastes which influence their food choices, leading some to dislike milk and others to hate raw vegetables. Some foods that are healthy, such as tofu, may be unappealing to some people. However, creative cooks can adapt healthy foods to meet most peoples' taste.
- **Economics.** Access to fresh fruits and vegetables may be difficult, particularly for those who live in economically disadvantaged or remote areas, where cheaper food options are limited to convenience stores and fast food.
- **Early food experiences.** People who were not exposed to different foods as children, or who were forced to swallow every last bite of overcooked vegetables, may make limited food choices as adults.
- **Habits.** It's common to establish eating routines, which can work for or against optimal health. Habitually grabbing a fast food sandwich for breakfast can seem convenient, but might not offer substantial nutrition. On the other hand, creating a healthy habit of drinking plenty of water each day can yield multiple benefits.
- **Culture.** The culture in which one grows up affects how one sees food in daily life and on special occasions.
- **Religion.** Various religious customs can influence foods eaten or avoided. For example, people of Jewish and Muslim faiths do not consume pork.
- **Geography.** Where a person lives influences food choices. For example, people who live in Midwestern US states have less access to fresh seafood than those living along the coasts.

- **Advertising.** Media greatly influences food choice by persuading consumers to eat certain foods.
- **Social factors.** Any school lunchroom observer can testify to the impact of peer pressure on eating habits. This influence can last through adulthood. People make food choices based on how they see others and want others to see them. For example, individuals can purchase cheap and fast pizzas or opt for high-end versions at fancy restaurants.
- **Learning.** Learning about new food, cultures, ways of eating, and even manufacturing practices can influence the foods we choose to eat and avoid.
- **Health concerns.** Some people have significant food allergies, to lactose or peanuts for example, and need to avoid those foods. Others may have developed health issues, which require them to follow a low-salt diet. In addition, people who have never worried about their weight have a very different approach to eating than those who have long struggled with excess pounds.
- **Emotions.** There is a wide range in how emotional issues affect eating habits. When faced with a great deal of stress, some people tend to overeat, while others find it hard to eat at all.
- **Environmental concerns.** Some people make food choices based on their environmental impact which may include opting for a vegetarian diet or purchasing local and/or organic food products.

References

1. Constitution. World Health Organization. Accessed January 21, 2026.
2. Diet. Institute for Health Metrics and Evaluation. Accessed January 20, 2026.
3. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans, 2025-2030*. Accessed January 21, 2026.

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1.2: Overview of Nutrients and Calories

Learning Objectives

- Define the word “nutrient”.
- Identify the six classes of nutrients essential for health.
- List the three main energy (calorie) yielding nutrients and how many calories each of these nutrients provide.

What is in Food?

Your "diet" is defined as the foods you choose to eat. The diet of most people contains a variety of foods: grains, nuts, fruits, vegetables and more! The foods we eat contain nutrients. Nutrients are substances required by the body to perform its basic functions. Nutrients must be obtained from the diet, since the human body does not make them, or does not make 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! There are six classes of essential nutrients required for the body to function and maintain overall health. These six classes of essential nutrients are: carbohydrates, lipids (fats), proteins, water, vitamins, and minerals. These nutrients can also be categorized as organic or inorganic. When discussing the chemical structure of nutrients, "organic" indicates that the nutrient contains carbon; "inorganic" indicates that the nutrient does not contain carbon.

Foods also contain non-nutrients. Some non-nutrients appear to be very important for human health, like fiber and antioxidants; other non-nutrients may be harmful to human health such as alcohol, preservatives, colorings, flavorings and pesticide residues.

Table 1.2.1*: Six Classes of Nutrients and Their Functions*

Nutrient	Organic vs. Inorganic	Functions
Carbohydrates	Organic	• Provide a ready source of energy for the body (sometimes referred to as the preferred source of energy for the body). • Provide structural constituents for the formation of cells.
Lipids (Fats)	Organic	• Provide stored energy for the body. • Function as structural components of cells. • Function as signaling molecules for proper cellular communication. • Provide insulation to vital organs. • Help maintain body temperature.
Proteins	Organic	• Necessary for: ◦ tissue formation ◦ cell repair ◦ regulating fluid balance ◦ hormone production ◦ enzyme production • Essential for building strong muscles. • Essential for a healthy immune system.

Nutrient	Organic vs. Inorganic	Functions
Water	Inorganic	• Transports essential nutrients to all body parts. • Involved in many body processes, including: ◦ fluid balance ◦ nerve impulses ◦ muscle contraction • Transports waste products for disposal. • Aids with body temperature regulation.
Vitamins	Organic	• Regulate body functions/processes. • Promote normal body-system functions.
Minerals	Inorganic	• Regulate body processes. • Necessary for proper cellular function. • Comprise body tissue.

Macronutrients

Nutrients that are needed in large amounts are called macronutrients. Macronutrients include carbohydrates, lipids (fats), proteins, and water. Carbohydrates, lipids, and proteins provide energy (calories) which can be used ("burned") by your body to perform basic functions. 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. Water is needed in large quantities but does not contain energy (calories).

The following video provides a nice overview of the energy-containing macronutrients (carbohydrates, lipids (fats), and proteins). You can also read more about macronutrients below the video.

YouTube Video

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"Macros: Explained! Mind Over Munch Kickstart 2016" by Mind Over Munch

Carbohydrates

The major food sources of carbohydrates are grains, dairy products, fruits, and starchy vegetables like potatoes. Non-starchy vegetables also contain carbohydrates, but in lesser quantities. When you eat a food that contains carbohydrates, like bread for example, you receive approximately 4 calories of energy for every gram of carbohydrate you eat. Chemically speaking, carbohydrates are molecules composed of carbon, hydrogen, and oxygen. Carbohydrates are the preferred source of energy (calories) for your body; you'll learn more about carbohydrates in Chapter 4.

Lipids (Fats)

Lipids (fats) are found predominately in butter, margarine, lard, oils, meats, animal fat, dairy products, nuts, seeds, and many processed foods. Lipids provide more energy per gram than carbohydrates (9 calories per gram of lipids versus 4 calories per gram of carbohydrates). Lipids are also a family of molecules composed of carbon, hydrogen, and oxygen, but unlike carbohydrates, they are insoluble in water. The main job of lipids is to store energy (calories) for later use. Lipids are an important energy source during rest and low-intensity exercise. In addition, lipids surround and protect organs, aid in temperature regulation, and regulate many other functions in the body. You'll learn more about lipids in Chapter 5.

Proteins

Major food sources of proteins include meats, dairy products, seafood, and a variety of different plant-based foods (e.g., soy, seeds, nuts, and legumes/beans). Proteins are macromolecules composed of chains of subunits called amino acids. Amino acids are composed of carbon, hydrogen, oxygen, and nitrogen. Proteins provide 4 calories of energy per gram; however providing energy is not protein's most important function. Proteins provide structure to bones, muscles, and skin; support tissue growth, repair, and maintenance; and play a role in conducting most of the chemical reactions that take place in the body. Chapter 6 will dive deeper into the multiple functions of proteins.

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. Unlike the energy-yielding macronutrients (carbohydrates, lipids, and protein), water does not provide any energy (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. You'll explore water in more detail in Chapter 8.

Micronutrients

Micronutrients are nutrients required by the body in lesser amounts, but are still essential for carrying out bodily functions. Micronutrients include all the essential vitamins and minerals. There are 13 essential vitamins and 16 essential minerals (see Tables 1.2.2 and 1.2.3 for a complete list and their major functions). In contrast to carbohydrates, lipids, 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 (cause or speed up) 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 which will be further investigated in Chapters 8-11.

Vitamins

The thirteen essential vitamins are categorized as either water-soluble or fat-soluble. Water-soluble vitamins dissolve easily in water; fat-soluble vitamins dissolve easily in fats and oils. Excess water-soluble vitamins are excreted in urine and are not typically stored in large amounts in the body; however, excess fat-soluble vitamins are stored in the body. The water-soluble vitamins are vitamin C and all the B vitamins, which include thiamin, 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. In addition, vitamins are essential to energy metabolism (process by which macronutrients are broken down into smaller molecules that our body can absorb and use).

Table 1.2.2: Vitamins and Their Major Functions

Vitamins	Major Functions
Water-soluble	
B_1 (thiamin)	Coenzyme, energy metabolism assistance
B_2 (riboflavin)	Coenzyme, energy metabolism assistance

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

The following video provides a nice overview of vitamins:

YouTube Video

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"How Do Vitamins Work?" by Ginnie Trinh Nguyen

Minerals

Minerals are solid inorganic substances that form crystals and do not break down; they maintain their structure no matter what environment they're in. Minerals are classified depending on how much of them we need. Trace minerals, such as molybdenum, selenium, zinc, iron, and iodine, are required in amounts *less* than 100 milligrams per day; macrominerals, such as calcium, magnesium, potassium, sodium, and phosphorus, are required in amounts *more* than 100 milligrams per day. Many minerals are critical for enzyme function, others are used to maintain fluid balance, build bone tissue, synthesize hormones, transmit nerve impulses, contract and relax muscles, and protect against harmful free radicals. In addition, minerals are essential to energy metabolism (process by which macronutrients are broken down into smaller molecules that our body can absorb and use).

Table 1.2.3: : 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

Minerals	Major Functions
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
Chromium	Assists insulin in glucose metabolism
Molybdenum	Coenzyme

Vitamin and mineral deficiencies can cause severe health problems. For example, a deficiency in vitamin A can lead to night blindness. Anemia, a condition where there aren't enough healthy red blood cells to carry adequate oxygen throughout the body, can result from an iron deficiency.

Food Energy

Though 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 food energy. Energy is the capacity to do work. Our bodies break down the energy-providing nutrients (carbohydrates, fats/oils, and proteins) and reassemble them into a fuel that supports physical activity and basic functioning.

As you read above, carbohydrates provide 4 calories for every gram we consume; proteins provide 4 calories for every gram we consume; and fats provide 9 calories for every gram we consume. Another source of calories is alcohol. Alcohol is *not* considered to be a nutrient (because it's not required by the body to perform its basic functions), but it does provide 7 calories of energy for every gram we consume. Vitamins, minerals and water do not provide any calories, but they are still essential nutrients.

Technically, food energy is measured in kilocalories. A kilocalorie is the amount of heat generated by a particular macronutrient that raises the temperature of 1 kilogram of water 1 degree Celsius. To measure the number of kilocalories in a particular food substance, a certain amount of food is burned in a device called a calorimeter. As the food burns, heat is created. The heat dissipates to the surrounding water while a thermometer detects the change in temperature of the water. A kilocalorie of energy performs 1,000 times more work than a calorie. In science, a kilocalorie is often written as "kcal" or "Calorie" (with a capital "C"). So, 1 kilocalorie = 1 kcal = 1 Calorie = 1,000 calories. Although kilocalories, kcals, or Calories (with a capital "C") are technically the appropriate terms, most people refer to the amount of energy in food as a calorie (with a lower case "c"), so this text will use calories (with a lower case "c") for the sake of simplicity. On food labels, “calorie” is used when referring to kilocalories. For more on calories, watch the video below.

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1.3: The Broad Role of Nutritional Science

Learning Objectives

- Describe the scientific method.
- Describe various types of scientific studies and where they fall on the hierarchy of evidence pyramid.

The Scientific Method

Similar to the method by which a police detective finally charges a criminal with a crime, nutrition 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 is called the scientific method.

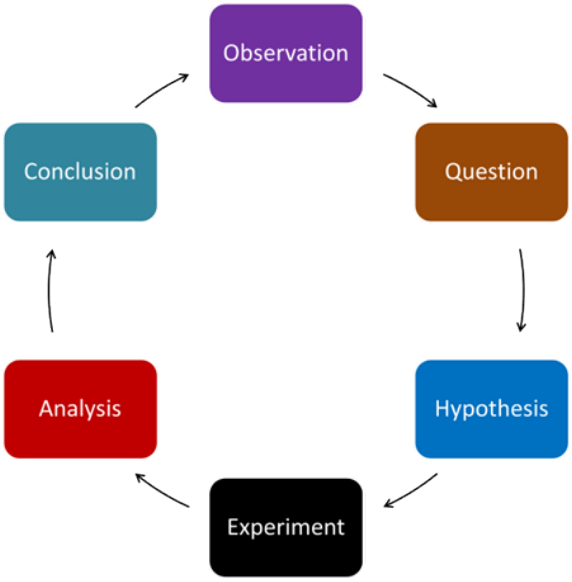


Figure 1.3.1: The Scientific Method (by Ann Diker; CC BY 4.0)

When confronted with a claim, scientists must consider the evidence that supports or does not support the claim. A standardized method, called the scientific method, is used to look at the evidence. The scientific method includes the following steps:

1. **Observation/Question**
   - Observations of an event lead the researcher to ask a question.
     - Example: You've noticed that the people you know who eat apples don't go to the doctor as often as other people you know who don't eat apples, leading you to the question "Does an apple a day really keep the doctor away?"
2. **Hypothesis**
   - The researcher proposes a hypothesis, or educated guess, to explain the observation/question.
   - A hypothesis is written in a way so that it can be evaluated as either true or false.
   - A hypothesis must be testable, unbiased and repeatable.
     - Example: Your hypothesis could be "People who eat an average of 1 or more apples per day have fewer visits to the doctor than people who eat less than 1 apple per day."
3. **Experiment**
   - An experiment is a scientific study that tests the hypothesis.
   - Some key elements of a well-designed experiment include:
     - *Sample Size* - enough people must be studied to ensure that the results obtained are not due to chance alone.
     - *Control Group* - a group of people who are as much like the group of people in the experiment as possible except for the variable being tested.

        - Using a control group helps the researcher judge whether the treatment worked or not.
            - Example: In the apple study you would want a group of people who eat apples regularly (experimental or treatment group) and a similar group of people who are like the treatment group in every way *except* that they don't eat apples (control group).
    - *Controlling for Other Variables*
        - Researchers should attempt to control for other variables that may influence the results
            - Example: Since age may be one reason why people go to the doctor more often, we would want to make sure that we had the same ages of people in each group.
4. **Analysis**
    - The researcher collects and analyzes data that will either support or reject the hypothesis.
    - Data should be collected in the most reliable and consistent way possible.
        - Example: More reliable information would be collected from the doctor's office charts than simply asking participants to remember how many times they went to the doctor over the past year.
    - If the data do *not* support the hypothesis, then the hypothesis is either rejected or a new/different hypothesis may be proposed and tested.
    - If the data support the original hypothesis, then additional experiments are completed to try to replicate the findings or test them in different ways.
        - Example: If this experiment shows that people who eat more apples have fewer visits to the doctor, then a follow-up experiment might be completed to see if certain types of apples (e.g., red vs. green) have the same impact.
5. **Conclusion**
    - After multiple experiments consistently support the hypothesis, then the research offers a conclusion or theory.

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



Figure 1.3.2: Woman with large goiter. (CC BY-SA 3.0; Dr. J.S. Bhandari via Wikimedia Commons)

- **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.
- **Experiment.** Coindet administered iodine tincture orally to his patients with goiter.
- **Interpret results.** Coindet's iodine treatment was successful.
- **Gathering more evidence.** Many other physicians contributed to the research on iodine deficiency and goiter.
- **Hypothesis.** French chemist Chatin hypothesized that the low iodine content in food and water of certain areas far away

from the ocean were the primary cause of goiter (as opposed to a former theory that goiter was the result of poor hygiene).
- **Experiment.** In the late 1860s the program, "The stamping-out of goiter," started with people in several villages in France being given iodine tablets.
- **Results.** The program was effective and 80 percent of goitrous children were cured.
- **Hypothesis.** In 1918, Swiss doctor Bayard proposed iodizing salt as a good way to treat areas endemic with goiter.
- **Experiment.** Iodized salt was transported by mules to a small village at the base of the Matterhorn where more than 75% of school children were goitrous. It was given to families to use for six months.
- **Results.** The iodized salt was beneficial in treating goiter in this remote population.
- **Experiment.** Physician David Marine conducted the first experiment of treating goiter with iodized salt in America in Akron, Ohio.
- **Results.** This study conducted on over four-thousand school children found that iodized salt prevented goiter.
- **Conclusions.** Seven other studies similar to Marine's were conducted in Italy and Switzerland that also demonstrated the effectiveness of iodized salt in treating goiter. In 1924, US public health officials initiated the program of iodizing salt and started eliminating goiterism. Today more than 70% of American households use iodized salt and many other countries have followed the same public health strategy to reduce the health consequences of iodine deficiency.

Evidence-Based Approach to Nutrition

It took the work of many different scientists and more than 100 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 also part of the overall evidence-based approach to designing nutritional guidelines. The Food and Nutrition Board of the Institute of Medicine, a nonprofit, nongovernmental organization, constructs its nutrient recommendations (i.e., Dietary Reference Intakes, or DRIs) using an evidence-based approach to nutrition. The entire procedure for setting the DRIs is documented and made available to the public. The same approach is used by the United States Department of Agriculture (USDA) and Department of Health and Human Services (HHS), which are departments of the US federal government that jointly develop the U.S. *Dietary Guidelines* every 5 years. The USDA and HHS websites can be used to discover ways to optimize health; however, it is important to gather nutrition information from multiple resources as there are often differences in opinion among various scientists and public health organizations. While the *Dietary Guidelines* have been well-received by some, there are nongovernmental public health organizations that are convinced that some pieces of the guidelines may be influenced by lobbying groups and/or the food industry.

Types of Scientific Studies

There are many types of scientific studies that can be used to provide supporting evidence for a particular hypothesis. Researchers use many different types of study designs depending on the question they are trying to answer, as well as factors such as time, funding, and ethical considerations. The study design affects how we interpret the results and the strength of the evidence as it relates to real-life nutrition decisions. It can be helpful to think about the types of studies within a pyramid representing a hierarchy of evidence, where the studies at the bottom of the pyramid usually give us the weakest evidence with the least relevance to real-life nutrition decisions, and the studies at the top offer the strongest evidence, with the most relevance to real-life nutrition decisions. There tend to be more laboratory and observational studies published (bottom of the pyramid) because they require less time, money, and other resources. Intervention studies are more expensive and resource-intensive, so there are fewer of these types of studies conducted. But they also give us higher quality evidence, so they're an important next step if observational and laboratory studies have shown promising results. Meta-analyses and systematic reviews combine the results of many studies already conducted, so they help researchers summarize scientific knowledge on a topic.

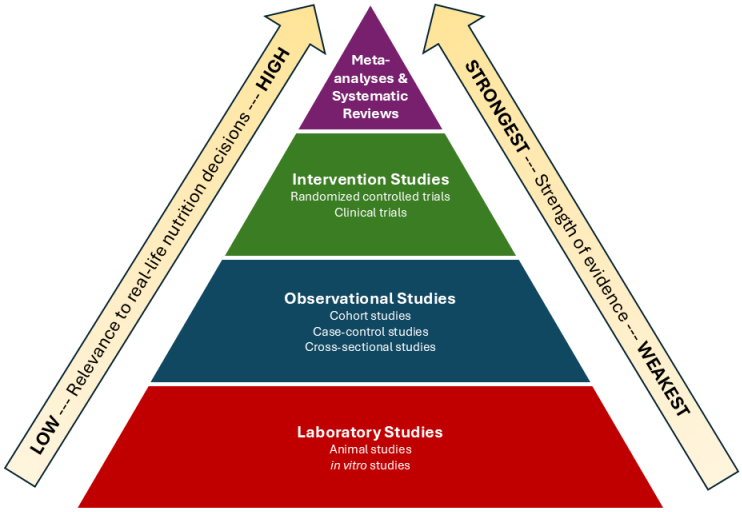


Figure 1.3.3: Hierarchy of Evidence. (CC BY 4.0; Ann Diker)

Laboratory Studies

Laboratory studies include experiments conducted on animals or cells. An advantage of this type of study is that they typically do not cost as much as human studies and they require less time to conduct. These studies can also provide preliminary information to assist in designing human studies. 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 and are also helpful in determining the exact mechanism by which a specific nutrient causes a change in health. Laboratory studies may also be used when research cannot be done with humans.

The disadvantage of these types of studies are that researchers are not working with whole humans and thus the results may not be relevant or may not always apply directly to humans. In addition, studies involving animals may have ethical implications. Nevertheless, well-conducted animal and cell studies, that can be repeated by multiple researchers and obtain the same conclusion, are helpful in building the evidence to support a scientific hypothesis.

Observational Studies

Observational studies look at what a group of people are already doing (e.g., diet, exercise) and see how it relates to their health. Observational studies that describe factors related to human health are also called epidemiological studies. 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.[3] One of the first major findings of the Framingham Heart Study was that higher cholesterol levels in the blood are a risk factor for heart disease.

Some advantages of epidemiological studies are that they can lead to the discovery of disease patterns and risk factors for diseases. In addition, 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 which lifestyle choices *may* contribute to a disease. They can show a *correlation (relationship)* between two things happening but *not* whether one factor *caused* the other. Epidemiological studies may give us ideas, but those ideas need intervention studies to figure out what the patterns mean.

Intervention Studies

Intervention studies, sometimes called clinical trials, are scientific investigations in which some type of treatment or change is imposed on study participants by the researcher. When well done, this type of study can provide evidence of cause and effect so they are higher in the hierarchy of the evidence pyramid. An example of a clinical trial is a study in Spain that is investigating the effect of the Mediterranean diet (a diet that focuses on whole grains, fruits and vegetables, beans/legumes, nuts, and olive oil) on prevention of cardiovascular diseases. There are many studies that are part of the Prevention with Mediterranean Diet (PREDIMED) trials. In one study,[4] over 7,400 participants were randomly assigned to three different groups; one group followed a Mediterranean diet supplemented with extra-virgin olive oil, the second group followed a Mediterranean diet supplemented with mixed nuts, and the third group was given advice to reduce dietary fat. The two groups following the Mediterranean diet are considered intervention groups; the third group that was simply given advice to follow a reduced-fat diet is considered a control group. All three groups were followed for nearly 5 years to determine effects of the various diets on major cardiovascular events (heart attack, stroke, or death from cardiovascular causes). Results of the study showed that the groups following the Mediterranean diet (supplemented with either extra-virgin olive oil or nuts) had a lower incidence of major cardiovascular events than participants who were assigned to a reduced-fat diet.

The attributes of high-quality intervention studies are those that:

- include a sufficient number of participants;
- include a control group, which does not receive the intervention, to which you can compare the people who receive the intervention being tested;
- randomly assign participants into the control 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.
    - What are confounding variables? These are factors other than the one being tested that could influence the results of the study. 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 major cardiovascular events among the groups.
- neither the researchers nor the participants know who is receiving the treatment - when this occurs, the experiment is known as a double-blind experiment.
    - the blinding process can include a placebo treatment (imitation treatment that has no effect on participants)
    - The "placebo effect" should always be considered. Sometimes, just knowing that they're in a study will cause participants to experience changes that they would attribute to the treatment - regardless of whether they receive the treatment or the placebo.

Randomized clinical intervention studies are powerful tools to provide supporting evidence for a particular relationship and are considered the “gold standard” of scientific studies. The limitations of clinical trials are that they are difficult to carry on for long periods of time, 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.)

Meta-Analyses and Systematic Reviews

At the top of the hierarchy of evidence pyramid are systematic reviews and meta-analyses**.** You can think of these as “studies of studies”. They attempt to combine all of the relevant studies that have been conducted on a research question and summarize their overall conclusions. Researchers conducting a systematic review formulate a research question and then systematically and independently identify, select, evaluate, and synthesize all high-quality evidence that relates to the research question. Since systematic reviews combine the results of many studies, they help researchers produce more reliable findings. A meta-analysis is a type of systematic review that goes one step further, combining the data from multiple studies and using statistics to summarize it, as if creating a mega-study from many smaller studies.[5] The Cochrane Collaboration(opens in new window) is an international consortium of researchers who conduct systematic reviews in order to inform evidence-based healthcare, including nutrition, and their reviews are among the most well-regarded and rigorous in science.

Evolving Science

Science is an ongoing and often slow process, and uncertainty and evolving questions are inherently a part of that process. One study is not enough to make a guideline, recommendation, or cure a disease. Science is a stepwise process that builds on past evidence and finally culminates into a well-accepted conclusion. 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, from every level of the hierarchy of evidence pyramid, to accumulate before incorporating some change in our diet.

One final note: If there's a lot of debate on a scientific question, then that probably means that the science is still young and messy, and there's not enough evidence for experts to settle on a consensus. In this scenario, be skeptical of anyone who claims to know the absolute truth or makes promises that seem too good to be true. We often see such claims in the field of nutrition, where book authors, podcasters, celebrity influencers, and companies selling products for a profit say they know the secrets of good health. They're often operating in areas of scientific uncertainty, extrapolating from a few interesting findings, or outside of consensus entirely.

Attributions

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1.4: Who Are the Experts in Nutrition Science?

Learning Objectives

- Describe indicators of expertise.
- Identify credentials associated with credible nutrition experts.

When looking for credible nutrition information, one of the most important aspects to consider is the expertise of the individual providing the information.

What Does It Mean to Have Expertise in the Field of Nutrition?

Expertise in nutrition can be tricky to assess, because many people claim expertise yet lack formal training in the field. Formal training, obtained through advanced study at a college or university and assessed by meeting credentialing and/or degree requirements, is the best indicator of expertise in any field, because it shows an investment in gaining foundational knowledge from experienced educators and practitioners who specialize in the area. This level of expertise is very difficult to obtain without the rigor of a college or university training program. People may believe that they have gained expertise in nutrition through self-taught study, such as by reading books, studies, and articles; listening to podcasts; watching YouTube videos; and through observation of what foods make *them* feel good or ways of eating *they* enjoy. These sources of information can be valuable (though they can also sometimes contain misinformation), but it is difficult to truly develop self-taught expertise, because we are so easily led astray by our own biases and can be unaware of our blind spots about food and nutrition.

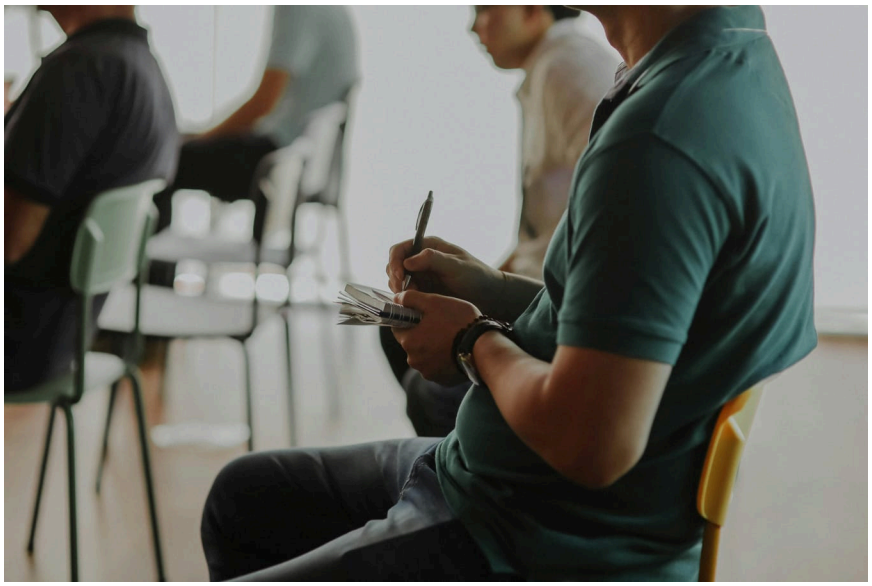


Figure 1.4.1: Note-taking in Class (photo by Douglas Lopez on Unsplash)

Let's consider for a moment why expertise is important. If you had an electrical problem in your home or a mechanical problem with your car, or if you had a broken bone or a heart attack, you probably wouldn't seek services or treatment from a celebrity, a social media influencer, or a tech executive. Instead, you would look to someone with specific training in the issue facing you, such as an electrician or mechanic who had completed a vocational program and a supervised apprenticeship, or an orthopedist or cardiologist with years of specialized training in their fields. If you tore a ligament in your knee, you wouldn't trust a cardiologist, much less a mechanic or a celebrity, to do orthopedic surgery on your joint. You also wouldn't bring your car to a cardiologist to diagnose why the check engine light was on, or why it was making that funny noise. Nutrition is no different; if we're looking for accurate information and advice, we should seek out experts with specific training and experience in the field.

This is not to dismiss other types of expertise that are related to food and nutrition. Traditional home cooks and formally-trained chefs have expertise in preparing tasty, comforting, or exciting food and in keeping food traditions alive. Farmers and home

gardeners can share their knowledge about sustainable practices for producing food. Climate scientists can share how our food choices affect the health of the planet. And each of us has our own personal expertise in our own bodies, such as which foods seem to not agree with us, and which make us feel satisfied or energized or connected with our cultures. Knowledge about food can span many areas, but when it comes to information about how eating patterns affect our health, we want to look for someone with training and experience grounded in the science and practice of nutrition.

How to Spot an Expert

If you're seeking a credible expert in nutrition, start by looking for professionals with the following degrees or backgrounds:

- Registered Dietitian (RD) / Registered Dietitian Nutritionist (RDN)
- Licensed dietitian/nutritionist (LD/LN)
- Professional with advanced degree(s) (master's/MS or doctoral/PhD) in nutrition

RDs/RDNs, LDs/LNs, or professionals with advanced degrees in the field of nutrition are the most credible sources for sound nutrition advice because their training was most likely grounded in science-based nutrition information and practice. For more information, watch this video about "Who Is A Dietitian?"

YouTube Video

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"Nutrition Diversity" by MSU Denver

What about your doctor? Physicians can be good sources of nutrition information, depending on their education and background. But be mindful that medical schools generally offer minimal or no nutrition education and training, so most physicians have limited knowledge in nutrition unless they have sought out specific nutrition training on their own.

Be skeptical of other official-sounding credentials, like "certified clinical nutritionist (CCN)", "certified nutritionist (CN)", "certified nutrition consultant (CNC)", "holistic nutrition practitioner," or even just "nutritionist." There are no national standards or regulations for what these titles mean. In many states, anyone can call themselves a "nutritionist," and you could be taking advice from a well-qualified individual with a graduate degree in nutrition or someone who just took a single course or got a mail-order certificate. It's worth taking a closer look at their training and credentials before assuming they have solid expertise in the field.

Keep in mind that every expert, regardless of their level of training and experience, is still human. No person can know everything or understand every perspective, and science is constantly evolving. Just as a single scientific study is never the last word on a scientific question, neither can a single expert have all of the answers. This is why good science reporters interview multiple experts and consider the scientific consensus (based on statements from professional organizations and publications like systematic reviews and meta-analyses) when they report on nutrition and health.

The video below delves further into how we can assess expertise.

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1.5: Fact-Checking Online Health and Nutrition Information

Learning Objective

- Describe the SIFT method of fact-checking an online information source.

In the digital age, we constantly encounter online information, and we have access to far more information than any one person could ever read or comprehend. Some sources are accurate and can be very useful, making us more informed people and citizens. Others are inaccurate and misleading, and engaging with them by reading, clicking, and sharing, can not only be a waste of valuable time but can also increase our chances of spending money on a useless product or even making risky decisions. How do we know which sources of information are worthy of our time and attention, worth sharing with others, or worth informing our own understanding of nutrition and health?

In the case of health information, we'll encounter plenty of conflicting information about the best diets for health, vaccines, medications, supplements, and wellness products. Social media feeds and search engine results unfortunately don't prioritize the information that is most accurate or relevant; instead, they often feed us information based on factors like number of clicks or likes, which means that more sensational, attention-grabbing information gets highlighted more often. This demands that we be very discerning about which information sources deserve our attention and which we should ignore. Because we may encounter hundreds of pieces of online information each day, we need to be able to do this efficiently, without taking too much time.

Despite the importance of online fact-checking skills, people often struggle to tell reliable web content from unreliable or false information. In fact, a Stanford experiment found that even Stanford students and professional historians weren't very good at it.[1] Watch the following video to learn more about this study.

YouTube Video

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VIDEO: "Online Verification Skills – Video 1: Introductory Video" by CTRL-F, YouTube (June 29, 2018), 3:13.

The SIFT Method

The SIFT method, developed by Mike Caulfield, is one approach for quickly fact-checking an online information source. The SIFT method includes 4 moves:

- Stop
- Investigate the source
- Find better coverage
- Trace claims to the original context



Figure 1.5.1: The SIFT Method. (CC BY 4.0; Mike Caulfield)

STOP.

The first move is the simplest. STOP reminds you of two things.

First, when you first hit a page or post and start to read it — STOP. Ask yourself whether you know the website, publication, or other source of information, and if so, if you believe it's a credible source. If the source is unfamiliar to you or you're not sure it's credible, use the other fact-checking moves that follow to get a better sense of what you're looking at. In other words, don't read, share, or use the source in your research until you know more about it, and you can verify that it is reliable.

Second, after you begin to use the other moves it can be easy to go down a rabbit hole, going off on tangents only distantly related to the question you were originally trying to answer. If you feel yourself getting overwhelmed in your fact-checking efforts, STOP and take a second to remember your purpose. If you just want to read an interesting story, repost something you think your friends will enjoy, or get a high-level explanation of a concept, it's probably good enough to find out whether the publication is reputable. If you're doing deeper research on a topic, such as for a paper you're writing for a class or to make a health-related decision for yourself or a family member, you'll want to dig deeper and cross-check multiple reputable sources.

Keep in mind that both sorts of investigations are equally useful. Quick and shallow investigations will form most of what we do on the web. We get quicker with the simple stuff in part so we can spend more time on the stuff that matters to us. But in either case, stopping periodically and reevaluating our reaction or search strategy is key.

INVESTIGATE the source.

The idea here is that you want to know *what* you're reading *before* you read it.

You don't have to do a three-hour investigation into a source before you engage with it. But if you're reading an article on why fluoride is added to municipal water supplies, and the author is a dental health researcher at a well-known university, you might engage with this source differently than you would with one authored by an anti-fluoridation activist. Likewise, if you're watching a video on the benefits of milk consumption, you would want to be aware if the video was produced by the dairy industry. This doesn't mean the dental health scientist will always be right, because as we've learned, science is an ongoing process in which uncertainty is normal, especially in emerging areas. And it doesn't mean that the dairy industry can never be trusted. But knowing the expertise and agenda of the person or organization behind the source will help you decide whether it deserves your attention at all, and if you engage with it, how you interpret the information it provides.

When investigating an online source, effective fact-checkers use a technique called lateral reading. This means that they open a new tab (or many tabs!) in their internet browser to research the source and see what others have said about it. This is usually much more effective than reading "vertically" or staying on the page to see what the source says about itself; if that source is biased or inaccurate, then you're likely just wasting your time.

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VIDEO: “Lateral Reading” by University of Louisville Research Assistance & Instruction, YouTube (June 26, 2020), 3:33.

Watch the following short video for strategies for investigating the source. Pay particular attention to how navigating off the original site in question can be used to quickly get useful information about publications, organizations, and authors.

YouTube Video

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VIDEO: “Online Verification Skills – Video 2: Investigate the Source” by CTRL-F, YouTube (June 29, 2018), 2:44.

FIND trusted coverage.

What if you realize that you’re looking at a low-quality or biased source of information, or you’re not sure whether it is reliable, but you still want to know if the claim it’s making is true or false? For example, you’re looking at an article that claims that a nutritional supplement will help you run faster, but the same website is also selling the supplement. It’s clearly a biased source of information, and you don’t trust it, but you’re still curious about the supplement.

Your best strategy in this case is to use your lateral reading skills to find a better source altogether, one that includes trusted reporting or analysis on the same claim. Rather than relying on the source that you initially found, you can trade up for a higher quality source. Specifically, you want to see if there is a scientific consensus on the benefits and risks of the supplement, or if there is too little evidence to support a consensus—or if there is controversy or disagreement around it.

The point is that you don’t have to stick with that initial source. We have the internet! You can go out and find a better source, and invest your time there. It helps to build a list of go-to trusted sites that you can check for health and nutrition information (we’ll cover how to search for better sources on the next page).

Watch the following video for a demonstration of this strategy, and note how fact-checkers build a library of trusted sources to provide better coverage.

YouTube Video

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VIDEO: “Online Verification Skills – Video 4: Look for Trusted Work” by CTRL-F, YouTube (May 25, 2018), 4:10.

TRACE claims, quotes, and media to the original context.

Much of what we find on the internet has been stripped of context, and leaving out the context can dramatically change how a claim, quote, or other media is interpreted.

Maybe you come across a claim about a new medical treatment based on a research finding—but you’re not certain if the cited research paper actually supports the claim. Or a celebrity may post a photo highlighting their glowing skin and shiny hairy and claim that these are the results of a scientifically-proven antioxidant-rich diet that they’ve adopted. This claim lacks the full context, like whether they also have a professional hairdresser and makeup artist, or whether the photo was digitally retouched, not to mention information about studies providing evidence on the diet. The missing context in these stories may be intentional—an effort to influence or mislead us—or they may get things wrong by mistake. Either way, searching for context can help us determine if the version of the claim we saw was accurately presented.

YouTube Video

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VIDEO: “Online Verification Skills – Video 3: Find the Original Sources” by CTRL-F, YouTube (May 25, 2018), 1:33.

Red Flags of Misinformation

If it sounds too good to be true, it probably is. That adage holds true for health and nutrition advice. There are several tell-tale signs of junk science—untested or unproven claims or ideas usually meant to push an agenda or promote special interests.[2] As you use the steps of the SIFT method, you can also keep an eye out for red flags of junk science. When you see one or more of these red flags, it’s safe to say you should at least take the information with a grain of salt, if not avoid it altogether.



Figure 1.5.2: 10 Red Flags of Junk Science. (International Food Information Council)

With so many health claims circulating on social media and other platforms, it's easy to feel overwhelmed and unsure of what to believe. But by practicing the SIFT method and watching for red flags of junk science, you'll learn to quickly and confidently sort credible information from the noise.

Self-Check Questions

Query 1.5.1

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1.6: Finding Accurate Sources of Health and Nutrition Information

Learning Objectives

- Describe evaluation criteria for websites.
- Describe criteria to evaluate nutrition news.
- Identify sources of reliable and accurate nutrition information.

In this chapter, we've already discussed how to assess expertise in the field of nutrition and how to fact-check health claims encountered in the news or on social media. Let's expand on that foundation to include strategies for finding accurate sources of health and nutrition information. These approaches become more important if you're seeking answers to a specific question, writing a paper for a class, or building your knowledge base for personal or professional reasons. In these scenarios, you need to do more than fact-check single claims or bits of nutrition information that come across your social media feeds. Instead, you'll need to sift through and assess many different resources, and you'll find that it's helpful to build a list of trusted sites and organizations that you can head to when you want to look something up.

Imagine that you're curious about the safety and efficacy of a nutritional supplement. You do a quick internet search, which yields pages and pages of search results. Among them are links to news articles, peer-reviewed studies, hospital and university websites, government agencies, blogs, sites selling supplements, YouTube videos, online discussion threads, and more. You can't read them all, nor would you want to. Where do you even begin?



Figure 1.6.1: Laptop showing vegetable dish. (photo by Igor Miske on Unsplash)

Searching for Online Health and Nutrition Information

If you're researching the safety and efficacy of a nutritional supplement, you probably don't want to start by reading 100 peer-reviewed studies or a bunch of different opinions from individuals. That approach is overwhelming and time consuming, and it leaves you vulnerable to misinformation. Instead, you'll want to start with trusted websites that summarize the scientific consensus, such as these from the following sources:

- Government agencies - websites ending in .gov, like PubMed and MedlinePlus.
- Colleges and universities - websites ending in .edu, such as the Harvard School of Public Health.
- Well-known healthcare and hospital systems - these websites usually end in .org, such as Mayo Clinic or Cleveland Clinic.

- Reputable professional organizations - these websites usually end in .org, such as the Academy of Nutrition and Dietetics, the American Heart Association, or the American Cancer Society.

We mention website domains because .gov and .edu sites are generally accurate sources of information. However, .org and .com domains are a mixed bag. Sites ending in .org generally represent organizations, including some of the trusted organizations listed above. But organizations can also be biased, and their sites may be more focused on pushing a certain agenda than representing the scientific consensus. In fact, any entity can buy a .org domain. Likewise, .com websites can be valuable sources of information, or they may be more interested in selling you something. When you encounter a .org or .com site, you'll want to do more digging to understand the site's intent. If an organization is unfamiliar to you, practice lateral reading (e.g., a Wikipedia check) to learn more. Keep in mind that organizations can represent many different interests, and biased organizations can have names that are deceptively official-sounding.

Beyond investigating the organization, corporation, or individual behind a website or article, here are some other aspects to evaluate:

- **Timeliness** — How old is the article? Because science is always evolving, articles published in about the last 5 years are preferred, as they'll have more current information. However, this isn't a hard and fast rule. Sometimes older articles provide important context, and sometimes an article that is even one year old is already out-of-date.
- **Relevance** — Is this information relevant to your topic? Or is it a distraction?
- **Credibility** — Does the information appear to be free of conflict of interest and bias? Does it cite or link to relevant peer-reviewed studies? Does it represent the findings accurately and fairly?
- **Expertise** — Whose expertise and views are represented? Based on what you learned earlier in this unit, do they have the appropriate expertise to provide accurate information on this topic?
- **Purpose** — What do you think is the purpose of this article or website? Is it intended to be educational? Is it an opinion piece, meant to convince you of one side or the other of an issue? Is it trying to get you to buy something or donate to a cause, or to attract more clicks? Is the language and layout inflammatory or extreme? Thinking about the author's purpose in creating the information or website can help you figure out if it is credible and useful to you.

Evaluating Health and Nutrition News

Health and nutrition content in both online and print media often comes in the form of news stories. Publications like to highlight what's new, and many consider it part of their mission to report information about new scientific studies. Evaluating health and nutrition news gives you a chance to apply what you've learned about types of studies and quality study design. Here are some things to look for and keep in mind:

- **The news source should be reputable.** Larger, national news sources like the New York Times, Washington Post, and National Public Radio have dedicated health and science reporters who know how to evaluate studies and will seek out multiple experts to provide additional insights. They also have editors and fact checkers to double check their work.
- **The new study should be published in a peer-reviewed journal.** Peer-reviewed articles are assessed and critiqued by the scientists and experts in the same field as the subject of the article; peer-reviewed nutrition articles are reviewed by nutrition scientists and experts. Question studies that come from less trustworthy sources (such as non peer-reviewed journals or websites).
- **The news article should provide context of previous research and comments from outside experts.** Remember that one study on its own doesn't usually tell us much, at least when it comes to making decisions about our own health. A good news article will tell us what was previously known about the topic and how the new study adds to our understanding. It will also include comments from experts who were not involved in the new study and who can discuss its limitations and relevance.



Figure 1.6.2: Man reading on phone. (photo by Timi David on Unsplash)

- **The study methodology should be sound and provide outcomes that are relevant.**
  - Consider the type of study and where it sits in the hierarchy of evidence. A study in humans is likely more meaningful than a study in cells or in animals; an intervention study is usually more meaningful than an observational study; and systematic reviews and meta-analyses often give you the best synthesis of the science to date.
  - Check the details of the study design. How many participants were included? How long did the study last? If it's an intervention study, check for some of the attributes of high-quality research, such as randomization, placebo control, and blinding.
  - Consider the real-world relevance and confounding factors. If an animal study reports that an artificial sweetener causes cancer, check to see how much of the sweetener was tested. If it was an amount 1,000 times normal consumption in humans, that raises questions of relevance. Likewise, if an observational study of blueberries and dementia risk reports that people who ate two servings of blueberries per day had an 8.5% risk of developing dementia compared to a 9% risk in those who didn't eat blueberries, this is a small difference in risk with questionable real-world relevance and might be explained by confounding factors (e.g., people who eat more blueberries live in neighborhoods with less air pollution, get more exercise, etc).

Following health and science news will make you a more informed consumer and citizen, and it's great practice applying the tools of information literacy that you're learning in this course.

Building a Bank of Trustworthy Nutrition Sources

If you find yourself regularly searching for and evaluating online health and nutrition information, it can be helpful to build a list of go-to sources that you know you can trust. A starter list is provided below, but you can add your own that are relevant to your areas of interest and that you can return to again and again when searching for information or fact-checking claims online.

US Government Websites:

- Centers for Disease Control and Prevention – https://www.cdc.gov
- Food and Drug Administration – http://www.fda.gov/
- Foodsafety.gov – https://www.foodsafety.gov/
- MedlinePlus – https://medlineplus.gov/
- National Institutes of Health Office of Dietary Supplements – https://ods.od.nih.gov/
- Nutrition.gov – https://www.nutrition.gov/
- Nutrition Evidence Systematic Review – https://nesr.usda.gov/
- Pubmed – https://pubmed.ncbi.nlm.nih.gov/

International Websites:

- Food and Agricultural Organization of the United Nations – https://www.fao.org/home/en
- World Health Organization – https://www.who.int/

Education and Organization Websites:

- American Cancer Society – https://www.cancer.org/
- American Diabetes Association – http://www.diabetes.org/
- American Heart Association – https://www.heart.org/
- American Society for Nutrition – http://www.nutrition.org/
- Center for Science in the Public Interest – https://cspinet.org/
- Eat Right (Academy of Nutrition and Dietetics) – https://www.eatright.org/
- Food Allergy Research & Education – https://www.foodallergy.org/
- GI Patient Center (American Gastroenterological Association) – https://patient.gastro.org/
- The Nutrition Source (Harvard School of Public Health) – https://nutritionsource.hsph.harvard.edu/
- Linus Pauling Institute – http://lpi.oregonstate.edu/
- Mayo Clinic – https://www.mayoclinic.org/
- National Eating Disorder Association – https://www.nationaleatingdisorders.org/
- Sugar Science – http://sugarscience.ucsf.edu/

News and Media Websites:

- BBC News Health – https://www.bbc.com/news/health
- CNN Health – https://www.cnn.com/health
- National Public Radio – Shots Health News – https://www.npr.org/sections/health-shots
- The New York Times Health and Wellness – https://www.nytimes.com/section/health; https://www.nytimes.com/section/well
- Time Health – https://time.com/section/health/
- The Washington Post – https://www.washingtonpost.com; https://www.washingtonpost.com/wellbeing/
- Scientific American – https://www.scientificamerican.com/
- STAT News – https://www.statnews.com/

Self-Check Questions

Query 1.6.1

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2: ACHIEVING A HEALTHY DIET

2.1: What is a Healthy Diet?
2.2: Understanding the Dietary Guidelines
2.3: Tools to Help Design a Healthy Diet
2.4: Understanding Dietary Reference Intakes (DRIs)
2.5: Understanding Food Labels
2.6: Understanding Portion Sizes

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2.1: What is a Healthy Diet?

Learning Objective

- Define the components of a healthful diet.

Achieving a Healthy Diet

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

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

A healthy diet is one that favors whole foods. As an alternative to modern processed foods, a healthy diet focuses on "real" fresh whole foods that have been sustaining people throughout the millenniums. Whole foods supply the needed vitamins, minerals, protein, carbohydrates, fats, and fiber that are essential to good health. Commercially prepared and fast foods are often lacking nutrients and often contain inordinate amounts of sugar, salt, and saturated fat, all of which are associated with the development of diseases such as heart disease, stroke, cancer, obesity, high cholesterol, diabetes, and other illnesses. A balanced diet is a mix of food from the different food groups (vegetables, fruits, grains, protein foods, and dairy). One example of processed vs. whole foods is pictured below: an egg sandwich with a medium latte vs. two hard-boiled eggs, a tortilla, 3/4 cup plain low-fat Greek yogurt, 2 clementine oranges, and tea. While both meals provide ~500 calories, the meal with the hard-boiled eggs, yogurt, and clementines has less sodium, fat, and saturated fat while also providing more protein, vitamin C, and calcium.



Figure 2.1.1: Comparison of two 500 calorie meals. (CC BY 4.0; Ann Diker)

Adequate

An adequate diet is one that provides enough nutrients, fiber, and calories to maintain your health. A diet adequate in many nutrients can still be inadequate in one (or a few) nutrient(s). For example, someone may eat enough calories to maintain

their weight but not get enough vitamins or minerals to maintain health. This scenario could happen if someone ate fast food frequently, but didn't eat many fruits or vegetables. Many people don't eat enough vegetables. Since vegetables are good sources of fiber, a diet low in vegetables may be inadequate in fiber.

Balanced

Balance the foods in your diet. Achieving balance in your diet entails not consuming one nutrient at the expense of another. A balanced diet contains the *right combinations* of foods to provide the proper proportions of nutrients. For example, calcium is essential for healthy teeth and bones, but too much calcium will interfere with iron absorption. Most foods that are good sources of iron are poor sources of calcium, so in order to get the necessary amounts of calcium and iron from your diet, a proper balance between food choices is critical. Another example is that while sodium is a vital nutrient, an overabundance of it can contribute to congestive heart failure and chronic kidney disease. Remember, everything must be consumed in the proper amounts. Different food groups are good sources of different nutrients. Meats and beans are good sources of protein, milk is a good source of calcium, whole grain breads are a good source of fiber, fruits and vegetables are good sources of many vitamins and minerals like vitamin C and potassium. By including all food groups in a diet it's easier to get the proper balance of nutrients.

Nutrient-Dense

Nutrient-dense foods are defined as foods that contain many essential nutrients per calorie. In other words, a nutrient-dense diet provides the *highest level of nutrients and fiber for the lowest number of calories*. Nutrient-dense foods are the opposite of "empty-calorie" foods, such as sugary carbonated beverages, which are also called "nutrient-poor". Nutrient-dense foods include fruits and vegetables, lean meats, poultry, fish, beans, low-fat dairy products, and whole grains. Choosing more nutrient-dense foods leads to a diet that provides more of the necessary nutrients. Consider two different snacks: 1 ounce of potato chips (~15 chips) vs. 2 medium carrots and 3 tablespoons of hummus. Both snacks are ~160 calories. The carrots and hummus are higher in protein, fiber, potassium, and Vitamin A than the chips. The carrots/hummus snack is the more nutrient-dense option because you get more nutrients for about the same number of calories.

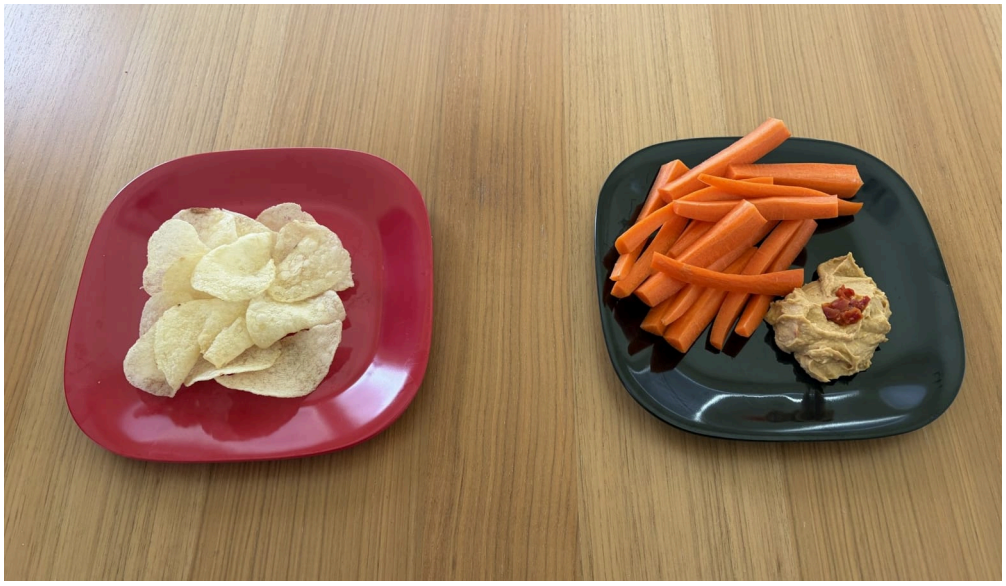


Figure 2.1.2: Nutrient density of two different snacks. (CC BY 4.0; Ann Diker)

Some additional examples of alternatives to move to a more nutrient-dense diet are included in Table 2.1.1 below; the difference in calories of even more examples can be seen in Figure 2.1.1.

Table 2.1.1: Nutrient-Dense Food Alternatives

Instead of...	Replace with...
Sweetened fruit yogurt	Plain fat-free yogurt with fresh fruit
Cheese	Low-fat or reduced-fat cheese

Instead of...	Replace with...
Bacon or sausage	Canadian bacon, turkey bacon, lean ham, turkey sausage
Fried chicken	Baked chicken
White bread, white rice	Whole-grain bread, brown rice
White flour tortillas	Whole wheat tortillas, corn tortillas
Sweetened cereals	Minimally sweetened cereals with fresh fruit
Apple or berry pie	Fresh apple or berries
Deep-fried French fries	Oven-baked French fries or sweet potato baked fries
Deep-fried egg rolls	Spring rolls
Fried samosas	Naan and vegetable chutney
Fried vegetables	Steamed or roasted vegetables
Sugary sweetened soft drinks	Seltzer mixed with 100 percent fruit juice

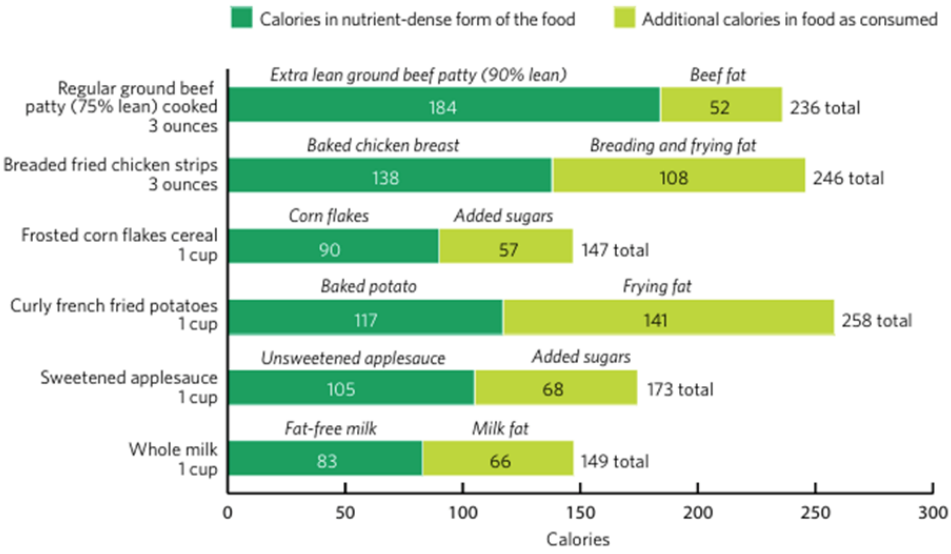


Figure 2.1.3: Examples of the calories found in nutrient-dense food choices compared with calories found in less nutrient-dense forms of these foods. (Public Domain; Dietary Guidelines for Americans 2010, Figure 5.2)

Moderation

Eat in moderation. Moderation is crucial for optimal health and survival. A moderate diet contains the *right amounts* (not too much and not too little) of foods for maintaining proper weight and optimizing the body's metabolic processes. Eating burgers, French fries, cake, and ice cream each night for dinner will lead to health complications. But as part of an otherwise healthful diet and consumed only on a weekly basis, this should not have too much of an impact on overall health. If this is done once per month, it will have even less of an impact upon overall health. It's important to remember that eating is, in part, about enjoyment and indulging with a spirit of moderation. This fits within a healthy diet.

Variety

Variety involves eating different foods from all the food groups (grains, vegetables, fruits, dairy, and protein) on a regular basis. Eating a varied diet helps to ensure that you receive all the nutrients necessary for a healthy diet. Some people tend to pack the same type of snack with them each day (e.g., protein bar) perhaps because the snack is easy to pack. Including other types of snack options that are also easy to pack (e.g., baby carrots, banana) on some days will help ensure that there is variety.One of the major drawbacks of a monotonous diet is the risk of consuming too much of some nutrients and not enough of others. Trying new

foods can also be a source of pleasure—you never know what foods you might like until you try them.

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

References

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2.2: Understanding the Dietary Guidelines

Learning Objective

- Identify recommendations from the *Dietary Guidelines for Americans*.

The first US dietary recommendations were set by the National Academy of Sciences in 1941. The recommended dietary allowances (RDA) were first established out of concern that America's overseas World War II troops were not consuming enough daily nutrients to maintain good health. The first Food and Nutrition Board was created in 1941, and in the same year set recommendations for the adequate intakes of caloric energy and eight essential nutrients. These were disseminated to officials responsible for food relief for armed forces and civilians supporting the war effort.

Since 1980, the dietary guidelines have been reevaluated and updated every five years by the advisory committees of the US Department of Agriculture (USDA) and the US Department of Health and Human Services (HHS). Instituting nationwide standard policies provides consistency across organizations and allows healthcare workers, nutrition educators, schools, and local governments to improve nutrition and subsequently the health of their respective populations. The guidelines are continually revised to keep up with new scientific evidence-based conclusions on the importance of nutritional adequacy and physical activity to overall health. While dietary recommendations set prior to 1980 focused only on preventing nutrient inadequacy, the current dietary guidelines have the additional goals of promoting health, reducing chronic disease, and decreasing the prevalence of overweight and obesity.

The *2025-2030 Dietary Guidelines for Americans*

The goal of the *2025-2030 Dietary Guidelines for Americans* is to provide "clear, actionable, transparent, evidence-based guidance empowering Americans to select foods that support health and reduce chronic disease".[1] The *2025-2030 Dietary Guidelines for Americans* include the following recommendations:[1-3]

1. Eat the Right Amount for You
    - pay attention to portion sizes, particularly for foods and beverages higher in calories
    - choose water or unsweetened beverages to accompany meals and snacks
2. Prioritize Protein Foods at Every Meal
    - consume a variety of protein foods from animal sources and plant sources
    - choose baked, broiled, roasted, stir-fried, or grilled cooking methods (instead of deep-fried)
3. Consume Dairy
    - choose whole, reduced-fat, low-fat, or nonfat dairy products with no added sugars
4. Eat Vegetables and Fruits Throughout the Day
    - include a variety of vegetables and fruits
    - fresh, frozen, canned, cooked, and dried vegetables and fruits are all good options
5. Incorporate Healthy Fats
    - saturated fat consumption should not exceed 10% of total daily calories
6. Focus on Whole Grains
    - prioritize fiber-rich whole grains
    - reduce the consumption of highly processed, refined carbohydrates
7. Limit Highly Processed Foods, Added Sugars, and Refined Carbohydrates
    - avoid highly processed packaged, prepared, ready-to-eat foods that have added sugars and sodium
    - avoid sugar-sweetened beverages
8. Limit Alcoholic Beverages
    - consume less alcohol for better overall health

In addition to the *Dietary Guidelines*, all Americans, regardless of age, should strive to meet the *Physical Activity Guidelines for Americans* which discuss the proven benefits of physical activity and outline the amounts and types of physical activity recommended for different ages and populations. Additional information about the *Physical Activity Guidelines for Americans* will be covered in Chapter 13.

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1. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *The Scientific Foundation for the Dietary Guidelines for Americans, 2025-2030*. January 2026. Available at realfood.gov.
2. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans, 2025-2030*. January 2026. Available at realfood.gov.
3. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Daily Servings By Calorie Level, 2025-2030*. January 2026. Available at realfood.gov.

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2.3: Tools to Help Design a Healthy Diet

Learning Objective

- Describe various food patterns that can be used to design a healthy diet.

The *Dietary Guidelines for Americans* is one tool that can be used to develop a heathy eating pattern. Let's take a look at this and other tools that can be used to design a healthy diet.

The New Pyramid

The New Pyramid is a pictorial representation of the *Dietary Guidelines*. This inverted pyramid promotes the inclusion of protein, dairy, healthy fats, vegetables, fruits, and whole grains in a healthy diet. Foods are assumed to be nutrient-dense, with no or limited added sugars, refined carbohydrates, or chemical additives. For more information on designing your diet visit realfood.gov.



Figure 2.3.1: The New Pyramid graphic (U.S. Department of Agriculture, Public Domain, CC0)

Harvard Healthy Eating Plate

Harvard's Healthy Eating Plate encourages eating whole grains and limiting refined grains; provides specific guidance related to healthy protein options; recommends healthy fat options; and encourages water as a beverage while limiting milk/dairy, juice, and sugary drinks.[1] For more information about The Healthy Eating Plate, please see The Nutrition Source and Harvard Health Publications.

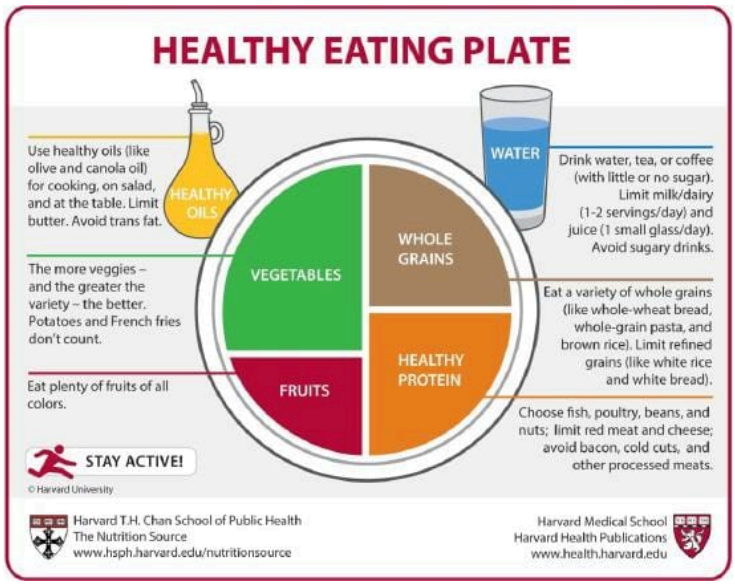


Figure 2.3.2: Harvard Healthy Eating Plate graphic ("Healthy Eating Plate" by Harvard University, Copyright © 2011, Harvard University.)

Dietary Approaches to Stop Hypertension (DASH) Eating Plan

The DASH Eating Plan has been shown through research to be the most effective eating plan for lowering blood pressure. This plan recommends:

- Eating vegetables, fruits, and whole grains
- Including fat-free or low-fat dairy products, fish, poultry, beans, nuts, and vegetable oils
- Limiting foods that are high in saturated fat, such as fatty meats, full-fat dairy products, and tropical oils such as coconut, palm kernel, and palm oils
- Limiting sugar-sweetened beverages and sweets[2]

Table 2.3.1: Daily and weekly DASH Eating Plan goals for a 2,000 calorie diet

Food Group	Daily Servings	Weekly Servings
Grains	6-8	
Meats, poultry, fish	6 or less	
Vegetables	4-5	
Fruit	4-5	
Low-fat or fat-free dairy products	2-3	
Fats and oils	2-3	
Sodium	2,300 mg (1,500 mg lowers blood pressure even further)	
Nuts, seeds, dry beans, and peas		4-5
Sweets		5 or less

Mediterranean Diet

The Mediterranean diet emphasizes plant-based foods and healthy fats to reduce risk of heart disease, metabolic syndrome, diabetes, certain cancers, depression, and in older adults, a decreased risk of frailty, along with better mental and physical function.[3] While not all cultures eat the same way, there are some guiding principles from the Mediterranean diet that could be included across cultures. The Mediterranean diet includes:

- Regular physical activity
- Water as a main beverage
- Plant-based eating that focuses on vegetables, fruits, whole grains, nuts, legumes/beans, and olive oil
- Cheese and yogurt consumed daily in low to moderate amounts
- Fish and poultry consumed in low to moderate amounts a few times a week
- Red meat consumed infrequently and in small amounts
- Limiting sweets[3]

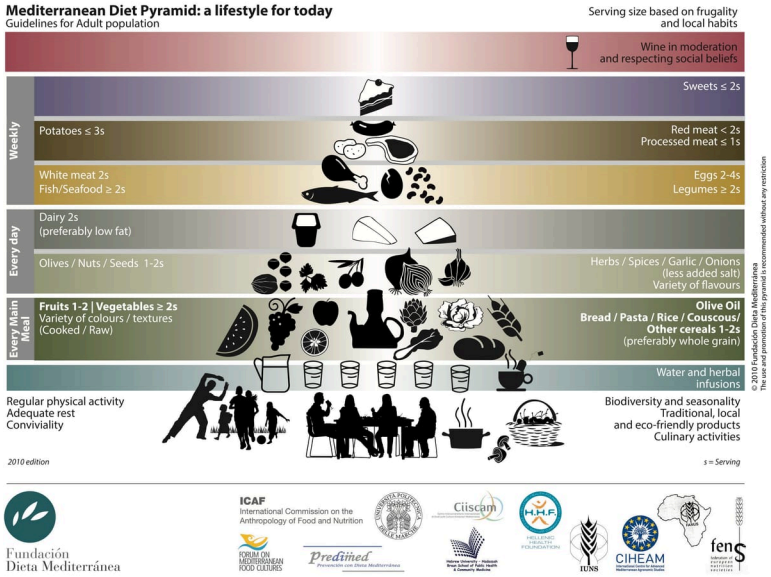


Figure 2.3.3: Mediterranean diet food pyramid. (Fundación Dieta Mediterránea, CC0 via Wikimedia Commons)

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3. A practical guide to the Mediterranean diet. Harvard Health Blog. health.harvard.edu. Accessed January 27, 2026.

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2.4: Understanding Dietary Reference Intakes (DRIs)

Learning Objective

- Use the Dietary Reference Intakes to determine daily nutrient recommendations.

Dietary Reference Intakes (DRIs) are the recommendation levels for specific nutrients and consist of a number of different types of recommendations. This 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 are the Dietary Reference Intakes (DRIs). The DRIs include 5 categories of values for micronutrients:

- **Estimated Average Requirement (EAR)**: expected to satisfy the needs of 50% of the people in that age group based on a review of the scientific literature.
- **Recommended Dietary Allowance (RDA)**: average daily level of intake sufficient to meet the nutrient requirements of nearly all (97%-98%) healthy people.
- **Adequate Intake (AI)**: established when evidence is insufficient to develop an RDA and is set at a level assumed to ensure nutritional adequacy.
- **Tolerable Upper Intake Level (UL)**: maximum daily intake unlikely to cause adverse health effects.
- **Chronic Disease Risk Reduction Intake (CDRR)**: level above which intake reduction is expected to reduce chronic disease risk within an apparently healthy population.

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. DRIs do not apply to people with diseases or those suffering from nutrient deficiencies. The Food and Nutrition Board of the Institute of Medicine, National Academy of Sciences issues updated reports on DRIs when scientific evidence warrants an update. For example, the DRIs for sodium and potassium were updated in 2019.[1]

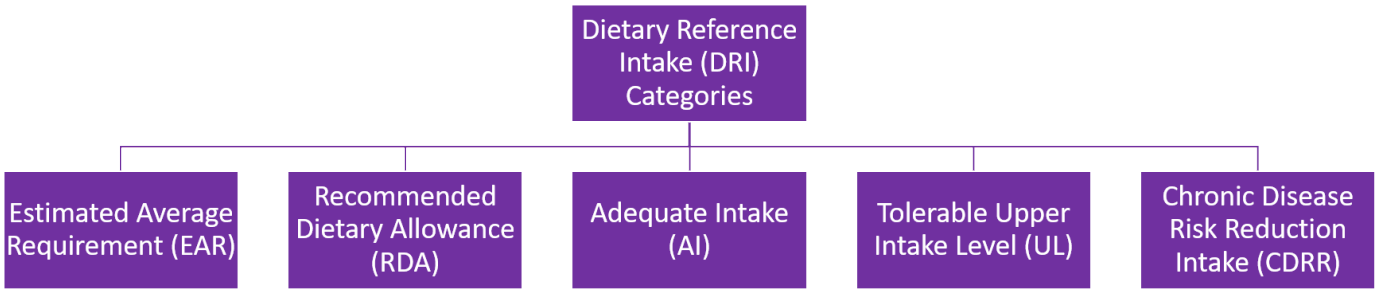


Figure 2.4.1: The DRIs include five reference values for micronutrients, the Estimated Average Requirement (EAR), Recommended Dietary Allowance (RDA), Adequate Intake (AI), Tolerable Upper Intake Level (UL), and Chronic Disease Risk Reduction Intake (CDRR). ("Dietary Reference Intake (DRI) Categories" by Ann Diker is licensed under CC BY 4.0)

DRIs are important not only to help the average person determine whether their intake of a particular nutrient is adequate, they are also used by healthcare professionals and policy makers to determine nutritional recommendations for special groups of

people who may need help reaching nutritional goals. This includes people who are participating in programs such as the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC). The DRIs are not appropriate for people who are ill or malnourished, even if they were healthy previously.

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 Requirement (EAR).** The EAR for a nutrient is determined by a committee of nutrition experts who review the scientific literature to determine a value that meets the requirements of 50% of people within a given life stage and for a particular sex (e.g., 4-8 year old children, pregnant women, males 19-30 years old, etc.). 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 are then used to determine the Recommended Dietary Allowance (RDA) values for each nutrient.
2. **Recommended Dietary Allowance (RDA).** Once the EAR for 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 (97-98%) of the target healthy population (see Figure below). Examples of nutrients having an RDA include Vitamin E, folate, iron, and zinc. It is important to note that RDAs are not the same thing as individual nutritional requirements. The actual nutrient needs of a given individual may be different than the RDA. However, since we know that 97 to 98 percent of the population's needs are met by the RDA, we can assume that if a person is consuming the RDA of a given nutrient, they are most likely meeting their nutritional need for that nutrient. The important thing to remember is that the RDA is meant as a *recommendation* and meeting the RDA means it is very likely that you are meeting your actual *requirement* for that nutrient.
    - There is a distinct difference between a *requirement* and a *recommendation*. For instance, the *recommendation* for vitamin D is a 15 micrograms (or 600 International Units) each day. However, in order to find out your true personal *requirement* for vitamin D, a blood test is necessary. The blood test will provide an accurate reading from which a medical professional can determine your required daily vitamin D amounts. This may be considerably more or less than the RDA, depending on what your level actually is.

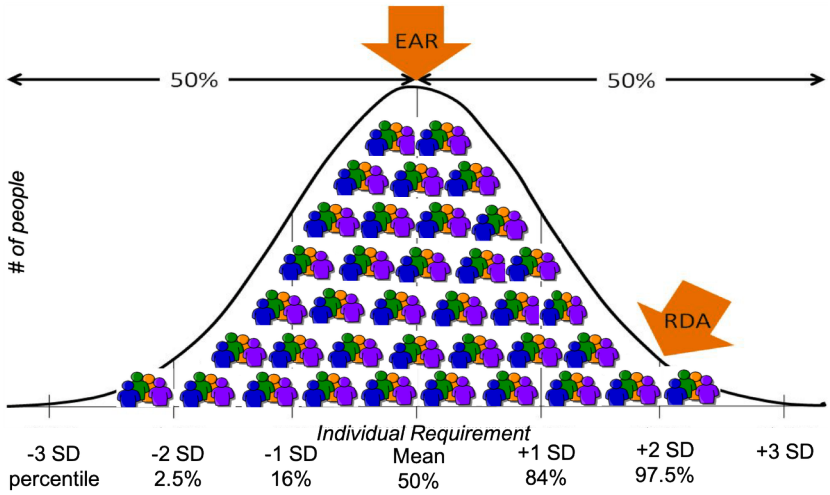


Figure 2.4.2: EAR and RDA relative to individual requirements for a given nutrient. (CC BY 4.0; Alice Callahan via Nutrition Science and Everyday Application (Callahan, Leonard, and Powell))

3. **Adequate Intake (AI).** AIs are created for nutrients when there is insufficient consistent scientific evidence to set an EAR for the entire population. Examples of nutrients having an AI include Vitamin K, potassium, and fluoride. As with RDAs, AIs can be used as nutrient-intake goals for a given nutrient. For example, there has not been sufficient scientific research into the particular nutritional requirements for infants. Consequently, all of the DRI values for infants are AIs derived from nutrient values in human breast milk.

4. **Tolerable Upper Intake Level (UL).** The UL was established to help distinguish healthful and harmful nutrient intakes. Developed in part as a response to the growing usage of dietary supplements, ULs indicate the highest level of continuous intake of a particular nutrient that may be taken without causing health problems for most people in a particular group. Consumption of a nutrient at levels above the UL is not considered safe. 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.
5. **Chronic Disease Risk Reduction Intake (CDRR).** The CDRR is the level above which intake reduction is expected to reduce chronic disease risk within an apparently healthy population. The CDRR is established through a process that evaluates the strength of scientific evidence related to a specific nutrient and chronic disease risk. A CDRR is typically set when there is at least moderate strength of evidence for both a causal and an intake-response relationship between nutrient intake and chronic disease risk.[2] For example, the CDRR for sodium is 2,300 mg, so someone consuming more than 2,300 mg of sodium could expect to reduce their risk of high blood pressure if they reduce their sodium intake.

The graph below summarizes several of the DRI values in relation to each other:

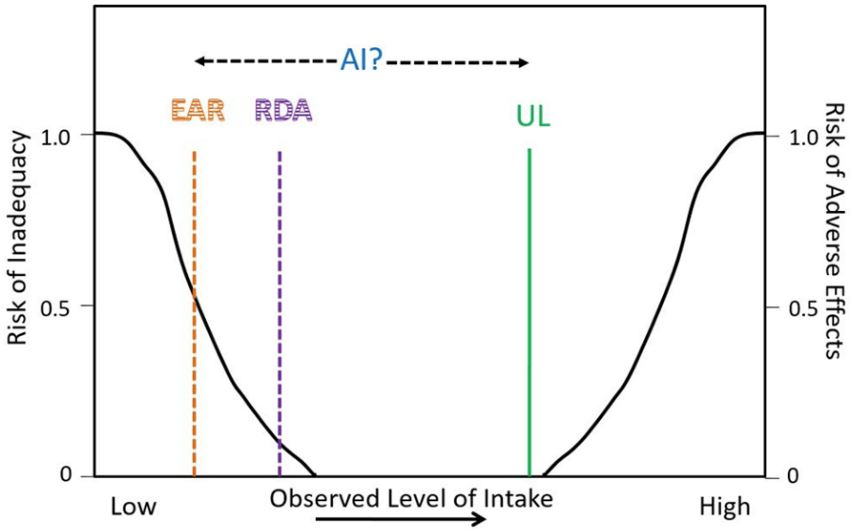


Figure 2.4.3: DRI values in relation to each other. This graph illustrates the risks of nutrient inadequacy and nutrient excess as we move from a low intake of a nutrient to a high intake. Starting on the left side of the graph, you can see that when you have a very low intake of a nutrient, your risk of nutrient deficiency (inadequacy) 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 needs is the EAR, and the point at which 97-98% 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. (CC BY-NC-SA 4.0; Brian Lindshield via Fig 8.44, Kansas State University Human Nutrition Flexbook)

Estimated Energy Requirement (EER)

The Estimated Energy Requirement (EER) is the average dietary energy (calorie) intake to maintain energy balance in a healthy individual. The EER is based on age, sex, weight, height, and level of physical activity.

Acceptable Macronutrient Distribution Ranges (AMDRs)

The Acceptable Macronutrient Distribution Ranges (AMDRs) are another component of the Dietary Reference Intakes (DRIs). The AMDRs are used specifically for macronutrients (carbohydrates, fats, and protein). The AMDR is the calculated range of how much energy from carbohydrates, fats, and protein is recommended for a healthy diet. The AMDR is expressed as a percent of total energy (% total calories). The AMDR is the range associated with reduced risk for chronic diseases, while providing essential nutrients like vitamins and minerals. People who do not reach the AMDRs for their target group increase their risk of developing health complications.

Table 2.4.1: AMDR Values for Adults

Nutrient	Value (% of total calories)[3]
Carbohydrate	45–65
Fat	20–35
Protein	10–35
Polyunsaturated fatty acids	5–10
Linolenic acid	0.6–1.2

References

1. Nutrient Recommendations: Dietary Reference Intakes (DRI). ods.od.nih.gov. Accessed May 9, 2025.
2. Expansion of the Dietary Reference Intake Model. The National Academies of Sciences, Engineering, Medicine. nap.edu. Accessed May 9, 2025.
3. Food and Nutrition Board of the Institute of Medicine. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*. Washington, DC: National Academies Press; 2005.

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2.5: Understanding Food Labels

Learning Objectives

- Use the Nutrition Facts label to discover the nutritional information of food.
- Identify foods that are a good/poor source of a nutrient using %DV.
- Describe various claims that can appear on a food label.
- Identify the nine most common food allergens.
- Distinguish between enrichment and fortification of foods.

The Labels on Your Food

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

The Food and Drug Administration (FDA) requires food labels on most prepared foods (e.g., bread, cereal, canned foods, frozen foods, snacks, desserts, drinks).[1] Food labels for raw produce (fruits and vegetables) and fish is voluntary.[1] Detailed food labels are not required for meat and poultry which are regulated by the U.S. Department of Agriculture (USDA). The Nutrition Labeling and Education Act of 1990 requires that all packaged foods sold in the United States have nutrition labels that accurately reflect the contents of the food products. Information that is required by law to appear somewhere on the food package includes:

- Statement of identity (the common name of what the product actually is; e.g., granola)
- Net contents of the package including weight, volume, measure, or numerical count
- Name and address of the manufacturer, packager, or distributor
- Ingredients, listed in descending order by weight (the first product on the list is the predominant ingredient in that food)
  - must also clearly state presence of any common food allergens (milk, eggs, peanuts, tree nuts, fish, shellfish, soy, sesame, wheat)
- Nutrition information (also known as the Nutrition Facts label)



Figure 2.5.1: The 5 required types of information on a food label. (CC BY-NC 4.0; Alice Callahan via Nutrition Science and Everyday Application (Callahan, Leonard, and Powell))

The Nutrition Facts label provides a wealth of information about the nutrition content of the product. The information also allows shoppers to compare products. Because the serving sizes are included on the label, you can see how much of each nutrient is in each serving to make the comparisons. Knowing how to read the label is important because of the way some foods are presented.

For example, a bag of peanuts at the grocery store may seem like a healthy snack to eat on the way to class. But have a look at that label. Does it contain one serving, or multiple servings? Unless you are buying the individual serving packages, chances are the bag you picked up has several servings.

Reading the Nutrition Facts Label

The first part of the Nutrition Facts label gives you information on the serving size and how many servings are in the container. For example, a label on a box of crackers might tell you that twenty crackers equals one serving and that the whole box contains 10 servings. Serving size information has been updated to reflect typical amounts eaten; it is important to pay attention to how many servings of a food you eat to accurately reflect the calories and nutrients consumed.

All other values listed thereafter, from the calories to the dietary fiber to the potassium, are based on this one serving. On the label, the serving size is followed by the number of calories and then a list of selected nutrients.

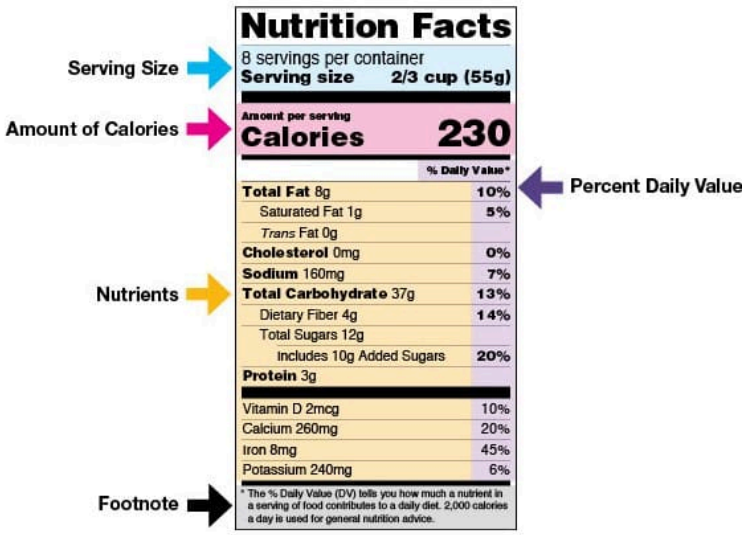


Figure 2.5.2: The Nutrition Facts label ("Nutrition Facts Label" by U.S. Food and Drug Administration)

% Daily Value (%DV)

You will also see "% Daily Value" on the far right-hand side. This helps you determine if the food is a good source of a particular nutrient or not. The Daily Value (DV) represents the recommended amount of a given nutrient based on the DRI of that nutrient in a 2,000 calorie diet. The % Daily Value (% DV) represents the proportion of the total daily recommended amount that you will get from one serving of the food. For example, in the food label in Figure 2.5.1, the % DV of calcium is 20%, which means that one serving of this food provides 20% of the daily recommended calcium intake. Whether you consume 2,000 calories per day or not you can still use the % DV as a target reference.

Foods that contain less than 5% DV of a nutrient are considered low in that nutrient. Foods that contain more than 20% DV of a nutrient are considered high in that nutrient. This means, as a general rule, for fat, saturated fat, trans fat, cholesterol, sodium or added sugar, look for foods with a low % DV. Alternatively, when concentrating on essential mineral or vitamin intake, look for a high % DV.

Interactive Nutrition Facts Label

The FDA has an Interactive Nutrition Facts Label that you can visit to explore each section of the label in more detail.

For a quick review of how you can use the food label while shopping, watch the following video.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

How to Read a Nutrition Facts Label by Osmosis from Elsevier

Claims on Labels

Food labels can display a variety of claims such as "good source of calcium" or "reduced fat". There are three categories of claims that are defined by statute and/or FDA regulations: nutrient content claims, health claims, and structure/function claims.[2]

Nutrient Content Claims

Any nutrient content claims on food labels must meet certain requirements. For example, a manufacturer cannot claim that a food is fat-free or low-fat if it is not, in reality, fat-free or low-fat. Low-fat indicates that the product has three or fewer grams of fat; low salt indicates there are fewer than 140 milligrams of sodium, and low-cholesterol indicates there are fewer than 20 milligrams of cholesterol and two grams of saturated fat. The Daily Values on food labels serve as the basis for many nutrient claims. See Table 2.5.1 for some examples.[3]

Table 2.5.1: Common Label Terms Defined

Term	Explanation
Lean	Fewer than a set amount of grams of fat for that particular cut of meat
High	Contains more than 20% of the nutrient's DV
Good source	Contains 10 to 19% of nutrient's DV
Reduced	Contains 25% less of a certain component (e.g., calories, sugar, fat) as compared to the original version
Light/lite	Contains ⅓ fewer calories or 50% less fat; if more than half of calories come from fat, then fat content must be reduced by 50% or more
Organic	Contains 95% organic ingredients



Figure 2.5.3: Examples of food packages with nutrient content claims. (CC BY 4.0; Ann Diker)

Health Claims

Often we hear news of a particular nutrient or food product that contributes to our health or may prevent disease. Food companies are allowed to make certain claims related to health and disease on food labels. A health claim is a statement that links a particular food with a reduced risk of developing disease. As such, health claims such as “reduces heart disease,” must be evaluated by the FDA before it may appear on packaging. All health claims must be substantiated by scientific evidence in order for it to be approved and put on a food label. To avoid having companies making false claims, laws also regulate how health claims are presented on food packaging. In addition to the claim being backed up by scientific evidence, it may never claim to cure or treat the disease. Health claims can be "authorized" or "qualified".

- Authorized health claims have *significant* scientific evidence and experts agree on the relationship between the nutrient and disease. As an example of an authorized health claim, a food that is low in sodium (per the FDA’s definition of less than 140 mg per serving) can include the following claim on their packaging: “Diets low in sodium may reduce the risk of high blood pressure, a disease associated with many factors.”[3]
- Qualified health claims have *credible* evidence, which is not as definitive as with authorized health claims. The evidence may suggest that the food or nutrient is beneficial. Wording for this type of claim may look like this: “Scientific evidence suggests but does not prove that eating 1.5 ounces per day of most nuts [such as name of specific nut] as part of a diet low in saturated fat and cholesterol may reduce the risk of heart disease."[3]



Figure 2.5.4: Examples of food packages with an authorized health claim (left) and qualified health claim (right). (CC BY 4.0; Ann Diker)

Structure/Function Claims

Some companies claim that certain foods and nutrients have benefits for health even though no scientific evidence exists. In these cases, food labels are permitted to claim that you may benefit from the food because it may boost your immune system, for example. These claims can be made *without* FDA approval and *without* proof. The claims are generic statements about a food's impact on the body (e.g., "builds stronger bones"). The claims *cannot* refer to a specific disease or symptom. There may not be claims of diagnosis, cures, treatment, or disease prevention, and there must be a disclaimer that the FDA has not evaluated the claim.[2]

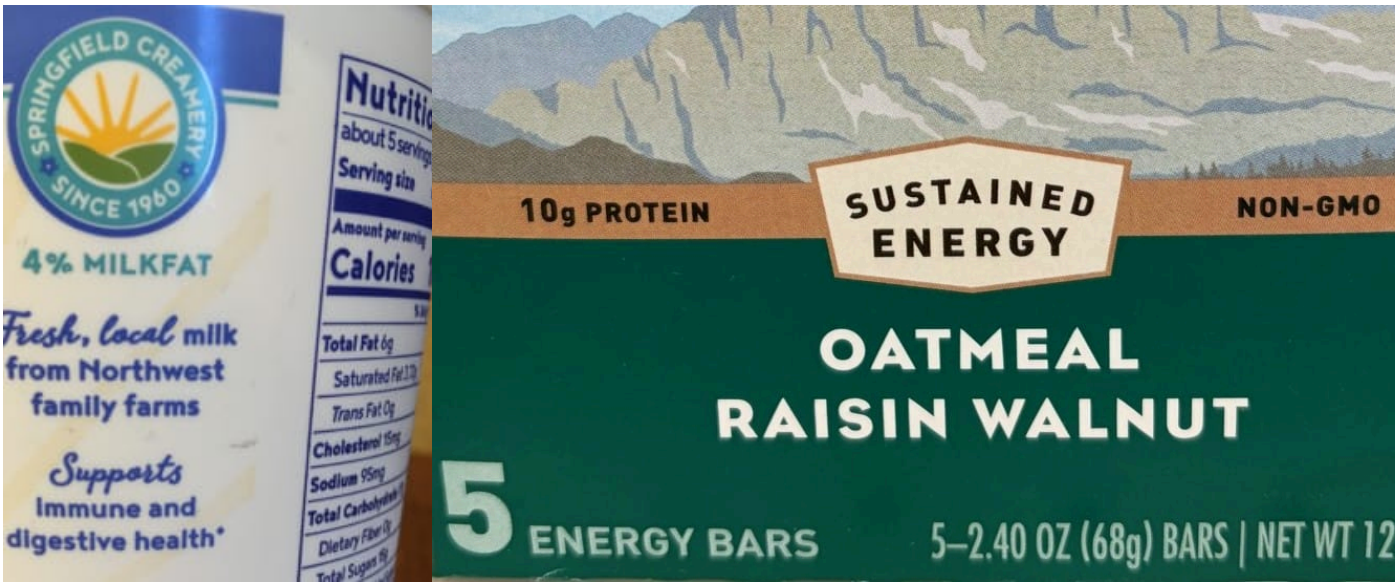


Figure 2.5.5: Examples of food packages with structure/function claims. (CC BY-NC 4.0; Alice Callahan (left), CC BY 4.0; Ann Diker (right))

Allergy Warnings

Food manufacturers are required by the FDA to list on their packages if the product contains any of the most common ingredients that cause food allergies.[4] The nine common allergens are 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.

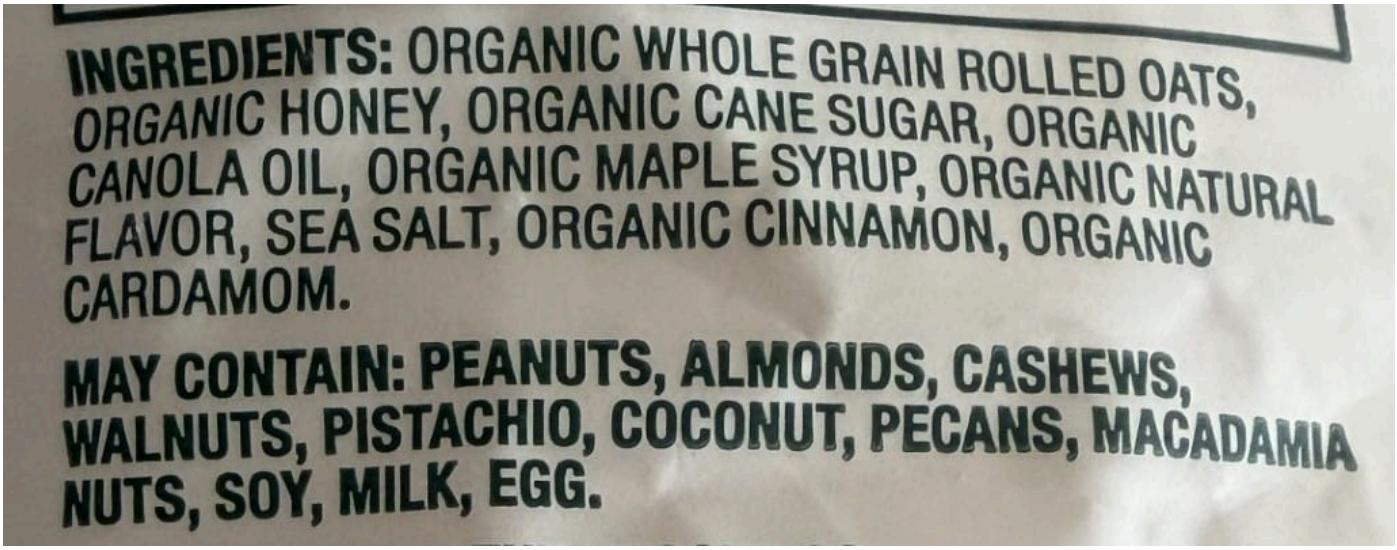


Figure 2.5.6: Example of an ingredient list with an allergy warning. (CC BY 4.0; Ann Diker)

Food Enrichment and Fortification

Many foods are enriched or fortified to boost their nutritional value.

- Enrichment involves adding nutrients to restore those that were lost during processing. For example, iron and certain B vitamins are added to white flour to replace the nutrients that are removed in the process of milling wheat.
- Fortification involves adding nutrients that didn't originally exist in the food; fortification is often done 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.



Figure 2.5.7: Enriched rice ingredient list showing vitamins/minerals added back after processing (left); Fortified orange juice ingredient list showing fortification/addition of calcium and Vitamin D (right). (CC BY 4.0; Ann Diker)

References

1. Food Labeling & Nutrition. fda.gov. Accessed May 9, 2025.
2. Label Claims for Conventional Foods and Dietary Supplements. fda.gov. Accessed May 9, 2025.
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2.6: Understanding Portion Sizes

Learning Objective

- Judge food portion sizes for adequacy.

Estimating Portion Size

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

Part of healthful eating means choosing appropriate amounts of different foods, so knowing more about appropriate portion sizes can be useful. As seen in Figure 2.6.1, portion sizes at fast food restaurants have increased over the past several decades and consequently the typical meal contains more calories than it used to.

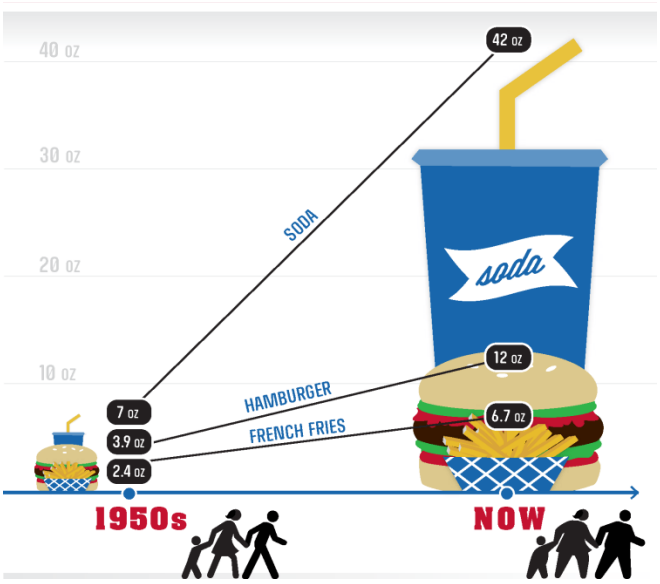


Figure 2.6.1: Fast food portion sizes over time ("The New (Ab)Normal" by CDC Division of Nutrition, Physical Activity, and Obesity)

It's not just fast food portions that have increased...portion sizes of many foods have gotten larger. Understanding food portions and serving sizes can help as you build a healthy diet. Keep in mind that if you eat 2 servings of a food you need to double the calories and nutrients listed on the food label. Check out the video below to see if you know what 100 calories look like!

"Americans Guess What 100 Calories Looks Like" by BuzzFeedVideo

Dietitians have come up with some good hints to help people tell how large a portion of food they really have. Some suggest using common items such as a deck of cards while others advocate using your hand as a measuring rule. See Table 2.6.1 for some examples.[1]

Table 2.6.1: Determining Food Portions

Amount	Object Comparison	Hand Comparison	Appropriate portion size for:
½ cup	tennis ball	small handful	cooked pasta, cooked rice
1 cup	baseball	average-sized fist	raw or cooked vegetables, whole fruits, beverages

Amount	Object Comparison	Hand Comparison	Appropriate portion size for:
1 ounce	golf ball		nuts, cheese
3 ounces	deck of cards	average-sized palm of a hand	fish, chicken, beef, other meats
1 Tablespoon		thumb	salad dressing, nut butters
1 teaspoon	postage stamp	thumb tip	oils, fats

Managing portion sizes while eating away from home can be challenging. A restaurant meal can be equivalent to the recommended fat or calorie intake for an entire day! Suggestions on how to eat out in moderation include:

- Avoid breaded or fried foods
- Order salad with dressing on the side
- Ask for steamed vegetables
- Avoid cream sauces or cheese sauces
- Order small portions (such as appetizers)
- Split your entrée with a friend
- Eat ½ your entrée and take home the leftovers - you can ask the wait staff to put ½ your entree in a to-go box before you start eating
- Order broth-based soups instead of cream soups
- Order meat, fish, and poultry grilled or broiled
- Skip dessert or share with the table!

References

1. Serving Size vs Portion Size: Is There a Difference? eatright.org. Accessed May 9, 2025.

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3: DIGESTION

3.1: Human Body Organization
3.2: Hunger vs. Appetite
3.3: Digestion and Absorption
3.4: Disorders That Can Compromise Health

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3.1: Human Body Organization

Learning Objectives

- Identify the components of a cell.
- Describe the cell membrane's structure and functions.
- Describe the organization of the human body.

Cells

What distinguishes a living organism from an inanimate object? A living organism conducts self-sustaining biological processes. A cell is the smallest and most basic form of life. Robert Hooke, one of the first scientists to use a light microscope, discovered the cell in 1665. In all life forms, including bacteria, plants, animals, and humans, the cell was defined as the most basic structural and functional unit. Based on scientific observations over the next 150 years, scientists formulated the cell theory, which is used for all living organisms no matter how simple or complex. The cell theory incorporates three principles:

- Cells are the most basic building units of life.
- All living things are composed of cells.
- New cells are made from preexisting cells, which divide into two.

Who you are has been determined because of two cells that came together inside your mother's womb. The two cells containing all of your genetic information (DNA) united to begin making new life. As seen in Figure 3.1.1, cells divided and differentiated into other cells with specific roles that led to the formation of the body's numerous body organs, systems, blood, blood vessels, bone, tissue, and skin. As an adult, you are comprised of trillions of cells. Each of your individual cells is a compact and efficient form of life—self-sufficient, yet interdependent upon the other cells within your body to supply its needs.

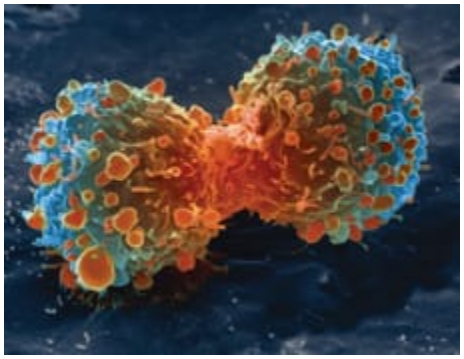


Figure 3.1.1: One cell divides into two, which begins the creation of millions of more cells that ultimately become you. (Public Domain; National Institutes of Health).

An independent single-celled organism must conduct all the basic processes of life: it must take in nutrients (energy capture), excrete waste, detect and respond to its environment, move, breathe, grow, and reproduce. Even a one-celled organism must be organized to perform these essential processes. All cells are organized from the atomic level to all its larger forms. Oxygen and hydrogen atoms combine to make the molecule water (H_2O). Molecules bond together to make bigger macromolecules. The carbon atom is often referred to as the backbone of life because it can readily bond with four other elements to form long chains and more complex macromolecules. Four macromolecules—carbohydrates, lipids, proteins, and nucleic acids—make up all of the structural and functional units of cells.

Cell structure and function

Although we defined the cell as the "most basic" unit of life, it is structurally and functionally complex. A cell can be thought of as a mini-organism consisting of tiny organs called organelles. The organelles are structural and functional units constructed from several macromolecules bonded together. A typical animal cell contains the following organelles:

- the nucleus (which houses DNA used to provide instructions for cells to make proteins)
- mitochondria (which produces adenosine triphosphate (ATP), an energy molecule, from basic food components)
- ribosomes (which produce proteins)
- endoplasmic reticulum (which is important for modifying proteins and lipid synthesis)
- golgi apparatus (which sorts, packages, and distributes proteins and lipids)
- lysosomes and peroxisomes (little digestive pouches which break down macromolecules and destroy foreign invaders)

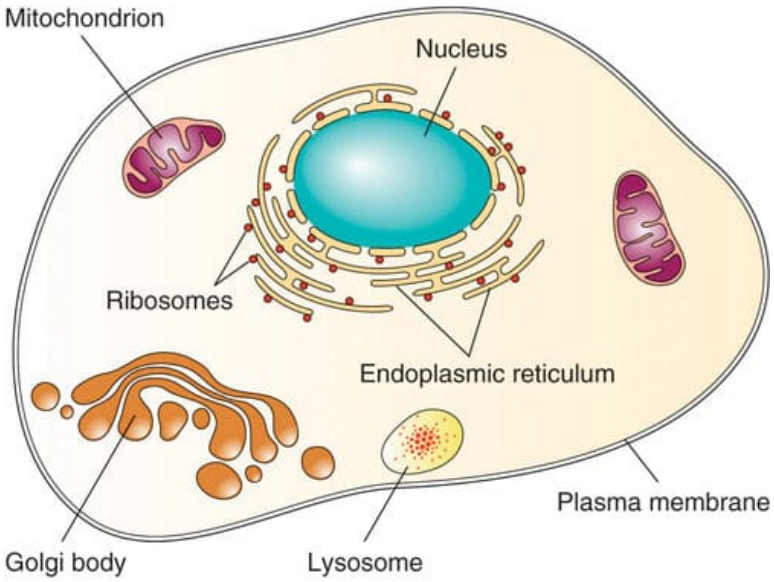


Figure 3.1.2: The components of a cell.

As seen in (Figure 3.1.2), all of the organelles are in the cell's cytoplasm. The cell's organelles are isolated from the surrounding environment by a plasma (cell) membrane. The cell membrane defines the cell's boundaries and regulates what can enter and exit the cell. The cell membrane is comprised of two layers of phospholipids with cholesterol and various proteins scattered throughout. Watch the video below for a simple explanation of the cell membrane structure.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

Human Body Organization

Single-celled organisms can function independently, but the cells of multicellular organisms are dependent upon each other and are organized into different levels in order to coordinate their specific functions and carry out all of life's biological processes.

- **Atoms.** Tiny units of matter.
- **Molecules.** Groups of atoms. Food that we eat is composed of molecules. Digestion breaks food down into molecules that can be absorbed.
- **Cells.** Cells are the basic structural and functional unit of all life. Examples include red blood cells and nerve cells.
- **Tissues.** Tissues are groups of cells that share a common structure and function and work together. There are four types of human tissues:
  - connective, which connects tissues;
  - epithelial, which lines and protects organs;
  - muscle, which contracts for movement and support; and

- nerve, which responds and reacts to signals in the environment.

- **Organs.** Organs are a group of tissues arranged in a specific manner to support a common physiological function. Examples include the brain, liver, and heart.
- **Organ systems.** Organ systems are two or more organs that support a specific physiological function. Examples include the digestive system and central nervous system. There are eleven organ systems in the human body (Table 3.1.1).
- **Organism.** An organism is the complete living system capable of conducting all of life's biological processes.

Table 3.1.1: The Eleven Organ Systems in the Human Body and Their Major Functions

Organ System	Organ Components	Major Function
Circulatory	heart, blood/lymph vessels, blood, lymph	transport nutrients and waste products
Digestive	mouth, esophagus, stomach, intestines	digestion and absorption
Endocrine	all glands (thyroid, ovaries, pancreas)	produce and release hormones
Immune	white blood cells, lymphatic tissue, marrow	defend against foreign invaders
Integumentary	skin, nails, hair, sweat glands	protective, body temperature regulation
Muscular	skeletal, smooth, and cardiac muscle	body movement
Nervous	brain, spinal cord, nerves	interprets and responds to stimuli
Reproductive	gonads, genitals	reproduction and sexual characteristics
Respiratory	lungs, nose, mouth, throat, trachea	gas exchange
Skeletal	bones, tendons, ligaments, joints	structure and support
Urinary	kidneys, bladder, ureters	waste excretion, water balance

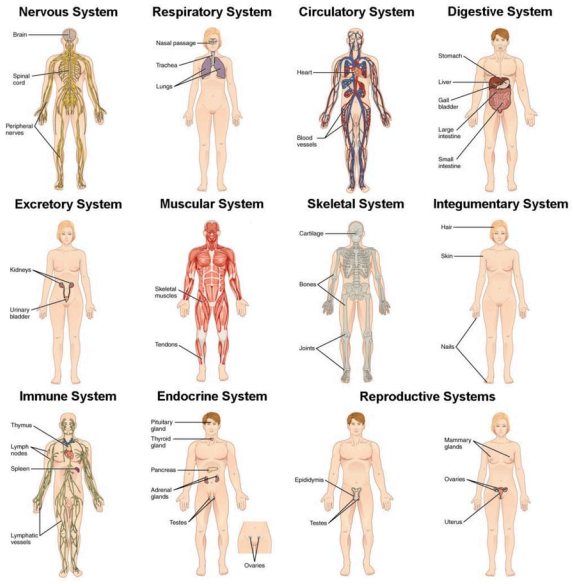


Figure 3.1.3: Organ systems of the human body. (CC BY 4.0; OpenStax)

In multicellular organisms, including humans, all cells, tissues, organs, and organ systems of the body work together to maintain the life and health of the organism.

References

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3.2: Hunger vs. Appetite

Learning Objective

- Describe what drives us to eat by using the concepts of appetite, hunger, and satiety, including the organs that are involved, as well as internal and external cues.

Why Do We Feel the Urge to Eat?

Two mechanisms prompt us to seek food - hunger and appetite. *Hunger* is a *physiological* drive for nonspecific foods. *Appetite* is a *psychological* desire to eat specific foods. Anorexia is a lack of appetite even when the physiologic need for food exists.

Hunger

The hypothalamus prompts *hunger* in response to various signals. The hypothalamus triggers feelings of either hunger or satiety (fullness) by integrating signals from nerve cells, hormones, and the amount and type of food we eat.

Nerve cells in the stomach and small intestine lining (that sense changes in pressure/fullness) send signals to the hypothalamus.

Hormones are chemical messengers produced in specialized glands, secreted into the bloodstream, and target organs in other parts of the body. The following hormones are involved in hunger and satiety:

- Insulin and glucagon are two hormones responsible for maintaining blood glucose levels.
  - When we have not eaten for a while, blood glucose levels fall, prompting a decrease in insulin levels and an increase in glucagon levels. This chemical message is relayed to the hypothalamus and triggers a feeling of hunger.
  - After we eat, the hypothalamus receives signals related to satiety including distention of the stomach and intestine, increased insulin levels, and decreased glucagon levels.
- Ghrelin, CCK, and Leptin
  - Ghrelin is a hormone produced by the stomach. Levels are low immediately after a meal. As time continues without food, ghrelin levels rise and trigger a feeling of hunger.
  - CCK (cholecystokinin) is a hormone produced by the small intestine. As food enters the small intestine, CCK levels increase and trigger a feeling of satiety.
  - Leptin is a protein hormone that acts more long-term. Adipose (fat) cells produce leptin which triggers satiety. However, research currently suggests that obese people may be resistant to leptin's effects on satiety.

The amount and type of food we eat can affect satiety. Foods containing protein have the highest satiety value. Bulky meals high in fiber and water provide satiety by stretching the stomach and small intestine. Beverages tend to be less satisfying than foods.

Watch the following video for a review of the hormone control of hunger.

YouTube Video

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"Hormone Control of Hunger" by khanacademymedicine

Appetite

Appetite is a psychological desire to eat and can be experienced at any point, whether you're hungry or not. Some reasons people eat that are unrelated to physical hunger are listed below and in Figure 3.2.1 :

- Emotion: Eating to soothe or suppress negative emotions like anger, stress, boredom, loneliness, or anxiety.
- Pleasure: Eating for the sheer pleasure of taste, driven by the brain's reward system, particularly with high-fat or sugary foods.
- Environmental Cues: Seeing, smelling, or having easy access to food, such as snacks on a desk or advertisements.
- Habit/Routine: Eating at specific times (e.g., watching TV), in specific environments, or cleaning the plate regardless of fullness.
- Social/Cultural/Religious: Eating to celebrate, fit in, avoid appearing rude, or connect with others.
- Physical/Biological Factors: Being tired or dehydrated (which can be mistaken as hunger).



Figure 3.2.1: Some reasons people eat that are unrelated to physical hunger. (CC BY 4.0; Ann Diker)

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3.3: Digestion and Absorption

Learning Objectives

- Identify major and accessory organs of the digestive system.
- Describe the processes of digestion, absorption, and elimination by listing the role(s) of each organ of the digestive system.

Digestion begins even before you put food into your mouth. When you feel hungry, your body sends a message to your brain that it is time to eat. Sights and smells influence your body's preparedness for food. Smelling food sends a message to your brain. Your brain then tells the mouth to get ready, and you start to salivate in preparation for a delicious meal.

Overview of the Digestive Process

The digestive process includes four activities:

- Ingestion: foods enter the gastrointestinal (GI) tract through the mouth
- Digestion: foods are broken down into molecules
- Absorption: molecules (from digestion) are taken across the GI tract walls and into circulation
- Elimination: undigested food and waste products are removed from the body

These processes occur in the gastrointestinal tract.

Once you have eaten, your digestive system breaks down the food into smaller components. The food we eat is made up of carbohydrates, lipids/fats, and proteins (listed as 'polymers' in Figure 3.3.1). The entire process of digestion converts the large polymers in food to smaller components (monomers) that can be absorbed. Carbohydrates are broken down to monosaccharides (e.g., glucose), lipids are broken down to fatty acids, and proteins are broken down to amino acids. Another word for the breakdown of complex molecules into smaller, simpler molecules is "catabolism" or a "catabolic reaction". To do this, catabolism functions on two levels, mechanical and chemical. Once the smaller particles have been broken down, they will be absorbed into the blood and delivered to cells throughout the body for energy or for building blocks needed for cells to function. The digestive system is one of the eleven organ systems of the human body and it is composed of several hollow tube-shaped organs including the mouth, esophagus, stomach, small intestine, and large intestine (or colon). It is lined with mucosal tissue that secretes digestive juices (which aid in the breakdown of food) and mucus (which facilitates the propulsion of food through the tract). Smooth muscle tissue surrounds the digestive tract and its contraction produces waves, known as peristalsis, that propel food down the tract. Nutrients as well as some non-nutrients are absorbed. Substances such as fiber get left behind and are appropriately excreted.

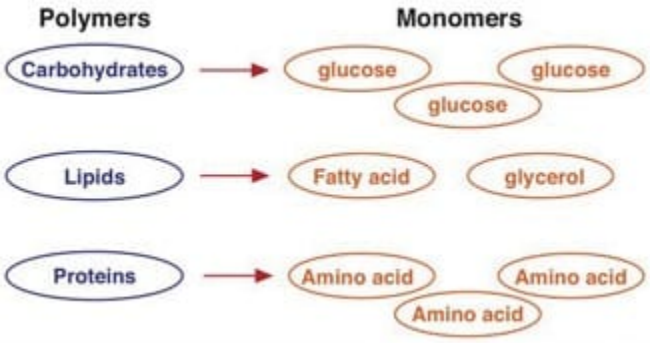


Figure 3.3.1: The Digestion Process. Digestion converts the food we eat into smaller particles, which will be processed into energy or used as building blocks. (CC BY-NC-SA 4.0; An Introduction to Nutrition (Zimmerman))

Mouth and Esophagus

There are multiple steps in the digestion process (Figure 3.3.2). The first step is ingestion, which is the collection of food into the digestive tract. It may seem a simple process, but ingestion involves smelling food, thinking about food, and the involuntary release of saliva in the mouth to prepare for food entry. This first step/phase is called the cephalic phase and helps prepare the GI tract to digest food. The second step, digestion, involves mechanical and chemical breakdown of food. Digestion also begins in the mouth. The chemical breakdown of food in the mouth involves enzymes secreted by the salivary glands. These enzymes start to break apart the components in food. Enzymes are proteins that speed up chemical reactions; one of the enzymes in saliva, amylase, begins the process of carbohydrate digestion. Enzyme names typically end in "-ase" (e.g., amylase, lactase). Mechanical breakdown starts in the mouth with chewing; teeth crush and grind large food particles. Saliva moistens the food, begins the chemical breakdown of food, and enables its movement downward.

The slippery mass of partially broken-down food is called bolus, which moves down the digestive tract as you swallow. Swallowing may seem voluntary at first because it requires conscious effort to push the food with the tongue back toward the throat, but after this, swallowing proceeds involuntarily, meaning it cannot be stopped once it begins.

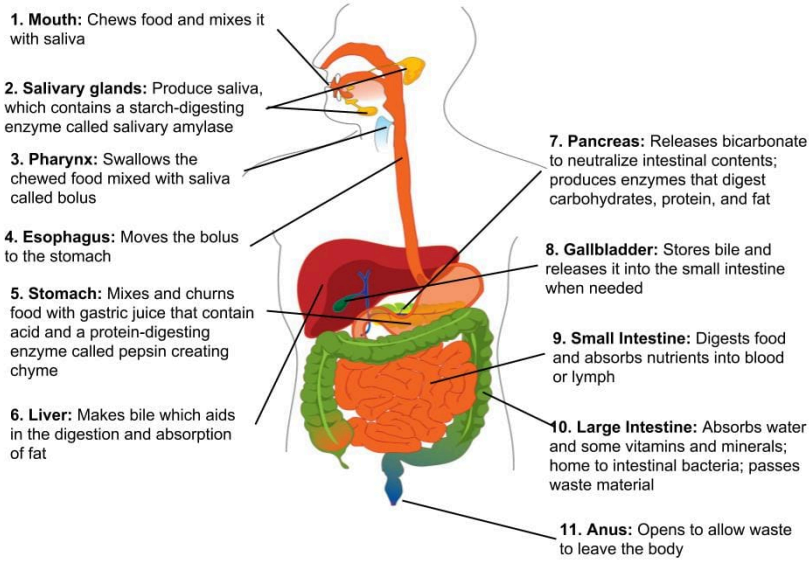


Figure 3.3.2: The Human Digestive System. (CC BY 4.0; Allison Calabrese)

As you swallow, the bolus is pushed from the mouth through the pharynx and into a muscular tube called the esophagus. As it travels through the pharynx, a small flap called the epiglottis closes, to prevent choking by keeping food from going into the trachea. Peristalsis (the rhythmic contraction and relaxation of circular and longitudinal muscles that move food in one direction through the GI tract) in the esophagus propels the food down to the stomach. This movement of food via peristalsis is shown in Figure 3.3.3. At the junction between the esophagus and stomach there is a sphincter muscle that remains closed until the food bolus approaches. The pressure of the food bolus stimulates the lower esophageal sphincter to relax and open and food then moves from the esophagus into the stomach. Solid food takes four to eight seconds to travel down the esophagus, and liquids take about one second.

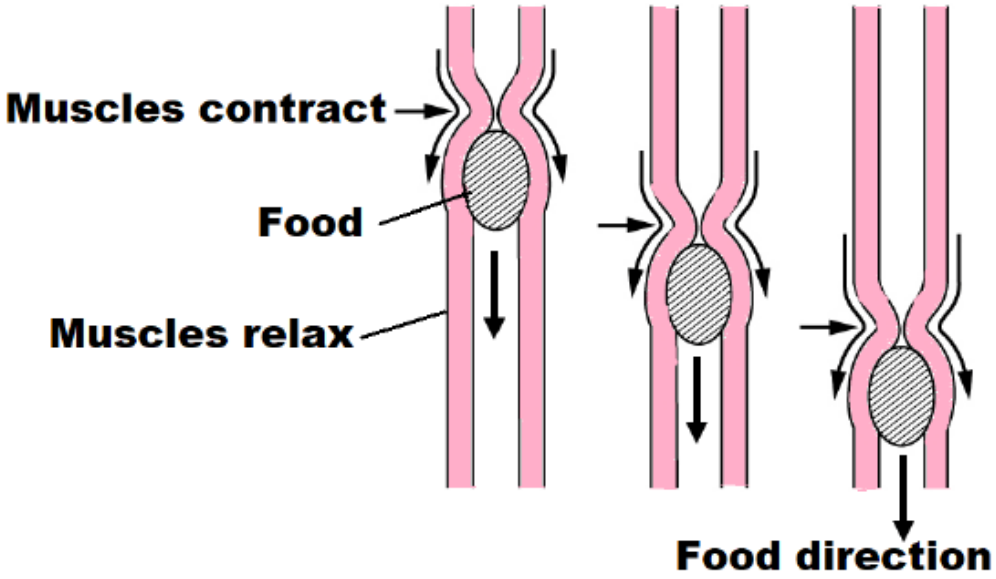


Figure 3.3.3: How Peristalsis Works. (CC-BY-SA-3.0; OpenStax)

Stomach

The stomach has three basic tasks - to store food, mechanically and chemically break down food, and empty partially broken-down food into the small intestine.

When food enters the stomach, a highly muscular organ, powerful peristaltic contractions help mash, pulverize, and churn food into a semiliquid mass of partially digested food and gastric juices called chyme which is then periodically released into the small intestine through the pyloric sphincter. A digestive fluid in the stomach, called gastric juice, contains several important compounds:

- Hydrochloric acid (HCl) - keeps the stomach interior acidic which:
  - protects the body from harmful bacteria
  - denatures protein to allow protein to be digested further
  - activates pepsin
- Pepsin - an enzyme that begins to digest protein
- Gastric lipase - an enzyme that starts to digest fat

Mucus protects the stomach lining from the acidic gastric juice.

The length of time that 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 high in carbohydrates. It usually takes a few hours after a meal to empty the stomach contents completely.

Small Intestine

Most digestion and absorption occurs in the small intestine.

The small intestine is divided into three structural parts: the duodenum, the jejunum, and the ileum. Once the chyme enters the duodenum, three accessory (or helper) organs - the pancreas, gallbladder, and liver - are stimulated to release juices that aid in digestion. The pancreas secretes pancreatic juice through a duct into the duodenum. Pancreatic juice consists mostly of water, but also contains bicarbonate ions (that neutralize the acidity of chyme) and enzymes that further breakdown proteins, carbohydrates, and lipids (proteases digest proteins, pancreatic amylase digests carbohydrates, pancreatic lipase digests lipids/fats). The gallbladder secretes bile through a different duct that also leads to the duodenum. Bile is made in the liver and stored in the gallbladder. Bile helps digest lipids/fats; bile's components act like detergents by surrounding fats similar to the way dish soap removes grease from a frying pan. This allows for the movement of fats in the watery environment of the small intestine. Two different types of muscular contractions, called peristalsis and segmentation, move and mix the food in various

stages of digestion through the small intestine. Similar to what occurs in the esophagus and stomach, peristalsis is circular waves of smooth muscle contraction that propel food forward. Segmentation moves food back and forth in both directions promoting further mixing of the chyme. Almost all the components of food are completely broken down to their simplest unit within the duodenum. Instead of proteins, carbohydrates, and lipids, the chyme now consists of amino acids, monosaccharides, and emulsified fatty acids.

The third step of digestion (nutrient absorption) takes place throughout the small intestine. The small intestine is perfectly structured for maximizing nutrient absorption because it has a large surface area. Its surface area is greater than 200 square meters, which is about the size of a tennis court. The large surface area is due to multiple levels of folding (see Figure 3.3.4). The internal tissue of the small intestine is covered in villi, which are tiny finger-like projections that are covered with even smaller hair-like projections, called microvilli or the "brush border". The digested nutrients pass through the absorptive cells of the intestine via diffusion or special transport proteins. Nutrients that are water-soluble like amino acids and monosaccharides (sugars) are transported from the intestinal cells into capillaries (blood), but the fat-soluble nutrients like fatty acids, fat-soluble vitamins, and other lipids are transported first through lymphatic vessels (lymph), which soon meet up with blood vessels.

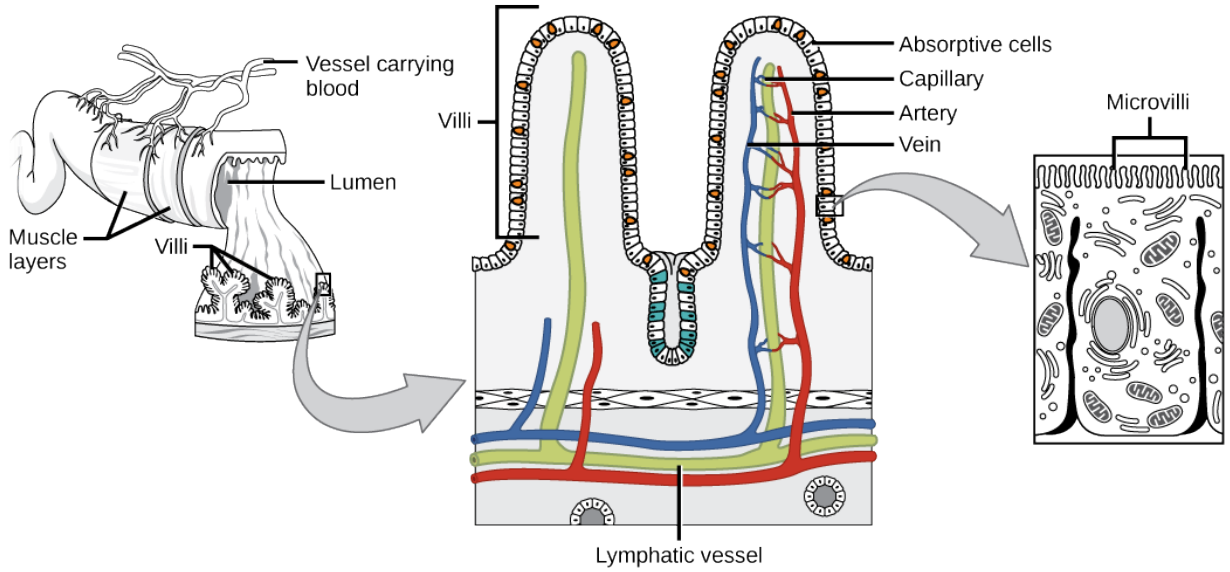


Figure 3.3.4: Small intestine structure including circular folds, villi, and microvilli which provides a huge surface area to maximize nutrient absorption. Digested nutrients are absorbed into either capillaries or lymphatic vessels contained within villi. (CC BY 4.0; OpenStax)

Large Intestine

The process of digestion is fairly efficient. Any food that is still incompletely broken down (usually less than 10% of food consumed) and the food's indigestible fiber content moves from the small intestine to the large intestine (colon) through a connecting valve. The main task of the large intestine is to reabsorb water. Remember, water is present not only in solid foods, but also in the gastric juice released by the stomach as well as the secretions from the pancreas. For the body to conserve water, it is important that the water be reabsorbed. In the large intestine, no further chemical or mechanical breakdown of food takes place, unless it is accomplished by the bacteria that inhabit this portion of the digestive tract.

After a few hours in the stomach, plus 3-6 hours in the small intestine, and about 16 hours in the large intestine, the digestion process enters step four, which is the elimination of indigestible food as feces. Feces contain indigestible food and gut bacteria (almost 50% of content). It is stored in the rectum until it is expelled through the anus via defecation.

Summary

The digestive system uses mechanical and chemical activities to break food down into absorbable substances during its journey through the digestive system. Table 3.3.1 provides a summary of the functions, mechanical digestion, and chemical digestion of each organ in the digestive tract that you learned about above.

Table 3.3.1: Digestive Organ Summary

Major Organ	Accessory Organ	Functions	Mechanical Digestion	Chemical Digestion
Mouth		• Ingests food • Moves food into the esophagus	• Chewing shreds and mixes food with saliva	• Salivary amylase begins breakdown of carbohydrates • Lingual lipase begins breakdown of lipids
	Salivary Glands	• Produces saliva which contains salivary amylase		
Esophagus		• Propels the food bolus to the stomach via peristalsis		
Stomach		• Stores food bolus • Releases bolus into the small intestine as chyme • Absorbs some fat-soluble substances (e.g., alcohol, aspirin)	• Mixes and churns food with gastric juices to form chyme	• Pepsin (part of gastric juice) begins breakdown of proteins • Gastric lipase (part of gastric juice) begins breakdown of lipids
Small intestine		• Propels food at a rate slow enough for digestion and absorption • Absorbs nutrients into blood or lymph	• Segmentation mixes chyme with digestive juices	• Pancreatic enzymes (secreted from the pancreas within pancreatic juice) break down carbohydrates, lipids, and proteins • Enzymes in the small intestine's "brush border" break down carbohydrates and proteins
	Liver	• Produces bile, which helps digestion and absorption of lipids		
	Gallbladder	• Stores bile and releases it into the small intestine when needed		
	Pancreas	• Produces pancreatic juice and releases it into the small intestine. Pancreatic juice includes: ◦ enzymes ◦ bicarbonate that neutralizes the acidity of chyme		

Major Organ	Accessory Organ	Functions	Mechanical Digestion	Chemical Digestion
Large intestine		• Reabsorbs water, electrolytes, and vitamins produced by bacteria within the large intestine • Propels feces toward rectum where it is stored until eliminated through the anus		• Bacteria break down some remaining food residues

You can also watch the following video for an additional summary of the digestive process.

YouTube Video

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"How your digestive system works" by Emma Bryce on TED-Ed

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3.4: Disorders That Can Compromise Health

Learning Objective

- Describe various disorders and diseases related to digestion.

When nutrients and energy are in short supply, cells, tissues, organs, and organ systems do not function properly. Unbalanced diets can cause diseases and, conversely, certain illnesses and diseases can cause an inadequate intake and absorption of nutrients, simulating the health consequences of an unbalanced diet. Overeating high-fat foods and nutrient-poor foods can lead to obesity and exacerbate the symptoms of gastroesophageal reflux disease (GERD) and irritable bowel syndrome (IBS). Many diseases and illnesses, such as celiac disease, interfere with the body getting its nutritional requirements. A host of other conditions and illnesses, such as food allergies, food intolerances, peptic ulcers, and Crohn's disease can impair the process of digestion and/or negatively affect nutrient balance and decrease overall health. We'll explore several of these disorders and diseases below.

Diarrhea

Diarrhea is defined as the frequent passage of loose, watery stools. 'Frequent passage' means more than three times in one day. Typical causes of diarrhea include ingesting food or water contaminated with bacteria, infection of the digestive tract, stress, certain foods/beverages, and reaction to medication. If the diarrhea lasts for a long period of time, a person could become dehydrated if fluids and minerals are not replaced. Fluids and minerals can typically be replaced through normal food and beverage consumption. However, beverages that contain electrolytes (e.g., pedialyte, sports drinks) are also an option.

Constipation

Constipation is generally described as having fewer than 3 bowel movements in a week. In addition, the bowel movements tend to be small, hard, and difficult to pass. Factors that contribute to constipation can include travel, change in diet, and certain medications. Common suggestions for relief of constipation include increasing fluid intake, increasing fiber intake, and regular exercise that incorporates leg movement (e.g., walking).

Gastroesophageal Reflux Disease

Gastroesophageal reflux disease (GERD) is a persistent form of acid reflux that occurs more than two times per week. Acid reflux occurs when the acidic contents of the stomach leak backward into the esophagus and cause irritation. In other words, it's a result of hydrochloric acid (HCl) flowing back up into the esophagus through an open or relaxed sphincter into the lower portion of the esophagus, burning the esophageal lining (Figure $3.4.1$). The pain is typically felt behind the sternum, over the heart, which is why the most common GERD symptom is called "heartburn". People with GERD may also experience regurgitation (flow of the stomach's acidic contents into the mouth), frequent coughing, and trouble swallowing. The exact causes of GERD are unknown. However, some contributing factors include overweight/obesity, pregnancy, cigarette smoking, and certain foods/beverages (e.g., spicy foods, chocolate, fried foods, tomato-based foods, caffeine, alcohol).

The first approach to GERD treatment is dietary and lifestyle modifications. Suggestions are to reduce weight if you are overweight or obese, avoid foods that worsen symptoms, eat smaller meals, stop smoking, and remain upright for at least three hours after a meal. There is some evidence that sleeping on a bed with the head raised at least six inches helps lessen the symptoms of GERD. Many medications are available to treat GERD, including antacids, histamine (H2) blockers, and proton-pump inhibitors. Some evidence from scientific studies indicates that medications used to treat GERD may accentuate certain nutrient deficiencies (e.g., Vitamin B12) in older populations.[1] When these treatment approaches do not work, surgery is an option. The most common surgery involves reinforcing the sphincter that serves as a barrier between the stomach and esophagus.

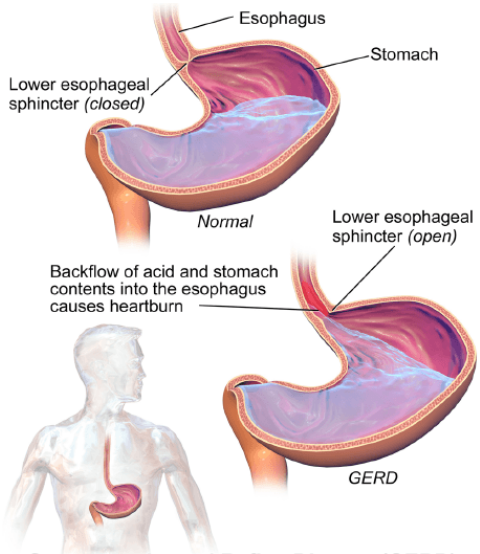


Figure 3.4.1: Gastroesophageal Reflux Disease (GERD). (CC BY-SA 4.0, BruceBlaus via Wikimedia Commons)

Peptic Ulcer

A peptic ulcer is an area of the GI tract that have been eroded by a combination of HCl and the enzyme pepsin. A gastric ulcer is located in the stomach area. A duodenal ulcer is located in the duodenum, usually close to the stomach. Common causes of peptic ulcers include the bacterium *Helicobacter pylori (H. pylori)* which can cause inflammation of the stomach's inner layer and lead to an ulcer and prolonged use of nonsteroidal anti-inflammatory drugs (NSAIDs) such as ibuprofen (Advil) and naproxen sodium (Aleve). Treatment of a peptic ulcer depends on the cause of the ulcer. Medications available include antibiotics to kill *H. pylori* or medications aimed at reducing or blocking acid production (e.g., proton pump inhibitors to reduce stomach acid production or histamine blockers to reduce the amount of stomach acid released).

The following 3-D animation shows the digestive process and some of the disorders described above.

YouTube Video

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"How the Digestive System Works" by Dr. Paulien Moyaert

Irritable Bowel Syndrome

Irritable bowel syndrome (IBS) is characterized by muscle spasms in the colon that result in abdominal pain, bloating, constipation, and/or diarrhea. Interestingly, IBS produces no permanent structural damage to the large intestine. The disorder is more prevalent in women than men. There is no specific test to diagnose IBS, but other conditions that have similar symptoms (such as celiac disease) must be ruled out. This involves stool tests, blood tests, and having a colonoscopy (which involves the insertion of a flexible tube with a tiny camera on the end through the anus so the doctor can see the colon tissues). The precise cause of IBS isn't known, but factors that appear to play a role include stress, severe infections, and certain foods/beverages (e.g., wheat, dairy products, citrus fruits, beans, fatty foods, coffee, alcohol). As with GERD, the first treatment approaches for IBS are diet and lifestyle modifications. People with IBS are often told to keep a daily food journal to help identify and eliminate foods that cause the most problems. Other recommendations are to eat slower, add more fiber to the diet, drink more water, and/

or consider following a low FODMAP diet.[2] FODMAP stands for **F**ermentable **O**ligosaccharides, **D**isaccharides, **M**onosaccharides **a**nd **P**olyols; following a low FODMAP diet is highly recommended for people with IBS.

Celiac Disease

Celiac disease is an autoimmune disorder caused by an abnormal immune reaction of small intestine cells to a type of protein, called gluten (and specifically gliadin, which is a component of gluten). Gluten is found in grains that are commonly used to make bread, such as wheat, rye, and barley. For those who are sensitive to gluten, it is good to know that corn, millet, buckwheat, and oats do not contain the proteins that make gluten. However, some people who have celiac disease also may have a response to products containing oats. This is most likely the result of cross-contamination of grains during harvest, storage, packaging, and processing. Symptoms can range from mild to severe and can include pale, fatty, loose stools, gastrointestinal upset, abdominal pain, weight loss and, in children, a failure to grow. The symptoms can appear in infancy or much later in life, even by age seventy. Celiac disease is not always diagnosed because the symptoms may be mild.

Celiac disease diagnosis requires a blood test and a biopsy of the small intestine. Because celiac disease is an autoimmune disease, antibodies produced by white blood cells circulate in the body and can be detected in the blood. When gluten-containing foods are consumed the antibodies attack cells lining the small intestine leading to a destruction of the small villi projections (see Figure 3.4.2). This tissue damage can be detected with a biopsy, a procedure that removes a portion of tissue from the damaged organ. Villi destruction is what causes many of the symptoms of celiac disease. The destruction of the absorptive surface of the small intestine also results in the malabsorption of nutrients, so that while people with this disease may eat enough, nutrients do not make it to the bloodstream because absorption is reduced. Over time these nutrient deficiencies can cause health problems. Poor absorption of iron and folic acid can cause anemia, which is a decrease in red blood cells. Anemia impairs oxygen transport to all cells in the body. Calcium and vitamin D deficiencies can lead to osteoporosis, a disease in which bones become brittle.

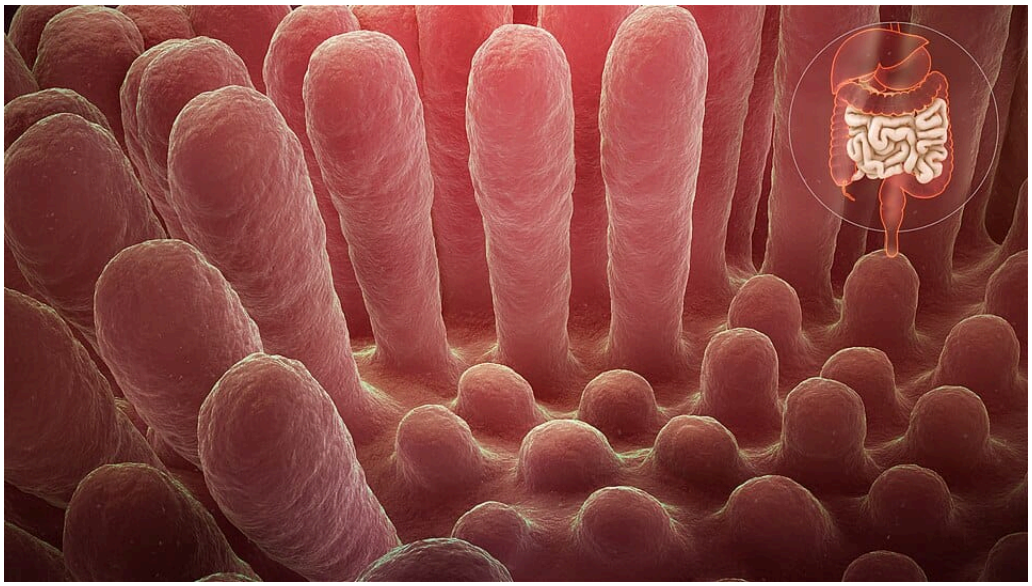


Figure 3.4.2: Normal villi of the small intestine (left side) compared to damaged villi (right side). (CC BY-SA 4.0; scientificanimations)

If you think you or someone close to you may have celiac disease, do not despair; it is a very treatable disease. Once diagnosed, a person follows a gluten-free diet for life. This requires dedication and careful detective work to seek out foods with hidden gluten, but many stores and restaurants carry gluten-free foods. After eliminating gluten from the diet, the tissues of the small intestine rapidly repair themselves and heal in less than six months.

Food Intolerances

A food intolerance is gastrointestinal discomfort caused by food; there is a physical reaction but no immune system reaction. One common food intolerance is lactose intolerance which is caused by the lack of the enzyme lactase. Lactase is produced in the small intestine and is used to break down the sugar in milk called lactose. Without the enzyme present to break down lactose, symptoms such as gas, bloating, cramping, and diarrhea occur. Food intolerances do not involve an immune system response which distinguishes them from food allergies.

Food Allergies

Unlike a food intolerance, when someone has a food allergy, there is an inflammatory reaction to food caused by an immune system reaction. The immune system mistakenly attacks a certain kind of food (usually the protein component of a food) as if it were a threat. Food allergy symptoms usually develop within a few minutes to two hours after a person has eaten a food to which they are allergic. These symptoms can range from the annoying to the potentially fatal, and include a tingling mouth, swelling tongue and/or throat, hives, difficulty breathing, loss of consciousness, and death. There are no clear treatments for food allergies. Epinephrine is sometimes used to control severe reactions; individuals with known and dangerous allergies may get prescriptions for self-injectable devices. The only certain way to avoid allergic reactions to food is to avoid the foods that cause them. Beyond avoidance, this can mean reading food labels carefully, or even calling manufacturers for product information.

Most food allergies are caused by these nine foods:

- Milk
- Eggs
- Peanuts
- Tree nuts
- Fish
- Shellfish
- Wheat
- Soy
- Sesame

References

1. Heidelbaugh, JJ. Proton pump inhibitors and risk of vitamin and mineral deficiency: evidence and clinical implications. Ther Adv Drug Saf. 2013;4(3):125–133.
2. Try a FODMAPs diet to manage irritable bowel syndrome. health.harvard.edu. Updated March 15, 2022. Accessed May 13, 2025.

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4: CARBOHYDRATES

4.1: Introduction to Carbohydrates

4.2: Benefits of Fiber

4.3: Digestion and Absorption of Carbohydrates

4.4: Functions of Carbohydrates

4.5: Carbohydrate Recommendations

4.6: Looking Closely at Diabetes

4.7: Sugar Substitutes

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4.1: Introduction to Carbohydrates

Learning Objectives

- Identify food groups that are sources of carbohydrates.
- Classify carbohydrates as simple or complex.
- Describe various simple and complex carbohydrates.
- Identify the body's preferred fuel source.

Carbohydrate Overview

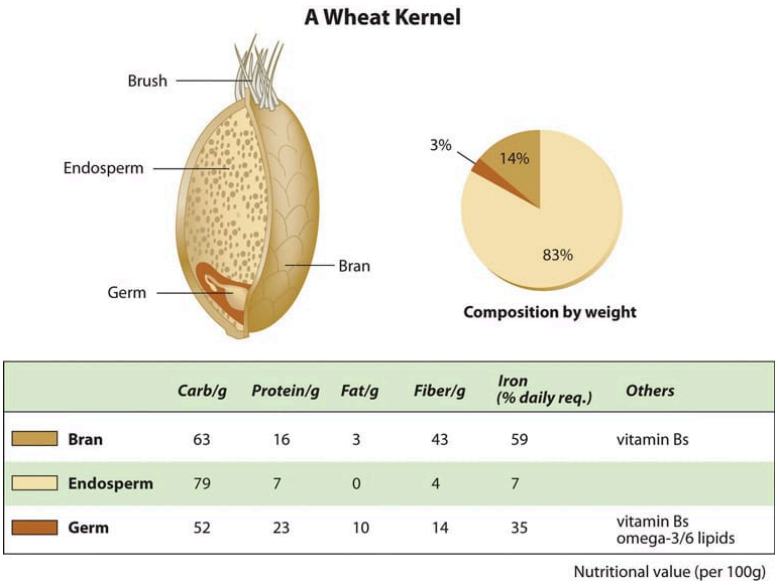
Many people think that we should avoid carbohydrates in the diet, but this important macronutrient is essential and needed in abundance. Carbohydrates are composed of carbon, hydrogen, and oxygen. The most abundant carbohydrate is glucose which is produced by plants through photosynthesis; water, carbon dioxide, and energy from the sun are combined to produce glucose.

Carbohydrate Sources

Food groups that contain carbohydrates include:

- fruits
- vegetables
- dairy
- protein (only in beans and some processed meats)
- grains

Many people immediately think of grains when they think about carbohydrates. You likely eat grains every day—cereal, a sandwich, pasta, or your favorite rice dish. When eating grains, it's important to know that overwhelming scientific evidence now shows that diets containing high amounts of whole grains rather than refined grains decrease weight gain and the risk for many chronic diseases, including certain types of cancer and diabetes. Whole grains contain the bran, endosperm, and germ of the grain (Figure 4.1.1). Refined grains (e.g., white rice) only contain the endosperm. The Food and Drug Administration (FDA) has provided the food industry with specifics on how to label whole-grain foods—to label it as made from 100% percent whole grains. The best way to ensure the product is made from 100% whole grains is to check the ingredient list and look for "*whole* [grain]" (e.g., whole wheat) as the first ingredient.



	Carb/g	Protein/g	Fat/g	Fiber/g	Iron (% daily req.)	Others
Bran	63	16	3	43	59	vitamin Bs
Endosperm	79	7	0	4	7	
Germ	52	23	10	14	35	vitamin Bs omega-3/6 lipids

Nutritional value (per 100g)

Figure 4.1.1: Wheat kernel anatomy and composition

Carbohydrate Classifications

Carbohydrates are the perfect nutrient to meet your body's nutritional needs. They provide energy to all of your cells, including your brain and nervous system. Digestible carbohydrates provide energy, vitamins, and minerals, while indigestible carbohydrates provide a good amount of fiber with a host of other health benefits.

Carbohydrates are broadly classified into two subgroups, "simple" and "complex". Simple carbohydrates are grouped into monosaccharides and disaccharides. The simplest unit of a carbohydrate is a monosaccharide. If you break down the word 'monosaccharide' it means 'one sugar' (mono=one, saccharide=sugar) which is referring to the fact that each monosaccharide is one molecule of sugar. Complex carbohydrates are long chains of monosaccharides. (Figure 4.1.2).

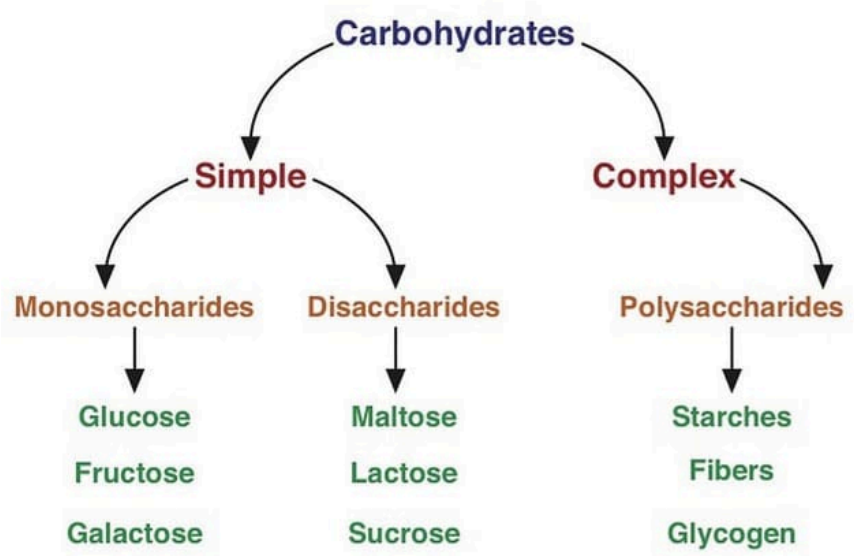


Figure 4.1.2: Carbohydrate Classification Scheme. Carbohydrates are broken down into "simple" and "complex" carbohydrates. These subgroups are further categorized into mono-, di-, and polysaccharides.

Simple Carbohydrates

Simple carbohydrates are grouped as either monosaccharides or disaccharides. Monosaccharides contain only one molecule;

glucose, fructose, and galactose are all monosaccharides. Disaccharides contain two molecules (di=two); lactose, maltose, and sucrose are classified as disaccharides.

Monosaccharides

Take a look at Figure 4.1.3. Notice that all three monosaccharides contain identical atoms: six carbon ("C"), twelve hydrogen ("H"), and six oxygen ("O"). It is only the arrangement of these atoms that differs. For all organisms, from bacteria to plants to animals (including humans), glucose is the preferred fuel source. The brain is completely dependent on glucose as its energy source (except during extreme starvation conditions). The monosaccharide galactose does not occur alone in foods; it binds with glucose to form lactose (a disaccharide). Galactose differs from glucose only in that a hydroxyl (–OH) group faces in a different direction on the number four carbon (Figure 4.1.3). This small structural alteration causes galactose to be less stable than glucose. As a result, the liver rapidly converts galactose to glucose. Most absorbed galactose is utilized for energy production in cells after its conversion to glucose. 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 4.1.3). 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 the sweetest natural sugar and 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. Simplified diagrams of glucose, galactose, and fructose can be seen in Figure 4.1.4.

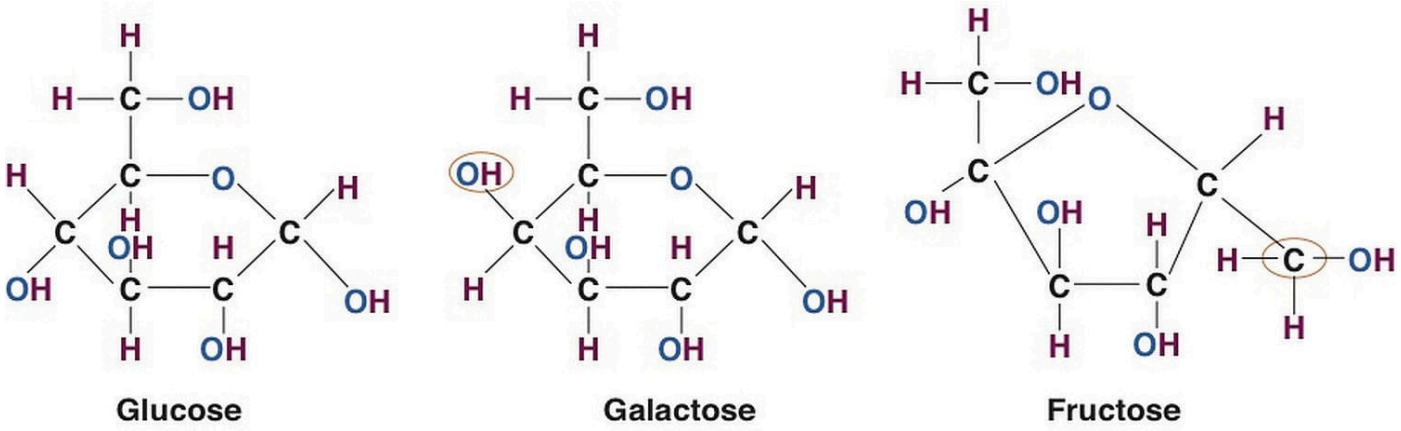


Figure 4.1.3: Chemical structures of the three most common monosaccharides: glucose, galactose, and fructose. Circled areas indicate the structural differences between the three molecules.

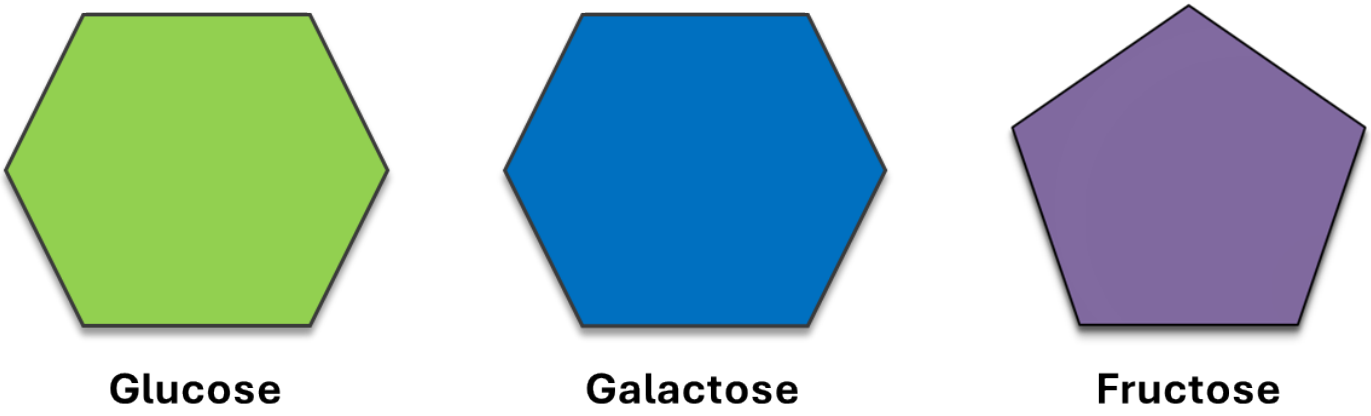


Figure 4.1.4: Simplified diagrams of glucose, galactose, and fructose. (CC BY 4.0; Diana DiMarco)

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

Lastly, there are sugar alcohols, which are industrially synthesized derivatives of monosaccharides. Some examples of sugar alcohols are sorbitol, xylitol, and glycerol. Sugar alcohols are often used in place of table sugar to sweeten foods as they are incompletely digested and absorbed, and therefore contain fewer calories. The bacteria in your mouth opposes them, hence sugar alcohols do not cause tooth decay. Interestingly, the sensation of “coolness” that occurs when chewing gum that contains sugar

alcohols comes from them dissolving in the mouth, a chemical reaction that requires heat from the inside of the mouth.

Disaccharides

Disaccharides are composed of pairs of two monosaccharides linked together. Disaccharides include sucrose, lactose, and maltose (Figure 4.1.5). All of the disaccharides contain at least one glucose molecule.

Sucrose, which contains both glucose and fructose molecules, is also 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. Lactose, which is commonly known as milk sugar, is composed of one glucose molecule and one galactose molecule. Lactose is prevalent in dairy products such as milk, yogurt, and cheese. Maltose consists of two glucose molecules bonded together. It is a common breakdown product of plant starches and is rarely found in foods as a disaccharide.

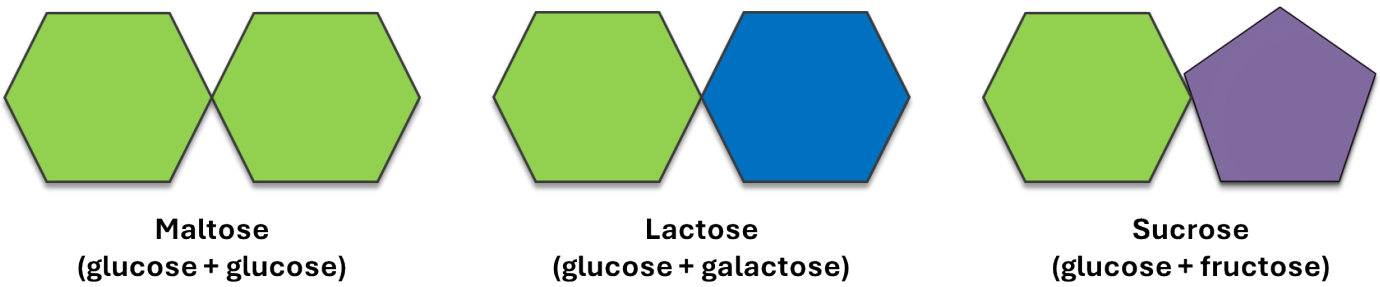


Figure 4.1.5: Simplified diagrams of the disaccharides maltose, lactose, and sucrose. (CC BY 4.0; Diana DiMarco)

Complex Carbohydrates

Complex carbohydrates are polysaccharides, long chains of monosaccharides that may be branched or not branched. Complex carbohydrates can be hundreds to thousands of molecules long. There are three main groups of polysaccharides: starch, glycogen, and fiber.

Starch

Starch molecules are found in abundance in grains, legumes, and root vegetables, such as potatoes. Amylose, a plant starch, is a linear chain containing hundreds of glucose units (Figure 4.1.6). Amylopectin, another plant starch, is a branched chain containing thousands of glucose units. These large starch molecules (amylose and amylopectin) are the storage form of glucose in plants.

Glycogen

Glycogen is not found in plants and very little exists in meat; therefore, it's not a source of carbohydrate that we get from food. However, humans and animals store glucose energy in the form of this very large molecule (glycogen, Figure 4.1.6). 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.

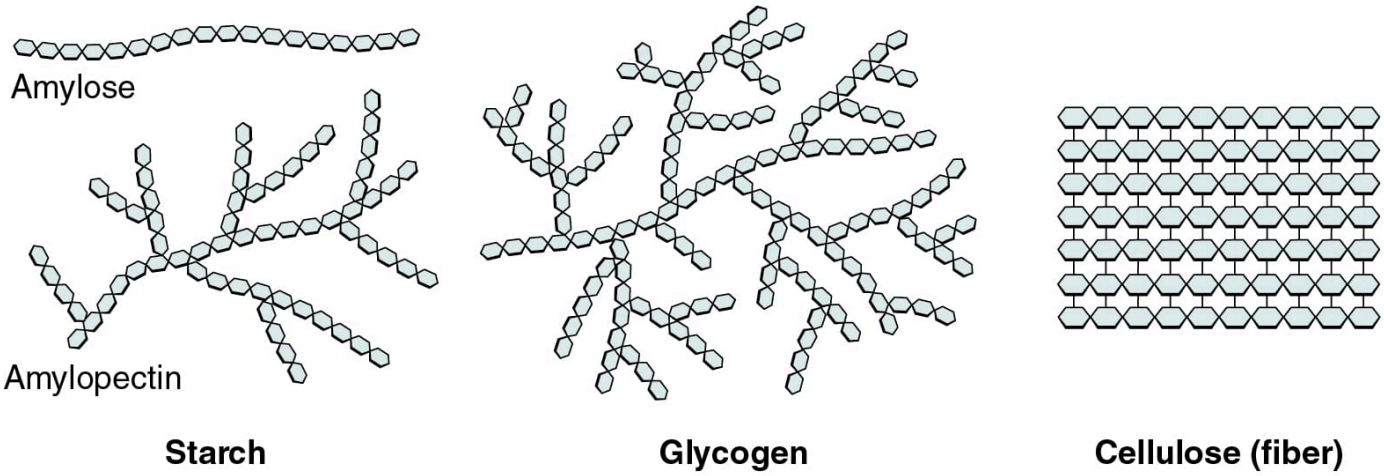


Figure 4.1.6: Structures of three groups of polysaccharides: starch (amylose and amylopectin), glycogen, and fiber. (CC BY 3.0; OpenStax)

Fiber

Fiber is a polysaccharide that is highly branched and cross-linked. Our bodies do not produce the enzymes that can break down fiber which means that most fiber passes through our intestines without being digested and absorbed.

Fiber can be classified in a few ways. One way is by using the categories dietary fiber, functional fiber, and total fiber.

- Dietary fiber: nondigestible parts of plants that form the supportive structure of the plant's seeds, leaves, and stems
- Functional fiber: nondigestible forms of carbohydrates that are extracted from plants or are synthetically made (and have been shown to provide health benefits to humans); examples of functional fibers include psyllium, cellulose, guar gum, and pectin
- Total fiber: dietary fiber + functional fiber

Fiber can also be classified according to its chemical and physical properties (soluble vs. insoluble):

- Soluble fiber: dissolves in water, is viscous (forms a gel in the digestive system), and is easily digested by bacteria in the large intestine (colon); citrus fruits, oats, and beans/legumes are foods that contain soluble fiber; research indicates that diets high in soluble fiber reduce the risk of cardiovascular diseases and Type 2 diabetes by lowering blood cholesterol and blood glucose levels
- Insoluble fiber: does not dissolve in water, is not usually viscous, and is not easily digested so it helps promote regular bowel movements and reduces the risk of diverticulosis; whole grains and vegetables are examples of food that contain insoluble fiber

Watch this short (1 minute) video on the difference between soluble and insoluble fiber.

YouTube Video

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"What's the Difference Between Soluble and Insoluble Fiber?" by WebMD

Self-Check Question

Query 4.1.1

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4.2: Benefits of Fiber

Learning Objectives

- Identify the health benefits of eating a diet high in fiber.

Health Benefits of Fiber in the Diet

Fruits, vegetables, and whole grains all contain fiber. Americans typically do not consume the recommended amount of fruits, vegetables, or whole grains (Figure 4.2.1). The average adult eats less than a cup (0.89)[1] of the recommended 1.5-2.5 cups of fruit per day,[2] 1.53 cups[1] of the recommended 2-4 cups of vegetables daily,[3] and only 0.81 ounce equivalents[1] of the recommended 3-5 ounce equivalents of whole grains per day.[4]

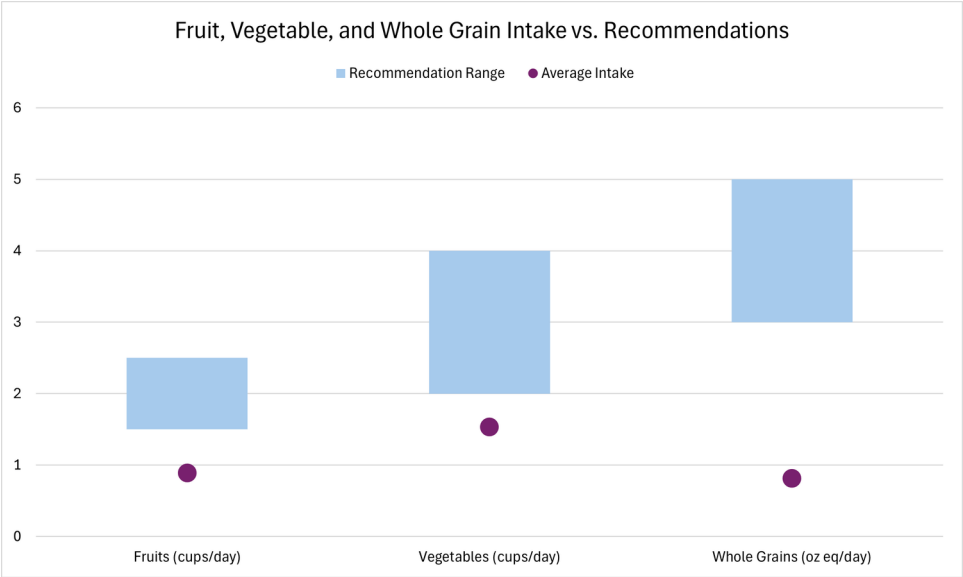


Figure 4.2.1: Fruit, Vegetable, and Whole Grain Intake Compared to Recommendations. (CC BY 4.0; Ann Diker)

Consuming higher amounts of dietary fiber decreases the risk for Type 2 diabetes[5] and cardiovascular disease.[6] Additional benefits of fiber include:

- improved blood glucose control (fiber helps delay the absorption of glucose into the blood)
- potential aid for weight control (fiber helps provide a feeling of fullness)
- helps reduce blood cholesterol levels by delaying or blocking absorption of dietary cholesterol
  - When eating a high-fiber diet, fiber binds to the bile that is produced from cholesterol, resulting in relatively more cholesterol being excreted in the feces
  - When a lower-fiber diet is consumed, less fiber (and thus less cholesterol) is bound to bile and excreted in the feces
- supports digestion and optimizes colon health by helping to prevent:
  - hemorrhoids, constipation, and other intestinal problems (keeps stool soft and moist, gives GI tract muscles “something to push on”)
  - colon cancer[7] (fiber binds cancer-causing substances and speeds elimination from colon)
  - diverticulosis (bulging pockets that can form in the wall of the colon) and diverticulitis (inflamed bulging pockets); see Figure 4.2.2

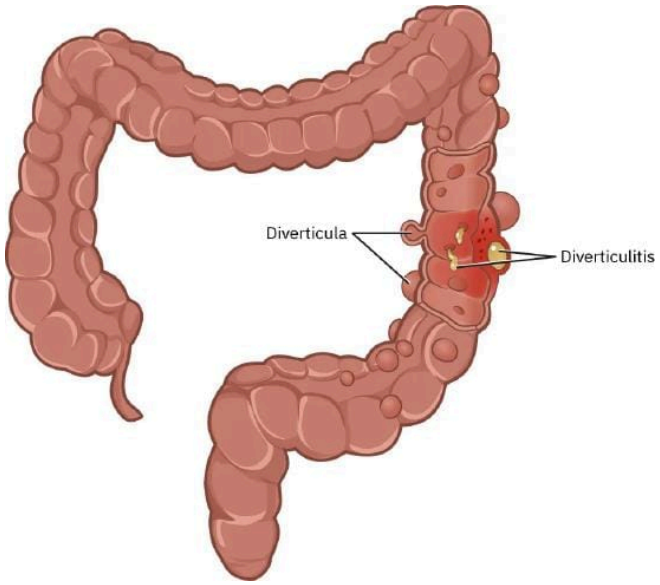


Figure 4.2.2: Diverticulosis is the presence of diverticula, or protrusions, on the walls of the large intestine. When the diverticula become inflamed, the condition is known as diverticulitis (CC BY 4.0; OpenStax)

Most Americans eat considerably less than the recommended amount of fiber.[8] People interested in increasing their fiber intake can include more whole grains, vegetables, fruits, nuts, and legumes/beans in their diet. Increasing fluid intake as you increase your fiber intake is also important to prevent constipation.

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4.3: Digestion and Absorption of Carbohydrates

Learning Objectives

- Discuss how carbohydrates are digested and absorbed in the human body.
- Describe blood glucose regulation.

The primary goal of carbohydrate digestion is to break down polysaccharides and disaccharides into monosaccharides that can then be converted to glucose.

Mouth

The mechanical and chemical digestion of carbohydrates begins in the mouth (see Figure 4.3.1). Chewing breaks the carbohydrate foods into smaller pieces. The salivary glands in the mouth secrete saliva that coats the food particles. Saliva contains the enzyme, salivary amylase. This enzyme begins carbohydrate digestion by breaking some of the bonds between individual units of disaccharides, oligosaccharides, and starches. The salivary amylase breaks down amylose and amylopectin into smaller chains of glucose, called dextrins and maltose. Only about 5% of starches are broken down in the mouth.

Stomach

When carbohydrates reach the stomach, no further chemical breakdown occurs because the amylase enzyme does not function in the acidic conditions of the stomach. But mechanical breakdown is ongoing—the strong peristaltic contractions of the stomach mix the carbohydrates into a semi-fluid mass of partly digested food known as chyme.

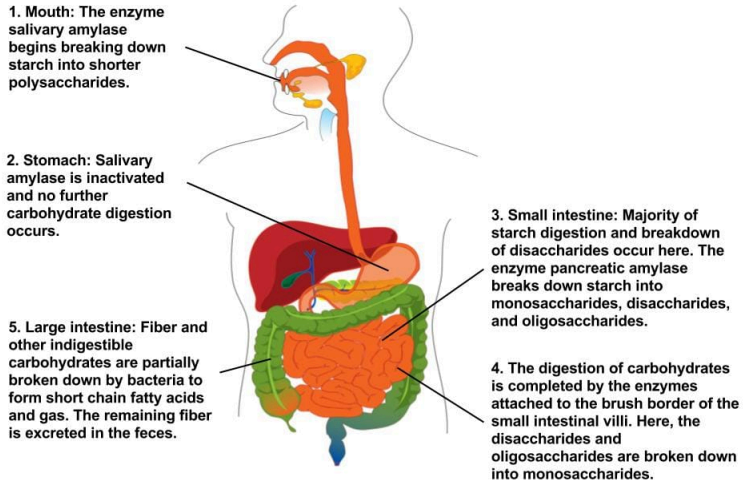


Figure 4.3.1: Overview of Carbohydrate Digestion. (CC BY 4.0; Allison Calabrese via Human Nutrition 2020e (Hawaii))

Small Intestine

Most digestion and absorption occurs in the small intestine.

Digestion

Most chemical digestion of carbohydrates occurs in the small intestine. Chyme from the stomach is gradually released 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 into the small intestine. This pancreatic juice contains the enzyme, pancreatic amylase, which breaks down dextrins into shorter and shorter carbohydrate chains. Additionally, enzymes are secreted by the intestinal cells that line the villi. These enzymes, known collectively as disaccharidases, are sucrase, maltase, and lactase. Sucrase breaks sucrose into glucose and fructose molecules. Maltase breaks the bond between the two glucose units of maltose, and lactase breaks the bond between the galactose and glucose units of lactose. Once carbohydrates are chemically broken down into single sugar units they are then transported into the inside of intestinal cells (enterocytes). See Figure 4.3.2 for a visual of this process.

When people do not have enough of the enzyme lactase, lactose is not sufficiently broken down resulting in a condition called lactose intolerance. The undigested lactose moves to the large intestine where bacteria are able to digest it. The bacterial digestion of lactose produces gases leading to symptoms of diarrhea, bloating, and abdominal cramps. Lactose intolerance usually occurs in adults and is associated with a gene that is inherited and associated with ancestry from certain parts of the world. African Americans, Hispanic Americans, American Indians, and Asian Americans have much higher incidences of lactose intolerance while those of northern European descent have the least.[1] Some people with lactose intolerance can tolerate a small amount of dairy products in their diet. The severity of the symptoms depends on how much lactose is consumed and the degree of lactase deficiency.

Absorption

The enterocytes have membranes that contain many transport proteins in order to get the monosaccharides and other nutrients into the blood where they can be distributed to the rest of the body (see Figure 4.3.2). 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.

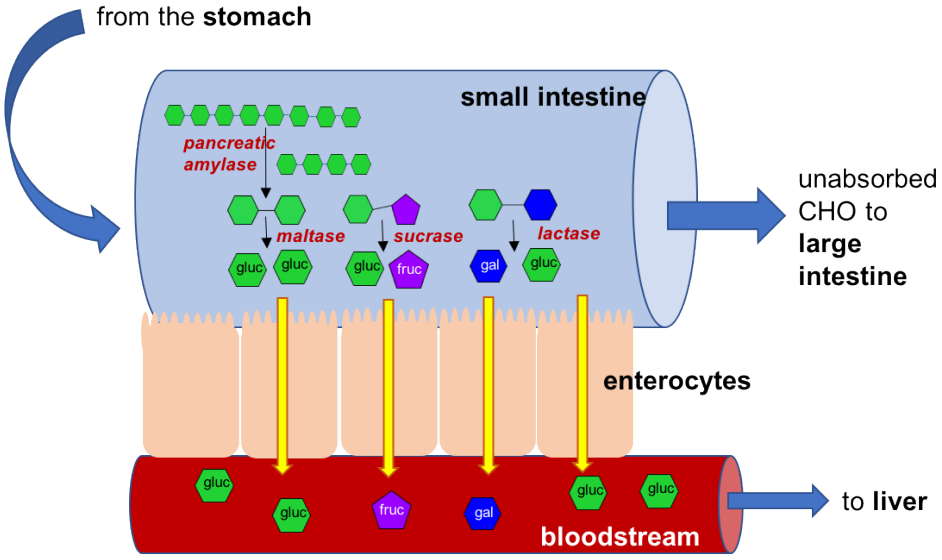


Figure 4.3.2: Digestion and absorption of carbohydrates in the small intestine. (CC BY-NC-SA 4.0; Alice Callahan)

Large Intestine

Almost all carbohydrates are efficiently digested and absorbed into the body. Some of these remaining carbohydrates (e.g., fiber) are broken down by enzymes released by bacteria that live in the large intestine. The products of bacterial digestion of these complex 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 feces, or are absorbed into cells of the colon, with a small amount being transported to the liver. Colonic cells use the short-chain fatty acids to support some of their functions. The liver can also metabolize the short-chain fatty acids into cellular energy. The yield of energy from dietary fiber is about 2 calories per gram for humans, but is

highly dependent upon the fiber type, with soluble fibers yielding more energy than insoluble fibers. Since dietary fiber is digested much less in the gastrointestinal tract than other carbohydrate types (simple sugars, many starches) the rise in blood glucose after eating them is less, and slower. These physiological attributes of high-fiber foods (i.e. whole grains) are linked to a decrease in weight gain and reduced risk of chronic diseases, such as Type 2 diabetes and cardiovascular disease.

Blood Glucose Regulation

Remember, the primary goal of carbohydrate digestion is to break down polysaccharides and disaccharides into monosaccharides that can then be converted to glucose. 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 bake a dessert at 375°F the thermostat senses the temperature and sends an electrical signal to turn the elements on and heat up the oven. When the temperature reaches 375°F the thermostat senses the temperature and sends a signal to turn the element off. Similarly, your body senses blood glucose levels and maintains the glucose “temperature” in the target range. The glucose thermostat is located within the cells of the pancreas.

After eating a meal containing carbohydrates, glucose levels rise in the blood (Figure 4.3.3). Beta cells in the pancreas sense the increase in blood glucose and release a hormone, 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 as fuel or to store any extra glucose. When glucose is stored, most of it is stored in muscle and liver tissues. In these tissues it is stored as glycogen, a highly branched macromolecule consisting of thousands of glucose molecules. Enzymes in the liver and muscles combine glucose molecules to form glycogen through a process known as glycogenesis ("-genesis" = production). Glycogen levels do not take long to reach their physiological limit and when this happens excess glucose will be converted to fat.

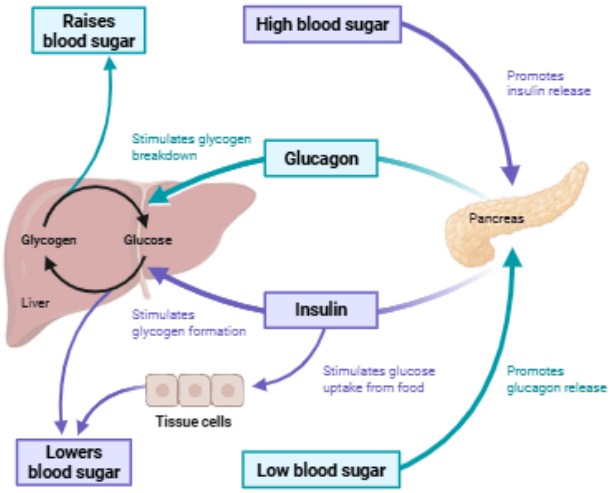


Figure 4.3.3: Blood Glucose Regulation (CC BY 4.0; Ann Diker, created in BioRender.com)

Insulin has an opposing hormone called glucagon. As the time after a meal increases, glucose levels decrease in the blood (Figure 4.3.3). Alpha 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 begin glycogenolysis ("-lysis" = break down) 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. If additional glucose is needed, glucagon will stimulate the production of new glucose from amino acids (a process known as gluconeogenesis).

Watch the video below for a review of blood glucose regulation.

YouTube Video

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"Blood Glucose Regulation and Diabetes" by Zero to Finals

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4.4: Functions of Carbohydrates

Learning Objectives

- List and describe functions of carbohydrates in the human body.

There are four primary functions of carbohydrates in the human body. They are energy production, energy storage, sparing protein, and preventing ketosis.

Energy Production

The primary role of carbohydrates is to supply energy to all cells in the body; each gram of carbohydrate supplies 4 kilocalories. Many cells prefer glucose as a source of energy versus other compounds like fatty acids. Some cells, such as red blood cells, are only able to produce cellular energy from glucose. The brain is also highly sensitive to low blood-glucose levels because it uses *only* glucose to produce energy and function (unless under extreme starvation conditions). About 70% of the glucose entering the body from digestion is redistributed (by the liver) back into the blood for use by other tissues. Cells that require energy remove the glucose from the blood with a transport protein in their membranes. The energy from glucose comes from the chemical bonds between the carbon atoms. Sunlight energy was required to produce these high-energy bonds in the process of photosynthesis. Cells in our bodies break these bonds and capture the energy to perform cellular respiration. Cellular respiration is basically a controlled burning of glucose versus an uncontrolled burning. A cell uses many chemical reactions in multiple enzymatic steps to slowly release and efficiently capture the energy held within the chemical bonds in glucose.

Energy Storage

If the body already has enough energy to support its functions, the excess glucose is stored as glycogen (the majority of which is stored in the muscle and liver). A molecule of glycogen may contain over 50,000 single glucose units and is highly branched, allowing for the rapid dissemination of glucose when it is needed to make cellular energy (Figure 4.4.1).

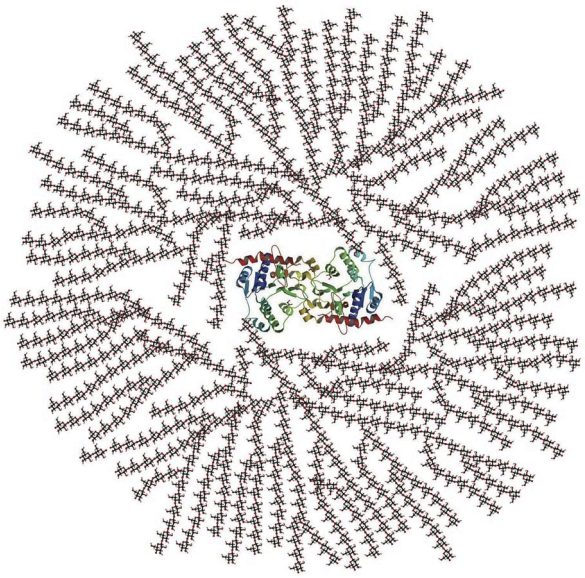


Figure 4.4.1:The structure of glycogen enables its rapid mobilization into free glucose to power cells.

The amount of glycogen in the body at any one time is equivalent to about 4,000 calories—3,000 in muscle tissue and 1,000 in the liver. During high intensity exercise, proportionally more carbohydrate is used as fuel. During low intensity exercise, proportionally more fat is used as fuel. Prolonged muscle use (such as exercise for longer than a few hours) can deplete the glycogen energy reserve. This is sometimes referred to as “hitting the wall” and is characterized by fatigue and a decrease

in exercise performance. The weakening of muscles occurs because it takes longer to transform the chemical energy in fatty acids and proteins to usable energy compared to using 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 through training combined with post-exercise carbohydrate intake. Additionally, athletes can increase their glycogen reserves short-term if they are competing in an endurance event longer than 90 minutes by increasing carbohydrate intake 1-3 days prior to the event. It is best for athletes interesting in increasing their glycogen stores to work with a sports and human performance dietitian. People who are not participating in long-term intense training and choose to run a 5-kilometer race for fun do not need to consume a big plate of pasta prior to a race since without long-term intense training the adaptation of increased muscle glycogen will not happen.

The liver, like muscle, can store glucose energy as glycogen, but in contrast to muscle tissue, the liver 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 breakdown of proteins (through a process known as gluconeogenesis).

Sparing Protein

In a situation where there is not enough glucose to meet the body's needs, glucose is synthesized from amino acids (through gluconeogenesis). Because there is no storage molecule of amino acids, this process requires the breakdown of proteins, primarily from muscle tissue. Therefore, the body cannot use proteins to make new cells, repair tissue damage, support our immune system, and perform many other functions. The presence of adequate glucose basically spares the breakdown of proteins from being used to make glucose needed by the body.

Preventing Ketosis

As blood-glucose levels rise, the use of lipids as an energy source is inhibited. Thus, glucose additionally has a "fat-sparing" effect. This is because an increase in blood glucose stimulates release of the hormone insulin, which tells cells to use glucose (instead of lipids) to make energy. Adequate glucose levels in the blood also prevent the development of ketosis. Ketosis is a metabolic condition resulting from an elevation of ketone bodies in the blood. Ketone bodies are an alternative energy source that cells can use when glucose supply is insufficient, such as during fasting. Ketone bodies are acidic and high levels of ketones in the blood can cause the blood to become too acidic (a condition known as ketoacidosis) and cause damage to body tissues. Ketoacidosis is rare in healthy adults, but can occur in alcoholics, people who are malnourished, and in individuals who have Type 1 diabetes. The minimum amount of carbohydrate in the diet required to inhibit ketosis in adults is 50 grams per day.[1,2] Symptoms of ketosis include dehydration, bad breath (sometimes called "keto breath"), and high blood acidity.

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4.5: Carbohydrate Recommendations

Learning Objectives

- Identify the Acceptable Macronutrient Distribution Range for carbohydrates.
- Identify the Adequate Intake for fiber.
- Identify recommendations for added sugar intake.

How Many Carbohydrates Does a Person Need?

The Food and Nutrition Board of the National Academies of Sciences, Engineering, and Medicine has set the Recommended Dietary Allowance (RDA) of carbohydrates for children and adults at 130 grams per day (Table 4.5.1).[1] This is the average minimum amount the brain requires to function properly. It does not include the amount of carbohydrate needed to support daily activities. The Acceptable Macronutrient Distribution Range (AMDR) for carbohydrates is 45-65% of total calories[1]; this range of intake is associated with a decreased risk for chronic diseases. When translating the AMDR into calories, it means that a person following a 2,000 kilocalorie diet should consume 900-1,300 carbohydrate calories (225-325 grams of carbohydrate) each day. The Food and Nutrition Board has also set the Adequate Intake (AI) for dietary fiber at 14 grams for every 1,000 calories consumed.[1] For men and women ages 19-50, this translates into an AI of 38 grams for men and 25 grams for women. For men and women ages 51 and older, this translates into an AI of 30 grams for men and 21 grams for women. The recommendations for dietary fiber are based on intake levels known to prevent heart disease.

Table 4.5.1: Dietary Reference Intakes for Carbohydrates and Fiber

Carbohydrate Type	AI (g/day)	RDA (g/day)	AMDR (% calories)
Total Carbohydrates		130	45–65
Fiber	14g / 1,000 kcal		

Added Sugars

There are two types of sugars in our diets: naturally occurring sugars and added sugars. Naturally occurring sugars are found in foods such as fruit (which contains fructose) and milk (which contains lactose). Added sugars include any sugar or sweetener that is added to foods or beverages during processing or preparation. The Dietary Guidelines for Americans recommends no more than 10 grams of added sugars in a meal,[2] which is similar to the American Heart Association's recommendation to limit added sugars to no more than 6% of calories each day.[3] A major source of added sugars in the American diet is sugar-sweetened beverages. There is consistent scientific evidence that consuming sugar-sweetened beverages increases weight gain and risk for diseases such as Type 2 diabetes and heart disease.[4,5] In addition, diets high in added sugars are associated with dental problems such as cavities and gum disease, increased levels of low-density lipoproteins (LDL, sometimes referred to as “bad cholesterol”), and decreased levels of high-density lipoproteins (HDL, sometimes referred to as “good cholesterol”). Currently, Americans consume 13% of their total calories from added sugars (Figure 4.5.1). The Nutrition Facts label includes information on added sugars which can be used to identify foods and beverages that have a high amount of added sugars.

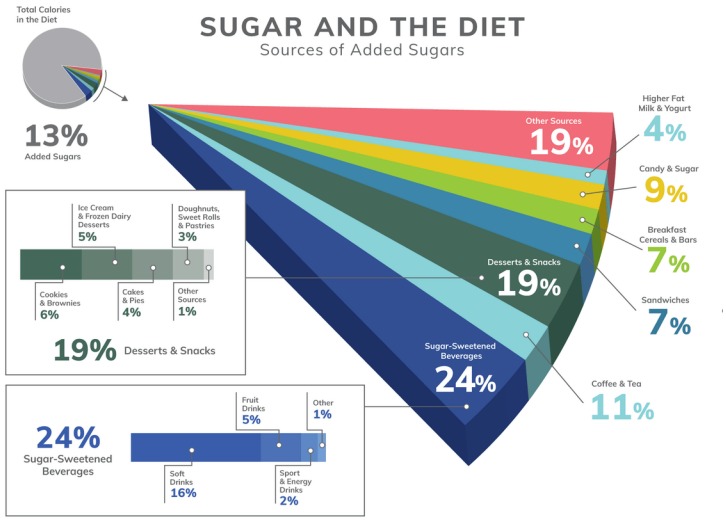


Figure 4.5.1: Sources of Added Sugar in the Diet ("Sugar and the Diet: Sources of Added Sugars" by The Sugar Association)

Dietary Sources of Carbohydrates

Carbohydrates are contained in all five food groups: grains, fruits, vegetables, protein (only in beans and some processed meats), and dairy products. Simple carbohydrates are more prevalent in fruits, fruit juices, and dairy products, while complex carbohydrates are more plentiful in starchy vegetables, beans, and whole grains. In choosing dietary sources of carbohydrates the best ones are those that are nutrient-dense, meaning they contain more essential nutrients per calorie of energy. In general, nutrient-dense carbohydrates are minimally processed and include whole grains, low-fat dairy products, fruits, vegetables, and beans. In contrast, empty-calorie carbohydrate foods are highly processed and often contain added sugars and fats. Sugar-sweetened beverages, cakes, cookies, and candy are examples of empty-calorie carbohydrates.

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4.6: Looking Closely at Diabetes

Learning Objectives

- Compare and contrast Type 1 diabetes, Type 2 diabetes, and gestational diabetes.
- Describe the long-term health consequences of diabetes.

Diabetes is one of the top diseases in America. Over 40 million Americans (12% of the population) are living with diabetes, and an estimated 115 million Americans age 18 and older are living with prediabetes (~36% of the population).[1] Poorly treated or untreated diabetes has many serious side effects, including kidney failure, blindness, limb loss, and a greatly accelerated risk of cardiovascular disease.

Diabetes is a metabolic disorder that results when the pancreas does not produce enough insulin to meet its needs or the body does not effectively utilize the insulin that it does produce. Remember from previous readings that insulin is one of the hormones that regulates blood glucose levels. The most common complication of poorly controlled diabetes is hyperglycemia (high blood sugar), which gradually leads to damage in many of the body's systems, most notably the eyes, kidneys, nerves, and heart and blood vessels. Uncontrolled diabetes can cause nerve damage, kidney damage, blindness, amputations, stroke, cardiovascular disease, and diabetic ketoacidosis (which can result in coma and/or death). Like other diseases, genetics, nutrition, environment, and lifestyle are all involved in determining a person's risk for developing diabetes. In this section, we'll discuss the 3 most common types of diabetes: Type 1 diabetes, Type 2 diabetes, and gestational diabetes.

Type 1 Diabetes

Type 1 diabetes is an autoimmune condition in which the pancreas does not produce insulin. Type 1 diabetes accounts for 5-10% of diabetes cases. Anyone can be diagnosed with Type 1 diabetes at any age.[2] The insulin-producing beta cells of the pancreas are destroyed, so the body cannot produce enough insulin, which causes hyperglycemia (high blood sugar). The only way to prevent the deadly symptoms of this disease is to deliver 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.

Many people with Type 1 diabetes have a rapid onset of symptoms that include increased hunger, excessive thirst, frequent urination, and rapid weight loss (see Figure 4.6.1). However, early detection can be done with a blood test that screens for antibodies associated with Type 1 diabetes.[3] Because the main function of glucose is to provide energy for the body, when insulin is no longer present, there is no message 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. Ketoacidosis is a severe form of ketosis with symptoms of vomiting, dehydration, rapid breathing, and confusion. In extreme situations, ketoacidosis can lead to coma and/or death.

People with Type 1 diabetes must balance the amount of carbohydrates eaten with the right dose of insulin.[4] There is no ideal percentage of calories from carbohydrate, protein, or fat for people with diabetes, so macronutrient distribution should be based on an individualized assessment of current eating patterns, preferences, and goals.[5] Ongoing support from a Registered Dietitian Nutritionist (RDN) who focuses on diabetes management and is a Certified Diabetes Care and Education Specialist (CDCES) can be helpful in developing an appropriate, individualized eating pattern for Type 1 diabetes management.

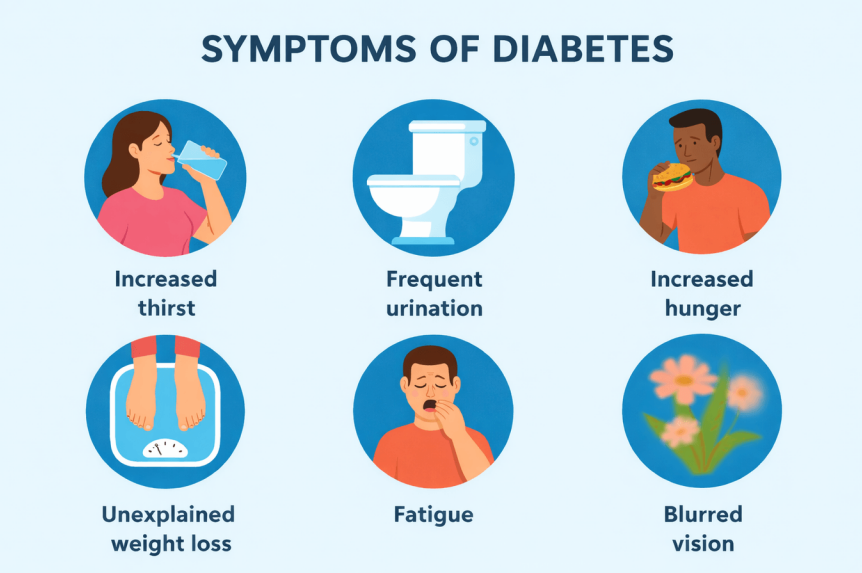


Figure 4.6.1: Diabetes symptoms. (OpenAI)

Type 2 Diabetes

The other 90-95% of diabetes cases are Type 2 diabetes. Type 2 diabetes results when the pancreas produces enough insulin initially, but the body's cells no longer respond appropriately and are unable to use the hormone properly (i.e., insulin resistance). During insulin resistance, the body's cells no longer receive the full physiological message of insulin to take up glucose from the blood (Figure 4.6.2). Hyperglycemia results because cells cannot take in the glucose from the blood. Thus, similar to patients with Type 1 diabetes, those with Type 2 diabetes also have high blood-glucose levels.

For Type 2 diabetics, the onset of symptoms can be gradual and less noticeable than for Type 1 diabetics. The symptoms are increased thirst and urination, unexplained weight loss, and hunger. The first stage of Type 2 diabetes is characterized by high glucose and insulin levels (Figure 4.6.2). 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, Type 2 diabetics also have to deliver insulin under the skin to help manage their blood glucose levels. 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. Since major contributing factors to the development of Type 2 diabetes include excessive body weight and physical inactivity, the front-line approach for treating Type 2 diabetes includes eating a healthy diet and increasing physical activity.

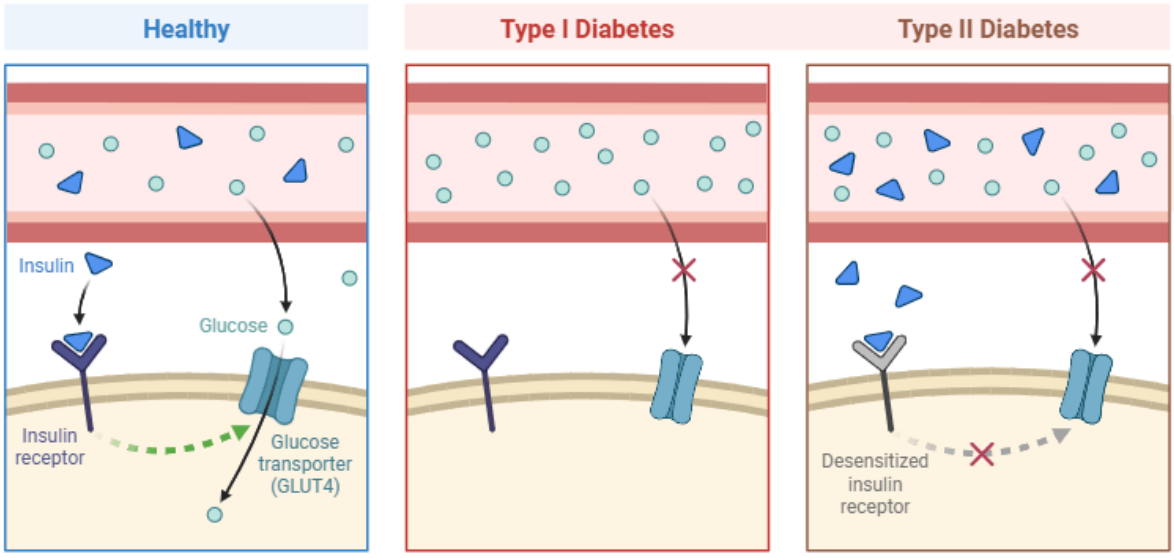


Figure 4.6.2: Differences in insulin and glucose between healthy condition, Type 1 Diabetes, and Type 2 Diabetes. (Eunice Huang via BioRender)

Genetics, environment, nutrition, and lifestyle all play a role in determining a person's risk for Type 2 diabetes. 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 4.6.3). 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 149 mg/dL; high-density lipoproteins (HDL) lower than 40 mg/dL for males (lower than 50 mg/dL for females); systolic blood pressure above 129 mmHg, or diastolic blood pressure above 84 mmHg; fasting blood glucose levels greater than 99 mg/dL.[6] Approximately 33% of adults in the U.S. meet criteria for metabolic syndrome,[7] which can lead to serious health problems including heart disease, stroke, and diabetes.[8]

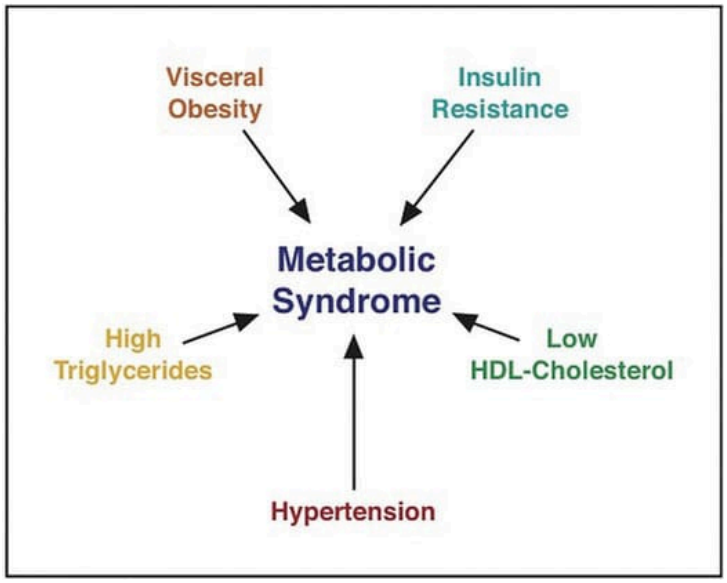


Figure 4.6.3: Metabolic Syndrome consists of a combination of risk factors that increase the chances for chronic disease. (CC BY-NC-SA 4.0; LibreTexts An Introduction to Nutrition (Zimmerman))

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 a diabetes diagnosis. More than 1/3 of adults in the United States are estimated to have prediabetes.[1] Over time, people with prediabetes may develop Type 2 diabetes. Although researchers don't fully understand what causes prediabetes, excess weight and lack of physical activity are considered to be major factors.

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 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 had gestational diabetes are more likely to develop Type 2 diabetes later in life.[9] 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.[9]

Long-Term Health Consequences of Diabetes

The long-term health consequences of diabetes are severe and result from chronically high glucose concentrations in the blood, accompanied by other metabolic abnormalities such as high blood lipid levels. People with diabetes are about twice as likely to die from cardiovascular disease compared to people without diabetes.[10] 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.

Diabetes Treatment

Keeping blood glucose levels in the target range (80–130 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. Type 1 diabetics begin delivering insulin under the skin as soon as they are diagnosed (Figure 4.6.4).

Type 2 diabetics may require oral medications and/or insulin delivery under the skin to maintain blood glucose levels in the target range. The major determinants of Type 2 diabetes that can be changed are overnutrition and a sedentary lifestyle. Therefore, reversing or improving these factors by lifestyle interventions can markedly improve the overall health of Type 2 diabetics and lower blood glucose levels. In fact, it has been shown that losing 5-7% of body weight and increasing physical activity to at least 150 minutes per week reduced the risk of developing Type 2 diabetes by 58% in adults at high risk.[11]

Having too low blood glucose levels, known as hypoglycemia, is also detrimental to health. Hypoglycemia is more common in Type 1 diabetics and is most often caused by delivering too much insulin or delivering it at the wrong time. The symptoms of hypoglycemia are more acute, including shakiness, sweating, nausea, hunger, clamminess, fatigue, confusion, irritability, stupor, seizures, and coma. Hypoglycemia can be rapidly and simply treated by eating foods containing about 15 grams of simple carbohydrates (e.g., 1/2 cup of fruit juice). 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 breaks down glycogen in the liver into glucose.

Some people who are not diabetic may experience reactive hypoglycemia. This is a condition in which blood sugar drops after a meal - usually within four hours after eating. 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 to a level below what is required for proper brain function.

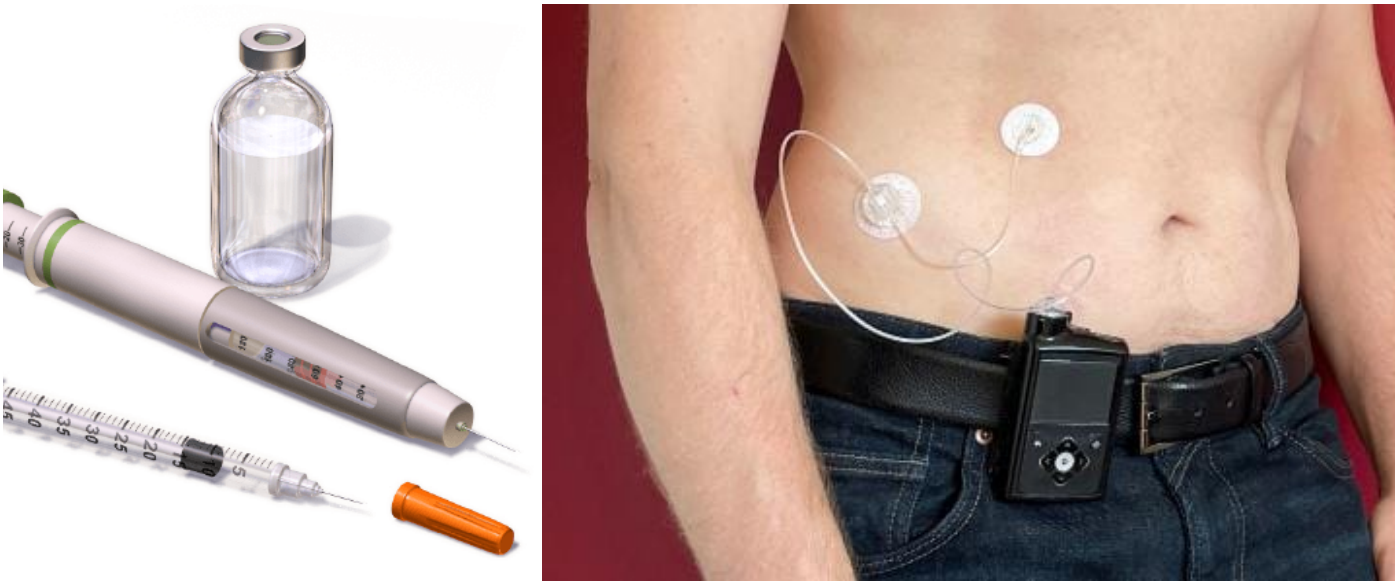


Figure 4.6.4: Insulin syringe and pen (right, CC BY-SA 3.0; BruceBlaus), insulin pump (left, CC BY-SA 4.0; Medtd1 via Wikimedia Commons).

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4.7: Sugar Substitutes

Learning Objectives

- Discuss the pros and cons of consuming foods and beverages that contain sugar substitutes.

Sugar substitutes have replaced added sugars in many foods and beverages due to the potential health consequences of consuming too many added sugars. Sugar substitutes include artificial sweeteners and sugar alcohols.

Artificial sweeteners are non-nutrients that provide little or no energy/calories (see Table 4.7.1). They are much more intense in sweetness when compared to sucrose (see Table 4.7.1), so they are added in very small amounts to foods and beverages. Artificial sweeteners must be approved by the U.S. Food and Drug Administration (FDA) for use in foods and beverages; those approved by the FDA include saccharin, aspartame, acesulfame potassium, advantame, neotame, and sucralose.[1]

Sugar alcohols, such as xylitol, sorbitol, erythritol, and mannitol, are carbohydrates that occur naturally in some fruits and vegetables. However, they are industrially synthesized with yeast and other microbes for use as food additives. The FDA requires that foods disclose the fact that they contain sugar alcohols, but does not require scientific testing of them (though many of them have undergone studies anyway). Sugar alcohols are typically less sweet than sucrose. Sugar alcohols are somewhat digested and absorbed and contribute fewer calories per gram compared to sucrose (see Table 4.7.1).

Benefits

Consuming foods and beverages containing sugar substitutes may benefit health by reducing the consumption of simple sugars, which are higher in calories, potentially linked to chronic disease, and cause tooth decay. There is limited scientific evidence that consuming products with artificial sweeteners decreases weight or improves blood glucose control.[2]

Artificial sweeteners and sugar alcohols are not “fermentable sugars” and therefore do not cause tooth decay. Chewing gum with artificial sweeteners is the only proven way that artificial sweeteners promote oral health. The American Dental Association (ADA) allows manufacturers of chewing gum to label packages with an ADA seal if they have convincing scientific evidence demonstrating their product either reduces plaque acids, cavities, or gum disease, or promotes tooth remineralization.

Health Concerns

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

In the early 1970s, scientific studies were published that demonstrated that high doses of saccharin caused bladder tumors in rats. This information fueled the still-ongoing debate of the health consequences of all artificial sweeteners. In actuality, the results from the early studies were completely irrelevant to humans. The large doses (2.5% of diet) of saccharin caused a pellet to form in the rat’s bladder. That pellet chronically irritated the bladder wall, eventually resulting in tumor development. Since this study, scientific investigation in rats, monkeys, and humans have not found any relationship between saccharine consumption and bladder cancer. In 2000, saccharin was removed from the US National Toxicology Program’s list of potential carcinogens.[3]

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

The International Agency for Research on Cancer (IARC) has classified aspartame as possibly carcinogenic to humans while also noting limitations in the available evidence for cancer and the need for more research.[4] The FDA disagrees with the IARC's conclusion, stating that FDA scientists do not have safety concerns when aspartame is used under approved conditions and that the sweetener is approved in many countries.[1] Navigating different information from different health organizations can be challenging, so, ultimately, individuals can decide whether or not to include sugar substitutes in their diet based on their individual level of concern.

Regulation

Prior to introducing any new artificial sweetener into foods, the artificial sweetener is rigorously tested and must be legally approved by the FDA. The FDA regulates artificial sweeteners along with other food additives, which number in the thousands. The FDA is responsible for determining whether a food additive presents “a reasonable certainty of no harm” to consumers when used as proposed and, if safe, is designated Generally Recognized As Safe (GRAS) for public use. As part of the approval process, the FDA establishes Acceptable Daily Intake (ADI) levels for artificial sweeteners. The ADIs are the maximum amount in milligrams per kilogram of body weight considered safe to consume daily (mg/kg bw/day) and incorporate a large safety factor. For more details on sugar substitutes including each sweetener's ADI please refer to Table 4.7.1.

Table 4.7.1: Sugar Substitutes[1]

Sweetener	Examples of Brand Names	Digestion and Absorption	Kcal per gram	# of Times Sweeter than Sucrose	ADI (mg/kg body weight/day)
Acesulfame Potassium (Ace-K)	Sweet One® Sunett®	Not digested, absorbed, and quickly excreted	0	200x	15 mg/kg body weight/day (23 packets or 20 cans diet soda)
Aspartame	Nutrasweet® Equal®	Digested and absorbed	4	200x	50 mg/kg body weight/day (75 packets or 14 cans diet soda)
Advantame	Advantame®	Minimally digested, absorbed, excreted	0	20,000x	32.8 mg/kg body weight/day (4,920 packets)
Allulose		Absorbed and eliminated	0.4	0.7x	no ADI established research indicates 0.5g/kg body weight is generally well-tolerated
Neotame	Newtame®	Absorbed and rapidly excreted	0	10,000x	0.3 mg/kg body weight/day (23 packets)
Saccharin	Sweet'N Low®	Not digested, excreted	0	400x	15 mg/kg body weight/day (45 packets)
Siraitia grosvenorii	Monk fruit	Not digested, minimally absorbed, excreted	0	100-250x	no ADI established

Sweetener	Examples of Brand Names	Digestion and Absorption	Kcal per gram	# of Times Sweeter than Sucrose	ADI (mg/kg body weight/day)
Steviol Glycosides	Truvia® PureVia®	Not digested or absorbed	N/A	300x	4 mg/kg body weight/day (27 packets)
Sucralose	Splenda®	Not digested, minimally absorbed, fully excreted	0	600x	5 mg/kg body weight/day (23 packets)
Sugar Alcohols	Sorbitol Xylitol Mannitol	Slowly and incompletely absorbed	1.6–2.6	0.25-1.00x	no ADI established

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5: LIPIDS

5.1: Introduction to Lipids

5.2: Digestion and Absorption of Lipids

5.3: Functions of Lipids

5.4: Lipid/Fat Recommendations

5.5: Understanding Blood Cholesterol and Heart Disease

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5.1: Introduction to Lipids

Learning Objectives

- Describe the three types of lipids.
- Compare and contrast fatty acid structures.

Does it surprise you to know that you should not eat a fat-free diet? Lipids are essential nutrients and we need these compounds in the diet in moderate amounts. Lipids are a family of organic compounds that are mostly insoluble in water. Lipids are molecules that yield high energy and have a chemical composition mainly of carbon, hydrogen, and oxygen. The three main types of lipids are triglycerides, phospholipids, and sterols (Figure 5.1.1).

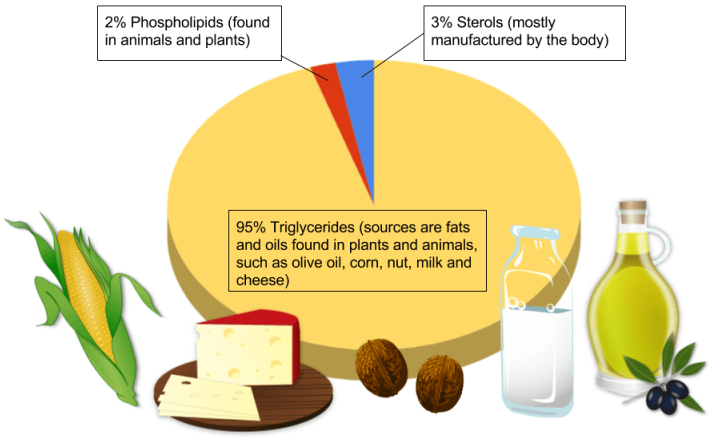


Figure 5.1.1: Types of Lipids (CC BY 4.0; Allison Calabrese)

Triglycerides

Triglycerides make up more than 95% of lipids in the diet. We commonly call the triglycerides in our food “fats” and “oils.” Fats are solid at room temperature; oils are generally liquid at room temperature.

Fatty acids and glycerol are the building blocks of triglycerides. To form a triglyceride, a glycerol molecule is bonded to three fatty acids (Figure 5.1.2). Glycerol is a 3-carbon alcohol that is the backbone of a triglyceride; any three fatty acids attach to the glycerol backbone.

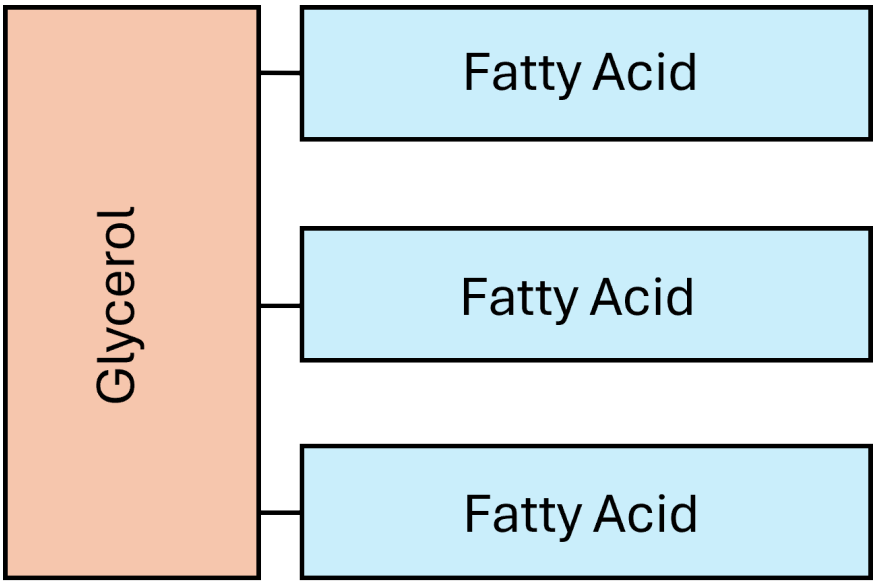


Figure 5.1.2: Structure of a triglyceride. (CC BY 4.0; Ann Diker)

Fatty Acids

Fatty acids determine if the fatty portion of a food is solid or liquid at room temperature. Fatty acids can differ from one another in three important ways—carbon chain length, degree of saturation, and shape.

Carbon Chain Length

Fatty acids have different chain lengths. Foods have fatty acids with chain lengths between 4 and 24 carbons and most of them contain an even number of carbon atoms. Fatty acids can be named based on their chain length; for example, short- (less than 6 carbons), medium- (6-12 carbons), or long-chain (14 or more carbons). When the carbon chain length is shorter, the melting point of the fatty acid becomes lower—and the fatty acid becomes more liquid. The length of the carbon chain determines the method of digestion, absorption, and transport in the body.

Degree of Saturation

Fatty acid chains are made of carbon atoms that attach to each other and to hydrogen atoms. The term *saturation* refers to whether or not a fatty acid chain is filled (or “saturated”) to capacity with hydrogen atoms. Each carbon can bond to 4 atoms; typically in a fatty acid chain, a carbon atom will be bonded to 2 other carbons. This leaves 2 bonds available to potentially bond to hydrogen atoms. If each of the available bonds hold a hydrogen atom it's a saturated fatty acid chain (Figure 5.1.3). All of the carbon atoms in a saturated fatty acid chain are bonded through single bonds. The formation created by single bonds means saturated fatty acids can pack tightly together and are solid at room temperature. Examples of foods high in saturated fatty acids include meats, butter, and lard.

If there is a place on the chain where a hydrogen atom is missing, it is known 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 (Figure 5.1.3). Any fatty acid that has only one double bond is a monounsaturated fatty acid. A polyunsaturated fatty acid is a fatty acid with two or more double bonds or two or more points of unsaturation. Unsaturated fatty acids do not stack together well and are liquid at room temperature. Examples of foods high in unsaturated fatty acids include olive oil (~75% of its fat is monounsaturated) and soybean oil (~60% of its fat is polyunsaturated).

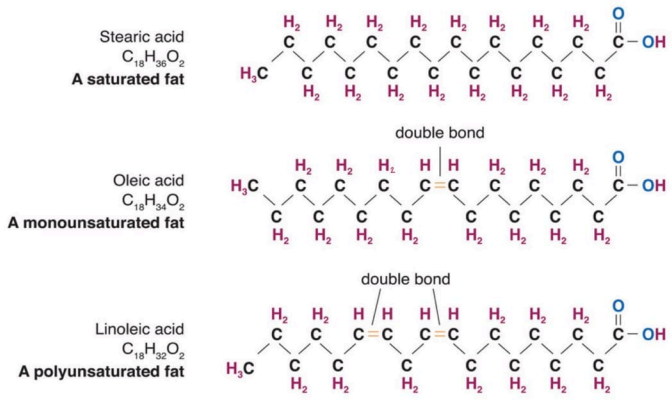


Figure 5.1.3: Chemical structure of saturated, monounsaturated, and polyunsaturated fats (CC BY-NC-SA 4.0; Lauren Groth)

Shape

The introduction of a carbon double bond (C=C) 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 around the double bond are bonded to the same side of the carbon chain, it is called a *cis* fatty acid (Figure 5.1.4). Because the hydrogen atoms are on the same side, the carbon chain has a bent structure. Naturally occurring fatty acids usually have a *cis* configuration.

In a *trans* fatty acid, the hydrogen atoms are attached on opposite sides of the C=C bond (Figure 5.1.4). Unlike *cis* fatty acids, most *trans* fatty acids are not found naturally in foods, but are a result of a process called hydrogenation. Hydrogenation is the process of adding hydrogen atoms to an unsaturated fat (the hydrogen atoms are added where there are 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. The hydrogenation process makes the fat more similar to a saturated fat and makes the fat more stable which is advantageous for the shelf-life of products that include *trans* fats. However, *trans* fatty acids have been associated with increased risk for heart disease because of the way they negatively impact blood cholesterol levels. The Nutrition Facts label includes *trans* fat as a separate line item under the "Total Fat" section. In addition, ingredients that include the word "hydrogenated" or "partially hydrogenated" indicate the presence of *trans* fat in the food.

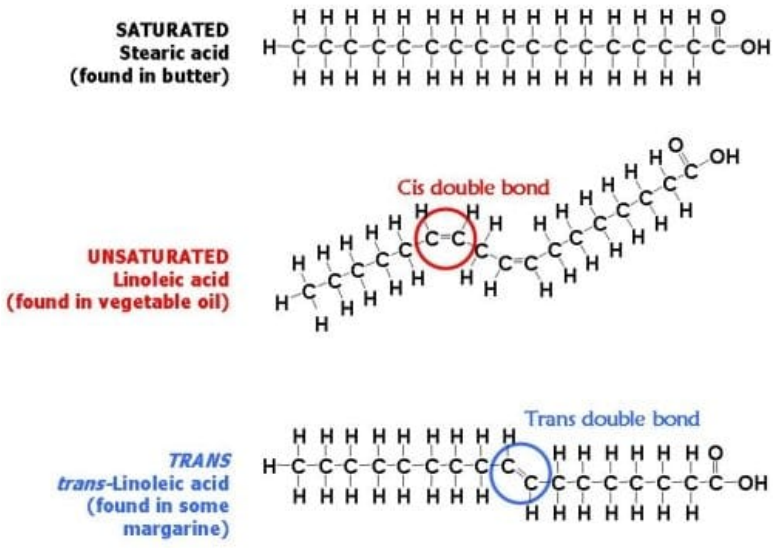


Figure 5.1.4: Cis vs trans fatty acid configurations. (Salway J. *Medical Biochemistry at a Glance*. Blackwell Publishing; 2006:144.)

Knowing the connection between chain length, degree of saturation, and the shape of the fatty acid is important for making food choices. If you decide to limit or redirect your intake of fat products, then choosing unsaturated fat is more beneficial than choosing a saturated fat. This choice is easy enough to make because unsaturated fats tend to be liquid at room temperature (e.g., olive oil) whereas saturated fats tend to be solid at room temperature (e.g., butter). Most vegetable and fish oils contain high quantities of polyunsaturated fats (see Figure 5.1.5). Olive oil and canola oil are rich in monounsaturated fats. However, not all oils are unsaturated - tropical oils like palm oil and coconut oil are semi-liquid at room temperature yet high in saturated fat. The *trans* fat created during manufacturing is associated with an increased risk for heart disease; fortunately, *trans* fats have been eliminated from most processed foods. Due to FDA rounding rules for macronutrients, products that contain less than 0.5 grams of *trans* fat per serving will express "0 grams of *trans* fat" on the Nutrition Facts label.[1] It's also important to keep in mind that small amounts of *trans* fat occur naturally in some meat and dairy products; this naturally occurring *trans* fat does not increase risk for heart disease.[2]

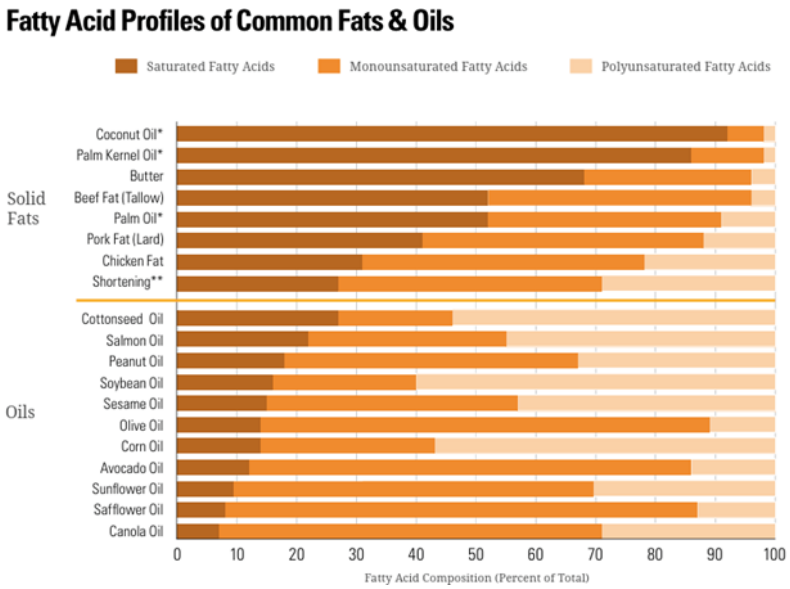


Figure 5.1.5: Fatty Acid Profiles of Common Fats and Oils. (Public Domain; 2015 Dietary Guidelines for Americans)

Nonessential and Essential Fatty Acids

Fatty acids are vital for the normal operation of all body systems. The body is capable of synthesizing most of the fatty acids it needs from the fatty acids we get from foods. 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. Just because a fatty acid is classified as nonessential, it doesn't mean that it's not important; it simply means that the body is able to synthesize the fatty acid.

Essential fatty acids must be obtained from food. They fall into two categories—omega-3 and omega-6. The "3" and "6" refer to the position of the first carbon double bond from the omega end of the chain. Omega-3 fatty acids are known for their role in supporting brain and heart health. Omega-6 fatty acids are beneficial for lowering the risk of heart disease, especially if the omega-6 fatty acids replace saturated fats.

Alpha-linolenic acid (an omega-3 fatty acid) is found in flax, chia, walnuts, canola oil, and soybean oil. Other important omega-3 fatty acids, such as EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid) are found in salmon, herring, sardines, mackerel, sea bass, and trout. Linoleic acid (an omega-6 fatty acid) is found in many vegetable and nut oils such as corn oil, sunflower oil, safflower oil, and soybean oil. Because these essential fatty acids are easily accessible, essential fatty acid deficiency is extremely rare.

Phospholipids

Phospholipids make up only about 2% of dietary lipids. They are semi-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. Although phospholipids are critical, they are not considered to be an essential nutrient because phospholipids are synthesized in the body. In blood and body fluids, phospholipids form structures in which fat is enclosed and transported through the bloodstream.

Like triglycerides, phospholipids have a glycerol backbone. But unlike triglycerides, phospholipids are diglycerides (two fatty-acid molecules attached to the glycerol backbone) with a phosphate group (Figure 5.1.6). This unique structure makes phospholipids semi-water-soluble. Phospholipids are what we call amphiphilic—the fatty-acid sides are hydrophobic (dislike water) and the phosphate group is hydrophilic (likes water).

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 (found in egg yolk, soybean oil, and sunflower oil) is a popular food emulsifier. When you read about lipid digestion later in this chapter, you'll see the importance of emulsifiers inside the body.

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

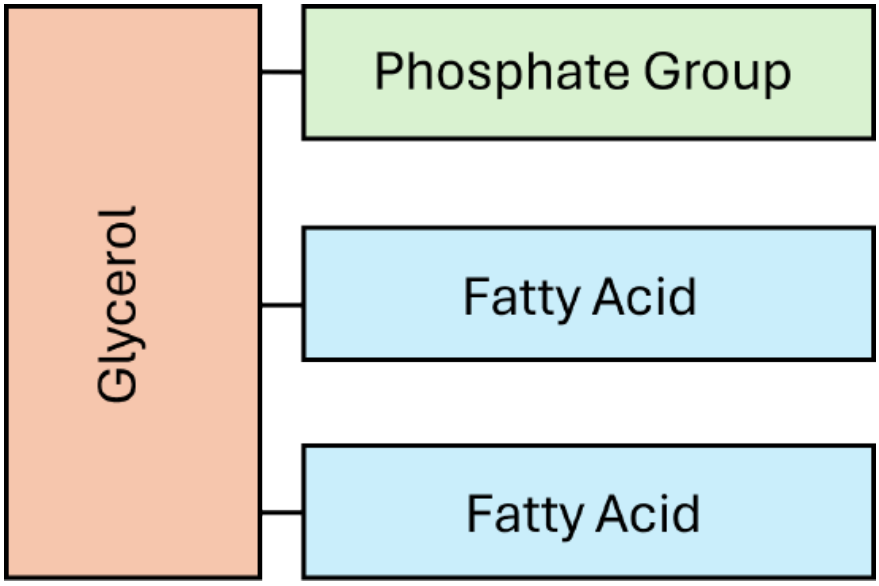


Figure 5.1.6*a*: Phospholipid Structure (CC BY 4.0; Ann Diker)

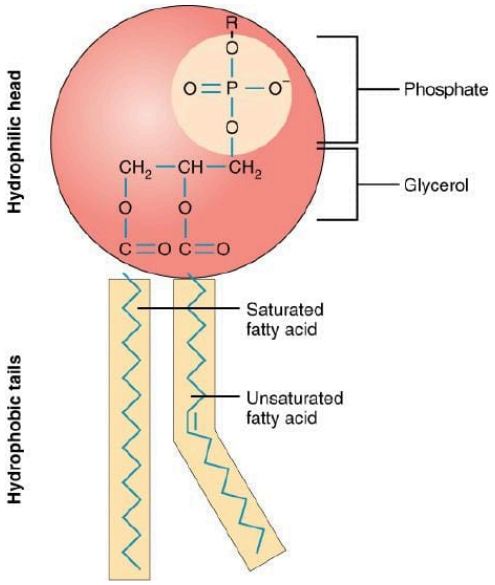


Figure 5.1.6*b*: Phospholipid Structure (CC BY 4.0; OpenStax via Wikimedia Commons)

Sterols

Sterols are the third type of lipid. Cholesterol is perhaps the most well-known sterol and is the most common sterol in the diet.

The body produces the majority of its cholesterol; however, a small amount does come from the diet (from animal foods). Since cholesterol is produced in our body, it is not essential that we get it from our food. Cholesterol is an important component of the cell membrane and is required for the synthesis of sex hormones, vitamin D, and bile salts.

Sterols have a very different structure from triglycerides and phospholipids. Most sterols do not contain any fatty acids but rather are multi-ring structures (Figure 5.1.7). They are complex molecules that contain interlinking rings of carbon atoms, with side chains of carbon, hydrogen, and oxygen attached. Cholesterol is the best-known sterol because of its role in heart disease. It forms a large part of the plaque that narrows the arteries in atherosclerosis. Although cholesterol has a bad reputation when it comes to heart health, it is a vital substance in the body that poses a concern only when there is excess accumulation of it in the blood.

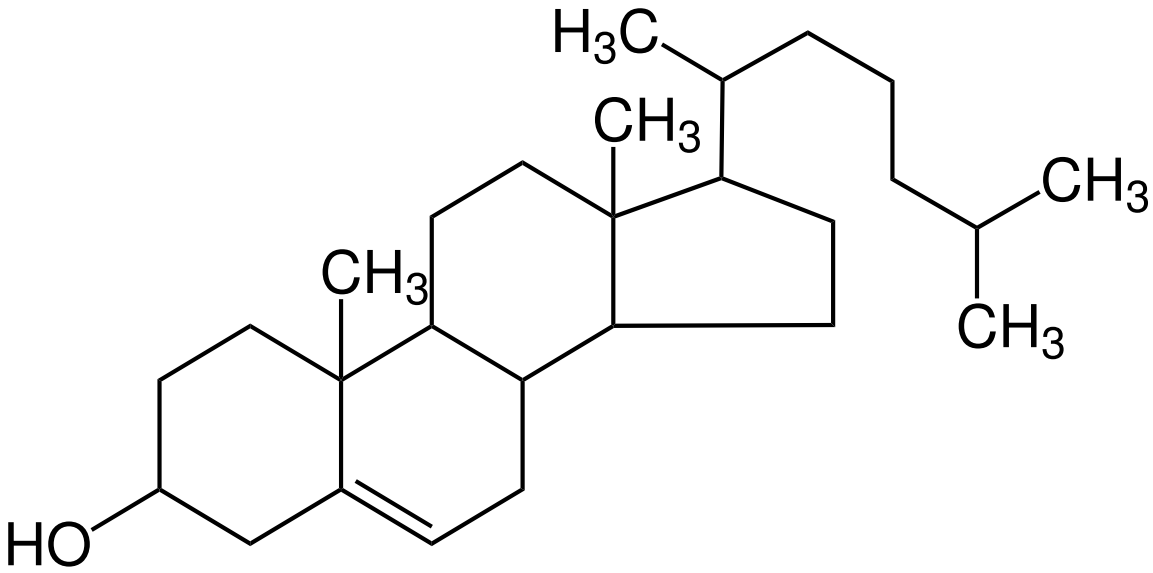


Figure 5.1.7: Cholesterol is made up of multiple carbon rings bonded together. ("Cholesterol Chemical Structure" by Wesalius is in the Public Domain)

References

1. US Food and Drug Administration. *Food Labeling Guide*. Last updated January 2013. Accessed May 13, 2025.
2. Pipoyan D, Stepanyan S, Stepanyan S, Beglaryan M, Costantini L, Molinari R, Merendino N. The Effect of Trans Fatty Acids on Human Health: Regulation and Consumption Patterns. Foods. 2021 Oct 14;10(10):2452. doi: 10.3390/foods10102452. PMID: 34681504; PMCID: PMC8535577.

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5.2: Digestion and Absorption of Lipids

Learning Objectives

- Summarize the steps in lipid digestion and absorption.
- Describe the structure and role of chylomicrons.

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

Mouth

Remember that the main types of lipids are triglycerides and phospholipids. Here we will discuss how they are digested and absorbed. Chewing mechanically breaks down food into smaller particles and mixes them with saliva. An enzyme called lingual lipase begins some chemical digestion of triglycerides breaking some of the triglycerides down into diglycerides and free fatty acids (Figure 5.2.1). These actions cause the fats to become more accessible to the digestive enzymes in the stomach and small intestine.

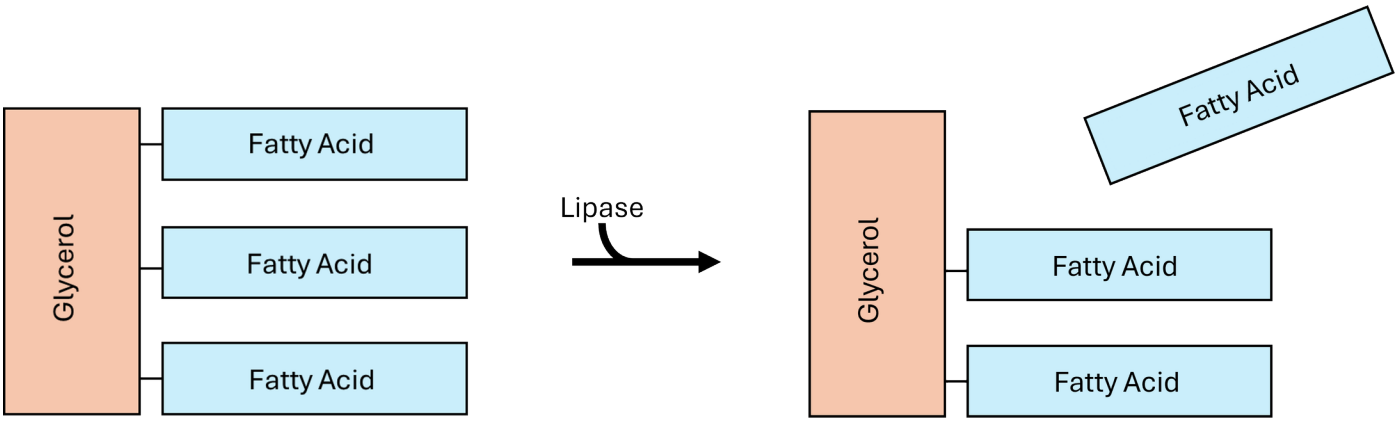


Figure 5.2.1: Enzymatic breakdown of a triglyceride (left) to a diglyceride + free fatty acid (right). (CC BY 4.0; Ann Diker)

Stomach

In the stomach, the enzyme gastric lipase starts to break down triglycerides into diglycerides and fatty acids (Figure 5.2.1 and Figure 5.2.2). Within 2-4 hours after eating a meal, roughly 30% of the triglycerides are converted to diglycerides and fatty acids. The stomach's churning and contractions help to disperse the fat molecules, while the diglycerides derived in this process act as further emulsifiers. However, even amid all of this activity, very little fat digestion occurs in the stomach.

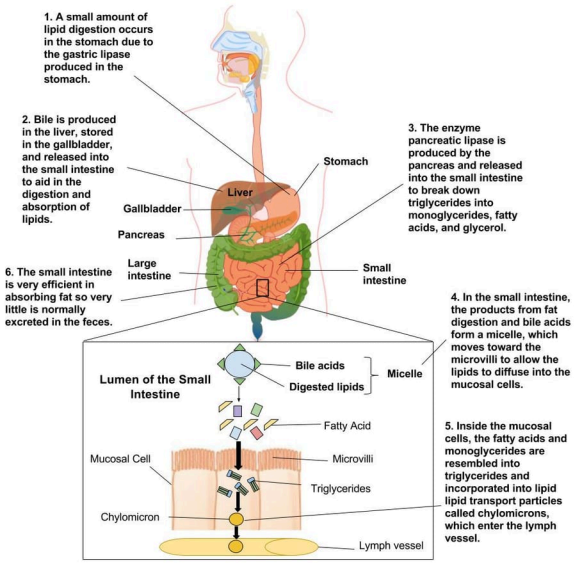


Figure 5.2.2: Lipid Digestion and Absorption (CC BY 4.0; Allison Calabrese)

Small Intestine

Most digestion and absorption occurs in the small intestine.

Digestion

As stomach contents enter the small intestine, most of the dietary lipids are undigested and clustered in large droplets. Additionally, the digestive system has to somehow combine the lipids with its own watery fluids. The solution is bile. Bile is produced by the liver and stored in the gallbladder; when needed, bile is secreted from the gallbladder into the small intestine. Bile contains bile salts, which are amphiphillic, so they are attracted to both fats and water. This makes them effective emulsifiers, meaning that they break large fat droplets into smaller droplets. Emulsification increases the surface area of lipids making them more accessible to the digestive enzymes.

Once the lipids have been emulsified, fat-breaking enzymes (known as lipases) work on the triglycerides and diglycerides to sever fatty acids from their glycerol foundations. As pancreatic lipase enters the small intestine, it breaks down the fats into free fatty acids and monoglycerides (Figure 5.2.3). The end result of triglyceride digestion is fatty acids, monoglycerides, and some free glycerol. Cholesterol and fat-soluble vitamins do not need to be enzymatically digested.

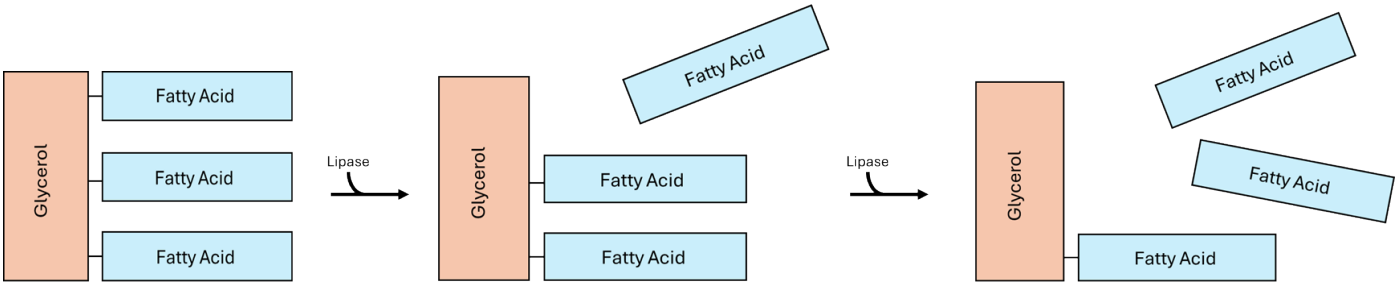


Figure 5.2.3: Enzymatic breakdown of a triglyceride (left) to a diglyceride + free fatty acid (middle) and then a monoglyceride + two free fatty acids (right). (CC BY 4.0; Ann Diker)

Absorption

Next, those products of lipid digestion (fatty acids, monoglycerides, glycerol, cholesterol, and fat-soluble vitamins) need to enter into the circulation so that they can be used by cells around the body. Again, bile helps with this process. Bile salts (shown as bile acids in Figure 5.2.2) cluster around the products of lipid digestion to form micelles. Micelles have a fatty acid core with a

water-soluble exterior (Figure 5.2.4) which helps the fats get close enough to the microvilli of intestinal cells so that they can be absorbed. The products of lipid digestion diffuse across the membrane of the instinal cells, and bile salts are recycled back to do more work emulsifying fat and forming micelles.

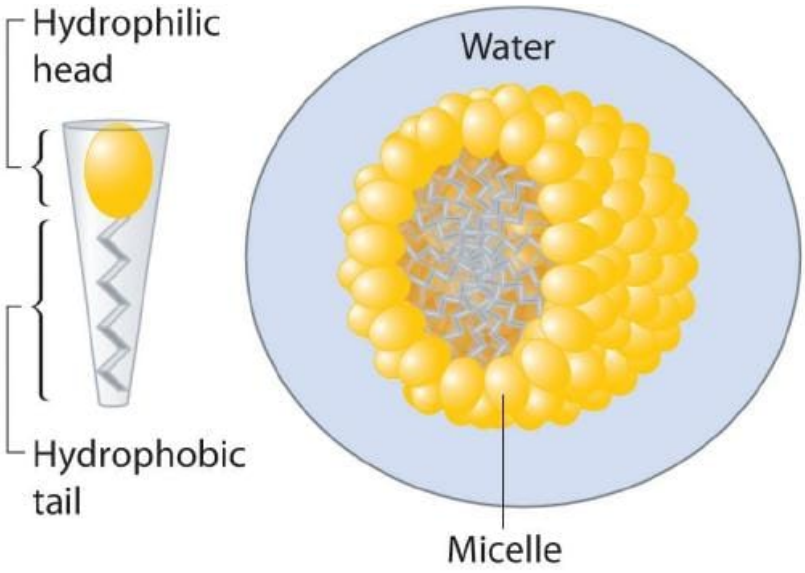


Figure 5.2.4: Micelle structure (CC BY-NC-SA 3.0; Principles of General Chemistry)

Just as lipids require special handling in the digestive tract to move within a water-based environment, they require similar handling to travel in the bloodstream. Inside the intestinal cells, the monoglycerides and fatty acids reassemble themselves into triglycerides. Triglycerides and cholesterol are large molecules that need help with absorption and transport to the bloodstream. Lipoproteins are the transport vehicles for lipids. Lipoproteins have an inner core that is primarily made up of triglycerides and cholesterol (Figure 5.2.5). The outer membrane is made of phospholipids interspersed with proteins (called apolipoproteins) and cholesterol. A chylomicron (Figure 5.2.5) is a type of lipoprotein that is used to transport fat from a meal. Once formed, chylomicrons are transported from the intestinal lining to 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.

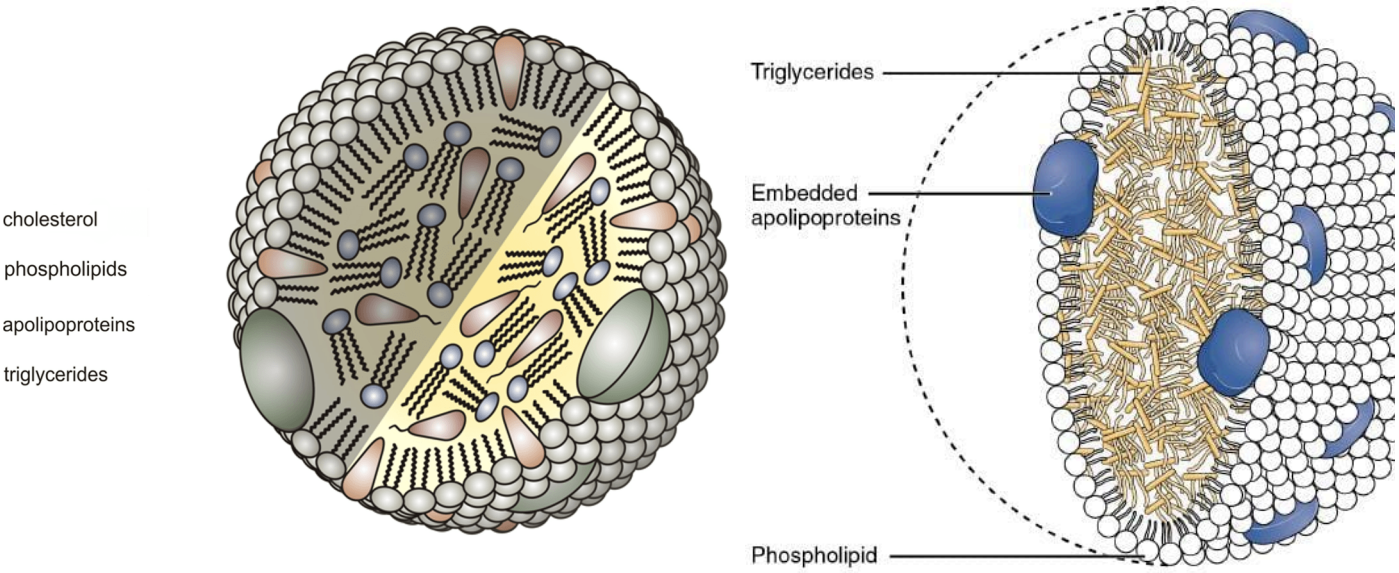


Figure 5.2.5: Lipoprotein structure (left) and chylomicron structure (right). ("Lipoprotein structure" CC BY 4.0; Ann Diker; edited from "Structure of a Lipoprotein" by Antisense with a CC BY-SA 3.0 license. "Chylomicron structure" CC BY 3.0; OpenStax)

Cholesterol molecules are poorly absorbed when compared to triglycerides. 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 for excretion.

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5.3: Functions of Lipids

Learning Objectives

- List and describe functions of lipids in the human body.
- List and describe the role of lipids in food.

Lipids perform functions both within the body and in food. Within the body, lipids function as an energy reserve, regulate hormones, transmit nerve impulses, cushion vital organs, and transport fat-soluble nutrients. Fat in food serves as an energy source with high caloric density, adds texture and taste, and contributes to satiety.

Functions of Lipids in the Body

Energy Storage and Use

The excess energy from the food we eat is digested and incorporated into adipose tissue, or fat tissue. Most of the energy required by the human body is provided by carbohydrates and lipids; in fact, 30-70% of the energy used during rest comes from fat. As discussed previously, glucose is stored in the body as glycogen. While glycogen provides a ready source of energy, lipids primarily function as an energy reserve. Glycogen is quite bulky with heavy water content, thus the body cannot store too much for long. Fats are packed together tightly without water and store far greater amounts of energy in a reduced space. A fat gram is densely concentrated with energy—it contains more than double the amount of energy than a gram of carbohydrate. Unlike other body cells that can store fat in limited supplies, fat cells are specialized for fat storage and are able to expand almost indefinitely in size.

One way the body stores fat involves the body's transformation of carbohydrates into glycogen (which is stored in the muscles for energy). When the muscles reach their capacity for glycogen storage, the excess carbohydrate is returned to the liver, where it is converted into triglycerides and then stored as fat. In a similar manner, much of the triglycerides the body receives from food is transported to adipose tissue within the body if not used for producing energy. When a person's energy requirements exceed the amount of available fuel from a recent meal, fat reserves are retrieved for energy utilization. Stored fat is also used for energy during exercise, especially after glycogen is depleted.

Regulating and Signaling

Lipids are part of the cell membrane structure which helps maintain cell membrane fluidity and flexibility. Triglycerides control the body's internal climate with the goal of maintaining constant temperature. Those who don't have enough fat in their bodies tend to feel cold sooner. Triglycerides also help the body produce and regulate hormones. For example, adipose tissue secretes the hormone leptin, which regulates appetite. In the reproductive system, fatty acids are required for proper reproductive health; women who lack proper amounts may stop menstruating and become infertile. Omega-3 and omega-6 essential fatty acids help regulate cholesterol and blood clotting and control inflammation in the joints, tissues, and bloodstream. Fats also play important functional roles in sustaining nerve impulse transmission, memory storage, and tissue structure. More specifically in the brain, lipids are focal to brain activity in structure and in function. They help form nerve cell membranes, insulate neurons, and facilitate the signaling of electrical impulses throughout the brain (Figure 5.3.1).

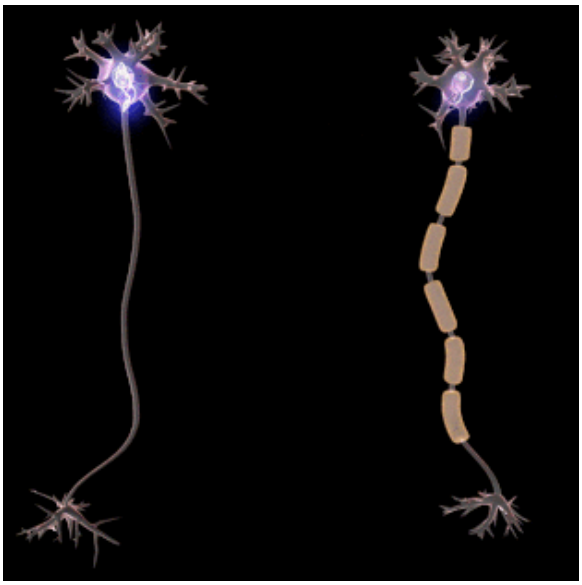


Figure 5.3.1: Lipids serve as signaling molecules; they are catalysts of electrical impulse activity within the brain. Nerve response in myelinated neurons (right) propagate faster than in unmyelinated neurons (left). Myelin is a mixture of proteins and phospholipids that insulates nerves. The myelin coating is ~70% lipids. (CC BY 4.0; Saltatory Conduction by Dr. Jana)

Insulating and Protecting

Within the body there are two types of fat - visceral and subcutaneous (Figure 5.3.2). Visceral fat surrounds vital organs such as the heart, kidneys, and liver. Subcutaneous fat, or fat underneath the skin, insulates the body from extreme temperatures and helps keep the internal climate under control. It pads our hands and buttocks and prevents friction, as these areas frequently come in contact with hard surfaces. It also gives the body the extra padding required when engaging in physically demanding activities such as ice- or roller skating, horseback riding, or snowboarding.

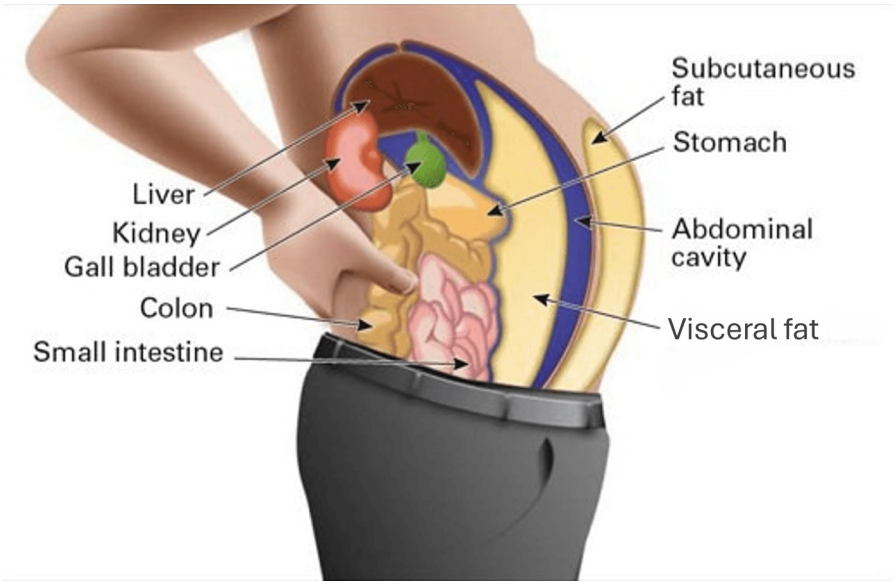


Figure 5.3.2: Visceral and Subcutaneous Fat. (CC BY 4.0; Ann Diker, edited from "Pandemic of Lifestyle Diseases" by Sandra Cohen-Rose and Colin Rose licensed under CC BY 2.0)

Transporting

Fat-soluble nutrients are 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. Fat-soluble nutrients require fat for effective absorption. These vitamins are best absorbed when combined with foods containing fat. Fats also increase the bioavailability of compounds known as

phytochemicals, which are plant constituents such as lycopene (found in tomatoes) and beta-carotene (found in carrots). Phytochemicals are believed to promote health and well-being. As a result, eating tomatoes with olive oil or salad dressing will facilitate lycopene absorption.

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 compared with 4 calories found in 1 gram of carbohydrate or protein. Depending on the level of physical activity and on nutritional needs, fat requirements vary greatly from person to person. When energy needs are high, the body welcomes the high-caloric density of fats. For instance, infants and growing children require higher 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.

Smell, Taste, Texture, and Satiety

Fat contains dissolved compounds that contribute to mouth-watering aromas and flavors. Fat also adds texture, making baked foods moist and flaky, fried foods crispy, and adding creaminess to foods like ice cream and cream cheese.

Fat also contributes to satiety, or the sensation of fullness. Fats take longer to digest than other macronutrients because fats move slower through the digestive tract, thus promoting an overall sense of fullness. Sometimes, 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.

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5.4: Lipid/Fat Recommendations

Learning Objectives

- Describe the current recommended intake levels for lipids.
- Recognize sources of saturated fat, *trans* fat, unsaturated fat, essential fatty acids, and cholesterol.

Recommended Fat Intake

Recall from the previous chapter that the Acceptable Macronutrient Distribution Range (AMDR) for carbohydrate intake is 45-65% of total calories.[1] In comparison, the AMDR for total fat intake is 20-35% of total calories (Table 5.4.1).[1] When translating the AMDR for total fat intake into calories, it means that a person following a 2,000 kilocalorie diet should consume 400-700 total fat calories (~44-78 grams of total fat) each day. Recommendations for adults for various lipids/fats are included in Table 5.4.1.

Table 5.4.1: Dietary Reference Intakes and Recommendations for Lipids

Lipid Type	AI (g/day)[1]	AMDR (% calories)[1]	Additional Recommendations
Total Fat		20–35	
Saturated Fat			< 10% of calories[2]
Trans Fat			minimize[1]
Cholesterol			minimize[1]
Omega-3 Fatty Acids (alpha-linolenic acid)	1.6 (male); 1.1 (female)	0.6-1.2	
Omega-6 Fatty Acids (linoleic acid)	17 (male); 12 (female)	5-10	

Sources of Fats

Most fat-containing foods have multiple types of fat in them, so even though a food may be classified as an unsaturated fat it could still contain some saturated fat. For example, olive oil contains approximately 75% monounsaturated fat, 11% polyunsaturated fat, and 14% saturated fat.[3] Olive oil is considered to be a monounsaturated fat because it is made up mostly of monounsaturated fat. Olive oil's high percentage of unsaturated fat (~86% from both mono- and polyunsaturated fats) is also what makes it a liquid at room temperature. Unsaturated fatty acids do not stack together well and are liquid at room temperature; saturated fatty acids stack together more compactly resulting in a solid substance at room temperature. Common sources of the different types of fats are included in Table 5.4.2.

Most fat in our diets should be from beneficial fats such as monounsaturated, polyunsaturated, and omega-3 fatty acids. Plants, plant oils, nuts, seeds, fish, and fish oils are high in these beneficial fats. It is also recommended to eat less than 10% of calories from saturated fat and consume as little dietary cholesterol as possible. Animal products and full-fat dairy products contain saturated fat and cholesterol (see Table 5.4.2 for additional foods). When discussing dietary cholesterol, it's important to note that our body makes cholesterol, so we don't have to get cholesterol from food. When we eat foods that contain cholesterol, the body makes less cholesterol, so it's ok to eat cholesterol-containing foods in moderation.

Table 5.4.2: Common Food Sources of Various Fats

Lipid Type	Common Sources
Saturated Fat	animal products, full-fat dairy products, palm and coconut oils, cocoa butter
Trans Fat	stick/tub margarines, fast foods, commercial baked goods, some snack foods
Cholesterol	animal products, shrimp, liver, eggs, full-fat dairy products

Lipid Type	Common Sources
Monounsaturated Fat	nuts (almonds, cashews, pecans, peanuts, and walnuts) and nut products, avocados, extra virgin olive oil, sesame oil, safflower oil, sunflower oil, and canola oil
Polyunsaturated Fat	nuts (walnuts, hazelnuts, pecans, almonds, and peanuts), soybean oil, corn oil, safflower oil, flaxseed oil, canola oil, and fish (trout, herring, and salmon)
Omega-3 Fatty Acids (alpha-linolenic acid)	canola oil, flaxseed oil, soybean oil, olive oil, nuts, seeds, whole grains, legumes, green leafy vegetables, cod liver oil, and fatty fish (tuna, herring, mackerel, salmon, and trout)
Omega-6 Fatty Acids (linoleic acid)	eggs, poultry, most vegetable oils, wheat germ oil, whole grains, baked goods, cereals, nuts and seeds (flaxseeds, sunflower seeds, sesame seeds)

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5.5: Understanding Blood Cholesterol and Heart Disease

Learning Objectives

- Compare and contrast the roles of low-density lipoprotein (LDL) and high-density lipoprotein (HDL) in your body.
- Identify healthy blood lipid profile ranges.

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). You learned earlier in this chapter that lipoproteins are transport vehicles for lipids and that the inner core is primarily made up of triglycerides and cholesterol. LDL and HDL are two of the lipoproteins that transport lipids throughout the body; learn more about them and a few other lipoproteins below.

Major Lipoproteins

While all lipoproteins have the same basic structure and contain the same four components (triglycerides, cholesterol, phospholipids, and protein), they differ by their functions, size (diameter), density, and composition. Major functions of each lipoprotein are described in Table 5.5.1; their size, density, and composition are illustrated in Figure 5.5.1.

Table 5.5.1: Lipoprotein Functions

Lipoprotein	Functions
Chylomicron	transport lipids from the small intestine; deliver triglycerides to body cells; remaining components delivered to liver
Very-low-density lipoprotein (VLDL)	transport lipids from the liver; deliver triglycerides and cholesterol to body cells
Low-density lipoprotein (LDL)	deliver cholesterol to body cells
High-density lipoprotein (HDL)	pick up excess cholesterol in the bloodstream and return it to the liver for reuse or disposal

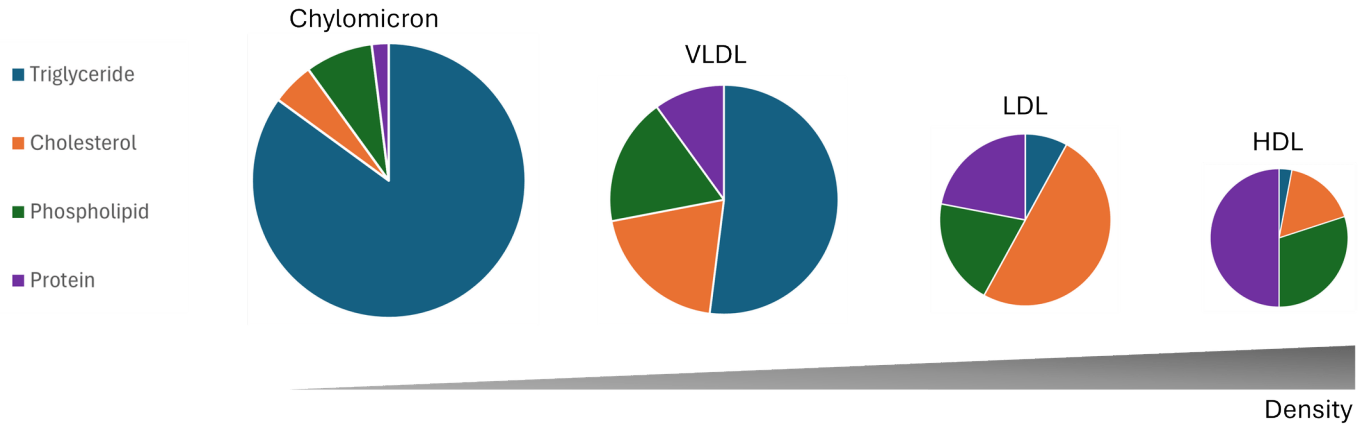


Figure 5.5.1: Composition and Density of Various Lipoproteins. (CC BY 4.0; Ann Diker)

Except for chylomicrons, the names of the lipoproteins refer to their density. Of the four components of lipoproteins, protein is the most dense and triglyceride is the least dense. Chylomicrons are the least dense because they contain so much triglyceride and relatively little protein. High-density lipoproteins are the most dense of the lipoproteins because they contain more protein and less triglyceride.

Lipid Transport

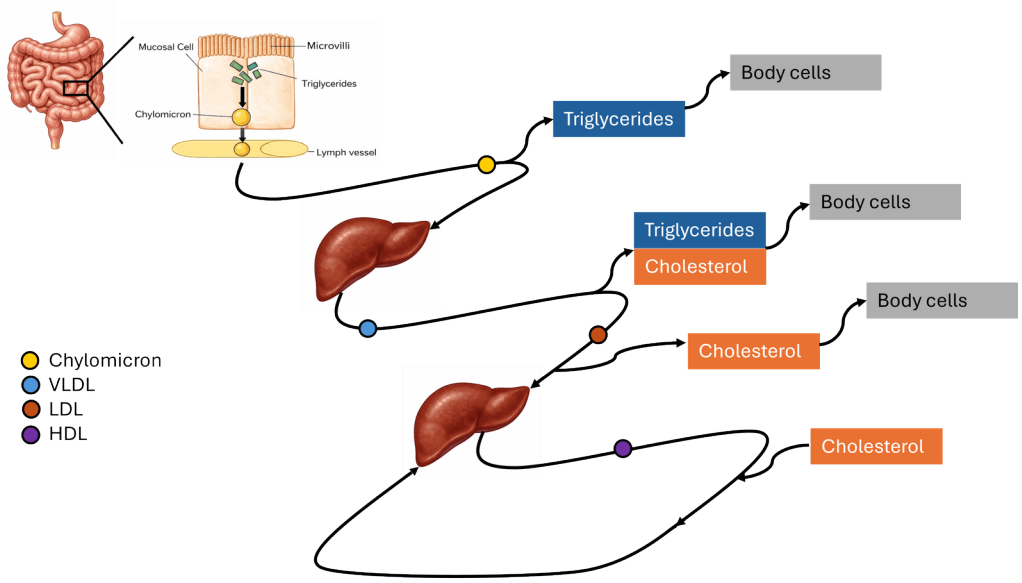


Figure 5.5.2: Lipid Transport and Distribution. (CC BY 4.0; Ann Diker)

Recall that the lipids we eat eventually get packaged into chylomicrons in the cells of our small intestine (top left of Figure 5.5.2).

Chylomicrons transport lipids from the small intestine through the lymph and on to the bloodstream where they deliver triglycerides to body cells. What's left of the chylomicrons travel to the liver where they combine with other liver lipids to form very-low-density lipoprotein (VLDL).

VLDL then delivers triglycerides and cholesterol to body cells. As triglycerides are removed from VLDL, they get smaller and more dense, eventually becoming low-density lipoprotein (LDL).

LDL delivers cholesterol to the body's cells. Cholesterol has many roles around the body, so this is an important job. However, too much LDL can increase a person's risk of cardiovascular disease. Diets high in saturated fats limit the amount of cholesterol delivered to the cells by LDL which leaves more cholesterol in the bloodstream that could be deposited in arteries and block blood flow.

High-density lipoprotein (HDL) picks up cholesterol in the bloodstream and returns it to the liver where it is either reused or removed from the body (as a component of bile).

Contrasting LDL and HDL

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

- **LDL/HDL composition**. LDL is approximately 25% protein and 75% lipid (including ~50% cholesterol). HDL is 50% protein and 50% lipid (including ~20% cholesterol). HDL is more dense because it contains more protein and less cholesterol/lipid.
- **LDL/HDL function**. LDL carries cholesterol to cells for normal usage, but LDL can also deposit cholesterol into the walls of blood vessels when present in excess, which can lead to harmful disease. HDL scavenges excess cholesterol from the cells, tissues, and blood vessels and delivers these back to the liver, where they are either reused or excreted.
- **LDL/HDL values on a blood test**. A standard blood test, called a lipid panel, reports total cholesterol, LDL, HDL, and triglycerides. When doctors assess a person's risk of cardiovascular disease, they consider these numbers along with other risk factors. High LDL values are linked to an increased risks for heart disease, while high HDL values typically indicate a reduced risk for heart disease.

Blood Cholesterol Recommendations

Desirable blood cholesterol levels for total cholesterol, LDL cholesterol, and HDL cholesterol are included in Table 5.5.2.[1] More specifically, when looking at individual lipid profiles, a lower amount of LDL and a higher amount of HDL prevents excess buildup of cholesterol in the arteries and wards off potential health hazards. In other words, elevated LDL indicates an increased risk of heart attack, while higher HDL indicates a reduced risk.

Table 5.5.2: Blood Cholesterol Classifications

Cholesterol Type	Healthy Levels (milligrams per deciliter; mg/dL)
Total Cholesterol	less than 200
LDL Cholesterol	less than 100
HDL Cholesterol	40 or higher (male); 50 or higher (female)

Steps to Improving Blood Cholesterol Levels

Recommendations to improve blood lipid levels include:

- Maintain total fat intake within 20-35% of energy with an emphasis on monounsaturated and polyunsaturated fats
- Decrease saturated fat to less than 6% of total energy intake and avoid *trans* fat[2]
- Increase omega-3 fats
- Consume the RDA for vitamin B_6, B_{12}, and folate
- Increase fruit, vegetable, and whole grain intake so fiber intake is 20-30 grams/day
- Don't smoke[2]
- Be active for at least 150 minutes of moderate-intensity aerobic activity each week[2]
- Maintain a healthful body weight

Heart Disease

According to the Centers for Disease Control and Prevention (CDC), heart disease is the leading cause of death in the United States.[3] The disease generally starts with atherosclerosis, or a hardening of the arteries. Arteries start to narrow and harden when excess lipids accumulate along their inner walls and form plaques (Figure 5.5.3). A plaque is made of fat, cholesterol, calcium, and other substances found in blood. The narrowing of the arteries causes the blood pressure to rise.

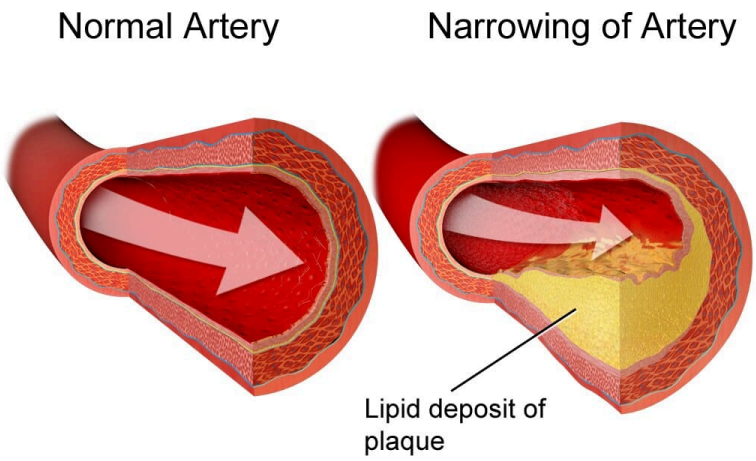


Figure 5.5.3: Illustration comparing a normal blood vessel and partially blocked vessel due to atherosclerotic plaque build-up. Plaque formation along arterial walls impedes blood flow and can create a thrombus, or stationary blood clot. (CC BY 3.0; Blausen.com staff (2014). "Medical gallery of Blausen Medical 2014". *WikiJournal of Medicine* **1**(2).)

Plaque formation causes arteries to narrow and harden, which elevates blood pressure because the vessels can't expand effectively to accommodate blood pulses. Higher blood pressure strains the heart and causes more damage. The plaques themselves can rupture due to a spike in blood pressure; the body responds to this perceived injury by forming blood clots. These clots are serious health threats, whether they are stationary (a thrombus) or moving (an embolus). A stationary clot can slowly kill off surrounding tissue, or grow so big that it blocks blood circulation. When a moving clot becomes stuck in an artery too small for its passage, it cuts off blood flow and causes cell death. This is referred to as an embolism. Blood clots in heart and brain arteries can cause heart attacks or strokes, respectively.

Heart Disease Risk

Risk factors for heart disease include unmodifiable risk factors (that you can't change) and modifiable risk factors (that you *can* change) (Table 5.5.3).

Table 5.5.3: Heart Disease Risk Factors

Unmodifiable Risk Factors	Modifiable Risk Factors
• **Age.** Risk increases for men at 45, and for women at 55. • **Sex.** Men have a higher risk than women, though the risk for women rises after menopause. • **Family history.** The more family members who have heart disease, the greater the risk.	• **Tobacco (cigarettes, vapes).** Nicotine constricts blood vessels, and carbon monoxide damages their inner lining, which increases the risk of atherosclerosis. • **Obesity.** Excess weight worsens other risk factors. • **Diabetes.** Diabetes is associated with an increased risk of heart disease. • **High blood pressure.** High blood pressure strains the heart. • **Physical inactivity.** Lack of exercise is associated with heart disease. • **Cholesterol levels in the blood (not in the diet).** High levels of blood cholesterol can increase the risk. High LDL and/or low HDL levels are associated with increased risk of heart disease.

Steps to Reducing Heart Disease Risk

Diet can play a significant role in reducing the risk of heart disease. It is helpful to limit consumption of saturated fat and *trans* fat which have negative impacts on LDL and HDL levels and promote plaque formation. Increasing consumption of dietary fiber can help improve blood cholesterol levels and may be helpful in maintaining or achieving a healthy weight. Being more active can

help improve blood cholesterol levels and weight status. Dietary guidance for cardiovascular health developed by the American Heart Association can be seen in Figure 5.5.4.



Figure 5.5.4: Features of a dietary pattern to promote cardiovascular health. (American Heart Association)

High Blood Pressure

Chronic high blood pressure, also known as hypertension, is a significant health hazard affecting almost half of the adults in the United States.[4] This chronic condition is a major cause of heart attacks and strokes, yet it has no symptoms until blood pressure reaches very high levels, which is why it is known as "the silent killer". The only way to find out if you have high blood pressure is to get an accurate reading of your resting blood pressure rate, which is best done by a medical professional and should be monitored regularly.

High blood pressure is such an important factor in cardiovascular disease, that keeping it within a healthy range is important. Blood pressure is the force of moving blood against arterial walls. Blood pressure readings consist of two numbers and is reported as systolic pressure/diastolic pressure (e.g., 130/90). The top number measures **systolic** pressure (when the heart contracts) and the bottom number measures **diastolic** pressure (when the heart is at rest). The results are recorded in millimeters of mercury (mm Hg). The key blood pressure numbers to keep in mind are shown in Figure 5.5.5.[5] High blood pressure is characterized by above-average blood pressure readings (systolic blood pressure at or above 130 mm Hg *or* diastolic blood pressure at or above 80 mm Hg). Optimal systolic blood pressure is less than 120 mm Hg; optimal diastolic blood pressure is less than 80 mm Hg.

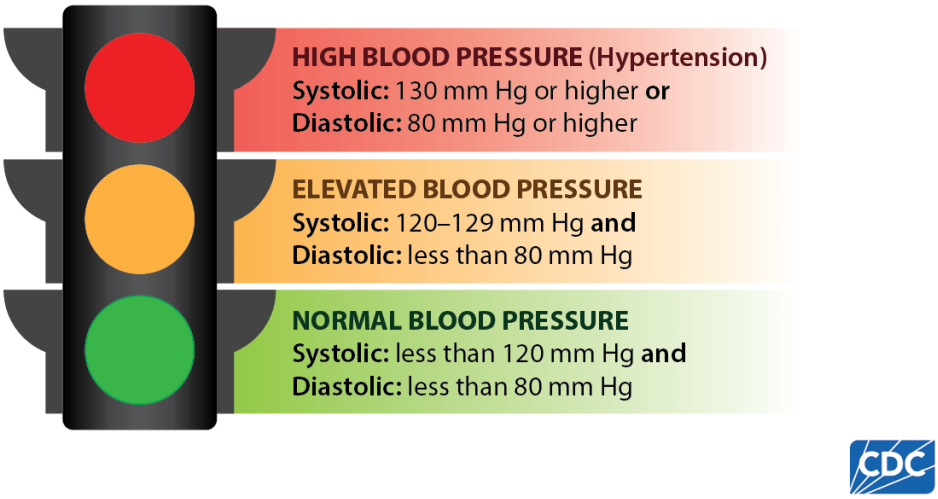


Figure 5.5.5: High Blood Pressure Categories. (Public Domain; Centers for Disease Control and Prevention)

Steps to Reducing the Risk of High Blood Pressure

Techniques to reduce blood pressure include being physically active, maintaining a healthy weight, reducing sodium intake to less than 2,300 mg per day, using alcohol moderately, and following the DASH eating plan. The DASH eating plan recommends:

- Eating vegetables, fruits, and whole grains
- Including fat-free or low-fat dairy products, fish, poultry, beans, nuts, and vegetable oils in the diet
- Limiting foods that are high in saturated fat, such as fatty meats, full-fat dairy products, and tropical oils such as coconut, palm kernel, and palm oils
- Limiting sugar-sweetened beverages and sweets.

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2. Prevention and Treatment of High Cholesterol (Hyperlipidemia). heart.org. Accessed February 20, 2026.
3. Heart Disease. FastStats - Heart Disease. cdc.gov. Accessed February 20, 2026.
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6: PROTEINS

6.1: Introduction to Proteins

6.2: Digestion and Absorption of Proteins

6.3: Functions of Protein

6.4: Protein Recommendations

6.5: Diseases Involving Proteins

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6.1: Introduction to Proteins

Learning Objectives

- Describe the structure of amino acids.
- Differentiate between an essential amino acid and a non-essential amino acid.
- Describe protein synthesis.

What Is Protein?

Proteins are large, complex molecules that are essential components of all human tissues (e.g., bones, blood, hormones, enzymes, antibodies). Proteins contain the elements carbon, hydrogen, and oxygen just as carbohydrates and lipids do, but proteins are the only macronutrient that contains nitrogen. Proteins are macromolecules composed of amino acids. Amino acids are sometimes called the "building blocks" of protein. Amino acids contain five elements (Figure 6.1.1). Each *amino acid* consists of a central carbon atom (C) connected to a nitrogen-containing *amino* group (NH_2), a hydrogen (H), a carboxylic *acid* group (COOH), and a side chain.

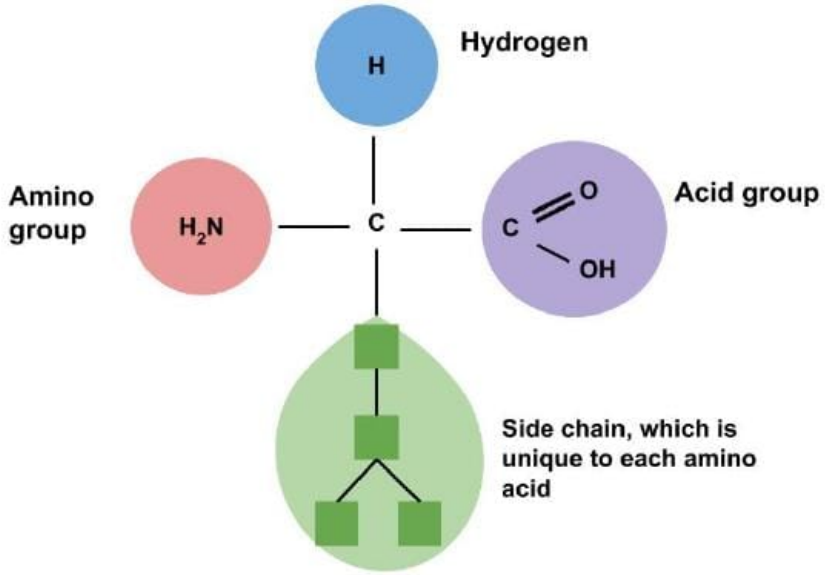


Figure 6.1.1: Amino Acid Structure. (CC BY 4.0; Allison Calabrese via Human Nutrition 2020e (Hawaii))

Amino acids differ from each other by which specific side chain is bonded to the carbon center. The side chains vary tremendously in their size and can be as simple as one hydrogen (e.g., glycine) or as complex as multiple carbon rings (e.g., tryptophan). They also differ in their chemical properties, thus impacting the way amino acids act in their environment and with other molecules. Because of their side chains, some amino acids are polar, making them hydrophilic and water-soluble, whereas others are nonpolar, making them hydrophobic or water-repelling. Some amino acids carry a negative charge and are acidic, while others carry a positive charge and are basic. Some carry no charge. The chemical structures of various amino acids are shown below in Figure 6.1.2. For this class, you don't need to memorize amino acid structures or names, but you should appreciate the diversity of amino acids and understand that it is the side chain (highlighted in blue in Figure 6.1.2) that makes each different.

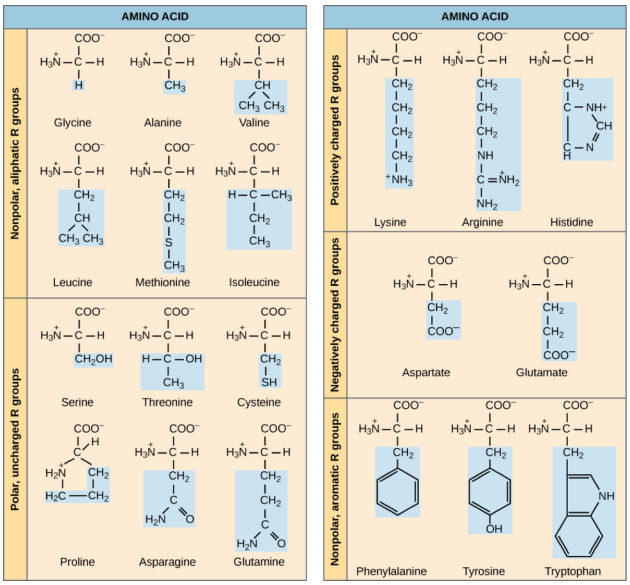


Figure 6.1.2: Amino acid structures and chemical properties. (CC BY 4.0; Open Stax Biology)

Essential and Nonessential Amino Acids

There are 20 different amino acids and we require all of them to make the many different proteins found throughout the body. Amino acids can be classified as essential or nonessential (Table 6.1.1). Eleven of the amino acids are considered nonessential because the body can synthesize them through transamination (which is the process of transferring the amine group from one amino acid to another acid group and side chain; see Figure 6.1.3). However, nine of the amino acids are called essential amino acids because we cannot synthesize them either at all or in sufficient amounts. These essential amino acids must be obtained from the diet. Sometimes during infancy, growth, and in diseased states the body cannot synthesize enough of some of the nonessential amino acids and more of them are required in the diet. These types of amino acids are called conditionally essential amino acids. For example, preterm infants can't make enough arginine to meet the high demands for growth and immune function, so dietary intake or supplementation of arginine can be important in this group.

Table 6.1.1: Essential and Nonessential Amino Acids

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

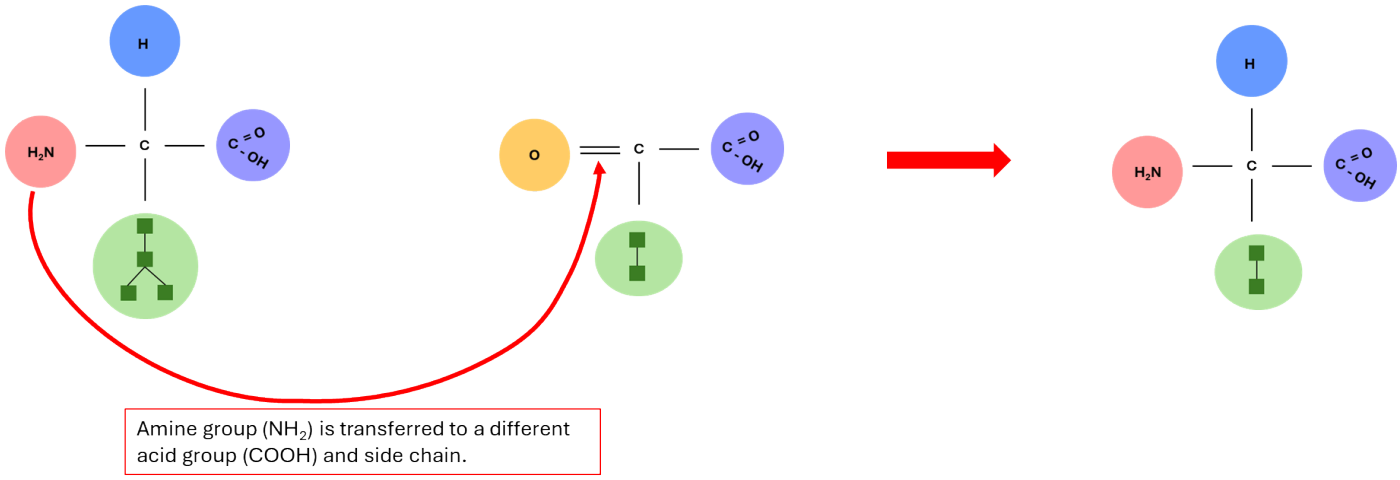


Figure 6.1.3: Transamination. (CC BY 4.0; Ann Diker)

Protein Synthesis

A protein consists of multiple amino acids. Different proteins are produced because there are 20 amino acids that can be combined in unique sequences. Each amino acid is connected to the next amino acid by a special chemical bond called a peptide bond (Figure 6.1.4). The peptide bond forms between the carboxylic acid group of one amino acid and the amino group of another, releasing a molecule of water. When amino acids join together, they form peptides and are named based on how many amino acids are in the peptide. For example, a dipeptide contains 2 amino acids, a tripeptide contains 3 amino acids, an oligopeptide has 4-9 amino acids, and a polypeptide contains 10 or more amino acids (Figure 6.1.4).

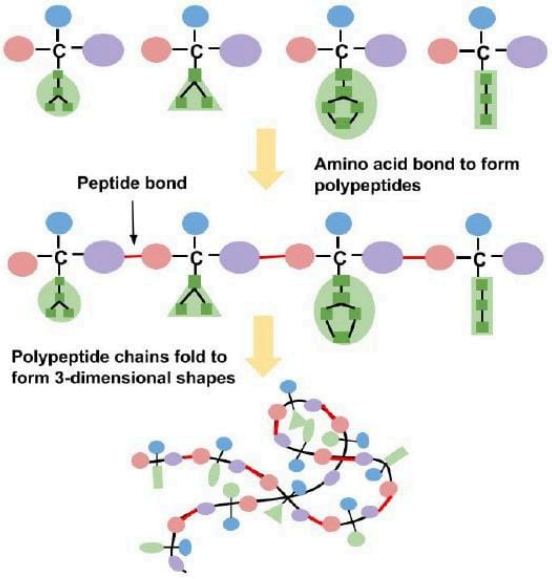


Figure 6.1.4: Polypeptide formation through peptide bonds. (CC BY 4.0; Allison Calabrese via Human Nutrition 2020e (Hawaii))

Each protein in the human body differs in its amino acid sequence. 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.

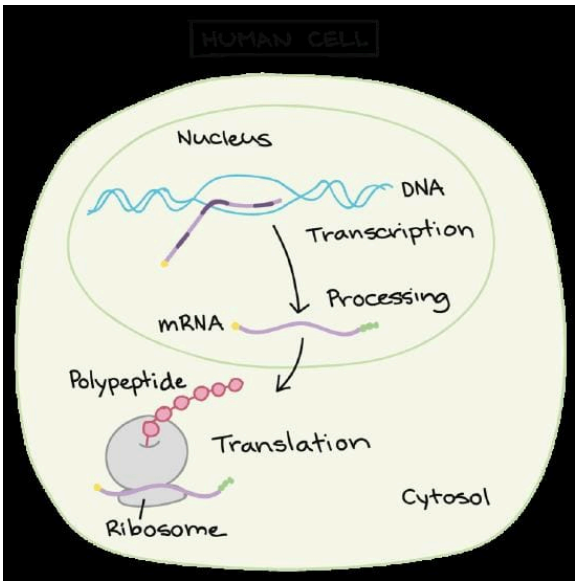


Figure 6.1.5: Transcription and translation. (CC BY-NC-SA 4.0; Khan Academy via Intro to gene expression (central dogma))

- Transcription (Figure 6.1.5): Deoxyribonucleic acid (DNA) is the long, double-stranded molecule containing instructions for making all of the proteins in your body. In the nucleus of the cell, the DNA must be copied (transcribed) into the single-stranded messenger ribonucleic acid (mRNA), which carries the genetic instructions into the cell's cytosol for protein synthesis.
- Translation (Figure 6.1.5): At the ribosome in the cell's cytosol, information from the mRNA is converted (translated) into a growing strand of amino acids that bind together to form a specific polypeptide chain.
- Protein folding: The polypeptide chain folds into a complex 3-D shape.

Watch the short (~3 minute) video below for an overview of the transcription, translation, and protein folding that occurs during protein synthesis.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

The newly synthesized protein is structured to perform a particular function in a cell. The 3-D protein shape is critical to its function. If the protein loses its shape then it loses its function. Denaturation is the term used to describe the protein's loss of shape. Exposure to heat, acids, bases, heavy metals, alcohol can denature proteins.

If needed, existing proteins can be broken down to provide amino acids for new protein synthesis. Protein synthesis can also be limited by missing amino acids. The amino acid that is missing or in the smallest supply is called the limiting amino acid. Without the proper amount of essential amino acids, proteins cannot be made which can impact the body's functions.

References

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6.2: Digestion and Absorption of Proteins

Learning Objectives

- Discuss how proteins are digested and absorbed by our bodies.

When you eat food, the body's digestive system breaks down the protein into the individual amino acids, which are absorbed and used by cells to build other proteins and a few other macromolecules, such as DNA. Let's follow the specific path that proteins take down the gastrointestinal tract and into the blood.

Mouth

The first step in protein digestion involves chewing (see Figure 6.2.1). The teeth begin the mechanical breakdown of food into smaller pieces that can be swallowed. The salivary glands provide some saliva to aid swallowing and the passage of the smaller pieces of food through the esophagus and then on to the stomach through the esophageal sphincter.

Stomach

The stomach releases gastric juices containing hydrochloric acid and pepsin (an enzyme) which initiate the chemical breakdown of protein. Hydrochloric acid (HCl) in the stomach begins protein digestion by denaturing the protein; denaturation results in the loss of the protein's function. HCl also converts inactive pepsinogen to its active form, pepsin. Pepsin begins breaking the peptide bonds between amino acids.

The powerful mechanical stomach contractions churn the partially digested protein into chyme. Protein digestion in the stomach takes a longer time than carbohydrate digestion, but a shorter time than fat digestion. Eating a high-protein meal increases the amount of time required to sufficiently break down the meal in the stomach. Food remains in the stomach longer, making you feel full longer.

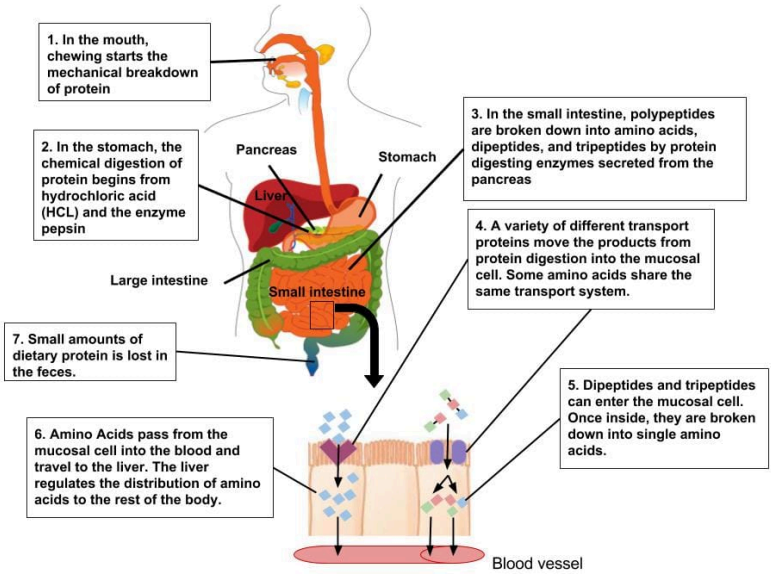


Figure 6.2.1: Digestion and Absorption of Protein. (CC BY 4.0; Allison Calabrese via Human Nutrition 2020e (Hawaii))

Small Intestine

Most digestion and absorption occurs in the small intestine.

Digestion

The stomach empties the chyme containing the partially digested protein into the small intestine, where the majority of protein digestion occurs. The pancreas secretes digestive juice that contains proteases (enzymes) that break down polypeptides into smaller peptides or single amino acids. The two major pancreatic enzymes that digest proteins are trypsin and chymotrypsin. Amino acids, dipeptides, and tripeptides are absorbed into the cells of the intestinal wall. The cells that line the small intestine release peptidases (enzymes) that break down dipeptides and tripeptides into single amino acids. The muscle contractions of the small intestine mix and propel the amino acids to the absorption sites.

Absorption

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 6.2.2). 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. Because amino acids are building blocks that the body reserves in order to synthesize other proteins, more than 90% of the protein ingested does not get broken down further than the amino acid monomers.

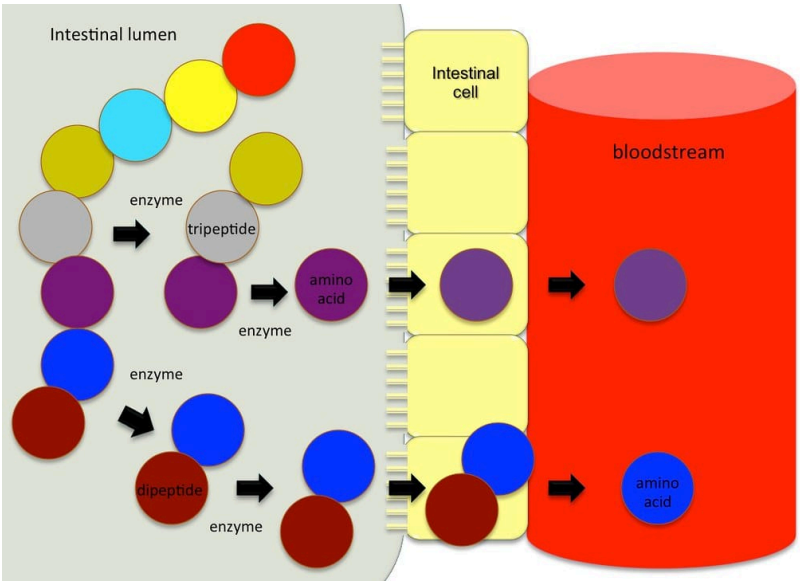


Figure 6.2.2: Once proteins are digested into dipeptides, tripeptides, and amino acids, they are absorbed into the intestinal cells and then enter the bloodstream as amino acids. (CC BY-NC-SA 2.0; by Nutritional Doublethink via Flickr)

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. To form these new proteins, amino acids from food and those from protein destruction are placed into a "pool" (see Figure 6.2.3). Though it is not a literal pool, when an amino acid is required to build another protein it can be acquired from the additional amino acids that exist within the body. Amino acids are used not only to build proteins, but also to build other biological molecules containing nitrogen, such as DNA 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, or the amino acids needed for building new proteins will be obtained by increasing protein destruction from other tissues within the body, especially muscle. This amino acid pool is less than 1% of total body-protein content. Thus, the body does not store protein as it does with carbohydrates (as glycogen in the muscles and liver) and lipids (as triglycerides in adipose tissue).

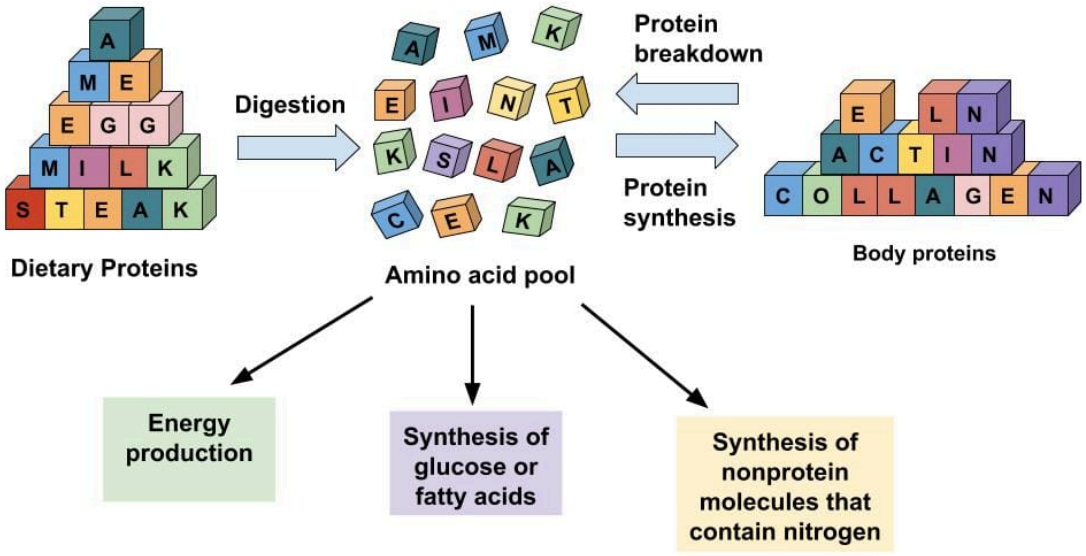


Figure 6.2.3: Options For Amino Acid Use In The Human Body. (CC BY 4.0; Allison Calabrese via Human Nutrition 2020e (Hawaii))

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6.3: Functions of Protein

Learning Objectives

- Describe the various functions of protein in the body.

Proteins participate in many bodily functions. Major functions of proteins are summarized in Table 6.3.1, and the subsequent sections of this page give more detail on each of them.

Table 6.3.1: Protein Functions

Function	Description	Examples
Structure	Give tissues (bone, tendons, ligaments, cartilage, skin, muscles) strength and structure	Collagen, elastin, keratin
Enzymes	Digest macronutrients into smaller monomers that can be absorbed; performs steps in metabolic pathways to allow for nutrient utilization	Amylase, lipase, pepsin, lactase
Hormones	Chemical messengers that travel in blood and coordinate processes around the body	Insulin, glucagon, thyroxine
Fluid and Electrolyte Balance	Maintains appropriate balance of fluids and electrolytes in different body compartments	Albumin, globulin
Acid-base (pH) Balance	Maintains appropriate pH in different body compartments	Albumin, hemoglobin
Transport	Carry substances around the body in the blood or lymph; help molecules cross cell membranes	Hemoglobin, albumin, protein channels, carrier proteins
Immunity	Protect the body from foreign pathogens	Collagen, lysozyme, antibodies
Wound Healing, Tissue Regeneration, and Nerve Function	Repair wounded areas of the body, replace old tissue, transmission of nerve signals	Bradykinin, fibrin, collagen, amino acid tryptophan converted to neurotransmitter serotonin
Energy Source	Provide energy if not enough carbohydrates and fats are consumed	some amino acids (e.g., leucine)

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 made up of three protein strands that twist around each other like a rope (Figure 6.3.1) and then these collagen ropes overlap with others. This highly ordered structure is even

stronger than steel fibers of the same size. Collagen makes bones strong but flexible. Collagen fibers in the skin provide it with structure, and the protein elastin makes skin flexible. Pinch the skin on your hand and then let go; the collagen and elastin proteins in skin allow it to go back to its original shape. Smooth-muscle cells that secrete collagen and elastin proteins surround blood vessels, providing the vessels with structure and the ability to stretch back after blood is pumped through them. Another strong, fibrous protein is keratin, an important component of skin, hair, and nails. Major categories and functions of proteins are summarized in the table below, and the subsequent sections of this page give more detail on each of them.

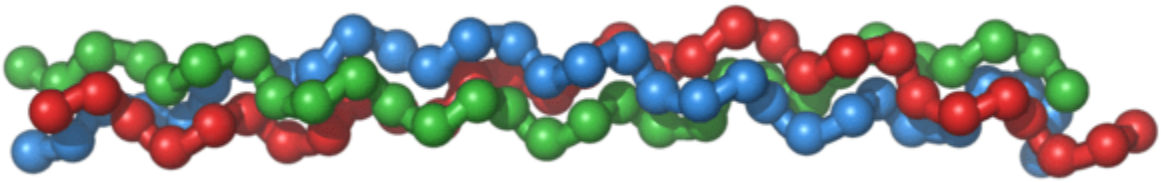


Figure 6.3.1: Triple-helix structure of collagen. (CC BY-SA 3.0; JWSchmidt via Wikimedia Commons)

Enzymes

Enzymes are proteins that conduct specific chemical reactions. An enzyme's job is to provide a site for a chemical reaction and to lower the amount of energy and time it takes for that chemical reaction to happen (Figure 6.3.2). This is why enzymes are sometimes called catalysts. On average, more than 100 chemical reactions occur in cells every single second and most of them require enzymes. The liver alone contains over 1,000 enzyme systems. Enzymes are specific and will use only particular substrates that fit into their active site, similar to the way a lock can be opened only with a specific key. Nearly every chemical reaction requires a specific enzyme (e.g., the lactase enzyme is used to break down lactose). Fortunately, an enzyme can fulfill its role as a catalyst over and over again, although eventually it is destroyed and rebuilt. All bodily functions, including the breakdown of nutrients in the stomach and small intestine, the transformation of nutrients into molecules a cell can use, and building all macromolecules, including protein itself, involve enzymes.

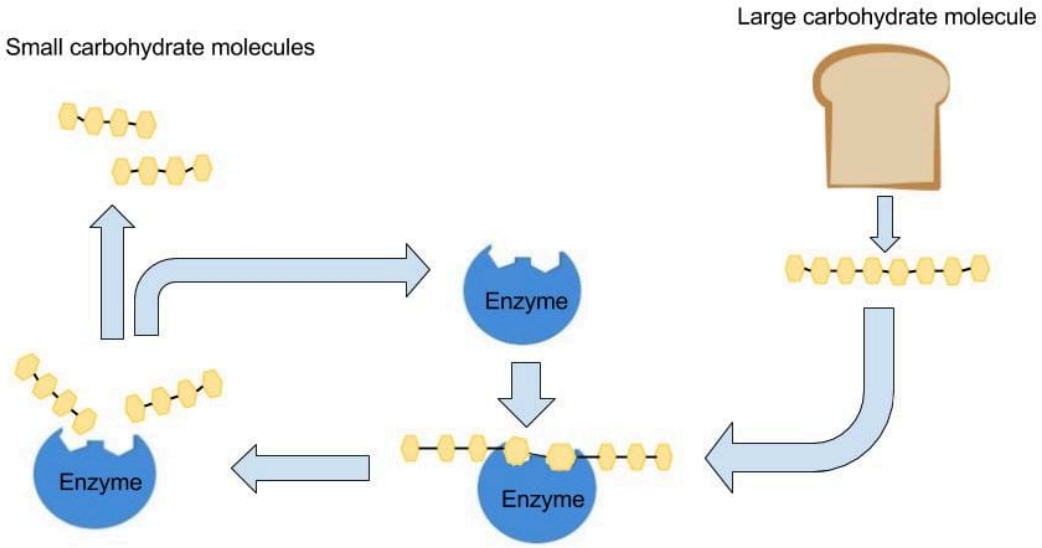


Figure 6.3.2: Enzymes Role in Carbohydrate Digestion. (CC BY 4.0; Allison Calabrese via Human Nutrition 2020e (Hawaii))

Hormones

Proteins are responsible for hormone synthesis. Hormones are chemical messengers produced in one part of the body and then transported in the blood to a different part of the body. When the hormone gets to the target tissue/part of the body, it communicates a message to initiate a specific reaction or cellular process. For instance, after you eat a meal, your blood glucose levels rise. In response to the increased blood glucose, the pancreas releases the hormone insulin. Insulin tells the cells of the body that glucose is available and to take it up from the blood and store it or use it for making energy or building macromolecules.

A major function of hormones is to turn enzymes on and off, so some proteins can even regulate the actions of other proteins. While not all hormones are made from proteins, many of them are.

Fluid and Electrolyte Balance

Proper protein intake enables the basic biological processes of the body to maintain the status quo in a changing environment. Fluid balance refers to maintaining the distribution of water in the body. If too much water in the blood suddenly moves into a tissue, the results are swelling and, potentially, cell death. Water always flows toward areas that have higher concentrations of other solutes (e.g., proteins, glucose). Proteins attract fluid, so to keep the water evenly distributed between blood and cells, proteins continuously circulate at high concentrations in the blood. When protein intake is deficient, the concentration of protein in the blood is too low to keep a good balance of fluid between the blood and tissues. Fluid then collects in the tissues, causing edema (swelling). The most abundant protein in the blood is albumin. Albumin's presence in the blood makes the protein concentration in the blood similar to that in cells. Therefore, fluid exchange between the blood and cells is not in the extreme, but rather is minimized to preserve the status quo. Transport proteins (discussed below) in the cell membrane help to maintain the proper balance of electrolytes (like sodium and potassium) inside and outside the cell.



Figure 6.3.3: Edema of right hand. (CC BY 4.0; OpenStax Anatomy and Physiology)

Acid-Base (pH) Balance

Protein is also essential in maintaining proper pH balance (the measure of how acidic or basic a substance is) in the blood. The pH scale ranges from 0 (strongly acidic) to 14 (strongly basic/alkaline). Blood pH is maintained between 7.35 and 7.45, which is slightly basic. If the blood becomes too acidic (a condition known as acidosis) it means that the level of hydrogen (H^+) in the blood is excessive. If the blood becomes too basic/alkaline (a condition known as alkalosis) it means that the level of H^+ in the blood is deficient. Even a slight change in blood pH can affect body functions. Two examples of this include:

- When proteins are exposed to acids or bases the proteins change shape and stop functioning as intended. This process of proteins uncoiling and losing their shape and function is known as denaturation. Denaturation of proteins also occurs with exposure to heat, heavy metals, alcohol, and other damaging substances.
- You learned in Chapter 4 that acidic blood (from ketoacidosis) can lead to coma and/or death in extreme cases.

The body has several systems that hold the blood pH within the normal range to prevent issues. Some proteins (e.g., albumin) act as buffers and release hydrogen (H^+) into the blood if it gets too basic. Other proteins (e.g., hemoglobin) can also take hydrogen from the blood if it gets too acidic. By releasing and taking hydrogen when needed, proteins maintain acid-base balance and keep blood pH within a normal range.

Transport

Proteins also play vital roles in transporting substances around the body. For example, albumin chemically binds to hormones, fatty acids, some vitamins, essential minerals, and drugs, and transports them throughout the circulatory system. Another example is hemoglobin; 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. Proteins also help with transport across the cell membrane. A cell's membrane is usually not permeable to large molecules. To get the required nutrients and molecules into the cell, many transport proteins exist in the cell membrane. Some of these proteins act as channels that allow particular molecules to move in and out of cells. Others act as one-way taxis and require energy to function (Figure 6.3.4).

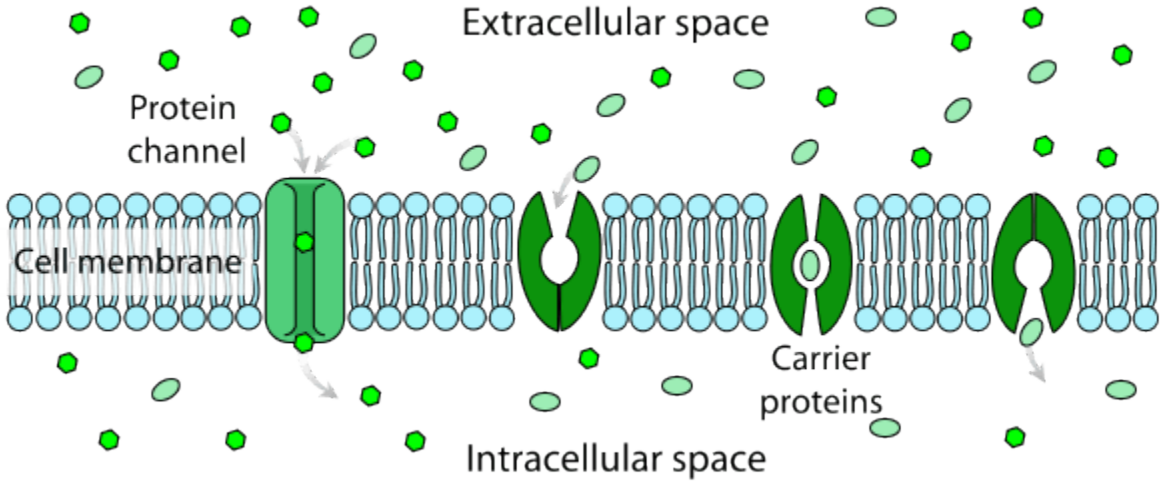


Figure 6.3.4: Molecules move in and out of cells through transport proteins, which are either channels or carriers. Facilitated diffusion in the cell membrane, showing ion channels (left) and carrier proteins (three on the right). (CC0; by LadyofHats via Wikimedia Commons)

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Immunity

Our immune system is designed to attack and destroy foreign substances. When a foreign substance attacks the body, the immune system produces antibodies to defend against it. Antibodies are special proteins that recognize a unique molecule (antigen) on harmful bacteria and viruses. Antibodies bind to the antigen and destroy it. Antibodies also trigger other factors in the immune system to seek and destroy unwanted intruders. Watch the short video (< 1 minute) to see antibodies in action.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

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Wound Healing, Tissue Regeneration, and Nerve Function

Proteins are involved in all aspects of wound healing, a process that takes place in three phases: inflammation, proliferation, and remodeling. For example, if you get a small cut, your skin will turn red and become inflamed. The healing process begins with proteins, such as bradykinin, which dilate blood vessels at the site of injury. An additional protein called fibrin helps to secure platelets that form a clot to stop the bleeding. Next, in the proliferation phase, cells move in and mend the injured tissue by installing newly made collagen (protein) fibers. The collagen fibers help pull the wound edges together. In the remodeling phase, more collagen is deposited, forming a scar. Scar tissue is only about 80 percent as functional as normal uninjured tissue. If a diet

is insufficient in protein, the process of wound healing is markedly slowed.

While wound healing takes place only after an injury is sustained, a different process called tissue regeneration is ongoing in the body. During tissue regeneration, an exact structural and functional copy of the old tissue is created. Ultimately, the old tissue is replaced with brand new, fully functional tissue. Cells are constantly being broken down, repaired, and replaced. When proteins in the cells are broken down, the amino acids are recycled into new proteins. Some cells (such as skin, hair, nails, and intestinal cells) have a very high rate of regeneration, while others, (such as heart-muscle cells and nerve cells) do not regenerate at any appreciable levels. Tissue regeneration is the creation of new cells (cell division), which requires many different proteins including enzymes, transport proteins, hormones, and collagen. The cells lining the intestine regenerate every three to five days. Protein-inadequate diets impair tissue regeneration, causing many health problems including impairment of nutrient digestion and absorption.

Amino acids can be used to make neurotransmitters (e.g., epinephrine, serotonin) that transmit messages from one nerve cell to another.

Energy Source

Some of the amino acids in proteins can be disassembled and used to make energy. In healthy people, protein contributes little to energy needs. If a person's diet does not contain enough carbohydrates and fats their body will use amino acids to make energy. When proteins are needed for energy, they are taken from the blood and body tissues (e.g., muscle). To use proteins for energy, deamination is required. Deamination is a process where the amine group is removed from the amino acid and the nitrogen is transported to the kidney for excretion. The remaining components are metabolized for energy. To protect our body tissues from being broken down for energy, it is important to eat an adequate amount of fat and carbohydrate. It's also important to note that our body cannot store excess protein. Excess protein intake results in nitrogen excretion; the remaining components are used for energy or converted to fat for later use.

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6.4: Protein Recommendations

Learning Objectives

- Identify the RDA and AMDR for protein.
- Describe nitrogen balance.
- Identify foods high in protein.
- Compare and contrast incomplete and complete proteins.

How Much Protein Does a Person Need in Their Diet?

You've learned in previous chapters that the Acceptable Macronutrient Distribution Ranges (AMDRs) for carbohydrate intake is 45-65% of total calories and 20-35% of total calories for total fat intake.[1] The remaining calories come from protein, making the AMDR for protein 10-35% of total calories (Table \(\PageIndex{1}\)).[1] The Recommended Dietary Allowance (RDA) for protein is 0.8 grams of protein per kilogram of body weight. The RDA for protein was established to prevent deficiency. Additional protein recommendations for adults are included in (Table \(\PageIndex{1}\)).

Table 6.4.1: Dietary Reference Intakes and Recommendations for Protein

	RDA (g/kg body weight/day)[1]	AMDR (% calories)[1]	Dietary Guidelines (g/kg body weight/day)[2]	Athletes (g/kg body weight/day)[3]	Healthy Older Adults (g/kg body weight/day)[4]
Total Protein	0.8	10-35	1.2-1.6	1.2-2.0	1.0-1.2

Using the RDA, how much protein does a 150-pound sedentary adult need to prevent deficiency? Steps to answer the question include:

1. convert the person's weight in pounds to kilograms by dividing their weight in pounds by 2.2 (150 pounds / 2.2 = 68.2 kg)
2. multiply the person's weight in kilograms by the RDA (68.2 kg x 0.8 grams/kg = 55 grams protein per day)

Most Americans meet or exceed the RDA for protein.

Nitrogen Balance

The appropriate amount of protein in a person's diet is that which maintains a balance between what is taken in and what is used. The RDA for protein was determined by assessing **nitrogen balance**. Nitrogen is one of the basic elements contained in all amino acids. When proteins are broken down and amino acids are catabolized, 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.

The National Academy of Medicine used data from multiple studies that determined nitrogen balance in people of different age groups to calculate the RDA for protein. A person is said to be in nitrogen balance when the nitrogen input equals the amount of nitrogen used and excreted (Table 6.4.2). A person is in negative nitrogen balance when the amount of excreted nitrogen is greater than that consumed, meaning that the body is breaking down more protein to meet its demands. This state of imbalance can occur in people who have certain diseases, such as cancer or muscular dystrophy. A person healing from a severe wound may also be in negative nitrogen balance because protein is being used up to repair tissues. Someone who has a low-protein diet may also be in negative nitrogen balance as they are taking in less protein than what they actually need. Positive nitrogen balance occurs when a person excretes less nitrogen than what is taken in by the diet, such as during child growth or pregnancy. At these times the body requires more protein to build new tissues, so more of what gets consumed gets used up and less nitrogen is

excreted.

Table 6.4.2: Nitrogen Balance

Term	Nitrogen Balance Equation	Associated Situations
Nitrogen Balance	Nitrogen intake = nitrogen used	healthy individuals eating a varied diet
Negative Nitrogen Balance	Nitrogen intake < nitrogen used	fasting, cancer, wound healing
Positive Nitrogen Balance	Nitrogen intake > nitrogen used	pregnancy, periods of high growth

Dietary Sources of Protein

The protein food group consists of foods made from meat, seafood, poultry, eggs, soy, beans, peas, nuts and seeds. Fruits and vegetables are not high in protein, but help to spare protein by providing carbohydrate. The overall suggestion is to eat a variety of protein-rich foods to benefit health. Different protein-containing foods provide different nutrients. For example, animal proteins contain Vitamin B_{12} and plant proteins contain a higher amount of fiber. In addition, recommendations suggest choosing leaner/less fatty cuts of meat.

Protein Quality

While protein is contained in a wide variety of foods, it differs in quality. High-quality protein contains all the essential amino acids in the proportions needed by the human body. The amino acid profile of different foods is therefore one component of protein quality. Foods that contain all 9 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.

Foods that do not contain all of the essential amino acids in sufficient amounts to support growth and health are called incomplete protein sources. 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 most legumes do not contain enough methionine or tryptophan. Because grains and legumes are not deficient in the same amino acids, they can complement each other in a diet. The process of combining two or more incomplete protein sources to make a complete protein is known as mutual supplementation. Some examples of mutual supplementation are provided in Table 6.4.3. 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.

Table 6.4.3: Mutual Supplementation Combinations

Foods	Lacking Amino Acids	Complementary Food	Complete Protein Combinations
Legumes (except soy)	Methionine, tryptophan	Grains, nuts, and seeds	• Hummus and whole-wheat pita • Black beans and rice
Grains (except quinoa)	Lysine, isoleucine, threonine	Legumes	• Cornbread and kidney bean chili • Bread with peanut butter
Nuts and seeds	Lysine, isoleucine	Legumes	• Cashews with stir-fried tofu • Tahini sauce over falafel

The second component of protein quality is digestibility, as not all protein sources are equally digested. In general, animal-based proteins are completely broken down during the process of digestion, whereas plant-based proteins are not. This is because some proteins are contained in the plant's fibrous cell walls and these pass through the digestive tract unabsorbed by the body. 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. Casein (milk protein), egg whites, whey, and soy all have a PDCAAS of 1, the highest score. Some additional foods' scores are shown in Figure 6.4.1.

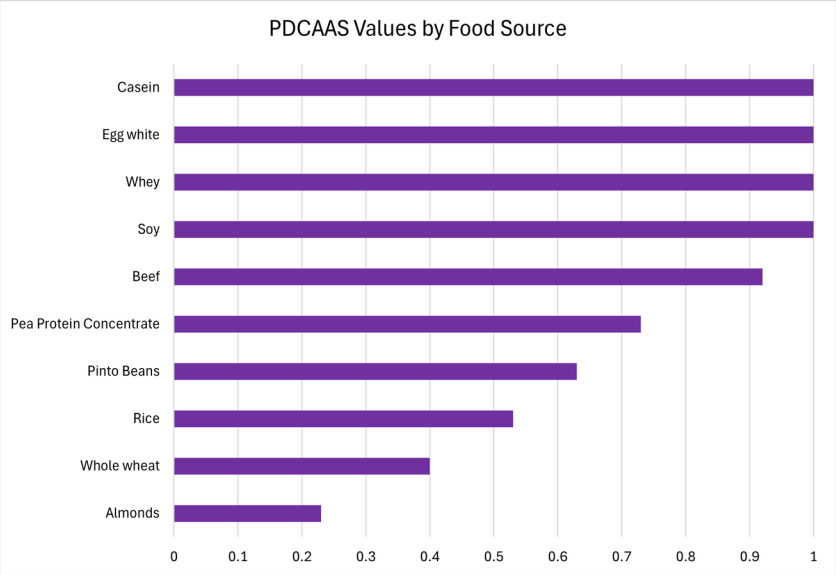


Figure 6.4.1: PDCAAS Values of Various Foods. (CC BY 4.0; Ann Diker)

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6.5: Diseases Involving Proteins

Learning Objective

- Identify the potential health risks associated with low and high protein intakes.

As you may recall, moderation refers to having the proper amount of a nutrient—having neither too little nor too much. A healthy diet incorporates all nutrients in moderation. Low protein intake has several health consequences, and a severe lack of protein in the diet eventually causes death. Although severe protein deficiency is a rare occurrence in children and adults in the United States, it is estimated that more than half of the elderly in nursing homes are protein-deficient. The Acceptable Macronutrient Distribution Range (AMDR) for protein for adults is 10-35% of calories, which is a fairly wide range. In this section, we will discuss the health consequences of protein intake that is either too low to support life's processes or too high, thereby increasing the risk of chronic disease.

Health Consequences of Protein Deficiency

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

Kwashiorkor

The name kwashiorkor comes from a language in Ghana and means, "the sickness the child gets when the new baby comes". The syndrome was named because it occurred most commonly in young children (1-3 years of age) who no longer drink breast milk, usually because another child had just been born. Subsequently, the child was fed watery porridge made from low-protein grains, which accounts for the low protein intake. Consequences of kwashiorkor (Figure 6.5.1) include:

- weight loss and muscle wasting, with some body fat retention
- retarded growth and development (less severe than with marasmus)
- swelling (edema), which results in extreme belly distention
- enlarged, fatty liver
- loss of appetite, sadness, irritability, apathy
- development of skin sores
- dry, brittle hair

Recall that one of protein's functional roles in the body is fluid balance. Diets extremely low in protein do not provide enough amino acids for the synthesis of albumin. One of the functions of albumin is to hold water in the blood vessels, so having lower concentrations of blood albumin results in water moving out of the blood vessels and into tissues, causing swelling (edema). 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.



Figure 6.5.1: Kwashiorkor. (Image by Press Association via Modern Ghana)

Marasmus

In addition to not getting enough protein, people with marasmus also don't get enough calories in their diet. Without enough protein or calories, people with marasmus also don't get enough of several other nutrients. Marasmus affects mostly young children in poor countries. Body weights of children with marasmus may be up to 80% less than that of a normal child of the same age. Marasmus is a Greek word, meaning “starvation.” Consequences of marasmus (Figure 6.5.2) include:

- wasting and weakening of muscles, including the heart muscle
- stunted brain development and learning impairment
- depressed metabolism and little insulation from body fat, causing a dangerously low body temperature
- stunted physical growth and development
- poor skin health
- deterioration of the intestinal lining, which further inhibits absorption of nutrients
- anemia
- severely weakened immune system
- fluid and electrolyte imbalances



Figure 6.5.2: Marasmus. (Michael Haninger via flickr)

Health Consequences of Too Much Protein in the Diet

The effects of high protein intakes on health is unclear. In the past, some research has linked high protein intakes with bone loss, kidney disease, and heart disease. High protein diets can increase calcium excretion, but current evidence does not support the idea that high protein diets lead to bone loss. In fact, recent systematic reviews on the topic showed no adverse effect of higher protein intakes on bone health and indicated some evidence in support of high protein intakes on bone density.[1,2] However, these reviews also stated that additional research is needed to come to any conclusions about the association between high protein diets and bone loss. High protein diets appear to only increase the progression of kidney disease in people who already have kidney disease, and not to *cause* these problems.[3] High protein diets that contain a lot of animal protein have been associated with heart disease and high blood cholesterol levels. However, diets that include lots of red meat are also high in saturated fat and cholesterol and sometimes linked to unhealthy lifestyles, so it is difficult to conclude that the high protein content is the culprit.

As with any nutrient, protein must be eaten in proper amounts. Moderation and variety are key strategies to achieving a healthy diet and need to be considered when optimizing protein intake. While the scientific community continues its debate about the particulars regarding the health consequences of too much protein in the diet, nutrition experts recommend having a moderate amount of protein in the diet and varying the sources of protein to include plant-based protein sources.

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6.6: Vegetarian and Vegan Diets

Learning Objective

- Describe various vegetarian diets.

Some people wonder if vegetarians and vegans get enough protein in their diet. People who follow variations of the vegetarian diet and consume eggs, fish, and/or dairy products can meet their protein requirements by consuming adequate amounts of these foods. Vegetarians and vegans can also attain their recommended protein intakes with high-quality plant-based protein sources.

Vegetarian and Vegan Diets

Vegetarianism is the practice of only eating foods of plant origin, including vegetables, fruits, grains, and nuts. Veganism extends vegetarianism by also excluding the use of all animal products (e.g., clothing, honey, products tested on animals, etc.). Vegetarian diets vary depending on the types of foods that are excluded. There are different types of vegetarian and vegan diets, but some commons forms are included in Table 6.6.1. The more restrictive the diet, the more challenging it becomes to achieve adequate protein intake.

Table 6.6.1: Types of Vegetarian and Vegan Diets

Type of Diet	Foods Consumed	Comments
Semi-vegetarian (also called flexitarian or plant-based diet)	Vegetables, grains, nuts, fruits, legumes; sometimes meat, seafood, poultry, eggs, and dairy products	Typically exclude or limit red meat; may also avoid other meats
Pescatarian	Similar to semi-vegetarian but excludes all sources of animal protein except fish	*Pesco* means "fish," the only animal source of protein in this diet
Lacto-ovo-vegetarian	Vegetables, grains, nuts, fruits, legumes, dairy products (lacto), and eggs (ovo)	Excludes animal flesh and seafood
Lacto-vegetarian	Similar to lacto-ovo-vegetarian but excludes eggs	Relies on milk and cheese for animal sources of protein
Ovo-vegetarian	Vegetables, grains, nuts, fruits, legumes, and eggs	Excludes dairy, animal flesh, and seafood products
Vegan (also called strict vegetarian)	Only plant-based foods (vegetables, grains, nuts, seeds, fruits, legumes)	May not provide adequate vitamin B_{12}, zinc, iron, or calcium
Macrobiotic diet	Vegan-type diet; becomes progressively more strict until almost all foods are eliminated; at the extreme, only brown rice and small amounts of water or herbal tea	Taken to the extreme, can cause malnutrition and death
Fruitarian	Only raw or dried fruit, seeds, nuts, honey, and vegetable oil	Very restrictive diet; deficient in protein calcium, zinc, iron, vitamin B12, riboflavin, and other nutrients

People choose vegetarianism for many different reasons, including:

- Religious or spiritual reasons
- Moral and ethical reasons
  - Some feel it is morally and ethically wrong to consume animals and animal products because they view the practices in the modern animal industries as inhumane.
- Concern about meat-handling practices
- Ecological reasons (effects on the environment)

- Health benefits
  - Reduced risk of obesity
  - Lower blood pressure
  - Reduced risk of heart disease
  - Fewer digestive problems
  - Reduced risk of some cancers
  - Reduced risk of kidney stones and gallstones

A vegetarian diet can also present some challenges. There is potential for inadequate intakes of some vitamins and minerals. Vegan diets may not provide enough vitamin B_{12}, vitamin D, riboflavin, zinc, iron, and calcium. It is important for vegetarians and non-vegetarians to consume a balanced and adequate diet. Appropriate planning can result in a healthful and nutritionally adequate vegetarian or vegan diet.

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7: ALCOHOL

7.1: Introduction to Alcohol
7.2: Alcohol Metabolism
7.3: Impact of Alcohol on Health

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7.1: Introduction to Alcohol

Learning Objective

- Identify recommendations for alcohol intake.

When considering total calorie intake, it is important to consider alcohol. Alcohol is not a nutrient, but it does contain calories – 7 kcal/g.

Recommendations[1,2]

It is not recommended for any non-drinker to start drinking alcohol. For those who do drink alcohol, it is recommended to limit alcoholic beverages and drink in moderation. Moderate drinking is defined as limiting intake to:

- 2 drinks or less per day (for men)
- 1 drink or less per day (for women)

Binge drinking (5 or more drinks in two hours for men; 4 or more drinks in two hours for women) should be avoided.

People who should not drink include people who are:

- pregnant
- might be pregnant
- younger than the legal drinking age
- living with certain medical conditions
- taking certain medications
- recovering from an alcohol-use disorder
- unable to control how much alcohol they drink

Alcohol Drink Equivalents[3]

One alcoholic drink is defined as containing 14 grams of pure alcohol. As seen in Figure 7.1.1, one drink is equal to:

- 12 fluid ounces of regular beer (5% alcohol)
- 8-9 fluid ounces of malt liquor (7% alcohol)
- 5 fluid ounces of wine (12% alcohol)
- 1.5 fluid ounces of 80-proof spirits (40% alcohol)



Figure 7.1.1: Examples of one standard drink. (public domain; National Institutes of Health)

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7.2: Alcohol Metabolism

Learning Objective

- Describe the process of alcohol metabolism.

Alcohol in chemistry refers to a group of similar organic compounds. In beverages, the only alcohol consumed is ethanol (Figure 7.2.1).

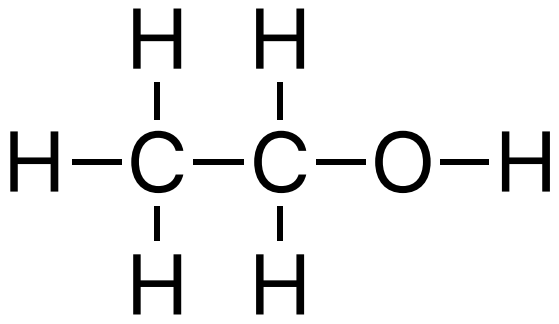


Figure 7.2.1: Chemical Structure of Ethanol. (public domain; Lukáš Mižoch via Wikimedia Commons)

Ethanol/Alcohol Metabolism

The majority of the alcohol consumed is metabolized by the liver. The only effective way to avoid alcohol toxicity is to give the liver enough time to metabolize the alcohol that has been consumed. As a general rule, the liver can metabolize one standard drink per hour. A legally intoxicated person takes about five hours to become sober – this is based on the rate that the liver metabolizes alcohol after drinking stops.

When alcohol is consumed, ~5% of the alcohol is absorbed and metabolized by cells of the gastrointestinal tract. The remaining 95% travels through the bloodstream which is why blood tests are accurate at measuring alcohol levels. Approximately 2-10% of this circulating alcohol is excreted by the lungs and kidneys. The lungs exhale alcohol as a gas. The more alcohol that a person drinks, the stronger the smell of alcohol will be on their breath. Breathalyzer tests measure the amount of alcohol exhaled from the lungs to determine the state of intoxication. Alcohol has the capability to suppress the anti-diuretic hormone (ADH). This action stimulates the kidneys to release water which causes an increase in urination and can lead to dehydration. Dehydration affects every cell in the body, including the brain cells. This is the cause of hangovers. When drinking or hung over, do not take Tylenol (acetaminophen) because alcohol metabolism activates an enzyme that transforms acetaminophen into a toxin that causes liver inflammation and damage. Instead, drink water with electrolytes or sports drinks to rehydrate the body's cells.

The remaining circulating alcohol (85-98% of what was consumed) is metabolized by the liver. The liver uses two metabolic processes to get rid of alcohol as quickly and safely as possible (see Figure 7.2.2).

- **Alcohol Dehydrogenase System:** About 80-90% of the alcohol that reaches the liver is processed via the Alcohol Dehydrogenase System. An enzyme, alcohol dehydrongenase (ADH), converts ethanol/alcohol to acetaldehyde. Acetaldehyde is toxic, so acetaldehyde dehydrogenase (ALDH) converts acetaldehyde into acetate, a non-toxic molecule.
- **Microsomal Ethanol Oxidizing System (MEOS):** In a moderate drinker, about 10-20% of the alcohol that reaches the liver is processed via the MEOS. During periods of heavy drinking, the Alcohol Dehydrogenase System cannot keep up, and the MEOS system will metabolize most of the excess ethanol ingested. Heavy drinking stimulates MEOS enzymes to clear ethanol faster from the body. Once the MEOS converts ethanol to acetaldehyde, ALDH will immediately convert acetaldehyde into acetate.

The acetate produced (from the alcohol dehydrogenase system and microsomal ethanol oxidizing system) is either released into circulation or retained inside the liver cells. In the liver cells, acetate is converted to acetyl CoA where it is used to produce other

molecules like CO_2 or used in the synthesis of fatty acids and cholesterol.

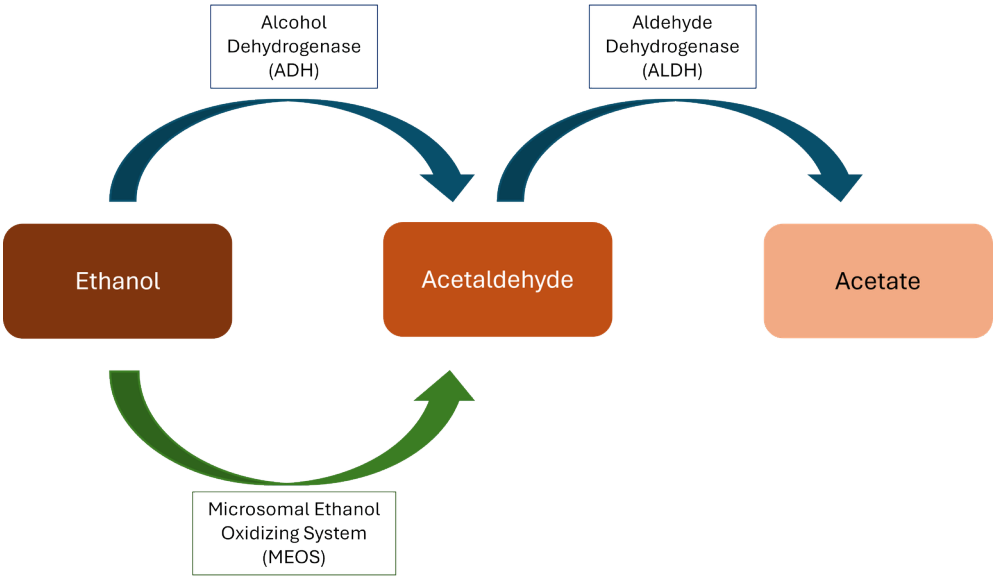


Figure 7.2.2: Alcohol Metabolism. (CC BY 4.0; Ann Diker)

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7.3: Impact of Alcohol on Health

Learning Objective

- Describe the health benefits and health risks associated with alcohol consumption.

Drinking alcohol in moderation is associated with some health benefits. However, alcohol intake has also been shown to be detrimental to health. Exploring the beneficial and harmful effects of alcohol may help you make informed decisions about alcohol consumption.

Health Benefits of Moderate Alcohol Intake

Drinking alcohol in moderation is associated with the following:

- Temporary reduction of stress and anxiety: Alcohol is a central nervous system depressant, so there is a temporary wave of calmness due to slower brain activity.
- Lower all-cause mortality compared to non-drinkers or heavy drinkers[1,2]
- Lower risk of cardiovascular disease mortality compared to non-drinkers[1,2]

Health Risks of Alcohol Consumption

Both moderate and heavy drinking are associated with risks; heavy drinking is related to an increased risk of death from all causes.[1] Other risks associated with drinking alcohol include:

- Trauma: Increased risk of morbidity and mortality from trauma[2] (e.g., car accidents, alcohol poisoning, risky sexual behaviors)
- Cancer: Any level of alcohol intake increases the risk of breast cancer, head and neck cancers, esophageal cancer, stomach cancer, liver cancer, and colorectal cancer.[3,4]
- Heart Disease: Heavy drinking is linked to high blood pressure, heart failure, and stroke.[5,6]
- Obesity: Alcohol consumption can contribute to obesity and diseases associated with obesity.[6]
- Liver Disease: Alcohol is a toxin and the liver plays a major role in detoxifying alcohol. If the liver has too much alcohol to detoxify, other liver functions suffer which can lead to the build-up of fat in the liver (i.e., fatty liver). As fat builds up in the liver, it can lead to scarring and cirrhosis (see Figure 7.3.1) or liver cancer.
- Fetal Alcohol Syndrome: During pregnancy, there is no safe level of alcohol consumption. When a mother drinks alcohol during pregnancy, it can cause growth, mental, and physical problems in the baby (known as Fetal Alcohol Syndrome; see Figure 7.3.2).

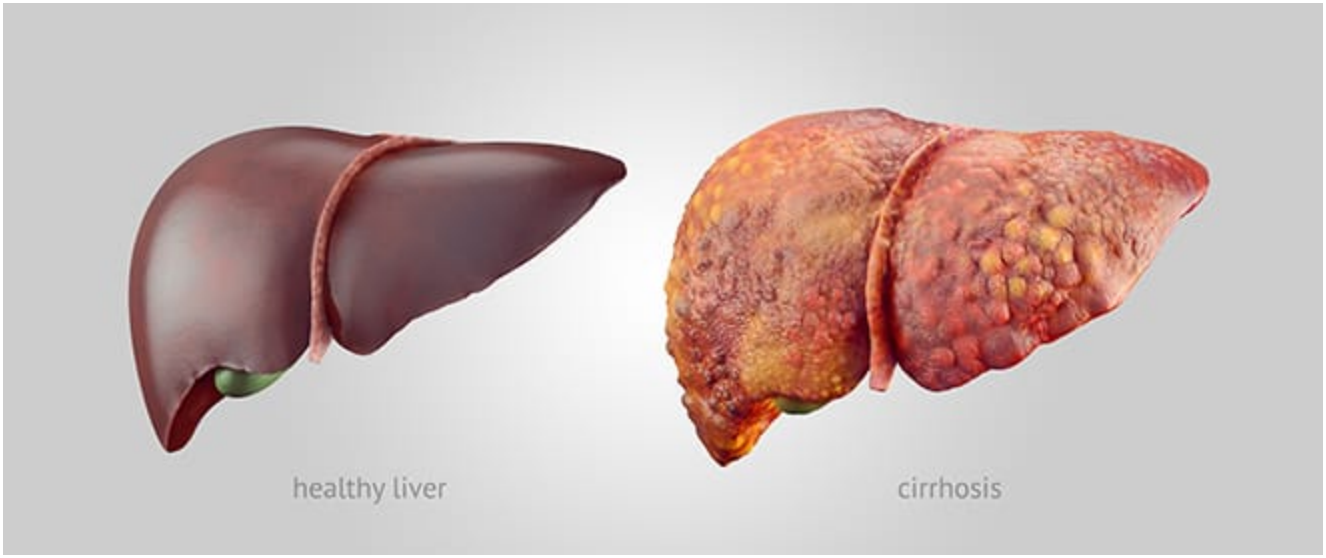


Figure 7.3.1: A healthy liver (left) and a liver with cirrhosis (right). (public domain; National Institute of Diabetes and Digestive and Kidney Diseases)

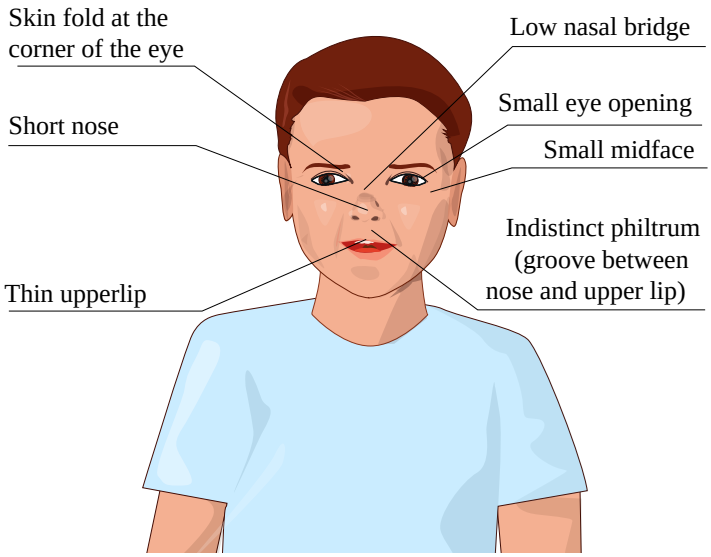


Figure 7.3.2: Fetal Alcohol Syndrome. (CC BY-SA 4.0; Hariadhi via Wikimedia Commons)

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8: NUTRIENTS IMPORTANT FOR FLUID AND ELECTROLYTE BALANCE

8.1: Overview of Fluid and Electrolyte Balance

8.2: Functions of Water

8.3: Regulation of Water Balance

8.4: Electrolytes

8.5: Understanding Dehydration and Heat Illnesses

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8.1: Overview of Fluid and Electrolyte Balance

Learning Objectives

- Identify components of body fluid.
- Describe osmosis.

A human body is made up of mostly water. An adult consists of about 37-42 liters of water, or about 80 pounds. Fortunately, humans have compartmentalized tissues; otherwise we might just look like a water balloon! Newborns are approximately 70% water. Adult males typically are composed of about 60% water and females are about 55% water. (This difference reflects the differences in body fat content, since body fat is practically water-free. This also means that if a person gains weight in the form of fat the percentage of total body water content declines.) As we age total body water content also diminishes so that by the time we are in our 80s the percent of water in our bodies has decreased to around 45%.

Fluid and Electrolyte Balance

Body fluid is the liquid portion of our cells and tissues. The body fluid composition of tissue can vary. As noted above, the body fluid composition of tissue can vary by:

- Tissue type – lean tissues have higher fluid content than fat tissues
- Sex – males have more lean tissue and therefore more body fluid
- Age – lean tissue is lost with age and body fluid is lost with it

In the human body, body fluid is composed of intracellular fluid and extracellular fluid (Figure $8.1.1a$ and $8.1.1b$). Intracellular fluid is the fluid that is inside cells; this fluid makes up about 67% of the fluid in an adult. Extracellular fluid is any fluid that is outside of the body's cells. Extracellular fluid is further subdivided into the fluids between cells (interstitial), blood plasma, and other tissue fluids (such as cerebrospinal fluid which surrounds and protects the brain and spinal cord).

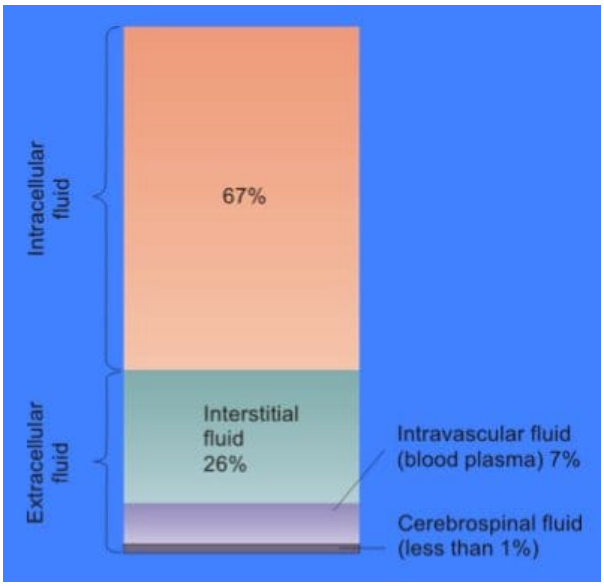


Figure $8.1.1a$: The components of body fluid.

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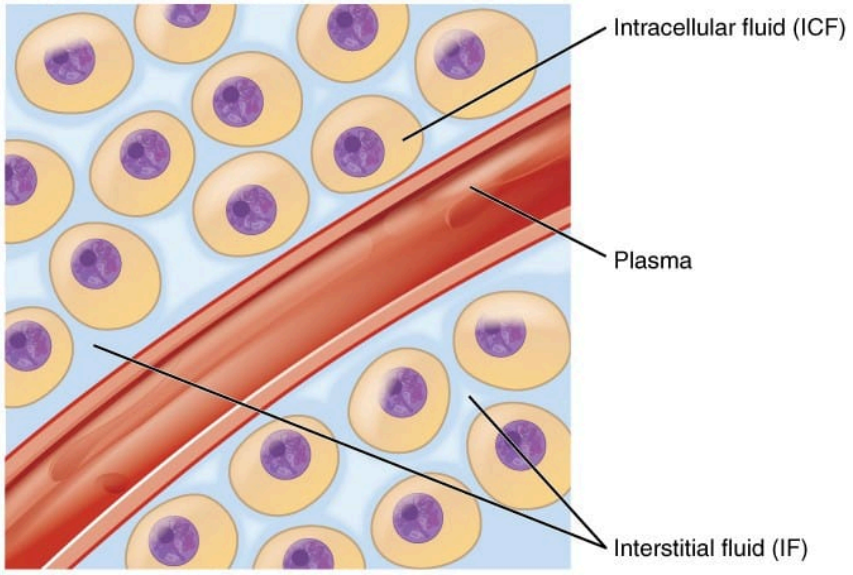


Figure 8.1.1*b*: Fluid compartments in the human body.

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Although water makes up the largest percentage of body volume, body fluids are not actually pure water but rather a mixture of dissolved substances (solutes), including electrolytes, that are critical to life. Electrolytes are minerals that, when dissolved in water, disassociate (separate) into charged ions. Positively charged electrolytes are called cations and negatively charged electrolytes are called anions. For example, sodium chloride (the chemical name for table salt) disassociates into sodium cations (Na^+) and chloride anions (Cl^-) when dissolved in water.

Osmoregulation

One of the essential functions of the body is to maintain fluid balance and the differences in solute composition between cells and their surrounding environment. Osmoregulation is the control of fluid balance and composition in the body. The processes involved keep fluids from becoming too dilute or too concentrated. Fluid compartments are separated by selectively permeable membranes, which allow some things, such as water, to move through while other substances require special transport proteins and often energy to move through the membranes. The movement of water between fluid compartments happens by osmosis (Figure 8.1.2), which is simply the movement of water through a selectively permeable membrane to the area that has more solutes. Water is never transported actively; that is, it never takes energy for water to move between compartments. Energy is used to move many solutes (e.g., sodium) through these membranes; this changes the concentration of solutes and causes water to follow the solute to maintain balance. Although cells do not directly control water movement, they do control movement of electrolytes and other solutes and thus indirectly regulate water movement by controlling where there will be regions of high and low concentrations of solutes.

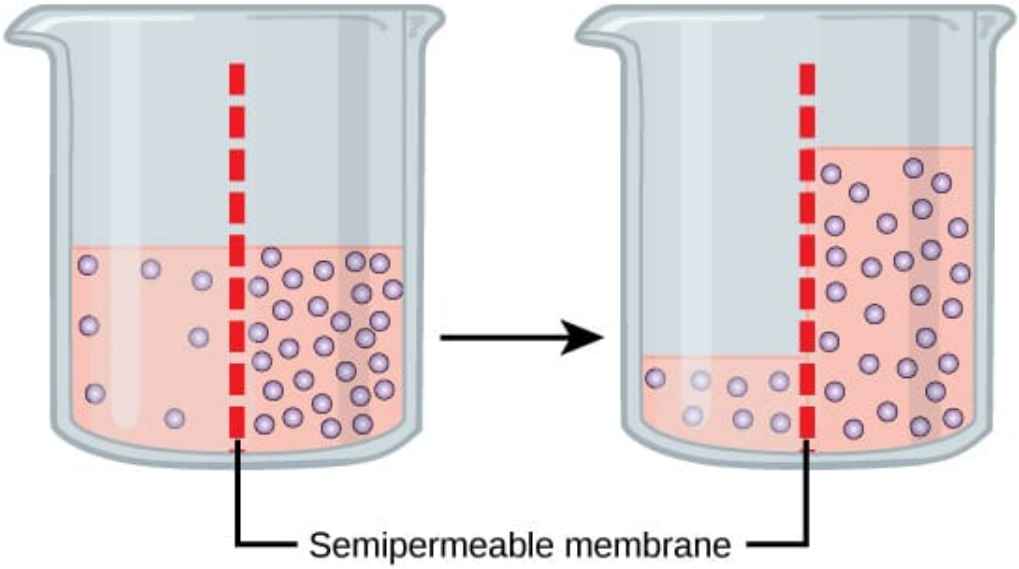


Figure 8.1.2: In osmosis, water always moves to the area that has more solutes. (CC BY 4.0; by OpenStax Concepts of Biology)

Cells maintain their water volume at a constant level, but the composition of solutes in a cell is in a continuous state of flux. This is because cells are bringing nutrients in, metabolizing them, and disposing of waste products. To maintain balance, a cell controls the movement of electrolytes to keep the total number of solutes and, therefore, water the same inside and outside of the cell. However, the composition of the fluids can differ. For example, sodium exists in extracellular fluid at 14 times the concentration as compared to that inside a cell.

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8.2: Functions of Water

Learning Objectives

- Describe the major functions of water in the human body.

Of all the nutrients, water is the most critical as its absence proves lethal within a few days. Water's importance in the human body can be loosely categorized into four basic functions: transportation vehicle, medium for chemical reactions, lubricant/shock absorber, and temperature regulator.

Water As a Transportation Vehicle

Water is called the “universal solvent” because more substances dissolve in it than any other fluid. The dissolved substances (solutes) include many materials including ions, sugars, amino acids, vitamins, and minerals. The solvent action of water allows for substances to be more readily transported. Blood, the primary transport fluid in the body, is mostly made up of water. Dissolved substances in blood include proteins, lipoproteins, glucose, electrolytes, and metabolic waste products, such as carbon dioxide and urea, all of which are either transported to cells to support basic functions or are removed from cells to prevent waste build-up and toxicity.

Water As a Medium for Chemical Reactions

Water is required for even the most basic chemical reactions. Previously, you learned that enzymes are proteins that conduct specific chemical reactions. Enzmyes conduct these reactions in a medium (environment); in the human body the medium is water. Water is an ideal medium for chemical reactions as it can store a large amount of heat, is electrically neutral, and has a pH of 7.0, meaning it is not acidic or basic. Additionally, water is involved in many enzymatic reactions as an agent to break bonds or, by its removal from a molecule, to form bonds.

Water As a Lubricant and Shock Absorber

Water is the main component of the fluids that protect and lubricate tissues. For example:

- cerebrospinal fluid surrounding the brain and spinal cord protects these organs against sudden changes in the environment
- amniotic fluid provides a cushion of protection for a pregnant woman's developing baby
- pleural fluid lubricates the lungs to make breathing easier
- digestive secretions allow for easy passage of material through the gastrointestinal tract
- mucus lines the walls of the intestines which eases the movement of food along the gastrointestinal tract
- synovial fluid lubricates joints and eases the movement
- lacrimal fluid lubricates the eyes

Water As a Temperature Regulator

Water plays an important role in thermoregulation (temperature regulation). Human life is supported within a narrow range of temperature, with the temperature set point of the body being 98.6°F (37°C). Too low or too high of a temperature causes enzymes to stop functioning and metabolism is halted. At 82.4°F (28°C) muscle failure occurs and hypothermia sets in. At the opposite extreme of 111.2°F (44°C) the central nervous system fails and death results. Water is good at storing heat, an attribute referred to as heat capacity. Water has a high heat capacity which means that it takes a lot of external energy to raise water's temperature. This ability helps maintain the temperature set point of the body despite changes in the surrounding environment (e.g., high temperatures outside).

There are several mechanisms in place that move body water from place to place as a method to distribute heat in the body and equalize body temperature. The hypothalamus in the brain is the thermoregulatory center (Figure 8.2.1). The hypothalamus

contains special protein sensors that detect blood temperature. The skin also contains temperature sensors that respond quickly to changes in immediate surroundings.

When the surrounding temperature is cold, sensors in the skin send a signal to the hypothalamus, which then sends a signal to smooth muscle tissue surrounding blood vessels causing them to constrict and reduce blood flow. This reduces heat lost to the environment. The hypothalamus also sends signals to muscles to shiver and erect hairs on our skin and to endocrine glands like the thyroid to secrete hormones capable of ramping up metabolism. These actions increase heat conservation and stimulate its production in the body in response to cooling temperatures.

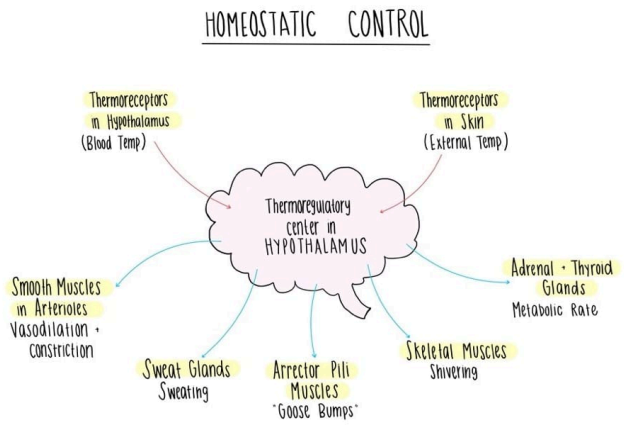


Figure 8.2.1: Thermoregulation is the ability of an organism to maintain body temperature despite changing environmental temperatures. (CC BY 4.0; by Lauren Groth)

When body temperature rises (for example, during exercise), the hypothalamus detects an increase in blood temperature. In response, the hypothalamus sends a signal to the smooth muscle of blood vessels in the skin causing them to dilate so that more blood flows to the skin. This allows heat to be carried away from vital internal organs to the skin's surface. Once on the skin, extra heat exits the body via perspiration (sweat), which is 98-99% water. Water on the skin's surface evaporates, a process that uses energy and results in the loss of heat, thereby cooling the body. Perspiration is a process that intertwines temperature regulation with fluid and electrolyte balance. Water and electrolytes lost in sweat need to be replenished in order to maintain fluid and electrolyte balance.

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8.3: Regulation of Water Balance

Learning Objectives

- Describe water balance including sources of water intake and water output.
- Describe the thirst mechanism.

When the body is in 'water balance', the intake and output of water are equal, indicating a person is hydrated. An imbalance of water leads to either overhydration (intake > output) or dehydration (output < intake). Total water output (loss) per day averages 2.5 liters, which must be balanced with water intake (gain) to stay in water balance (Figure 8.3.1).

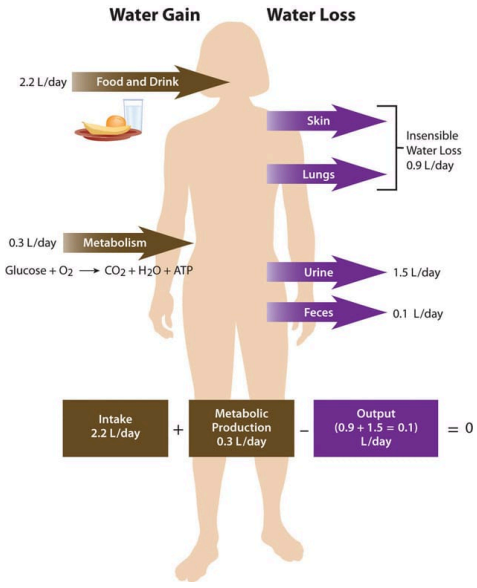


Figure 8.3.1: Daily Water Gain and Loss. (CC BY 4.0; Allison Calabrese via Human Nutrition 2020e (Hawaii))

Water Intake

Most of the water we gain each day comes from drinking fluids and eating solid foods; however, there is a small amount of water produced by our tissues through various metabolic processes. The National Academies of Sciences, Engineering, and Medicine determined that the Adequate Intake (AI) for total fluid intake is:

- About 15.5 cups (3.7 liters) of fluids for men, which includes ~3.0 liters (13 cups) as beverages, including water
- About 11.5 cups (2.7 liters) of fluids a day for women, which includes ~2.2 liters (9 cups) as beverages, including water[1]

It is important to note that the AI for fluids includes fluid intake from *all dietary sources*; that is, fluids coming from food as well as non-alcoholic beverages (including water, tea, coffee, sugar-sweetened beverages, and juices). People are not expected to consume 15.5 or 11.5 cups of pure water per day. In America, approximately 20% of total water intake comes from solid foods.[1] Even foods that seem dry still contain some water (Table 8.3.1). Fluid is also obtained from metabolic reactions. Metabolic water is a product of many chemical reactions in the body and contributes 10-14% of the body's needs.

Table 8.3.1: Water Content of Foods

Foods	Percentage of Water
Nonfat milk, asparagus, broccoli, cabbage, cantaloupe, celery, cucumbers, lettuce, peppers, spinach, strawberries, watermelon, yellow squash, zucchini	90-99

Foods	Percentage of Water
Whole milk, apples, carrots, low-fat cottage cheese, fruit juice, green grapes, oranges, pears, peaches, pineapple, plain yogurt, winter squash (acorn, butternut)	80-89
Avocados, bananas, full-fat cottage cheese, potatoes (baked), rice (cooked), ricotta cheese, shrimp (cooked), tuna (canned in water)	70-79
Chicken breast, ground beef, legumes, pasta, salmon (cooked)	60-69
Feta cheese, hot dogs, hummus, steak, pork (cooked)	50-59
Pizza	40-49
Bagel, bread, cheddar cheese, dried fruit	30-39
Biscuits, cake	20-29
Butter, margarine, raisins	10-19
Cereals, crackers, nuts, nut butters, potato chips, pretzels	1-9
Oils, sugars	0

There is some debate over the amount of water required to maintain health. You may be surprised to find out that the commonly held belief that people need to drink eight 8-ounce glasses of water per day isn't an official recommendation and isn't based on any scientific evidence! The amount of water/fluids a person should consume every day is actually variable and should be based on the climate a person lives in, as well as their age, physical activity level, and kidney function. Your fluid intake is probably adequate if you rarely feel thirsty and your urine is colorless or light yellow.

Thirst Mechanism - One Way to Increase Water Intake

Thirst is a regulatory mechanism to increase water intake. The "thirst center" is contained within the hypothalamus. The thirst mechanism is activated in response to changes in water volume in the blood and the concentration of sodium in the blood. The urge to drink results from a complex interplay of hormones and nervous system responses that coordinate to increase water intake and contribute toward fluid balance and composition in the body. Thirst happens in the following sequence of physiological events:

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

The physiological control of thirst is the back-up mechanism to increase water intake. Fluid intake is controlled primarily by conscious eating and drinking habits. For example, you might have a habit of drinking a beverage with meals. It's important to also note that the thirst mechanism is not always sufficient and has limitations. For example, in older people the thirst mechanism is not as responsive so as we age there is a higher risk for dehydration.

Water Output

The kidneys are the organ primarily responsible for maintaining water balance. They constantly help maintain water balance by either excreting or retaining the fluid we consume. As shown in Figure 8.3.1, daily water output averages 2,500 milliliters. There are two types of outputs:

- insensible water loss: occurs without us being aware of it and includes water lost through breathing (exhalation) and evaporation from the skin

- sensible water loss: noticeable water loss through sweating as well as excretion of urine and feces

Certain situations can cause a significant loss of fluid from the body:

- Illnesses
- Blood loss
- Exercise (causing increased sweating)
- Environmental conditions
- Pregnancy and breastfeeding
- Diuretics (increase fluid loss via urine), including:
  - certain medications
  - alcohol

References

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8.4: Electrolytes

Learning Objectives

- Describe the functions of the following electrolytes:
  - sodium
  - chloride
  - potassium
  - phosphorus
- Describe the impact of sodium, chloride, potassium, and phosphorus imbalances
- Identify food sources of sodium, chloride, potassium, and phosphorus

Electrolytes

Electrolytes are minerals, including sodium, potassium, chloride, and phosphorus. Electrolytes carry electrical charges:

- Sodium (Na^+) and potassium (K^+) are positively charged
- Chloride (Cl^-) and phosphorus (HPO_4^{2-}, hydrogen phosphate) are negatively charged

In intracellular fluid, K^+ and HPO_4^{2-} are the predominant electrolytes; in extracellular fluid, Na^+ and Cl^- predominate. Fluids have an overall neutral charge due to the balance between electrolytes.

One of the major functions of electrolytes is to help regulate fluid balance. Water follows the movement of electrolytes, moving by osmosis to areas where the concentration of electrolytes is high. This allows for the controlled movement of fluids into and out of cells.

Sodium

Sodium is a major extracellular cation (positively-charged ion) that is water-soluble. Very little sodium is required in the diet because sodium absorption the small intestine is extremely efficient. Additionally, hormones ensure that there's a relatively constant concentration of sodium in the blood. Sodium that is not needed is excreted in urine, feces, and sweat.

Functions of Sodium

To maintain water and electrolyte balance, cells control the movement of electrolytes (e.g., sodium) across their membranes, and water follows the electrolytes by osmosis. The cell is able to control the movement of the two major cations, sodium and potassium, with a sodium-potassium pump (Na^+/K^+ pump). This pump transports sodium out of cells while moving potassium into cells (Figure 8.4.1).

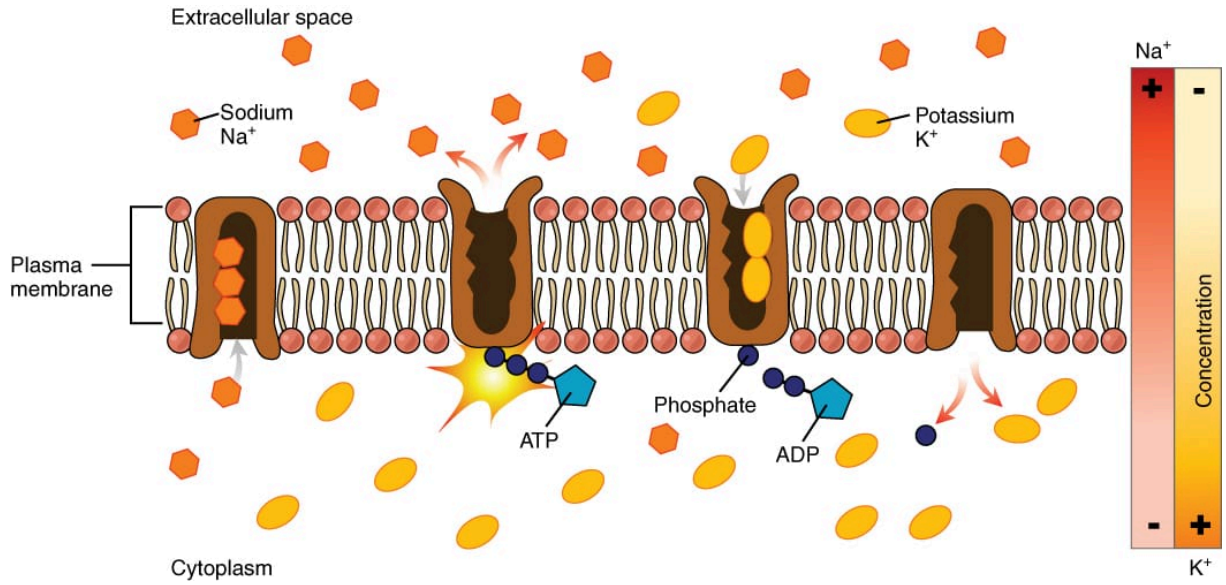


Figure 8.4.1: The sodium-potassium pump. (CC BY 4.0; by OpenStax Anatomy and Physiology)

The sodium-potassium pump is also important for assisting with nutrient transport across the cell membrane, nerve transmission, and muscle contraction. Digested nutrients must make their way from the small intestine to the blood. To do so they pass through intestinal cells on their way to the blood. The transport of nutrients through intestinal cells is facilitated by the sodium-potassium pump. The sodium-potassium pump is found in many types of cells and is particularly abundant in nerve cells. When a nerve cell is stimulated (e.g., the touch of a hand), there is an influx of sodium ions into the nerve cell which creates an electrical impulse or current. Similar to how a current moves along a wire, a sodium current moves along a nerve cell. Stimulating a muscle contraction also involves the movement of sodium ions. For a muscle to contract, a nerve impulse travels to a muscle. The movement of the sodium current in the nerve signals the muscle cell membrane to open and sodium rushes in, creating another current that travels along the muscle and eventually leads to muscle contraction. In both the nerve cell and the muscle cell, the sodium that went in during a stimulus now has to be moved out by the sodium-potassium pump.

Sodium Imbalances

Sweating is a homeostatic mechanism for maintaining body temperature, which influences fluid and electrolyte balance. Sweat is mostly water but also contains some electrolytes, mostly sodium and chloride. Under normal environmental conditions (i.e., not hot, humid days) water and sodium loss through sweat are negligible but is highly variable among individuals. It is estimated that 60 minutes of high-intensity physical activity can produce approximately one liter of sweat; however, the amount of sweat produced is highly dependent on environmental conditions. A liter of sweat typically contains between 1 and 2 grams of sodium and therefore exercising for multiple hours can result in a high amount of sodium loss in some people. Additionally, hard labor can produce substantial sodium loss through sweat. In either case, the lost sodium is easily replaced in the next snack or meal.

Hyponatremia, or a low blood-sodium level, can result from excessive sodium loss in sweat or drinking too much water. For example, hyponatremia has been seen in people engaged in strenuous physical activity who consume large amounts of water and fail to replace sodium. The excess water dilutes the sodium concentration in blood. Illnesses causing sodium loss via vomiting, sweating, and diarrhea may also cause hyponatremia. The symptoms of hyponatremia, also called water intoxication, include nausea, muscle cramps, confusion, dizziness, and in severe cases, seizures, coma and death. Hyponatremia is rare because healthy kidneys are capable of excreting up to one liter of excess water per hour. However, when hyponatremia occurs, the physiological events that occur include:

1. Excessive sodium loss and/or water intake.
2. Low sodium levels in the blood and in the fluid between cells (interstitial fluid).
3. Water moves to where solutes are more concentrated (i.e., into the cells).
4. Cells swell.
5. Symptoms, including nausea, muscle cramps, confusion, and dizziness appear. In severe cases, coma and death can result.

Other people at risk of hyponatremia are people with a very low sodium intake due to special diets. These types of diets are used to treat kidney disease, high blood pressure (hypertension), and heart disease. Excessive vomiting or excessive diarrhea can also

cause a loss of sodium resulting in hyponatremia.

On the other end of the spectrum is a condition known as **hypernatremia** (an abnormally high blood-sodium level). Hypernatremia can happen in patients with congestive heart failure or kidney disease when the kidneys are not excreting sodium effectively. Hypernatremia can result in high blood volume, edema (swelling), and hypertension. Eating too much sodium does not typically cause hypernatremia, but eating too much sodium does lead to higher blood pressure because the extra sodium will be in the blood. This leads to extra water in the blood since water follows sodium and collectively leads to a higher blood volume which then leads to extra pressure on your blood vessel walls and raising your blood pressure.

Sodium Recommendations

The National Academies of Sciences, Engineering, and Medicine set an Adequate Intake (AI) level for sodium for healthy adults at 1,500 milligrams (Table 8.4.1).[1] Table salt is approximately 40% sodium and 60% chloride. One teaspoon of salt contains approximately 2,300 mg sodium, so only ⅔ teaspoon of salt is needed in the diet to meet the AI for sodium. An additional DRI category, called the Chronic Disease Risk Reduction Intake (CDRR), was established for sodium. The CDRR considers evidence related to chronic disease risk. For sodium, individuals with intake levels above the CDRR should consider reducing their intake to reduce chronic disease risk including hypertension.

Table 8.4.1: Dietary Reference Intakes for Sodium[1]

Age Group	Adequate Intake (mg/day)	Tolerable Upper Intake Level (mg/day)	Chronic Disease Risk Reduction Intake (CDRR)
Infants (0–6 months)	110	ND	ND
Infants (7–12 months)	370	ND	ND
Children (1–3 years)	800	ND	Reduce intakes if above 1,200 mg/day
Children (4–8 years)	1,000	ND	Reduce intakes if above 1,500 mg/day
Children (9–13 years)	1,200	ND	Reduce intakes if above 1,800 mg/day
Adolescents (14–18 years)	1,500	ND	Reduce intakes if above 2,300 mg/day
Adults (19–50 years)	1,500	ND	Reduce intakes if above 2,300 mg/day
Adults (51–70 years)	1,500	ND	Reduce intakes if above 2,300 mg/day
Adults (> 70 years)	1,500	ND	Reduce intakes if above 2,300 mg/day
ND = not determined			

Sources of Sodium

Most sodium in the typical American diet comes from salt, which is 40% sodium, including that in processed and prepared foods, including restaurant foods (Figure 8.4.2). 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 foods, contain naturally-occurring sodium. Naturally-occurring sodium accounts for less than 12% of intake in a typical diet.

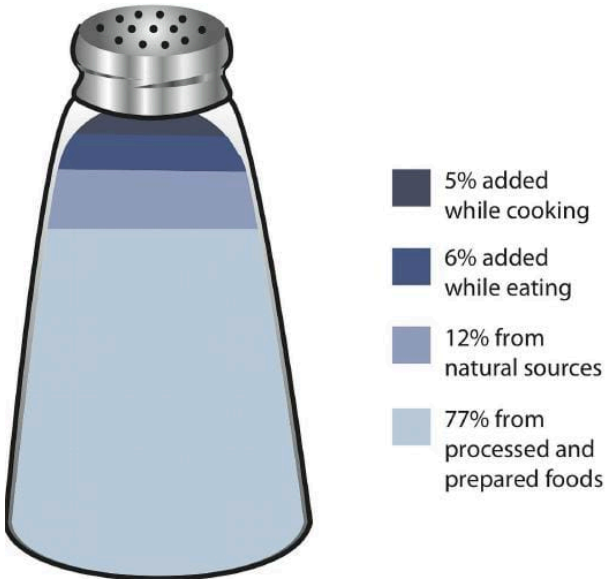
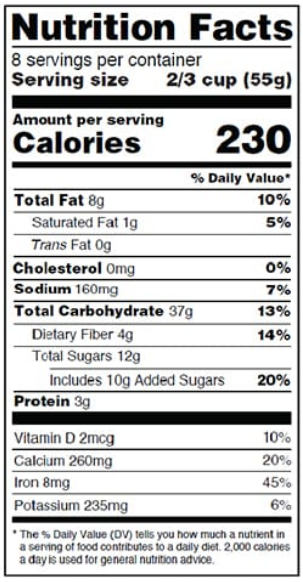


Figure 8.4.2: Dietary Sources of Sodium (CC BY-NC-SA 4.0; LibreTexts An Introduction to Nutrition (Zimmerman))

The Nutrition Facts label displays the amount of sodium (in milligrams) per serving of the food in question (Figure 8.4.3). Information in the % Daily Value (% DV) section of the food label can be used to determine if the food is high in sodium (> 20% DV) or low in sodium (< 5% DV). Various claims about the sodium content in foods can also be seen on a food's label; these claims must be in accordance with Food and Drug Administration (FDA) regulations (Table 8.4.2).[2]



Nutrition Facts

8 servings per container

Serving size **2/3 cup (55g)**

Amount per serving

Calories **230**

	% Daily Value*
Total Fat 8g	**10%**
Saturated Fat 1g	**5%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 160mg	**7%**
Total Carbohydrate 37g	**13%**
Dietary Fiber 4g	**14%**
Total Sugars 12g	
Includes 10g Added Sugars	**20%**
Protein 3g	
Vitamin D 2mcg	10%
Calcium 260mg	20%
Iron 8mg	45%
Potassium 235mg	6%

* The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Figure 8.4.3: Sodium levels in milligrams is a required listing on a nutrition facts label. (CC0; What's New with the Nutrition Facts Label)

Table 8.4.2: Food Packaging Claims Regarding Sodium[2]

Claim	Meaning
“Light in Sodium” or “Low in Sodium”	Sodium is reduced by at least 50%
“No Salt Added” or “Unsalted”	No salt added during preparation and processing*
“Lightly Salted”	50% less sodium than that added to similar food
***Must also declare on package “This is not a sodium-free food” if food is not sodium-free.**	

Claim	Meaning
“Sodium Free” or “Salt Free”	Contains less than 5 mg sodium per serving
“Very Low Salt”	Contains less than 35 mg sodium per serving
“Low Salt”	Contains less than 140 mg sodium per serving
***Must also declare on package “This is not a sodium-free food” if food is not sodium-free.**	

For those with hypertension or those looking for a way to decrease salt use, using a salt substitute for food preparation is one option. However, many salt substitutes still contain sodium, just in lesser amounts than table salt. Also, remember that most salt in the diet is not from table-salt use, but from processed foods. Salt substitutes often replace the sodium with potassium. People with kidney disorders often have problems getting rid of excess potassium in the diet and are advised to avoid salt substitutes containing potassium. People with liver disorders should also avoid salt substitutes containing potassium because their treatment is often accompanied by issues with potassium regulation. Alternatively, spices can be used to add flavor without using salt or salt substitutes.

Chloride

Chloride is the primary anion (negatively-charged ion) in extracellular fluid. Chloride moves easily across membranes following the sodium and potassium gradients. In addition to passively following sodium and potassium, chloride has its own protein channels that reside in cell membranes. These protein channels are especially abundant in the gastrointestinal tract, pancreas, and lungs. Chloride is the major anion in sweat and vomit. It is the anion of stomach acid (hydrochloric acid, HCl).

Functions of Chloride

Chloride aids in fluid balance mainly because it follows sodium in order to maintain charge neutrality. Chloride channels in the gastrointestinal tract, pancreas, and lungs play a role in regulating fluid secretion, such as pancreatic juice into the small intestine and the flow of water into mucus. Fluid secretion and mucus are important for many of life’s processes. Chloride has several other functions in the body, most importantly in acid-base balance. Blood pH is maintained in a narrow range and the number of positively charged substances is equal to the number of negatively charged substances. Proteins, such as albumin, as well as bicarbonate ions and chloride ions, are negatively charged and aid in maintaining blood pH. Hydrochloric acid aids in digestion and also prevents the growth of unwanted microbes in the stomach. Immune-system cells require chloride, and red blood cells use chloride anions to remove carbon dioxide from the body. Chloride also assists in the transmission of nerve impulses.

Chloride Imbalances

Low dietary intake of chloride is rare. However, low blood levels of chloride can occur with severe dehydration, diarrhea, and/or frequent vomiting. 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.

Chloride Recommendations

The National Academies of Sciences, Engineering, and Medicine set an Adequate Intake (AI) level for chloride for healthy adults at 2,300 milligrams (Table 8.4.3).[3] Just ⅔ teaspoon of table salt per day is sufficient for chloride as well as sodium. The AIs for other age groups are listed in Table 8.4.3.

Table 8.4.3: Adequate Intakes for Chloride[3]

Age Group	Adequate Intake (mg/day)
Infants (0–6 months)	180
Infants (7–12 months)	570

Age Group	Adequate Intake (mg/day)
Children (1–3 years)	1,500
Children (4–8 years)	1,900
Children (9–13 years)	2,300
Adolescents (14–18 years)	2,300
Adults (19–50 years)	2,300
Adults (51–70 years)	2,000
Adults (> 70 years)	1,800

Sources of Chloride

Table salt is 60% chloride, so most of the chloride in the diet comes from salt. Other dietary sources of chloride include processed 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.

Potassium

Potassium is the major positively-charged ion in intracellular fluid. About 90% of potassium exists in intracellular fluid, with about 10% in extracellular fluid, and only 1% in blood plasma. As with sodium, potassium levels in the blood are strictly regulated. The hormone aldosterone is what primarily controls potassium levels, but other hormones (such as insulin) also play a role. When potassium levels in the blood increase, the adrenal glands release aldosterone. The aldosterone acts on the collecting ducts of the kidneys, where it stimulates an increase in the number of sodium-potassium pumps. Sodium is then reabsorbed and more potassium is excreted. Because potassium is required for maintaining sodium levels, and, therefore, fluid balance, only about 200 mg of potassium is lost from the body every day. Most potassium is lost in the urine (80-90%) and the remainder leaves via the feces.

Functions of Potassium

Potassium plays a role in fluid balance as described earlier in this section. In addition, nerve impulse transmission involves potassium. A nerve impulse moves along a nerve via the movement of sodium ions into the cell. To end the impulse, potassium ions rush out of the nerve cell, thereby decreasing the positive charge inside the nerve cell. This diminishes the stimulus. To restore the original concentrations of ions between the intracellular and extracellular fluid, the sodium-potassium pump transfers sodium ions out in exchange for potassium ions in. On completion of the restored ion concentrations, a nerve cell is now ready to receive the next impulse. Similarly, in muscle cells, potassium is involved in restoring the normal ion concentrations and ending the muscle contraction. Potassium is also involved in protein synthesis, energy metabolism, and platelet function, and acts as a buffer in blood, playing a role in acid-base balance.

Imbalances of Potassium

Insufficient potassium levels in the body (**hypokalemia**) can be caused by a low dietary intake of potassium or by high sodium intakes, but more commonly it results from medications that increase water excretion, mainly diuretics. The signs and symptoms of hypokalemia are related to the functions of potassium in nerve cells and, consequently, skeletal and smooth muscle contraction. The signs and symptoms include muscle weakness and cramps, respiratory distress, and constipation. Severe potassium depletion can cause the heart to have abnormal contractions and can even be fatal. Groups at risk of developing hypokalemia are individuals with kidney 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 vomiting; and, certain drugs like diuretics, steroids or laxatives. These deficiencies are due to excessive potassium loss and not a dietary deficiency.

High levels of potassium in the blood (**hyperkalemia)** are toxic and affect the heart. It is a silent condition as it often displays no signs or symptoms. Extremely high levels of potassium in the blood disrupt the electrical impulses that stimulate the heart and can cause the heart to stop. Hyperkalemia is usually the result of kidney dysfunction, not dietary intake of potassium.

Potassium Recommendations

The National Academies of Sciences, Engineering, and Medicine set Adequate Intake (AI) levels for potassium as outlined in (Table 8.4.4).[1]

Table 8.4.4: Dietary Reference Intakes for Potassium[1]

Age Group	Adequate Intake (mg/day)	Tolerable Upper Intake Level (mg/day)	Chronic Disease Risk Reduction Intake (CDRR)
Infants (0–6 months)	400	ND	ND
Infants (7–12 months)	860	ND	ND
Children (1–3 years)	2,000	ND	ND
Children (4–8 years)	2,300	ND	ND
Children (9–13 years)	2,500 (males), 2,300 (females)	ND	ND
Adolescents (14–18 years)	3,000 (males), 2,300 (females)	ND	ND
Adults (> 19 years)	3,400 (males), 2,600 (females)	ND	ND
ND = not determined			

Sources of Potassium

All fruits and vegetables contain some potassium; fruits and vegetables that contain high amounts of potassium include spinach, lettuce, broccoli, peas, tomatoes, potatoes, bananas, apples, and apricots. Whole grains and seeds, certain fish (such as salmon, cod, and flounder), meats, and dairy are also high in potassium. The Dietary Approaches to Stop Hypertension (DASH) Eating Plan that you learned about in Chapter 2 emphasizes potassium-rich foods.

Phosphorus

Phosphorus is the primary negatively-charged ion in the intracellular fluid. It is typically found in the form of hydrogen phosphate (HPO_4^{2-}).

Functions of Phosphorus

Like other nutrients in this section, phosphorus assists with maintaining fluid balance. In addition, phosphorus plays a critical role in bone formation; regulates biochemical pathways by activating or deactivating enzymes; is found in ATP (adenosine triphosphate), DNA (deoxyribonucleic acid), and RNA (ribonucleic acid); and is a component of cell membranes (as phospholipids) and lipoproteins.

Imbalances of Phosphorus

Deficiencies of phosphorus are rare but can occur with vitamin D deficiency or over-secretion of parathyroid hormone. On the other hand, high blood phosphorus can occur with kidney disease, taking excessive amounts of vitamin D supplements, or taking too many phosphorus-containing antacids. Too much phosphorus can lead to muscle spasms and convulsions.

Phosphorus Recommendations

The National Academies of Sciences, Engineering, and Medicine set the Dietary Reference Intake levels for phosphorus as outlined in (Table 8.4.5).[4]

Table 8.4.5: Dietary Reference Intakes for Phosphorus[4]

Age Group	Recommended Dietary Allowance (mg/day)	Tolerable Upper Intake Level (mg/day)
Infants (0–6 months)	100*	ND
Infants (7–12 months)	275*	ND
Children (1–3 years)	460	3,000
Children (4–8 years)	500	3,000
Children (9–13 years)	1,250	4,000
Adolescents (14–18 years)	1,250	4,000
Adults (19 - 70 years)	700	4,000
Adults (> 70 years)	700	3,000
*** denotes Adequate Intake; ND = not determined**		

Sources of Phosphorus

Phosphorus is found in many foods and is found in high amounts in animal-based foods that contain protein (e.g., meat, milk, eggs).

References

1. National Academies of Sciences, Engineering, and Medicine. 2019. *Dietary Reference Intakes for Sodium and Potassium*. Washington, DC: The National Academies Press.
2. US Food and Drug Administration. *Food Labeling Guide*. Last updated January 2013. Accessed May 17, 2025.
3. Institute of Medicine. 2005. *Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate*. Washington, DC: The National Academies Press.
4. Institute of Medicine. 1997. *Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride*. Washington, DC: The National Academies Press.

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8.5: Understanding Dehydration and Heat Illnesses

Learning Objectives

- Summarize the following fluid and electrolyte imbalance disorders:
  - overhydration
  - dehydration
  - various heat illnesses (heat cramps, heat exhaustion, heat stroke)

Disorders related to fluid and electrolyte imbalance include overhydration, dehydration, and heat illnesses (heat cramps, heat exhaustion, and heat stroke).

Overhydration

Overhydration (sometimes called water intoxication) can occur with excessive water intake or excessive water retention. This results in hyponatremia; symptoms of hyponatremia include nausea, muscle cramps, confusion, dizziness, and in severe cases, seizures, coma, and death.

Dehydration

Dehydration refers to water loss from the body without adequate replacement; in other words, fluid loss exceeds fluid intake. 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, dark-colored urine, low to no urine output, inability to regulate body temperature, weakness and lethargy, and, in extreme cases, loss of consciousness and death. Signs and symptoms are usually noticeable after about 2% of total body water is lost. The elderly, infants, and athletes are the most at risk for dehydration.

Fluid replacement guidance from the American College of Sports Medicine focuses on preventing excessive dehydration during exercise (defined as >2% body weight loss) and replacing fluid losses after exercise by gradually drinking ~1.5 liters of fluid for each kilogram of body weight lost during the activity (20-24 fluid ounces for each pound lost). During exercise, consuming beverages containing electrolytes and carbohydrates can provide benefits over water alone under certain circumstances (e.g., vigorous activity lasting longer than one hour). After exercise, the goal is to replace any fluid and electrolytes lost which can be accomplished with normal meals/snacks and water under most circumstances.[1] Another method that can be used to prevent dehydration (by all people) is to regularly observe urine color and drink enough liquids to maintain clear to pale yellow urine (see Figure 8.5.1).

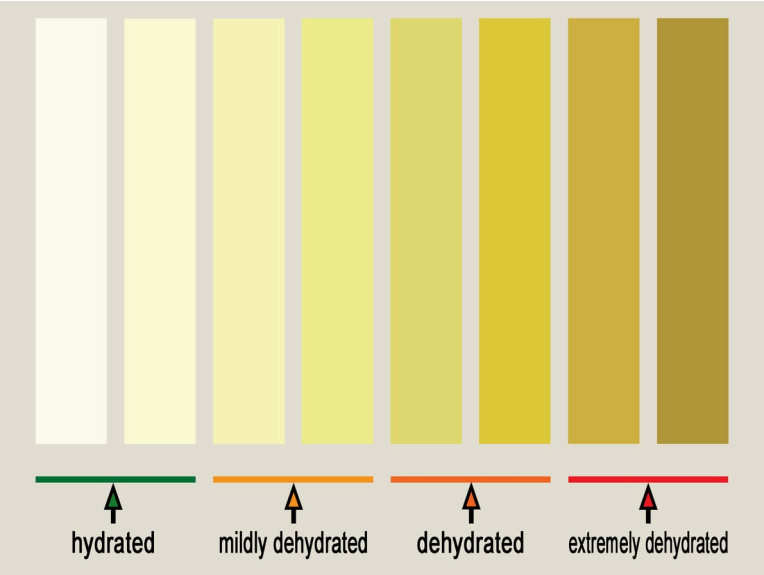


Figure 8.5.1: Urine color chart. (CC BY-SA 4.0; by Petar Milosevic via Wikimedia Commons)

Diuretics such as caffeine and alcohol can increase urinary output. If the output is not matched by input, then the person can become dehydrated. Chronic dehydration is linked to several issues including poor mental function, urinary tract infections, and kidney stones.[2,3] Older people often suffer from chronic dehydration as their thirst mechanism is no longer as sensitive as it used to be.

Heat Illnesses

Heat Cramps

Heat cramps are painful muscle cramps (usually in the abdomen, arms, or legs) that develop during vigorous physical activity in a hot environment. The cramps are caused by a fluid and electrolyte imbalance. Stopping activity immediately, resting in a cool place, and drinking a sports beverage or juice are steps to take to speed recovery.

Heat Exhaustion

Heat exhaustion typically occurs when people are engaging in vigorous physical activity in a hot environment. Normally, sweating helps cool body temperature, but during heat exhaustion, sweating doesn't cool the body enough. Heat exhaustion is characterized by heavy sweating, dizziness, rapid breathing, and fast pulse. Immediate cooling and fluid intake are critical to avoid heat stroke.

Heat Stroke

Heat stroke is a life-threatening condition that occurs when the body temperature is greater than 105.1°F (40.6°C). It is the result of the body being unable to sufficiently cool itself by thermoregulatory mechanisms (e.g., sweating). 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.

References

1. Exercise and Fluid Replacement. *Medicine & Science in Sports & Exercise*. 2007;39(2):377-390. doi: 10.1249/mss.0b013e31802ca597.
2. Institute of Medicine. 2005. *Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate*. Washington, DC: The National Academies Press.

3. Mayo Clinic. Dehydration. Accessed March 20, 2026.

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9: NUTRIENTS IMPORTANT FOR ANTIOXIDANT ACTIVITY AND VISION

9.1: Introduction to Free Radicals and Antioxidants

9.2: Antioxidant Nutrients

9.3: Vitamin A and Vision

9.4: Cancer

Template:HideTOC

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9.1: Introduction to Free Radicals and Antioxidants

Learning Objectives

- Describe free radicals.
- Explain oxidative stress and identify diseases associated with oxidative stress.
- Identify sources of free radicals that contribute to oxidative stress.
- Define the term antioxidant and identify various dietary antioxidants.
- Describe the impact of antioxidant supplements on health.

You may have heard that antioxidants can help prevent disease and slow the aging process. But what are antioxidants? Where do you get them? And how do they work in the body? After reading this chapter, you will be able to answer these questions, and your new knowledge will assist you in making dietary decisions to optimize your health.

Keep in mind as you read...there is no scientific evidence that taking high doses of antioxidants as a supplement helps prevent or treat certain diseases. There *is* evidence that eating antioxidant-rich foods as part of a balanced, healthy, nutrient-rich diet provides many health benefits. Antioxidants may go a long way toward preventing and repairing damage to cells and tissues, and work alongside other nutrients to sustain health...but, no one nutrient acts alone!

Free Radicals

Recall from Chapter 3 that our body's tissues and organs are made up of molecules, and molecules are made of atoms. Atoms are composed of a nucleus and electrons that orbit the nucleus. Atoms are most stable when they have an even number of electrons, so that they can orbit the nucleus in pairs (right side of (Figure 9.1.1)). An atom with an unpaired electron is called a free radical (left side of (Figure 9.1.1)).

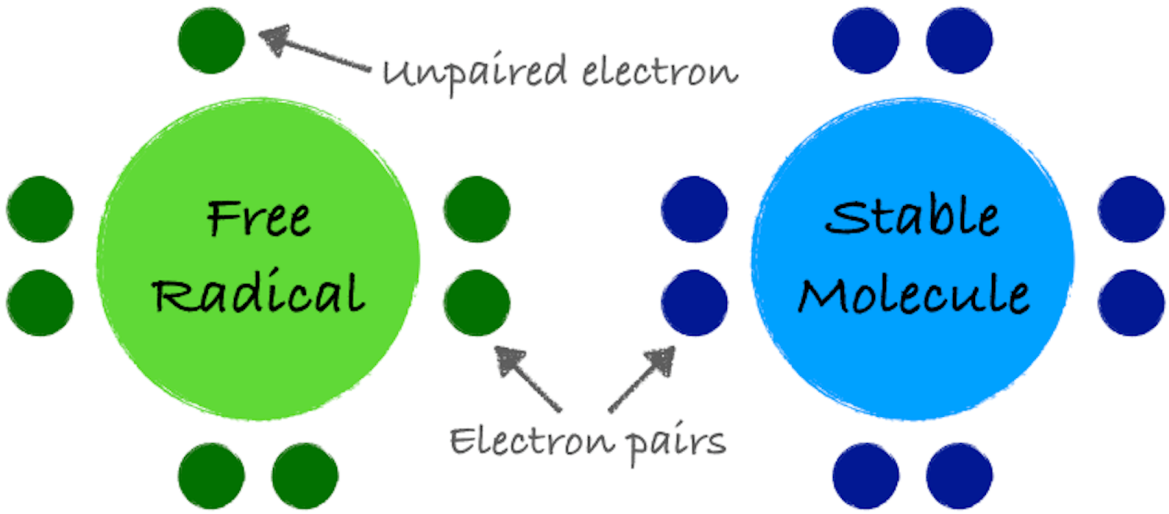


Figure 9.1.1: Free radical (left) and stable molecule (right). (CC BY-NC-ND 4.0; by Jacqui Adcock)

Electrons in atoms "hate" not existing in pairs. The unpaired electron in free radicals makes the atom or molecule unstable. An atom with an unpaired electron (a free radical) wants to become stable again, so it quickly seeks out an electron to "steal" from another atom or molecule, but in doing so, a new free radical is created (Figure 9.1.2). This electron stealing 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.

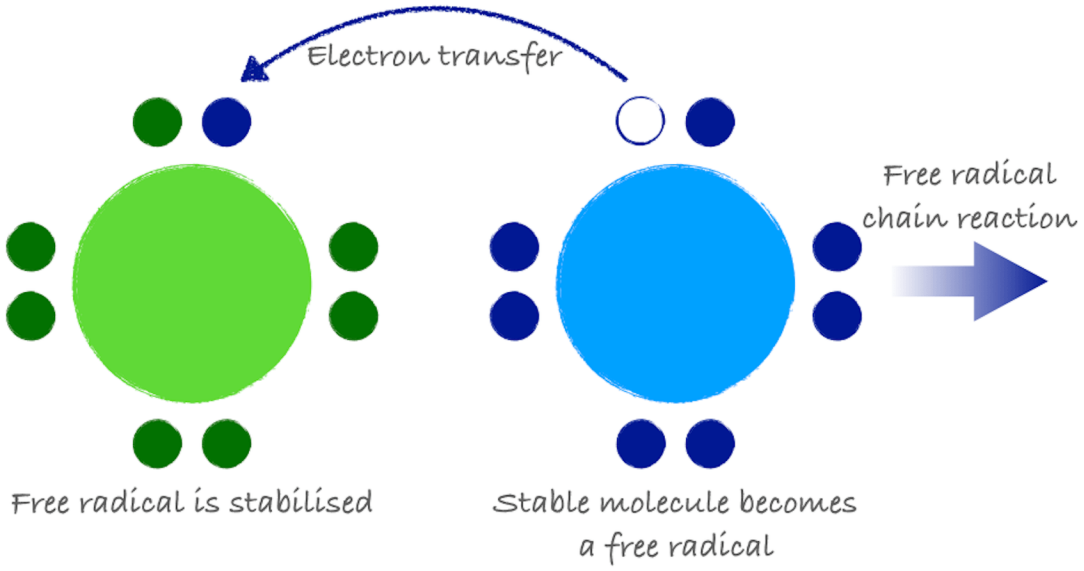


Figure 9.1.2: A free radical (left) with an unpaired electron steals an electron from a stable molecule (right) creating a new free radical and initiating a chain reaction. (CC BY-NC-ND 4.0; by Jacqui Adcock)

Where Do Free Radicals Come From?

Free radicals are a natural byproduct of metabolic reactions and exercise - it's normal to have low levels of free radicals in the body. In fact, free radicals play a role in normal functioning of the body, including the ability to fight off pathogens and send signals from one cell to another. Substances and energy sources from the environment can add to the production of free radicals within the body, leading to too high a level of free radicals in the body. Exposure to excessive sunlight, pollution, 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 additional damage to the body's cells.

Oxidative Stress

When the amount of free radicals exceeds the body's ability to eliminate or neutralize them, a situation called oxidative stress occurs. 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, heart disease, arthritis, diabetes, kidney disease, Alzheimer's disease, cataracts, Parkinson's disease, and aging.

Antioxidants

An antioxidant is any molecule that can block free radicals from stealing electrons (i.e., block oxidation and help reduce damage caused by oxidative stress). Antioxidants donate an electron to free radicals (Figure 9.1.3). 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 have processes to quickly stabilize (and stop the damaging chain reaction).

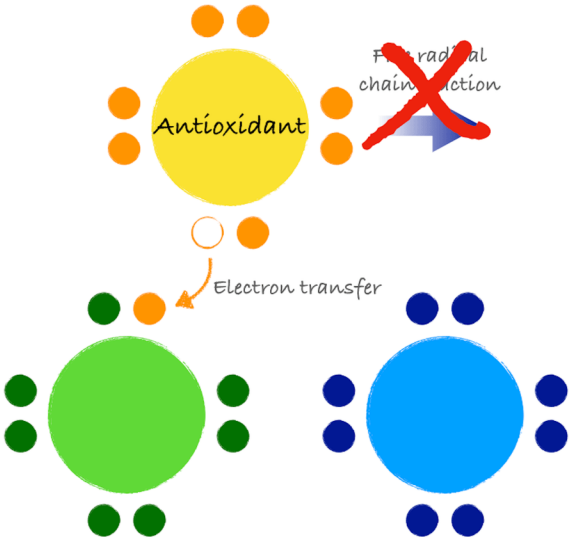


Figure 9.1.3: Antioxidants stabilize free radicals by donating electrons, preventing the chain reaction that can create more free radicals. (CC BY-NC-ND 4.0; by Jacqui Adcock)

Some antioxidants are made by the body, and some are consumed in the diet. Antioxidants made in the body help protect various body components (e.g., cell membranes, DNA) from damage. The antioxidants made by the body rely on certain vitamins and minerals (e.g., vitamin C, vitamin E, selenium, iron, manganese, zinc) to function. This is one of many reasons we need to eat a variety of foods from within each food group to get the vitamins and minerals needed to activate the antioxidants we synthesize. We also get antioxidants in the diet; examples of dietary antioxidants include vitamin C, vitamin E, phytochemicals such as beta-carotene, and the mineral selenium. These, and a few other antioxidants, will be discussed on the next page.

For a review of antioxidants, free radicals, and oxidative stress, watch the video below.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

Antioxidant Supplements

Eating a diet rich in antioxidant-containing foods (e.g., fruits, vegetables, whole grains) helps provide antioxidants that protect the body from oxidative stress and associated chronic diseases. You might think taking antioxidant supplements would also offer protection. However, after several decades of research, studies have shown that antioxidant supplements generally aren't beneficial and some supplements have been shown to increase health risks. For example, high doses of beta-carotene increased the risk of lung cancer and cardiovascular disease death.[1] High doses of vitamin E may increase the risk of bleeding by reducing the blood's ability to form clots after an injury.[1]

Reference

1. National Center for Complementary and Integrative Health. Antioxidant Supplements: What You Need To Know. nccih.nih.gov. Accessed March 24, 2026.

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9.2: Antioxidant Nutrients

Learning Objectives

- List the antioxidant nutrients and describe their functions.
- Give examples of good food sources of antioxidant nutrients.

In this section, we will review how particular antioxidants function in the body, learn how they work together to protect the body against free radicals, and explore nutrient-rich dietary sources of antioxidants.

Vitamin C

Vitamin C, also known as ascorbic acid, is a water-soluble micronutrient essential in the diet for humans, although most other mammals can readily synthesize it.

Functions of Vitamin C

Vitamin C's ability to easily donate electrons makes it a highly effective antioxidant. It protects lipids both by disabling free radicals and by aiding in the regeneration of vitamin E. In addition to its role as an antioxidant, vitamin C is a required part of several enzymes involved in the synthesis of collagen, signaling molecules in the brain (neurotransmitters), some hormones, bile, and amino acids. Vitamin C also reduces formation of nitrosamines (cancer-causing agents in some cured and processed meats).

Vitamin C levels in the body are affected by the amount in the diet, which influences how much is absorbed and how much the kidney allows to be excreted, such that the higher the intake, the more vitamin C is excreted. Vitamin C is not stored in any significant amount in the body, but once it has neutralized a free radical, it is very effectively regenerated and therefore it can exist in the body as a functioning antioxidant for many weeks.

Vitamin C Imbalances

High doses of vitamin C have been reported to cause numerous problems, but the only consistently shown side effects are gastrointestinal upset, abdominal cramps, and diarrhea. Very high doses of vitamin C from supplementation, in combination with iron, have sometimes been found to increase oxidative stress, reaffirming that getting your antioxidants from foods is better than getting them from supplements, as that helps regulate your intake levels. If a person has hemochromatosis (a disorder where extra iron builds up in the body) or preexisting kidney disease, excess Vitamin C can be harmful.

The classic condition associated with vitamin C deficiency is scurvy. The signs and symptoms of scurvy include skin disorders, bleeding gums, loose teeth, painful joints, weakness, depression, and increased susceptibility to infections.

Vitamin C Recommendations

The RDAs and ULs for different age groups for vitamin C are listed in Table 9.2.1. They are considered adequate to prevent scurvy. Vitamin C's effectiveness as a free radical scavenger motivated the Institute of Medicine (IOM) to increase the RDA for smokers by 35 milligrams, as tobacco smoke is an environmental and behavioral contributor to free radicals in the body.

Table 9.2.1: Dietary Reference Intakes for Vitamin C[1]

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	40*	ND
Infants (7–12 months)	50*	ND
***denotes Adequate Intake; ND=not determined**		

Age Group	RDA (mg/day)	UL (mg/day)
Children (1–3 years)	15	400
Children (4–8 years)	25	650
Children (9–13 years)	45	1200
Adolescents (14–18 years)	75 (males), 65 (females)	1800
Adults (> 19 years)	90 (males), 75 (females)	2000
***denotes Adequate Intake; ND=not determined**		

Sources of Vitamin C

Citrus fruits are great sources of vitamin C and so are many vegetables. In fact, British sailors in the past were often referred to as "limeys" as they carried sacks of limes onto ships to prevent scurvy. Vitamin C is not found in significant amounts in animal-based foods. For the vitamin C content of various foods, see Table 9.2.2. A couple of things to keep in mind about Vitamin C levels in food - cooking at high temperature for long periods of time and excessive exposure to oxygen (such as when there is only a little orange juice left in a large carton) destroys vitamin C.

Table 9.2.2: Vitamin C Content of Various Foods[2]

Food	Vitamin C (mg)	% Daily Value
Red pepper, raw (1/2 cup)	95	106
Orange juice (3/4 cup)	93	103
Grapefruit juice (3/4 cup)	70	78
Orange (1 medium)	70	78
Kiwifruit (1 medium)	64	71
Green pepper, raw (1/2 cup)	60	67
Broccoli, cooked (1/2 cup)	51	57
Strawberries, sliced (1/2 cup)	49	54
Grapefruit (1/2 medium)	39	43
Cantaloupe (1/2 cup)	29	32
Cassava, cooked (1 cup)	29	32
Potato, baked (1 medium)	17	19

Learn even more about this nutrient by reading the Vitamin C Fact Sheet from the National Institutes of Health, Office of Dietary Supplements.

Does Vitamin C Help Cure A Cold?



Many people believe that taking a vitamin C supplement can prevent the common cold or decrease its symptoms. Over-the-counter supplements typically contain 1,000mg of vitamin C, which is far higher than the recommended amount and enough to reach the UL of 2,000mg if a person takes two doses per day. Do these high-dose vitamin C supplements do anything to prevent or treat the common cold? A systematic review and meta-analysis concluded that for most people, these supplements don't prevent the common cold but can reduce the duration of the 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.[3]

Vitamin E

Vitamin E is a fat-soluble vitamin that is present naturally in a variety of foods. "Vitamin E" is the collective name for eight chemically similar forms of the nutrient; alpha-tocopherol appears to be the most potent form.

Functions of Vitamin E

The primary function of Vitamin E is as an antioxidant. Alpha-tocopherol and vitamin E's other constituents are primarily responsible for protecting cell membranes against lipid destruction caused by free radicals. For example, free radical oxidation/damage to the lipids in low-density lipoproteins (LDLs) causes LDLs to stick to the walls of arteries. This contributes to the development of fatty streaks and, eventually, plaque, which hardens the arteries (also called atherosclerosis) and can lead to a heart attack. Alpha-tocopherol protects LDL from being oxidized, and therefore helps protect against heart 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 plays a role in nerve and muscle development and function. It also helps maintain immune system function and helps dilate blood vessels.

Vitamin E Imbalances

Getting too much or too little vitamin E can cause issues. Vitamin E supplementation can increase the risk for prostate cancer and premature mortality. In addition, Vitamin E can interfere with anticoagulant medications (aspirin and Coumadin) and cause uncontrollable bleeding. Long-term supplement use in some people can cause hemorrhagic stroke.

Vitamin E deficiencies are uncommon but can occur with diseases that cause fat malabsorption. Vitamin E deficiency can result

in erythrocyte hemolysis (the rupture of red blood cells), anemia, and immune system impairment.

Vitamin E Recommendations

The Recommended Dietary Allowances (RDAs) and Tolerable Upper Intake Levels (ULs) for different age groups for vitamin E are provided in Table 9.2.3. The RDAs are based on scientific evidence that these levels of vitamin E in the diet prevent conditions associated with vitamin E deficiency, which are rare but are primarily the result of nerve degeneration. People with malabsorption disorders, such as Crohn's disease or cystic fibrosis, and babies born prematurely, are at higher risk for vitamin E deficiency.

Fat in the diet is required for vitamin E absorption as it is packaged into lipid-rich chylomicrons in intestinal cells and transported to the liver. The liver stores some of the vitamin E or packages it into lipoproteins, which deliver it to cells.

Table 9.2.3: Dietary Reference Intakes for Vitamin E[1]

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	4*	ND
Infants (7–12 months)	5*	ND
Children (1–3 years)	6	200
Children (4–8 years)	7	300
Children (9–13 years)	11	600
Adolescents (14–18 years)	15	800
Adults (> 19 years)	15	1,000
***denotes Adequate Intake; ND=not determined**		

Sources of Vitamin E

Vitamin E is found in many foods, especially those higher in fat, such as nuts and oils. See Table 9.2.4 for a list of foods and their vitamin E content.

Table 9.2.4: Vitamin E Content of Various Foods[4]

Food	Vitamin E (mg)	% Daily Value
Wheat-germ oil (1 Tbsp.)	20.3	135
Sunflower seeds (1 oz.)	7.4	49
Almonds (1 oz.)	6.8	45
Sunflower oil (1 Tbsp.)	5.6	37
Safflower oil (1 Tbsp.)	4.6	31
Hazelnuts (1 oz.)	4.3	29
Peanut butter (2 Tbsp.)	2.9	19
Peanuts (1 oz.)	2.2	15
Broccoli, boiled (1/2 cup)	1.2	8
Kiwifruit (1 medium)	1.1	7
Tomato, raw (1 medium)	0.7	5
Spinach, raw (1 cup)	0.6	4

Learn even more about this nutrient by reading the Vitamin E Fact Sheet from the National Institutes of Health, Office of Dietary Supplements.

Vitamin E Tip



Vitamin E is easily destroyed by oxygen, light, heat, cooking, processing, and storage. So, when you buy oil for cooking or using in salad dressings, choose one in a dark bottle and store it inside your kitchen cabinet. Vitamin E is also easily destroyed by deep fat frying and other heat sources used to cook or process foods. This makes highly processed and fried foods poor sources of vitamin E. What would be a better choice? How about a fresh salad made with spinach, tomatoes, salad dressing (made with an oil like sunflower oil that is high in vitamin E), and throw in some sunflower seeds for crunch!

Phytochemicals

Phytochemicals are chemicals in plants that may provide some health benefit. Carotenoids are one type of phytochemical that we will discuss in more detail below. Other phytochemicals include indoles, lignans, phytoestrogens, stanols, flavonoids, anthocyanidins, phenolic acids, and many more. They are found not only in fruits and vegetables, but also in grains, seeds, nuts, and legumes. Many phytochemicals act as antioxidants, but they have several other functions, such as mimicking hormones, altering absorption of cholesterol, inhibiting inflammatory responses, and blocking the actions of certain enzymes.

Phytochemicals are present in small amounts in the food supply, and although thousands have been and are currently being scientifically studied, their health benefits remain largely unknown. Also largely unknown is their potential for toxicity, which could be substantial if taken in large amounts in the form of supplements. Moreover, phytochemicals often act in conjunction with each other and with micronutrients. Thus, supplementing with only a few may impair the functions of other phytochemicals or micronutrients. As with the antioxidant vitamins, it is the mixture and variety of phytochemicals in foods that are linked to health benefits.

Functions of Carotenoids

Carotenoids are pigments synthesized by plants that give them their yellow, orange, red and deep green color. Over six hundred carotenoids have been identified; the vast majority are found in plant foods. Beta-carotene and some other carotenoids, such as lycopene and lutein, act as antioxidants. Through their antioxidant activities, carotenoids enhance immune function, protect cell membranes and LDL from oxidative damage, protect skin from sun damage, and protect our eyes from oxidative damage that can lead to vision impairment.

Carotenoid Imbalances

When considering if you can get too much beta-carotene, it appears that large quantities from food sources do not appear to be toxic. However, large quantities of beta-carotene from food can cause yellowing or even "oranging" of the skin. Beta-carotene supplements may be harmful in certain populations. On the other hand, there are no known deficiency symptoms from consuming too little beta-carotene.

Carotenoid Recommendations

Carotenoids are not considered essential nutrients, so no DRIs have been established. Eating five servings of fruits and vegetables daily provides 6-8 mg of beta-carotene.[5] Beta-carotene is a provitamin (an inactive form of a vitamin that must be converted to the active form in the body). Beta-carotene is the precursor of retinol, the active form of Vitamin A.

Sources of Carotenoids

Carotenoids are not absorbed as well as vitamin A, but similar to vitamin A, they do require fat in the meal for absorption. In intestinal cells, carotenoids are packaged into the lipid-containing chylomicrons inside small intestine mucosal cells and then transported to the liver. In the liver, carotenoids are repackaged into lipoproteins, which transport them to cells.

In contrast to most micronutrients, carotenoid availability is actually increased by the cooking process because cooking releases carotenoids from the plant matrix. Thus, eating cooked tomato sauce provides more lycopene than eating a raw tomato. 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. Cooking carotenoid-containing foods in oil also enhances the bioavailability of carotenoids. In the United States, the most consumed carotenoids are alpha-carotene, beta-carotene, beta-cryptoxanthin, lycopene, lutein, and zeaxanthin. See Table 9.2.5 for the beta-carotene content of various foods.

Table 9.2.5: Beta-Carotene Content of Various Foods[6]

Food	Serving Size	Beta-carotene (mg)
Sweet potato, baked	1 cup	23
Pumpkin, canned	1 cup	17
Collards (frozen), cooked	1 cup	11.6
Carrots, raw	1 cup	10.6
Butternut squash, baked	1 cup	9.4
Cantaloupe	1 cup	3.6

Selenium

Selenium is a trace mineral which means our body contains less than 5 grams of the nutrient and we need to consume it in small amounts (less than 100 mg per day).

Functions of Selenium

Selenium is part of 25 different proteins in our bodies, called selenoproteins, which include 9 antioxidant proteins. These proteins function to protect cell membranes and lipids in the body from damage done by free radicals. Selenium also helps regenerate oxidized vitamin C. Having adequate selenium helps protect lipids from free radicals, and, in doing so, spares vitamin E which allows vitamin E to neutralize more free radicals in the body. This illustrates how antioxidants work together to protect the body against free radical-induced damage. Other functions of selenium-containing proteins include protecting endothelial cells that line tissues, converting inactive thyroid hormone to the active form to help regulate our metabolism, and mediating inflammatory and immune system responses.

Selenium Imbalances

Selenium toxicity can result from supplements. Symptoms of selenium toxicity include brittle hair and nails, skin rashes, nausea, vomiting, and weakness. Selenium deficiency has been seen in areas of the world where the soil is very low in selenium. For example, Keshan disease (a heart disease) was discovered in the Keshan province of China where soil levels of selenium were low. Selenium deficiency can also lead to Kashin-Beck disease, a form of arthritis.

Selenium Recommendations

The Institute of Medicine set the RDA for selenium based on the amount required to maximize the activity of antioxidants that contain selenium. The RDA for different age groups are listed in Table 9.2.6.

Table 9.2.6: Dietary Reference Intakes for Selenium[1]

Age Group	RDA (mcg/day)	UL (mcg/day)
Infants (0–6 months)	15*	45
Infants (7–12 months)	20*	60
Children (1–3 years)	20	90
Children (4–8 years)	30	150
Children (9–13 years)	40	280
Adolescents (14–18 years)	55	400
Adults (> 19 years)	55	400
***denotes Adequate Intake**		

Sources of Selenium

Selenium is stored in the tissues of animals, so organ meats, muscle meats, and seafood tend to have high selenium content. Plants do not require selenium, so the selenium content in fruits and vegetables is usually low. Grains and some nuts contain selenium when grown in selenium-containing soils. See Table 9.2.7 for the selenium content of various foods.

Table 9.2.7: Selenium Content of Various Foods[7]

Food	Selenium (mcg)	% Daily Value
Brazil nuts (1 ounce)	544	989
Yellowfin tuna, cooked (3 ounces)	92	167
Ham (3 ounces)	42	76
Turkey (3 ounces)	31	56
Cottage Cheese (1 cup)	20	36
Brown Rice, cooked (1 cup)	19	35
Whole Wheat Bread (1 slice)	13	24

Learn even more about this nutrient by reading the Selenium Fact Sheet from the National Institutes of Health, Office of Dietary Supplements.

Brazil Nuts





Brazil nuts are technically not nuts. They are highly nutritious seeds that grow in large, woody, coconut-like pods in trees within the Amazon rainforest. Inside each "pod", 10-24 Brazil nuts are packed tightly, similar to segments of an orange. Due to their high natural concentration of selenium (one nut provides ~175% of the RDA), consumption should be limited to 1-3 nuts per day to avoid toxicity.

Manganese, Copper, Zinc, and Iron

Manganese, copper, and zinc are trace minerals (nutrients that we need to consume in amounts less than 100 mg per day). They activate antioxidant proteins and are part of enzyme systems that convert free radicals into neutral compounds in cells, which ultimately protects against oxidative stress. In proper doses, they allow for optimal detoxification of free radicals. In excess, they can actually accelerate the production of free radicals, which is another reason why it's best to eat a diet rich in antioxidant-containing foods (e.g., fruits, vegetables, whole grains) instead of taking high doses of antioxidant supplements.

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9.3: Vitamin A and Vision

Learning Objectives

- Describe the functions of Vitamin A.
- Give examples of good food sources of Vitamin A.

Vitamin A

Vitamin A is an important nutrient that is connected to our vision, immune system function, and growth and development. Vitamin A is present in many foods. Vitamin A can also be synthesized in our body from certain carotenoids, including beta-carotene (the phytochemical you read about on the previous page). Vitamin A is a fat-soluble vitamin, meaning it dissolves easily into fats and oils. Vitamin A is stored primarily in the liver (about 90%), which gets transported to our cells when needed.

Functions of Vitamin A

Vitamin A has several important functions in the body, including maintaining vision and a healthy immune system. Many of vitamin A's functions in the body are similar to the functions of hormones (for example, vitamin A can interact with DNA, causing a change in protein function). Vitamin A assists in maintaining healthy skin and the linings and coverings of tissues; it also regulates growth and development.

Vision

Retinol (a form of vitamin A found in animal-based foods) that is circulating in the blood is taken up by cells in the retina, where it is converted to retinal (a biologically active form of vitamin A) and is used as part of the pigment rhodopsin, which is involved in the eye's ability to see under low light conditions. A deficiency in vitamin A thus results in less rhodopsin and a decrease in the detection of low-level light, a condition referred to as night blindness.

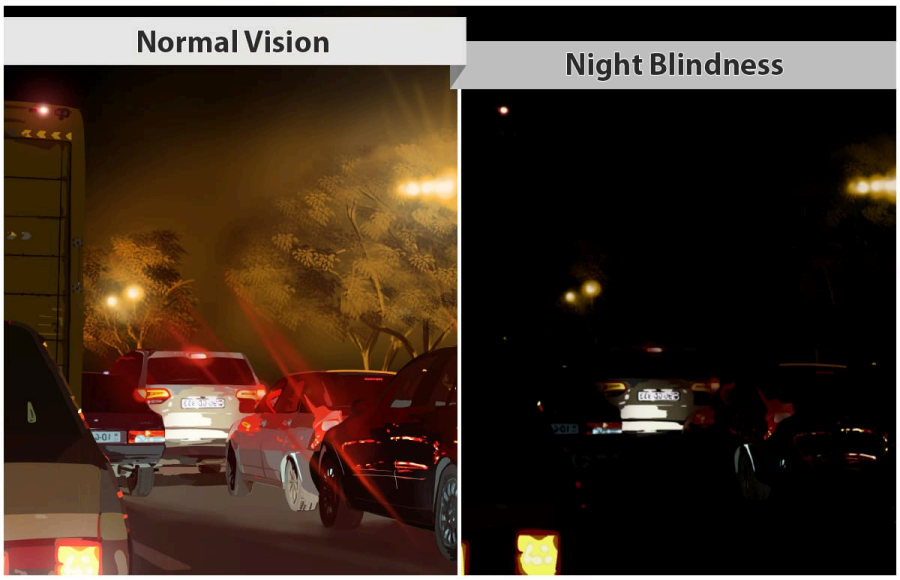


Figure 9.3.1: A depiction of the night vision of a person with normal vision (left) and a person suffering from night blindness, in which there is inadequate rhodopsin for detection of light (right). (CC BY-SA 4.0; MyUpchar via Wikimedia Commons)

Insufficient intake of dietary vitamin A over time can also cause complete vision loss. In fact, vitamin A deficiency is the number one cause of preventable blindness worldwide. Vitamin A not only supports the vision function of eyes but also maintains the

coverings and linings of the eyes. Vitamin A deficiency can lead to the dysfunction of the linings and coverings of the eye, causing dryness of the eyes, a condition called xerophthalmia. This condition can progress, causing ulceration of the cornea and eventually blindness.

Immunity

The common occurrence of advanced xerophthalmia in children who died from infectious diseases led scientists to hypothesize that supplementing vitamin A in the diet for children with xerophthalmia might reduce disease-related mortality. In Asia in the late 1980s, targeted populations of children were administered vitamin A supplements, and the death rates from measles and diarrhea declined by up to 50%. Vitamin A supplementation in these deficient populations did not reduce the number of children who contracted these diseases, but it did decrease the severity of the diseases so that they were no longer fatal. Soon after the results of these studies were communicated to the rest of the world, the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) commenced worldwide campaigns against vitamin A deficiency. UNICEF estimates that the distribution of over half a billion vitamin A capsules prevents 350,000 childhood deaths annually.[1]

In the 21st century, science has demonstrated that vitamin A greatly affects the immune system. What we are still lacking are clinical trials investigating the proper doses of vitamin A required to help ward off infectious disease and how large of an effect vitamin A supplementation has on populations that are not deficient in this vitamin. This brings up one of our common themes in this text—micronutrient deficiencies may contribute to the development, progression, and severity of a disease, but this does not mean that an increased intake of these micronutrients will solely prevent or cure disease. The effect, as usual, is cumulative and depends on the diet as a whole, among other things.

Growth and Development

Vitamin A acts similarly to some hormones in that it is able to change the amount of proteins in cells by interacting with DNA. This is the primary way that vitamin A affects growth and development. Vitamin A deficiency in children is linked to growth retardation; however, vitamin A deficiency is often accompanied by protein malnutrition and iron deficiency, thereby confounding the investigation of vitamin A's specific effects on growth and development.

Both males and females require vitamin A in the diet to effectively reproduce. In the fetus, vitamin A is important for limb, heart, eye, and ear development; however, too much vitamin A in the diet of pregnant women can lead to birth defects.

Vitamin A Imbalances

Vitamin A is highly toxic, especially from supplements. During pregnancy, vitamin A toxicity can lead to spontaneous abortion or the baby being born with permanent birth defects (as noted above). Toxicity can also lead to permanent damage of the liver and/or eyes. On the other end of the spectrum, night blindness is the most common disease of vitamin A deficiency.

As noted earlier, Vitamin A can be synthesized in our body from certain carotenoids, including beta-carotene. Beta-carotene from food does not appear to be toxic, but beta-carotene supplements should be avoided as high doses increase the risk of lung cancer and cardiovascular disease death.[2]

Vitamin A Recommendations

The Recommended Dietary Allowances (RDAs) and Tolerable Upper Intake Levels (ULs) for different age groups for vitamin A are provided in Table 9.3.1. The RDA for vitamin A includes all sources of vitamin A (e.g., vitamin A from animal sources plus the vitamin A that is synthesized from carotenoids in plant sources). The RDA for vitamin A is considered sufficient to support growth and development, reproduction, vision, and immune system function while maintaining adequate stores (good for 4 months) in the liver.

Table 9.3.1: Dietary Reference Intakes for Vitamin A[3]

Age Group	RDA (mcg/day)	UL (mcg/day)
Infants (0–6 months)	400*	600
***denotes Adequate Intake**		

Age Group	RDA (mcg/day)	UL (mcg/day)
Infants (7–12 months)	500*	600
Children (1–3 years)	300	600
Children (4–8 years)	400	900
Children (9–13 years)	600	1,700
Adolescents (14–18 years)	900 (males), 700 (females)	2,800
Adults (> 19 years)	900 (males), 700 (females)	3,000
***denotes Adequate Intake**		

Sources of Vitamin A

Preformed vitamin A is found only in foods from animals, with the liver being the richest source because that's where vitamin A is stored. Plant sources (dark green, orange, and deep yellow fruits and vegetables) provide beta-carotene which can be converted to vitamin A. See (Table 9.3.2) for a list of foods and their vitamin A content (given in mcg of Retinol Activity Equivalent).

Table 9.3.2: Vitamin A Content of Various Foods[4]

Food	Vitamin A (mcg RAE)	% Daily Value
Beef liver (3 ounces)	6,582	731
Sweet potato (1 whole)	1,403	156
Spinach, boiled (1/2 cup)	573	64
Ricotta cheese (1 cup)	263	29
Milk, fat-free (1 cup)	149	17

Learn even more about this nutrient by reading the Vitamin A Fact Sheet from the National Institutes of Health, Office of Dietary Supplements.

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9.4: Cancer

Learning Objectives

- Describe the development of cancer.
- Identify risk factors for cancer.
- Identify dietary and lifestyle choices that can help prevent cancer.

Cancer

Cancer is a group of diseases characterized by the uncontrolled growth of abnormal cells. Cancer progresses in 3 stages:

- Initiation – cell's DNA is changed (mutated)
- Promotion – mutated cell divides repeatedly
- Progression – cancerous cells invade surrounding tissues and spread to other parts of the body

Cancer is triggered by mutations in a cell's genetic material (initiation). The cause of these changes may be inherited, or it may result from exposure to carcinogens, which are agents that can cause cancer. Carcinogens include chemicals, viruses, certain medical treatments such as radiation, pollution, or other substances and exposures that are known or suspected to cause cancer.

Under normal conditions, a healthy cell will either repair any damage that has been done or self-destruct so that no future cells will be affected. Cells become cancerous when their DNA is damaged, but they do not self-destruct or stop reproducing as normal cells would. As these abnormal cells continue their rapid growth (promotion), in most cancers they come together and form a mass called a tumor. Cancer cells can overwhelm healthy cells and interfere with the healthy functioning of the body. They can also invade other organs and spread throughout the body (progression) in a process known as metastasis.

For even more information about cancer, watch the short (3-minute) video below:

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

"Cancer 101" by National Geographic

The risk factors for different cancers can vary. For example, exposure to ultraviolet radiation from the sun and from tanning beds is a risk factor for skin cancer, while exposure to asbestos is a risk factor for mesothelioma cancer. Table $9.4.1$ shows some common risk factors for a number of different types of cancer.

Table 9.4.1: Some Risk Factors for Cancer[1,2,3,4]

Unmodifiable Risk Factors	Modifiable Risk Factors
• **Age.** Most cancers occur in people over the age of sixty-five. However, people of all ages, including children, can get cancer. • **Family history.** Certain types of cancer have a genetic link (e.g., hereditary breast cancer, inherited genetic syndrome leading to pancreatic cancer). However, environmental factors may also play a part.	• **Tobacco.** Smoking or chewing tobacco greatly increases the risk for certain cancers, including cancer of the lungs, mouth, and pancreas. • **Obesity.** Linked to cancers of the colon, uterus, pancreas, esophagus, kidney, and breast. • **Alcohol.** Drinking alcohol is linked to cancers of the mouth, throat, esophagus, liver and breast. • **Red meat and processed meat.** The risk of colon cancer seems to increase with the consumption of red meat and processed meat. • **Physical inactivity.** Linked to colon, breast, and other cancers. • **Viruses or bacteria.** Certain viruses or bacteria may increase the risk of developing cancer. For example, *Human papillomavirus (HPV)*, which is sexually transmitted, can cause cervical cancer. • **Ultraviolet (UV) radiation.** UV radiation from the sun and indoor tanning beds is associated with skin cancer.

Signs and Symptoms of Cancer

Signs and symptoms of cancer include:

- Unexplained weight loss
- Fever
- Fatigue
- Skin changes
- Changes in bowel habits or bladder function
- Indigestion or trouble swallowing
- White patches inside the mouth or on the tongue
- Any thickening or lump

Steps to Reducing the Risk of Cancer

It's estimated that at least 40% of all cancers are avoidable by managing modifiable risk factors.[2]

The World Cancer Research Fund and the American Institute for Cancer Research (AICR) have published recommendations for preventing cancer and staying healthy.[5] They include several dietary and lifestyle choices, such as:

- follow a dietary pattern that:
  - is rich in whole grains, vegetables, fruit, and beans
  - limits sugar-sweetened beverages
    - drink more water and unsweetened drinks
  - limits red and processed meat
  - limits foods high in fat, salts, and sugars
  - limits alcohol consumption
- maintain a healthy weight
- be physically active by engaging in at least 150 minutes of moderate physical activity each week (or 75 minutes of vigorous physical activity each week)
- do not use supplements for cancer prevention
- for mothers: breastfeed your baby if you can

- after a cancer diagnosis follow the recommendations listed here if you can

One way to implement the dietary pattern described above is to have vegetables, fruits, whole grains and beans make up 2/3 (or more) of each meal, and animal protein to make up 1/3 (or less).[6] For example, a 3-ounce serving of meat (fish, poultry, or red meat) with a whole grain (e.g., brown rice, barley, kasha, bulgur, millet, quinoa) and a variety of vegetables (see Figure 9.4.1) follows this recommended pattern. Drinking water with the meal and going for a walk afterwards helps meet additional recommendations for preventing cancer and staying healthy.



Figure 9.4.1: Sample meal that meets cancer prevention recommendations. (AICR)

The meal shown above is also an antioxidant-rich meal. Antioxidants may work to reduce cancer risk by:

- Enhancing the immune system
- Preventing oxidative damage to cells
- Inhibiting growth of cancer cells
- Limiting cancer cells' natural ability to avoid cell death

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10: NUTRIENTS IMPORTANT FOR BONE HEALTH

10.1: Bone Structure and Function
10.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D
10.3: Other Essential Micronutrients for Bone Health
10.4: Osteoporosis

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10.1: Bone Structure and Function

Learning Objectives

- Identify the functions of the skeletal system.
- Identify the two types of bone tissue.
- Explain the process of bone remodeling.

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

Why is the Skeletal System Important?

The human skeleton consists of 206 bones and other connective tissues called ligaments, tendons, and cartilage. Ligaments connect bones to other bones, tendons connect bones to muscles, and cartilage provides bones with more flexibility and acts as a cushion in the joints between bones. Bone has multiple functions related to structure, support, and metabolic processes as outlined in Table 10.1.1 below.

Table 10.1.1: Functions of Bone

Functions Related to Structure and Support	
• Physical support for organs and body segments. • Protect vital organs; for example, the rib cage protects the lungs, the skull protects the brain, and the vertebrae of the spine protect the spinal cord. • Work with muscles and tendons to allow movement - muscles attach to bones via tendons, and their contraction moves the body's joints.	• Act as a storag reservoirs wher • Most blood cell

Bone Anatomy and Structure

The composition of bone allows for the bone to be hard and flexible at the same time. Bone contains about 65% minerals (e.g., calcium, phosphorus) that provide the hardness of bone. The other 35% of bone is made up of organic structures (e.g., collagen) that provide strength, durability, and flexibility. Bones consist of two different tissue types. There is trabecular (or spongy) bone and cortical (also known as compact or hard) bone (Figure 10.1.1a and Figure 10.1.1b).

- Trabecular bone is 50-90% porous and appears as a lattice-like structure under the microscope. Trabecular bone supports cortical bone and can be thought of as the "scaffolding" on the inside of bones. It is found at the ends of long bones, in the cores of vertebrae, inside flat bones, and in the pelvis. Trabecular bone tissue makes up about 20% of the adult skeleton.
- Cortical bone is found on the outer surface of all bones. The more dense cortical bone is about 10% porous and makes up approximately 80% of the adult skeleton. It surrounds all trabecular tissue and is the only bone tissue in the shafts of long bones.

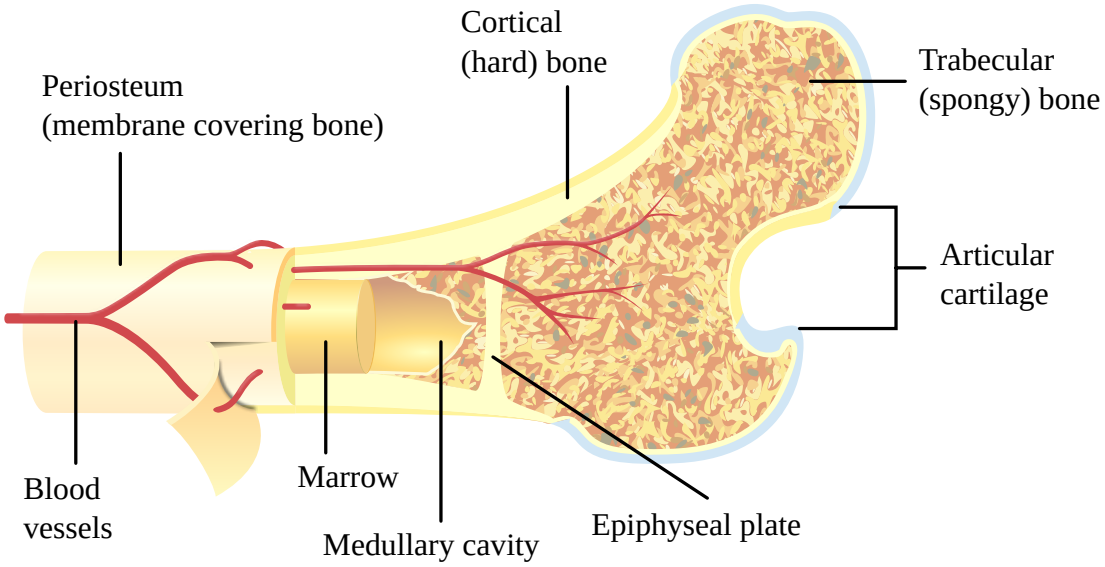


Figure 10.1.1*a*: Cross-section of a bone.

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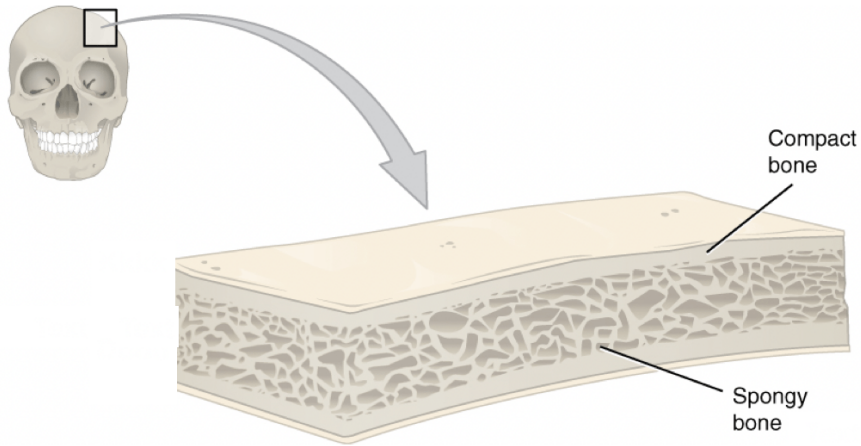


Figure 10.1.1*b*: Anatomy of a flat bone.

(CC BY 4.0; by OpenStax Anatomy and Physiology)

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

Bone Tissues and Cells

Bone tissue contains many different cell types that constantly resize and reshape bones throughout growth and adulthood. Bone tissue cells include osteoprogenitor cells, osteoblasts, osteoclasts, and osteocytes. The osteoprogenitor cells are cells that have not matured yet. Once they are stimulated, some will become osteoblasts, the bone builders, and others will become osteoclasts, the cells that break bone down. Osteocytes are the most abundant cells in bone tissue. Osteocytes are star-shaped cells that are

connected throughout the bone and exchange nutrients from bones to the blood and lymph.

Bone Modeling and Remodeling

During infancy, childhood, and adolescence, bones are continuously growing and changing shape through two processes called growth and modeling. In fact, in the first year of life, almost 100% of the bone tissue in the skeleton is replaced. In the process of modeling, bone tissue is dismantled at one site and built up at a different site. In adulthood, our bones stop growing and modeling, but continue to go through a process of bone remodeling. In the process of remodeling, bone tissue is degraded and built up at the same location. Bone remodeling has multiple purposes including repairing damaged bone, recycling bone tissue, and maintaining blood calcium levels. About 10% of bone tissue is remodeled each year in adults.

The first step in bone remodeling is osteocyte activation. Osteocytes detect changes in mechanical forces, calcium homeostasis, or hormone levels. In the second step, osteoclasts are recruited to the site of the degradation. Osteoclasts are large cells with a highly irregular ruffled membrane (Figure 10.1.2). These cells fuse tightly to the bone and secrete hydrogen ions, which makes the environment acidic and dissolves the minerals in the bone tissue matrix. This process is called bone resorption and resembles pit excavation. Our bodies excavate pits in our bone tissue because bones act as storehouses for calcium and other minerals. Bones supply these minerals to other body tissues as the demand arises. Bone tissue also remodels when it breaks so that it can repair itself.

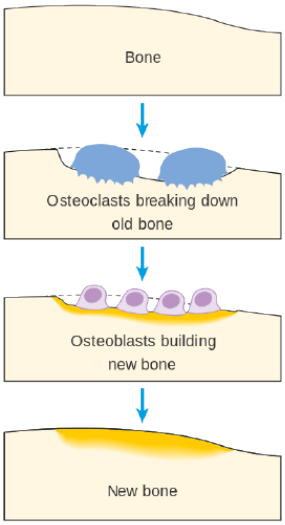


Figure 10.1.2: Bone remodeling requires osteoclast activity to break down old bone and osteoblast activity to build new bone tissue. (CC BY-SA 4.0; by Cancer Research UK via Wikimedia Commons)

After a certain amount of bone is excavated, the osteoclasts begin to die and bone resorption stops. In the third step of bone remodeling, the site is prepared for building. In this stage, sugars and proteins accumulate along the bone's surface, forming a cement line which acts to form a strong bond between the old bone and the new bone that will be made. These first three steps take approximately two to three weeks to complete. In the last step of bone remodeling, osteoblasts lay down new osteoid tissue that fills up the cavities that were excavated during the resorption process (Figure 10.1.2). Osteoid is bone matrix tissue that is composed of proteins such as collagen and is not mineralized yet. To make collagen, vitamin C is required. A symptom of vitamin C deficiency (known as scurvy) is bone pain, which is caused by diminished bone remodeling. After the osteoid tissue is built up, the bone tissue begins to mineralize. The last step of bone remodeling continues for months, and for much longer afterwards, the mineralized bone is continuously packed in a more dense fashion.

Thus, we can say that bone is a living tissue that continually adapts itself to mechanical stress through the process of remodeling. For bone tissue to remodel, certain nutrients such as calcium, phosphorus, magnesium, fluoride, vitamin D, and vitamin K are required. Watch these short videos to see osteoblasts, osteoclasts, bone remodeling, and bone modeling in action:

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

"Osteoblasts and Osteoclasts" by Amgen

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"Bone Remodeling and Modeling" by Amgen

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10.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D

Learning Objectives

- Describe the functions of calcium and vitamin D.
- Describe how blood calcium levels are regulated.
- Give examples of good food sources of calcium and vitamin D.

Calcium

The most abundant mineral in the body is calcium, and more than 99% of it is stored in bone tissue. Although only 1% of the calcium in the human body is found in the blood and soft tissues, it is here that calcium performs its most critical functions. Blood calcium levels are rigorously controlled so that if blood levels drop, the body will rapidly respond by stimulating bone resorption, thereby releasing stored calcium into the blood. Thus, bone tissue sacrifices its stored calcium to maintain blood calcium levels. This is why bone health is dependent on the intake of dietary calcium and also why blood levels of calcium do not always correspond to dietary intake.

Functions of Calcium

Calcium plays a role in several different functions in the body:

- **Bone and tooth formation.** The most well-known function of calcium is building and strengthening bones and teeth. Recall that when bone tissue first forms during the modeling or remodeling process, it is unhardened, protein-rich osteoid tissue. In the osteoblast-directed process of bone mineralization, calcium and phosphorus are deposited on the protein matrix and eventually crystallize into hydroxyapatite, which makes up about 65% of bone tissue. When your diet is too low in calcium, the mineral content of bone decreases, causing it to become brittle and weak. Thus, increased calcium intake increases the mineralized content of bone tissue, which leads to greater bone strength.
- **Nerve impulse transmission.** Calcium facilitates electrical impulse transmission from one nerve cell to another. Calcium acts as the trigger that allows nerve cells to release chemical messengers that transmit the nerve impulse to the next nerve cell. If calcium levels are too low, the signal/transmission weakens or fails.
- **Muscle contraction and relaxation.** The flow of calcium ions along the muscle cell's surface and the influx of calcium into the muscle cell are critical for muscle contraction. With inadequate calcium, muscles can't relax, and instead become stiff and contract involuntary, a condition known as tetany.
- **Clotting factors.** When a blood vessel is injured and bleeding starts, it must be stopped or death may result. Clotting factors and platelets are continuously circulating in the blood in case of such an emergency. When an injury occurs, the damaged tissue releases specific factors that activate the circulating clotting factors and platelets. Some of the clotting factors require calcium for activation. If clotting factors weren't activated, blood clots would not form.

In addition to these primary functions calcium has several other minor functions that are also critical for maintaining normal physiology. For example, without calcium, the hormone insulin could not be released from cells in the pancreas and glycogen could not be broken down in muscle cells and used to provide energy for muscle contraction.

Maintaining Calcium Levels

Because calcium performs such vital functions in the body, blood calcium levels are closely regulated by the hormones parathyroid hormone (PTH), calcitriol, and calcitonin. Calcitriol is the active form of vitamin D. Parathyroid hormone and calcitriol act together to increase calcium levels in the blood, while calcitonin does the opposite and decreases blood calcium levels.

Parathyroid Hormone (PTH) and Calcitriol (1,25-dihydroxyvitamin D_3)

Four parathyroid glands, each the size of a grain of rice, can be found in the neck on the sides of the thyroid gland. PTH and calcitriol increase blood calcium (Ca^{2+}) levels via three different mechanisms (left side of Figure 10.2.1):

1. PTH stimulates osteoclast activity to release calcium stored in bone.
2. PTH acts on the kidney to decrease the amount of calcium lost in urine, which returns more calcium to circulation.
3. PTH stimulates enzymes in the kidney that convert vitamin D to calcitriol. Calcitriol acts on intestinal cells to increase dietary calcium absorption. Calcitriol also works together with PTH to increase calcium release from bone and decrease calcium loss in urine.

Ultimately, PTH and calcitriol work together to ensure that stored calcium is released, more calcium is absorbed from the diet, and less calcium is excreted, all of which increase calcium levels in the blood. Once blood calcium levels are normal, PTH levels drop, turning off all of these mechanisms used to increase blood calcium.

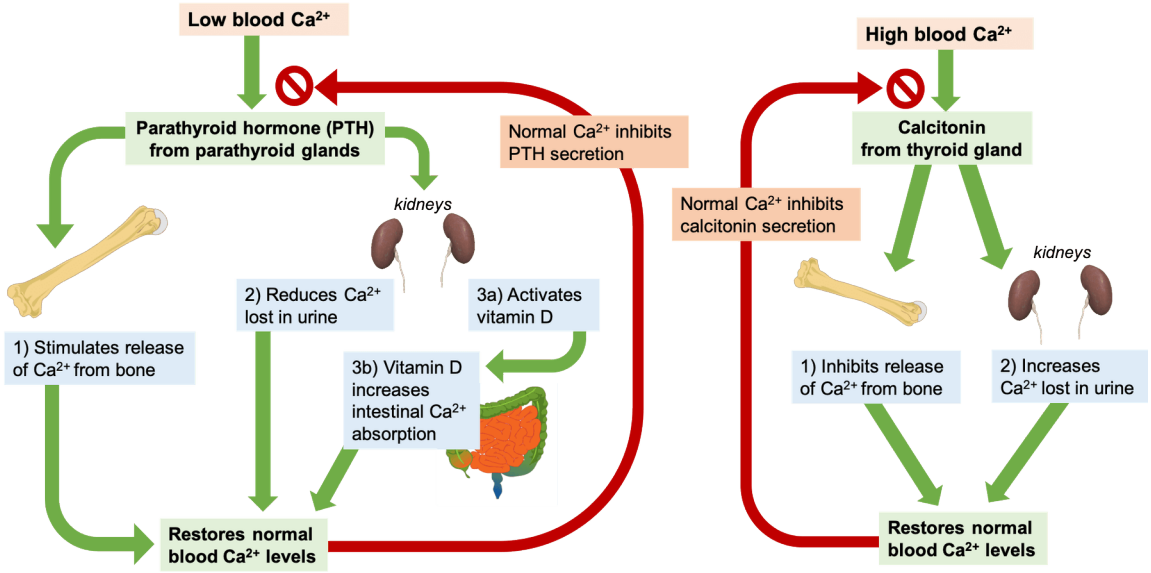


Figure 10.2.1: Calcium regulation. (CC BY 4.0; Alice Callahan via Nutrition Science and Everyday Application with kidney, bone, and intestine images in the public domain by Mikael Häggström)

Calcitonin

Calcitonin is a hormone secreted by cells in the thyroid gland in response to high calcium levels in the blood. In comparison to PTH and calcitriol, calcitonin plays a small role in regulating calcium levels on a day-to-day basis. This is because as calcium levels rise in the blood, calcium feedback inhibits PTH release and effectively shuts off the actions of PTH and calcitriol (left side of Figure 10.2.1). This route of feedback inhibition helps prevent calcium's further accumulation in the blood. When needed, calcitonin lowers blood calcium levels by inhibiting bone resorption (release of calcium from bone) and increasing calcium excretion in the urine (right side of Figure 10.2.1).

Calcium Imbalances

As noted above, most excess calcium from food is excreted from the body. However, excessive intake from calcium supplements can lead to mineral imbalances (e.g., iron, zinc, magnesium). Hypercalcemia (high blood calcium levels) can be caused by cancer or overproduction of parathyroid hormone (PTH) as discussed in detail above.

Hypocalcemia (low blood calcium) can be caused by kidney disease, vitamin D deficiency, or limited PTH production. A long-term effect of low calcium intake is known as osteoporosis (very low bone density); osteoporosis is discussed in more detail later in this chapter.

Calcium Recommendations

The Dietary Reference Intakes (DRIs) for calcium are listed in Table 10.2.1. The RDA increases to 1,300 milligrams per day during adolescence because this is the life stage with accelerated bone growth. Studies have shown that a higher intake of calcium during puberty increases the total amount of bone tissue that accumulates in the body. The bioavailability (degree to which our bodies can absorb and utilize any nutrient) of calcium is also considered in the recommendations. When calcium needs are high (infants, children, and pregnant and lactating women), our bodies can generally absorb more calcium. As we age, our ability to absorb nutrients generally decreases. This is why the RDAs for women older than 50 and men older than 70 are a bit higher. As we age, calcium absorption in the gut decreases, vitamin D_3 activation is reduced, and maintaining adequate blood levels of calcium is important to prevent an acceleration of bone tissue loss.

Table 10.2.1: Dietary Reference Intakes for Calcium[1]

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	200*	1,000
Infants (7–12 months)	260*	1,500
Children (1–3 years)	700	2,500
Children (4–8 years)	1,000	2,500
Children (9–13 years)	1,300	3,000
Adolescents (14–18 years)	1,300	3,000
Adults (19–50 years)	1,000	2,500
Adults (51–70 years)	1,000 (males), 1,200 (females)	2,000
Adults (> 70 years)	1,200	2,000
*** denotes Adequate Intake**		

Sources of Calcium

Calcium can be obtained from dairy product as well as nondairy sources of calcium (Table 10.2.2).

Table 10.2.2: Dietary Sources of Calcium[2,3]

Food	Calcium (mg)	% Daily Value
Yogurt, low fat, plain (8 ounces)	415	32
Almonds (1 cup)	385	30
Orange juice, calcium fortified (1 cup)	349	27
Sardines, canned in oil, with bones (3 ounces)	325	25
Cheddar cheese (1½ ounces)	307	24
Soymilk, calcium fortified (1 cup)	299	23
Milk, reduced fat 2% (1 cup)	293	23
Tofu, firm, made with calcium sulfate (½ cup)	253	19
Chickpeas/garbanzo beans (1 cup)	210	16
Kale, cooked from frozen (1 cup)	179	14

Learn even more about this nutrient by reading the Calcium Fact Sheet from the National Institutes of Health, Office of Dietary Supplements.

Vitamin D

Vitamin D refers to a group of fat-soluble vitamins derived from cholesterol. Vitamins D_2 and D_3 are the only ones known to have biological actions in the human body. Although vitamin D_3 is called a vitamin, the body can actually synthesize vitamin D_3. When exposed to sunlight, a cholesterol precursor in the skin is transformed into vitamin D_3 (Figure 10.2.2). However, this is not the biologically active form of vitamin D. It first must be acted upon by enzymes in the liver and then transported to the kidney where vitamin D_3 is finally transformed into the active hormone, calcitriol (1,25-dihydroxyvitamin D_3).

The skin synthesizes vitamin D when exposed to sunlight. In fact, for most people, more than 90% of their vitamin D_3 comes from the casual exposure to the UVB rays in sunlight. Anything that reduces your exposure to the sun's UVB rays decreases the amount of vitamin D_3 your skin synthesizes, including:

- Geographic latitude and season: In locations that are ± 40 degrees latitude (e.g., Denver), vitamin D synthesis is nearly impossible from November until early March because the sun is lower in the sky to provide enough UVB rays. In addition, in the winter, day length is shorter and cloud cover is more likely to block the sun's rays which also decrease opportunities to synthesize vitamin D.
- Skin pigmentation: Darker skin pigmentation, caused by greater melanin production in the skin, decreases UVB light absorption.
- Age: The efficiency of vitamin D synthesis declines with age. In addition, older adults often spend less time outside so may receive less exposure to sunlight.
- Sun-protective behaviors: While UVB rays are needed to synthesize vitamin D, UV radiation from the sun is associated with skin cancer. It's wise to protect your skin from UV radiation by applying sunscreen, wearing protective 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 aren't able to go outside during the day may not get enough UVB rays for vitamin D synthesis. Some experts recommend 5-30 minutes of sun exposure, without sunscreen, most days of the week to provide adequate vitamin D synthesis.[4] Other experts recommend getting vitamin D from food or supplements to lower your risk for skin cancer.[5]

A person's vitamin D status is determined by measuring 25-hydroxyvitamin D_3 levels in the blood because it reflects both the vitamin D obtained from production in the skin and that from dietary sources (see Figure 10.2.2). Measuring the active hormone, calcitriol (1,25-dihydroxyvitamin D_3), does not accurately reflect one's vitamin D status because of its short half-life (6-12 hours). The vast majority of nutrition experts consider a concentration of 25-hydroxyvitamin D_3 in the blood less than 20 nanograms per milliliter as an indicator of vitamin D deficiency.

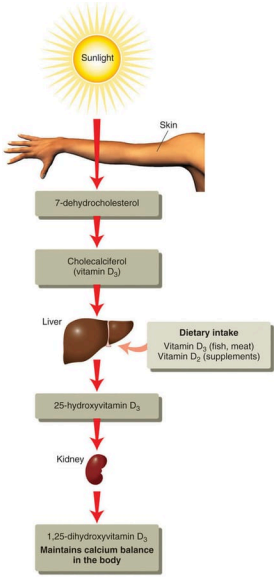


Figure 10.2.2: The Activation of Vitamin D to Calcitriol. © Networkgraphics

Functions of Vitamin D

As previously discussed, activated vitamin D_3 (calcitriol) regulates blood calcium levels together with parathyroid hormone (PTH).

Vitamin D works with PTH to stimulate osteoclasts that break down bone when calcium is needed elsewhere in the body. Vitamin D is also required for calcium absorption; in the absence of an adequate intake of vitamin D, less than 15% of calcium is absorbed from foods or supplements.

Vitamin D Imbalances

We can't get too much vitamin D from sun exposure or from food intake. However, vitamin D toxicity can occur from vitamin supplements. Getting too much vitamin D results in hypercalcemia (high blood calcium); symptoms of hypercalcemia include weakness, loss of appetite, constipation, and mental confusion. Hypercalcemia can also lead to calcium deposits in soft tissues such as the kidneys, liver, and heart.

A deficiency of vitamin D leads to loss of bone mass. In children, a vitamin D deficiency causes a bone disease called rickets. Rickets is characterized by soft, weak, deformed bones that are exceptionally susceptible to fracture. In adults, vitamin D deficiency causes a similar disease called osteomalacia, which is characterized by low bone density. Vitamin D deficiency is common, especially in the elderly population, dark-skinned populations, and in people who live in the northern latitudes where sunlight exposure is decreased during the long winter season. Vitamin D deficiency can also happen in people who have diseases that reduce intestinal absorption of fat; the decreased fat absorption leads to decreased absorption of fat-soluble vitamins (e.g., vitamin D).

Vitamin D Recommendations

The DRIs for vitamin D for different age groups are listed in Table 10.2.3. For adults, the RDA is 15 micrograms (mcg) of vitamin D. The National Osteoporosis Foundation recommends slightly higher levels and that adults under age 50 get 400-800 international units (10-20 mcg) of vitamin D every day, and adults 50 and older get 800-1,000 international units (20-25 mcg) of vitamin D every day.[6] Toxicity from excess vitamin D is rare, but certain diseases such as hyperparathyroidism, lymphoma, and tuberculosis make people more sensitive to the increases in calcium caused by high intakes of vitamin D.

Table 10.2.3: Dietary Reference Intakes for Vitamin D[1]

Age Group	RDA (mcg/day)	UL (mcg/day)
Infant (0–6 months)	10*	25
Infants (7–12 months)	10*	38
Children (1–3 years)	15	63
Children (4–8 years)	15	75
Children (9–13 years)	15	100
Adolescents (14–18 years)	15	100
Adults (19–70 years)	15	100
Adults (> 70 years)	20	100
*** denotes Adequate Intake**		

Sources of Vitamin D

There are few food sources of vitamin D. Fatty fish (e.g., trout, salmon) are some of the best sources. Many foods, including dairy products, orange juice, and cereals are now fortified with vitamin D. Many people are deficient in vitamin D as a result of the few dietary sources for this vitamin.

Table 10.2.4: Dietary Sources of Vitamin D

Food	Vitamin D (mcg)	% Daily Value
Cod liver oil (1 tablespoon)	34	170
Rainbow trout (3 ounces)	16.2	81

Food	Vitamin D (mcg)	% Daily Value
Salmon (3 ounces)	14.2	71
Mushrooms (1/2 cup)	9.2	46
2% milk, vitamin D fortified (1 cup)	2.9	15

Learn even more about this nutrient by reading the Vitamin D Fact Sheet from the National Institutes of Health, Office of Dietary Supplements.

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10.3: Other Essential Micronutrients for Bone Health

Learning Objectives

- Identify additional nutrients that are vital in maintaining bone health and state their primary role.
- Identify food sources for each nutrient.

In addition to calcium and vitamin D, other nutrients critical for bone health include phosphorus, magnesium, fluoride, and vitamin K. We'll discuss phosphorus, magnesium, and fluoride on this page; vitamin K will be discussed in the next chapter. The fact that there are many bone-friendly nutrients provides us with one more reason why it is better to eat a diet rich in many nutrients than take one particular supplement.

Phosphorus

Phosphorus is classified as a macromineral (major mineral). Macrominerals are those that the body requires in amounts of at least 100 mg per day.

Functions of Phosphorus

Phosphorus is the second most abundant mineral in the human body; 85% of it is housed in the skeleton. In addition to serving as a primary mineral in the skeleton, phosphorus in the form of phosphate is a component of RNA, DNA, adenosine triphosphate (ATP; the cell's energy storing molecule), and phospholipids. Because phosphorus is present with calcium in mineralized bone, it is somewhat regulated in parallel to calcium. PTH and calcitriol stimulate bone resorption, increasing not only blood levels of calcium, 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. You may also remember that phosphorus is the primary negatively charged electrolyte in intracellular fluid and helps maintain fluid balance. In addition, phosphorus helps activate and deactivate enzymes in various metabolic processes throughout the body.

Phosphorus Imbalances

Both deficiencies and toxicities of phosphorus are rare in healthy adults. Excessive vitamin D supplements can cause high phosphorus levels, muscle spasms, and convulsions.

Phosphorus Recommendations

The Dietary Reference Intakes (DRIs) for phosphorus are listed in Table 10.3.1.

Table 10.3.1: Dietary Reference Intakes for Phosphorus[1]

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	100*	ND
Infants (7–12 months)	275*	ND
Children (1–3 years)	460	3,000
Children (4–8 years)	500	3,000
Children (9–13 years)	1,250	4,000
Adolescents (14–18 years)	1,250	4,000
*** denotes Adequate Intake; ND=not determined**		

Age Group	RDA (mg/day)	UL (mg/day)
Adults (19–70 years)	700	4,000
Adults (> 70 years)	700	3,000
*** denotes Adequate Intake; ND=not determined**		

Sources of Phosphorus

Most Americans are not at risk for having a phosphorus deficiency. Phosphorus is present in many foods popular in the American diet including meat, fish, dairy products, and processed foods (see Table 10.3.2). Phosphorus is also added to many foods because it acts as an emulsifying agent, prevents clumping, improves texture and taste, and extends shelf-life. For example, phosphorus is found in soda as phosphoric acid which gives soda a more tart flavor and helps slow growth of molds and bacteria. The average intake of phosphorus in US adults ranges between 1,100 and 1,600 milligrams (mg) per day,[2] well above the RDA of 700 mg per day.

Table 10.3.2: Dietary Sources of Phosphorus[2]

Food	Phosphorus (mg)	% Daily Value
Yogurt, plain, low fat (6 ounces)	245	20
2% milk (1 cup)	226	18
Salmon (3 ounces)	214	17
Chicken breast (3 ounces)	182	15
Lentils (1/2 cup)	178	14
Hamburger, 90% lean (3 ounces)	172	14

Learn even more about this nutrient by reading the Phosphorus Fact Sheet from the National Institutes of Health, Office of Dietary Supplements.

Magnesium

Magnesium is classified as a macromineral (major mineral).

Functions of Magnesium

Approximately 60% of magnesium in the human body is stored in the skeleton, making up about 1% of mineralized bone tissue. Magnesium is not an integral part of the hydroxyapatite crystal, but it does reside on the surface of the crystal and helps maximize bone structure. In addition to participating in bone maintenance, magnesium has several other functions in the body. Every reaction that involves ATP requires magnesium, so more than 300 enzymatic reactions require magnesium. Magnesium plays a role in the synthesis of DNA and RNA, carbohydrates, and lipids, and is essential for nerve conduction, muscle contraction, and regulating blood pressure.

Magnesium Imbalances

Most people in the U.S. 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.[3] More studies are needed to determine whether magnesium supplements may help prevent these diseases. However, since magnesium is present in many healthful whole foods, improving magnesium intake through diet may bring multiple benefits.

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.[3] 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] Observational studies link magnesium deficiency with an increased risk for osteoporosis. A magnesium-deficient diet is associated with decreased levels of parathyroid hormone and the activation of vitamin D, which may lead to an impairment of bone remodeling. Hypomagnesemia (low magnesium in your blood) can also be caused by kidney disease, chronic diarrhea, or chronic alcohol intake.

Generally, excessive intake of magnesium from foods is not a risk, as the kidneys can effectively excrete it if it's in excess. However, people should take care not to consume more than the UL for magnesium from supplements and medications.[3] Magnesium supplements can cause diarrhea, nausea, cramps, and dehydration. Hypermagnesemia (high magnesium in your blood) can also occur in individuals with impaired kidney function.

Magnesium Recommendations

The DRIs for magnesium are listed in Table 10.3.3. It's important to note that the upper limit (UL) for magnesium applies only to magnesium supplements and is not a UL for magnesium intake from food and water.

Table 10.3.3: Dietary Reference Intakes for Magnesium[1]

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	30*	ND
Infants (7–12 months)	75*	ND
Children (1–3 years)	80	65
Children (4–8 years)	130	110
Children (9–13 years)	240	350
Adolescents (14–18 years)	410 (males), 360 (females)	350
Adults (19–30 years)	400 (males), 310 (females)	350
Adults (> 30 years)	420 (males), 320 (females)	350
*** denotes Adequate Intake**		

Sources of Magnesium

Magnesium is part of the green pigment, chlorophyll, which is vital for photosynthesis in plants; therefore, green leafy vegetables are a good dietary source for magnesium (Table 10.3.4). Magnesium is also found in high concentrations in fish, dairy products, meats, whole grains, and nuts. Additionally, chocolate, coffee, and hard water contain a good amount of magnesium. Most people in America do not fulfill the RDA for magnesium in their diets.

Table 10.3.4: Dietary Sources of Magnesium[3]

Food	Magnesium (mg)	% Daily Value
Almonds (1 ounce)	80	19
Spinach, boiled (1/2 cup)	78	19
Soy milk (1 cup)	61	15
Black beans, cooked (1/2 cup)	60	14

Learn even more about this nutrient by reading the Magnesium Fact Sheet from the National Institutes of Health, Office of Dietary Supplements.

Fluoride

Fluoride is classified as a trace mineral. Trace minerals are nutrients that we need to consume in amounts less than 100 mg per day.

Functions of Fluoride

Approximately 99% of the body's fluoride is stored in teeth and bones. So, it may not be surprising that it assists in tooth and bone development and maintenance. Fluoride is known mostly as the mineral that combats tooth decay. Fluoride combats tooth decay (cavities) via three mechanisms:

1. Blocking acid formation by bacteria
2. Preventing demineralization of teeth
3. Enhancing remineralization of destroyed enamel

Fluoride Imbalances

Fluorosis (excess fluoride) creates porous tooth enamel; teeth become mottled (white speckling), stained and pitted as shown in Figure 10.3.1. The highest risk for fluorosis is during the first 8 years of life when the permanent teeth are developing. Toothpastes that contain fluoride help reduce tooth decay. However, if fluoride toothpaste is swallowed by young children it can lead to fluorosis. This is why young children should be supervised while brushing their teeth and taught to spit out toothpaste instead of swallowing it.

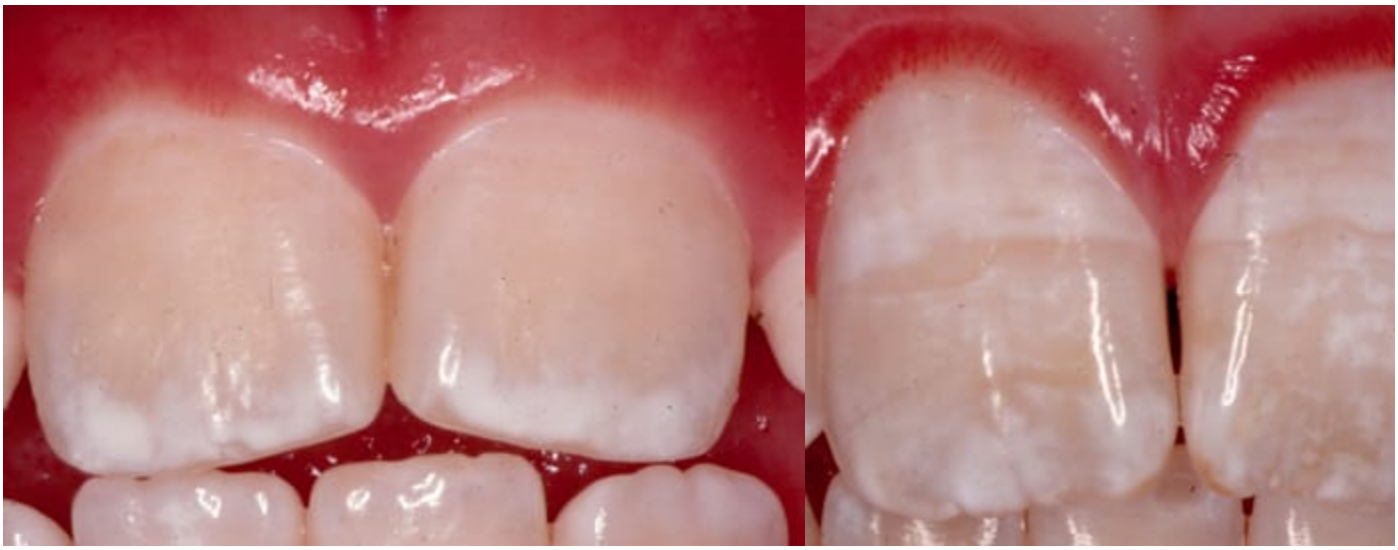


Figure 10.3.1: Fluorosis Progression: normal teeth, mild fluorosis, moderate fluorosis, and severe fluorosis including pitted surfaces.

The largest risk associated with not consuming enough fluoride is development of tooth decay (cavities). The Centers for Disease Control and Prevention (CDC) has reported that fluoridation of water reduces tooth decay by about 25% in children and adults.[4]

Fluoride Recommendations

The Institute of Medicine has given Adequate Intakes (AIs) for fluoride, but has not yet developed RDAs (Table 10.3.5). The AIs are based on the doses of fluoride shown to reduce the incidence of tooth decay, but not cause dental fluorosis.

Table 10.3.5: Dietary Reference Intakes for Fluoride[1]

Age Group	AI (mg/day)	UL (mg/day)
Infants (0–6 months)	0.01	0.7

Age Group	AI (mg/day)	UL (mg/day)
Infants (7–12 months)	0.50	0.9
Children (1–3 years)	0.70	1.3
Children (4–8 years)	1.00	2.2
Children (9–13 years)	2.00	10.0
Adolescents (14–18 years)	3.00	10.0
Adults (> 19 years)	4.00 (males), 3.00 (females)	10.0

Sources of Fluoride

More than 70% of a person's fluoride intake comes from drinking fluoridated (tap) water when they live in a community that fluoridates the drinking water. Solid foods do not contain a large amount of fluoride. Fluoride content in foods depends on whether they were grown in soils and water that contained fluoride or cooked with fluoridated water. Canned meats and fish that contain bones do contain some fluoride. In addition, most toothpastes contain fluoride.

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10.4: Osteoporosis

Learning Objectives

- Describe bone density, including how it's measured and age ranges for peak bone density/mass.
- Describe osteoporosis, including its notable characteristics
- Discuss risk factors for osteoporosis.
- Describe prevention and treatment options for osteoporosis.

Osteoporosis is the excessive loss of bone density or bone mass over time. The bone becomes thinner and more porous over time which leads to decreased bone strength and an increased risk for bone fractures. Osteoporosis affects more women than men, but men are also at risk for developing osteoporosis, especially after the age of 70.

Bone Density

Bones grow and mineralize predominantly during infancy, childhood, and puberty. During this time, bone growth exceeds bone loss, leading to increases in bone mass. Bone mass refers to the total weight of bone tissue in the human body. The greatest quantity of bone tissue a person develops during his or her lifetime is called peak bone mass. Peak bone mass is reached by age 30, and then gradually declines after age 40 (Figure 10.4.1). The decline in bone mass after age 40 occurs because bone loss is greater than bone growth. On a cellular level, this means that the osteoclast-mediated bone breakdown exceeds that of the bone-building activity of osteoblasts. The increased breakdown of bone decreases the mineral content of bone tissue leading to a decrease in bone strength and increased fracture risk.

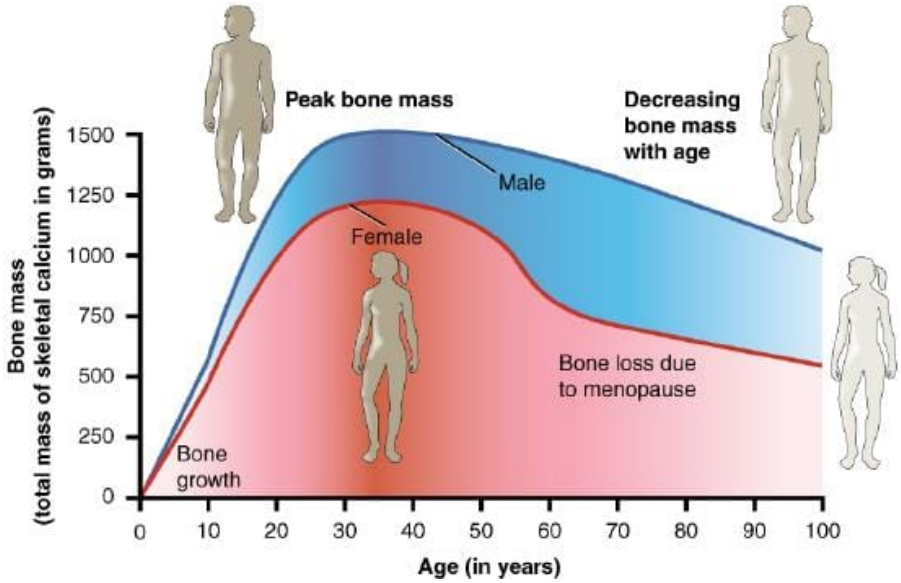


Figure 10.4.1: Age and bone mass. (CC BY 4.0; Anatomy and Physiology OpenStax)

Bone density is the concentration of minerals (e.g., calcium) within the bone. When bone density is high, bone strength will be great. Conversely, when bone density is low, bones are weaker and the risk of bone fractures increases. The most common tool used to measure bone density is called dual energy X-ray absorptiometry (DEXA). DEXA is the cheapest and most accurate way to measure bone density; typically, a DEXA scan focuses on measuring bone density in the hip and the spine. These measurements are then compared to the average peak bone density of a healthy 30-year-old population of the same sex and are used as indicators of overall bone strength and health. Results of a DEXA scan can be used to diagnose osteopenia (low bone density) or osteoporosis (very low bone density).

Osteoporosis

Osteoporosis is a bone disease that occurs when bone density and bone mass decrease. Excessive bone resorption (breakdown of bone tissue) in the trabecular tissue increases the size of the holes in the lattice-like structure, making it more porous and weaker (right side of Figure 10.4.2). A disproportionate amount of resorption of the strong cortical bone causes it to become thinner. The deterioration of one or both types of bone tissue causes bones to weaken and, consequently, become more susceptible to fractures. When the vertebral bone tissue is weakened, it can cause the spine to curve (left side of Figure 10.4.2). The increase in spine curvature not only causes pain but also decreases a person's height. Curvature of the upper spine produces what is called *Dowager's hump*, also known as *kyphosis*.

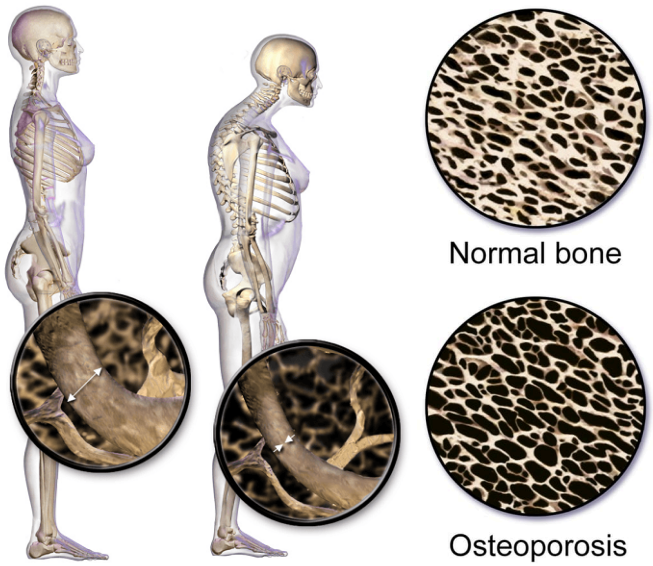


Figure 10.4.2: Normal bone (thicker, less porous) vs. bone with osteoporosis (thinner, more porous). (CC BY-SA 4.0; Bruce Blaus)

Risk Factors for Osteoporosis

There are risk factors for osteoporosis that cannot be changed (unmodifiable), but there are also factors that can be modified to reduce risk for osteoporosis. Table 10.4.1 reviews the unmodifiable and modifiable risk factors for osteoporosis.

Table 10.4.1: Osteoporosis Risk Factors[1]

Unmodifiable Risk Factors	Modifiable Risk Factors
• **Body frame size.** People with small frames are at higher risk for osteoporosis. • **Age.** Risk increases after the age of 40 due to bone breakdown exceeding bone building. In addition, older adults have a decreased ability to metabolize vitamin D. • **Sex.** Females have a higher risk than males due to generally lower peak bone density in females and estrogen loss in post-menopausal women causes increased bone loss. • **Family history.** A family history of osteoporosis increases risk for this disease. • **Race.** Caucasian and Asian races are at greater risk than other races.	• **Physical inactivity.** Lack of exercise lowers peak bone mass, decreases bone density at all ages, and is linked to increased fracture risk in the elderly. • **Nutrition.** Low dietary intake of calcium and vitamin D can increase risk for osteoporosis and fractures. Inadequate protein intake may increase your risk for bone loss. • **Cigarette smoking.** Smoking decreases bone density due to its effects on hormones that influence bone formation and resorption. • **Low body weight.** Being underweight increases the risk for osteoporosis (which is often tied to also having a small frame size). • **Hormone deficiency.** Both estrogen and testosterone stimulate osteoblast-mediated bone building and reduce osteoclast activity. Reduced estrogen or testosterone levels lead to less bone building and more bone resorption. This leads to decreased bone density and increased risk for osteoporosis.

Prevention and Treatment for Osteoporosis

Preventing osteoporosis begins with building strong bones when you are growing. Maintaining healthy bones requires good nutrition, physical activity, and fall prevention.

Nutrition

Eating a balanced diet throughout life is helpful in preventing the onset of osteoporosis and deleterious fractures in old age. There is ample scientific evidence to suggest that low intakes of calcium and vitamin D in adulthood are linked to an increased risk for developing osteoporosis. Therefore, it is essential to make sure your diet contains adequate levels of these nutrients.

Physical Activity

Mechanical stress is one of the activation signals for bone remodeling and can increase bone strength. Exercises that apply forces to the bone increase bone density. The most helpful are weight-bearing exercises (e.g., walking, running, hiking, dancing, stair climbing) and resistance exercises (e.g., lifting weights, using resistance bands, doing body weight exercises).

Fall Prevention

Reducing the number of falls a person has decreases the likelihood of sustaining a fracture. Fairly simple modifications to a person's environment, such as installing night lights, railings on stairs, bars to hold onto in showers, and removing cords and throw rugs in walking paths can significantly reduce the likelihood of falling. Importantly, people at risk should have their vision and balance checked frequently.

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11: NUTRIENTS IMPORTANT FOR METABOLISM AND BLOOD FUNCTION

11.1: Overview of Blood and Metabolism

11.2: Nutrients Important for Metabolism

11.3: Nutrients Important in Blood Function

11.4: Dietary Supplements

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11.1: Overview of Blood and Metabolism

Learning Objectives

- List the components of blood.
- Describe the major role of blood.
- Define metabolism, catabolism, and anabolism.
- Identify functions of various catabolic and anabolic pathways.

Blood

Blood is a connective tissue of the circulatory system. Blood transports nutrients and oxygen to cells, removes waste products from cells, and transports molecules, such as hormones, allowing for communication between organs. Blood is made up of red blood cells (erythrocytes), white blood cells (leukocytes), platelets, and plasma (Figure 11.1.1).

The liquid part of blood is called plasma and it is mostly water (~90%), but also contains proteins, ions, glucose, lipids, vitamins, minerals, waste products, gases, enzymes, and hormones. Plasma makes up ~55% of total blood.

The cellular components of blood include red blood cells, white blood cells, and platelets. Red blood cells (erythrocytes) make up ~45% of total blood; their function is to transport oxygen from the lungs to all cells in the body. The white blood cells (leukocytes) that circulate in blood are part of the immune system and they survey the entire body looking for foreign invaders to destroy. Platelets are fragments of cells that are always circulating in the blood in case of an emergency. When blood vessels are injured, platelets rush to the site of injury to help form blood clots to stop bleeding at the wound site. White blood cells and platelets make up ~1% of total blood.

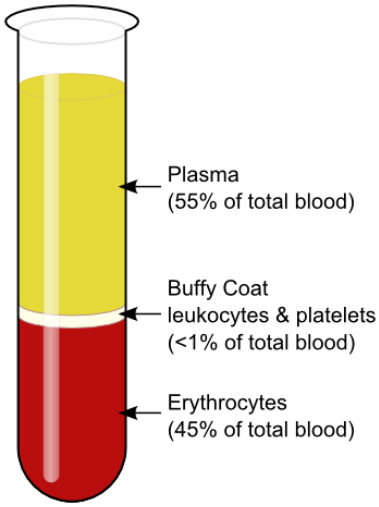


Figure 11.1.1: Components of blood include erythrocytes, leukocytes, platelets, and plasma. (CC BY 3.0; by KnuteKnudsen via Wikimedia Commons)

Metabolism

Metabolism is defined as the sum of all chemical reactions required to support cellular functions. Metabolism is either categorized as catabolism, referring to all metabolic processes involved in molecule breakdown, or anabolism, which includes all metabolic processes involved in building bigger molecules.

The food and beverages that we consume are broken down into nutrients during digestion. Once absorbed, blood transports the nutrients to cells. Cells requiring energy or building blocks take up the nutrients from the blood and process them in either catabolic or anabolic pathways. Generally, catabolic processes release energy and anabolic processes consume energy. When energy levels are low, catabolic pathways are initiated to make energy (Table 11.1.1); when energy levels are high, cells build molecules using anabolic pathways (Table 11.1.2).

Table 11.1.1: Catabolic Pathways

Catabolic Pathways	Function
Glycolysis	Glucose breakdown
Glycogenolysis	Glycogen breakdown
β-oxidation	Fatty-acid breakdown
Proteolysis	Protein breakdown to amino acids

Table 11.1.2: Anabolic Pathways

Anabolic Pathways	Function
Gluconeogenesis	Synthesize glucose
Glycogenesis	Synthesize glycogen
Lipogenesis	Synthesize triglycerides
Amino-acid synthesis	Synthesize amino acids

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11.2: Nutrients Important for Metabolism

Learning Objectives

- Summarize the role of the B vitamins in metabolism.
- Identify the primary function of each of the minerals involved in metabolism.

While macronutrients (carbohydrates, lipids, and proteins) and alcohol can be broken down (catabolized) to release energy, vitamins and minerals play a different kind of role in energy metabolism; they are required as functional parts of enzymes involved in energy release and storage. In other words, they're necessary for obtaining energy from the macronutrients, but vitamins and minerals don't directly provide energy/calories.

The Role of B Vitamins and Minerals in Energy Metabolism

All of the B vitamins and several minerals play a role in energy metabolism; they assist enzymes involved in energy release and storage. In Chapter 6, you learned that enzymes are proteins and that the job of an enzyme is to catalyze (speed up) chemical reactions. Without enzymes, chemical reactions would not happen at a fast enough rate and would use up too much energy for life to exist. Many enzymes don't work optimally, or even at all, unless bound to other specific helper molecules, called ***coenzymes*** or ***cofactors***. Vitamins that make up part of enzymes are referred to as coenzymes; minerals that make up part of enzymes are referred to as cofactors. Coenzymes and cofactors are required by enzymes to catalyze a specific reaction. They assist in converting a substrate to an end-product (Figure 11.2.1).

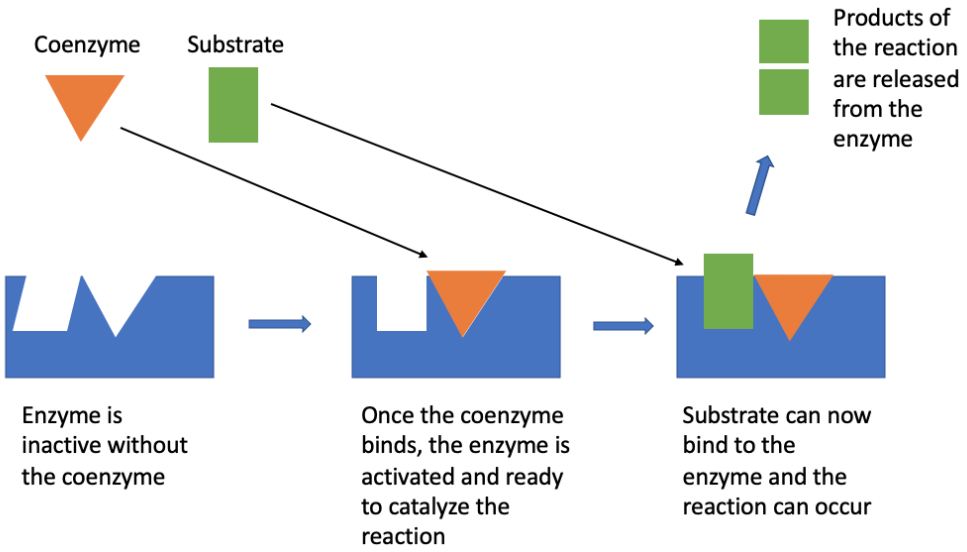


Figure 11.2.1: Role of coenzyme in an enzymatic reaction. (CC BY 4.0; Heather Leonard via Nutrition Science and Everyday Application)

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 11.2.1 lists the vitamins and minerals that participate in energy metabolism and summarizes their key roles in energy metabolism, the RDA for adults, good food sources of the nutrient, and deficiency symptoms that can occur with inadequate intake of the nutrient.

Table 11.2.1: *Nutrients Involved in Energy Metabolism: Role, RDA, Food Sources, and Deficiency Symptoms*[1-12]

Nutrient	Role in Energy Metabolism	RDA for Adults (units/day)	Food Sources	Deficiency Symptoms
Thiamin (Vitamin B_1)	Coenzyme: assists in glucose metabolism; assists with RNA, DNA, and ATP synthesis	1.2 mg (males), 1.1 mg (females)	whole grains, meat, fish, pork, enriched grains, fortified grains	Beriberi: fatigue, confusion, movement impairment, swelling, heart failure
Riboflavin (Vitamin B_2)	Coenzyme: assists in carbohydrate and fat metabolism	1.3 mg (males), 1.1 mg (females)	liver, fortified grains, eggs, dairy, mushrooms	Ariboflavinosis: dry scaly skin, mouth inflammation and sores, sore throat, itchy eyes, light sensitivity
Niacin (Vitamin B_3)	Coenzyme: assists in carbohydrate, fat, and protein metabolism	16 mg (males), 14 mg (females)	meat, chicken, fish, peanuts, potatoes	Pellagra: diarrhea, dermatitis, dementia, death
Pantothenic Acid (Vitamin B_5)	Coenzyme: assists in carbohydrate, fat, and protein metabolism; assists with cholesterol and neurotransmitter synthesis	5 mg	beef, chicken, organ meats, whole grains, fortified grains, mushrooms, sunflower seeds	Numbness and burning of the hands and feet, headache, fatigue, irritability, restlessness, disturbed sleep
Pyridoxine (Vitamin B_6)	Coenzyme: assists in the breakdown of glycogen; assists with amino acid, neurotransmitter, and hemoglobin synthesis	1.3 mg	chickpeas, fish, beef, chicken, fortified grains, potatoes, bananas	Muscle weakness, dermatitis, mouth sores, fatigue, confusion
Biotin (Vitamin B_7)	Coenzyme: assists with carbohydrate, fat, and protein metabolism; assists in amino acid synthesis	30 mcg	eggs, meat, fish	Muscle weakness, dermatitis, fatigue, hair loss
Folate (Vitamin B_9)	Coenzyme: assists with amino acid, RNA, DNA, and red blood cell synthesis	400 mcg	whole grains, legumes, fortified grains, green vegetables	Diarrhea, mouth sores, confusion, macrocytic anemia, neural-tube defects
Cobalamin (Vitamin B_{12})	Coenzyme: assists with fat and protein catabolism, red blood cell synthesis, folate function; protects nerve cells	2.4 mcg	most animal foods, algae, nutritional yeast, fortified plant foods	Muscle weakness, sore tongue, macrocytic anemia, nerve damage, neural-tube defects
Chromium	Cofactor: assists in carbohydrate, lipid, and protein metabolism by enhancing insulin's actions	AI: 35 mcg (males), 25 mcg (females)	grape juice, ham, beef, whole wheat, brewer's yeast	abnormal glucose metabolism
Iodine	Cofactor: assists in metabolism, growth, development, and synthesis of thyroid hormone	150 mcg	cod, seaweed (nori), oysters, iodized salt, eggs	goiter, cretinism, fatigue, depression, weight gain, itchy skin, low heart rate
Magnesium	Cofactor: assists with carbohydrate, lipid, protein, RNA, and DNA synthesis; muscle and nerve function	400 mg (males), 310 mg (females)	green leafy vegetables, legumes, nuts, seeds	decreased appetite, nausea, vomiting, fatigue, muscle cramps
Selenium	Cofactor: assists with thyroid hormone activation	55 mcg	Brazil nuts, meat, seafood, poultry	fatigue

Do B Vitamins Give You Energy?



Because B vitamins play so many important roles in energy metabolism, it's common to see marketing claims that extra B vitamins will boost metabolism and energy. It's common for energy drinks to have more than 100% Daily Value of several B vitamins. But, having excess coenzymes (B vitamins) doesn't make metabolism go faster...just like having more gas in the car doesn't make the car go faster. The feeling of more energy from these drinks comes from the added sugars, caffeine, and other herbal stimulants. The additional B vitamins are only beneficial if you're deficient in those nutrients. And, because B vitamins are water-soluble, they aren't stored in the body - so, any excess will be excreted from the body, essentially flushing out the added expense of the supplement/drink.

Nutrient Imbalances

B vitamins are water-soluble and are not stored in significant amounts in the body. Therefore, they must be continuously obtained from the diet. The B vitamins 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 are not frequently deficient in the diet. Although rare, deficiencies do occur; 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.[13] 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 (see Table 11.2.1). For example, low iodine levels can lead to hypothyroidism, which has many signs and symptoms, including fatigue, sensitivity to cold, constipation, weight gain, depression, dry skin, and paleness. The development of goiter (Figure 11.2.2) may often be the most visible sign of chronic iodine deficiency.



Figure 11.2.2: Woman with large goiter. (CC BY-SA 3.0; Dr. J.S. Bhandari via Wikimedia Commons)

Because of their water-solubility, toxicities of most of the minerals and B vitamins involved in energy metabolism are also uncommon. 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 flushing of the skin (Figure 11.2.3) or dangerous drops in blood pressure, and a high intake of vitamin B_6 can lead to nerve damage. When taking vitamin or mineral supplements, always pay attention to the recommended dietary allowance and avoid exceeding the tolerable upper intake level (UL).



Figure 11.2.3: Niacin flushing on back (left) and face (right). (CC BY-SA 4.0; Doc James (left) and JBCH (right) via Wikimedia Commons)

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11.3: Nutrients Important in Blood Function

Learning Objectives

- Describe the role of the B vitamins in blood function.
- Explain how Vitamin K supports blood function.
- Summarize the roles of minerals important in blood function.
- Identify iron-deficiency anemia as the most prevalent nutritional deficiency worldwide.

The Role of B Vitamins and Minerals in Blood Function

In addition to being essential for metabolism, many vitamins and minerals are required for blood to function properly. At insufficient levels in the diet these vitamins and minerals impair the health of blood and consequently the delivery of nutrients and removal of waste. Table 11.3.1 lists the vitamins and minerals that are critical for proper blood function and summarizes their key roles, the RDA for adults, good food sources of the nutrient, and deficiency symptoms that can occur with inadequate intake of the nutrient.

Table 11.3.1: Nutrients Involved in Blood Function: Role, RDA, Food Sources, and Deficiency Symptoms[1-8]

Nutrient	Role in Blood Function	RDA for Adults (units/day)	Food Sources	Deficiency Symptoms
Pyridoxine (Vitamin B_6)	Coenzyme: assists with hemoglobin synthesis	1.3 mg	chickpeas, fish, beef, chicken, fortified grains, potatoes, bananas	muscle weakness, fatigue, confusion, dermatitis, anemia
Folate (Vitamin B_9)	Coenzyme: assists with red blood cell synthesis	400 mcg	whole grains, legumes, fortified grains, green vegetables	macrocytic anemia, neural-tube defects
Cobalamin (Vitamin B_{12})	Coenzyme: assists with red blood cell synthesis and folate function	2.4 mcg	most animal foods, algae, nutritional yeast, fortified plant foods	macrocytic anemia, neural-tube defects
Vitamin K	Coenzyme: assists with blood clotting	AI: 120 mcg (males), 90 mcg (females)	green leafy vegetables, natto (fermented soybeans), broccoli, soybeans	nosebleeds, easy bruising, broken blood vessels, bleeding gums
Copper	Cofactor: assists with iron absorption and transport	900 mcg	oysters, potatoes, mushrooms, tofu, avocado	anemia, neurological problems
Iron	Component of hemoglobin, transports oxygen to cells	8 mg (persons with no menstrual cycle), 18 mg (persons with menstrual cycle)	meat, seafood, beans, spinach, fortified grains	microcytic anemia
Zinc	Cofactor: assists with hemoglobin synthesis	11 mg (males), 8 mg (females)	meat, pork, chicken, beans, pumpkin seeds	growth retardation in children, hair loss, loss of appetite, anemia

Vitamin K and the Microbiome



Vitamin K can be synthesized in the large intestine by desirable intestinal bacteria. While gut bacteria contribute to vitamin K levels, dietary sources (e.g., leafy greens, natto) are still crucial for meeting the recommended intake. Newborns have low vitamin K stores, and it takes time for the sterile newborn gut to acquire the good bacteria it needs to produce vitamin K. So, it has become a routine practice to inject newborns with a single intramuscular dose of vitamin K. This practice has basically eliminated vitamin K-dependent bleeding disorders in babies.

Anemia

Anemia is a condition where there are not enough properly formed red blood cells to carry oxygen to the body's tissues. Many people have heard of anemia, but did you know that there are different types of anemia? Microcytic anemia occurs when the red blood cells are smaller than normal (micro = small; see (Figure $11.3.1a$)). Microcytic anemia can develop with iron, copper, or vitamin B_6 deficiencies. When iron, copper, or vitamin B_6 is inadequate, microcytic anemia develops because there is not enough hemoglobin synthesis to make normal red blood cells. On the other hand, macrocytic anemia is when the red blood cells are larger than normal (macro = large). Macrocytic anemia can develop with folate or vitamin B_{12} deficiencies. When folate or vitamin B_{12} is inadequate, macrocytic anemia develops because the red blood cells cannot mature and divide appropriately (Figure $11.3.1b$).

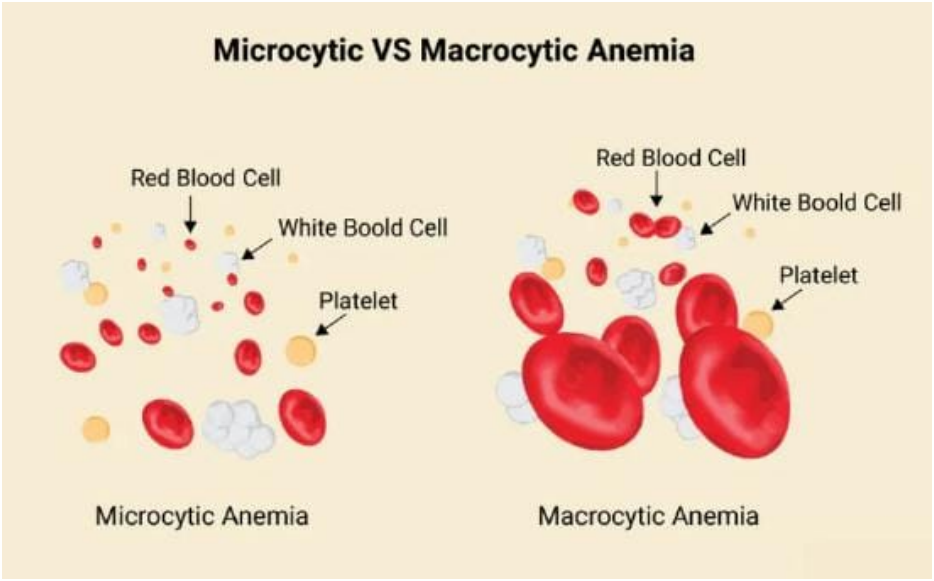


Figure $11.3.1a$: Microcytic vs macrocytic red blood cells. (by Knya)

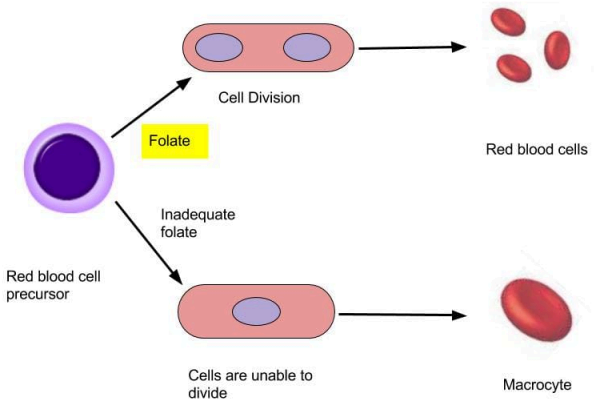


Figure 11.3.1b: Folate and the formation of macrocytic anemia. (CC BY 4.0; Allison Calabrese)

Iron-Deficiency Anemia

Iron-deficiency anemia is the most widespread nutritional disorder in the world.[9] It's a condition that develops from having insufficient iron levels in the body, resulting in fewer and smaller red blood cells containing lower amounts of hemoglobin. As a result, flood carries less oxygen from the lungs to the 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
- Abnormal heart rate

Iron-deficiency anemia is diagnosed from characteristic signs and symptoms and confirmed with simple blood tests that count red blood cells and determine hemoglobin and iron content in blood. Anemia is most often treated with iron supplements and increasing the consumption of foods that are higher in iron.

Infants, children, adolescents, and women are the populations most at risk worldwide for iron-deficiency anemia. Infants, children, and teens require more iron because iron is essential for growth. In these populations, iron deficiency (and eventually iron-deficiency anemia) can also cause the following signs and symptoms: poor growth, failure-to-thrive, and poor performance in school, as well as mental, motor, and behavioral disorders. Women who experience heavy menstrual bleeding or who are pregnant require more iron in the diet.

Mineral Bioavailability

Minerals are not as efficiently absorbed as most vitamins, so the bioavailability of minerals (the ability for your body to absorb and use minerals) can be very low. Plant-based foods often contain chemicals (such as oxalates and phytates), that bind to minerals and inhibit their absorption. In general, minerals are better absorbed from animal-based foods. The mineral content of plant foods is greatly affected by the soil from which they grew, and thus, geographic location is the primary determinant of the mineral content of foods. For instance, iodine comes mostly from seawater so, the further from the sea, the lesser the iodine content in the soil. The bioavailability of iron is highly dependent on the source of the iron. Foods have two types of iron: heme iron and non-heme iron. Heme iron is found only in animal-based foods. Non-heme iron is found in plant-based and animal-based foods. Heme iron is more bioavailable than non-heme iron. However, eating fruits and vegetables rich in vitamin C at the same time as iron-containing foods markedly increases iron absorption. In addition, cooking foods in an iron skillet can increase the iron content of the cooked food.

In most cases, if dietary intake of a particular mineral is increased, absorption will decrease. Some minerals influence the absorption of others. For instance, excess zinc in the diet can impair iron and copper absorption. Conversely, certain vitamins enhance mineral absorption. For example, vitamin C boosts iron absorption, and vitamin D boosts calcium and magnesium absorption.

Tips for Boosting Iron





Iron absorption can be enhanced in a few ways. Including a source of vitamin C when eating iron-containing foods can increase iron absorption. This could look like including vitamin C-rich peppers, strawberries, or mandarin oranges on your iron-rich spinach salad. You can also increase iron by cooking foods in a cast iron skillet; small amounts of non-heme iron transfer from the skillet to the food. If you don't have a cast iron skillet, you could boost the iron content of any liquid by boiling the liquid with a cooking tool like the Lucky Iron Fish.

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11.4: Dietary Supplements

Learning Objectives

- Understand what dietary supplements are and when they are needed.
- Explain the safety and regulation of dietary supplements.

Understanding Dietary Supplements

To supplement literally means to add to complete a thing, supply a deficiency, or reinforce or extend a whole.[1] When referring to dietary supplements, the US Food and Drug Administration defines them as any substance, such as a vitamin or mineral, taken as a supplement to food to replace nutrients that would otherwise be missing in a person's diet.[2] Simply stated, the main purpose of dietary supplements is to treat and prevent nutrient deficiencies if inadequate levels of nutrients are not obtained from the diet.

The global supplement market is worth over $200 billion, and over 75% of U.S. adults use dietary supplements for one reason or another.[3] Although many can justify their consumption, dietary supplements are not always used for the purpose intended: to enhance or supplement one's diet.

Generally speaking, nutrients are best absorbed when they're in foods and they are complemented by additional nutrients within those same foods. However, a dietary supplement can be a great addition to filling in the gaps if someone is not able to consume an adequate amount of a nutrient straight from their diet. For example, if a person is allergic to milk, they might not be able to get in a sufficient amount of calcium needed to maintain bone health. Another instance in which a dietary supplement can be necessary is the extra need for folate during pregnancy, since the need for folate is so high during pregnancy.

Regulation of Dietary Supplements

When taking supplements, it is important to understand how they are regulated and how to know if they are safe. The Dietary Supplement Health and Education Act (DSHEA) of 1994 defines dietary supplements as food and not drugs. This is critical to maintaining access to high quality, natural food-supplements.[4] It is within this act in which the US Food and Drug Administration (FDA) regulates dietary supplements. Under the directive of the FDA, it is the obligation of the manufacturers and distributors of the dietary supplements to ensure safety and proper labeling of their products put on the market. Should a claim of harm or falsification of one or more ingredients be made against a supplement, it is the FDA's responsibility to take action in removing the product from the marketplace.

Here are some safety points for a consumer when purchasing or even considering the inclusion of a dietary supplement:

- Discuss possible supplement needs with a medical provider. This helps make sure there is even a need for a supplement and to check if there is a contraindication with any already used supplements or medications. A supplement can interfere with a medication's effectiveness or can cause complications. As an example, the medication, Warfarin, is taken as a blood thinner. Vitamin K helps your blood to clot. So, taking a vitamin K supplement will have an impact on Warfarin's action.
- Manufacturers can obtain voluntary seals of approval. Independent organizations such as ConsumerLab.com, NSF International, and United States Pharmacopeia (USP) (Figure 11.4.1) offer voluntary seals of approval if a product passes the organization's quality tests for potency and the product is free of harmful contaminants. However, these seals do not ensure effectiveness of the product for any specific health condition.



Figure 11.4.1: ConsumerLab.com, NSF International, and USP Verified seals. (ConsumerLab.com; nsf.org; usp.org)

- Select brands that are established. It should have been around for a while, not a “pop-up” brand. The longer it has been in the market, the more likely it has not had a claim made against it.
- “Natural” on the label may not mean it is harmless. Natural substances such as arsenic, mercury, lead and others have proven to be harmful in different capacities.
- Be wary of testimonials used to market supplements. A company of a dependable product can rely on the science behind its formula to “speak” on its behalf.
- Consider whether the supplement's health claim is "too good to be true". A supplement is not meant to cure a disease or cause weight loss without the effort of proper diet and physical activity.
- Never hesitate to contact the supplement company to ask any questions. Trustworthy companies will be forthcoming with any answers about the product.

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12: ENERGY BALANCE

12.1: Balancing Energy Intake with Energy Output
12.2: Indicators of Health- Body Mass Index, Body Composition, and Fat Distribution
12.3: Health Risks of Overweight and Underweight
12.4: Recommendations for Safe and Effective Weight Loss and Weight Gain

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12.1: Balancing Energy Intake with Energy Output

Learning Objectives

- Describe energy balance.
- Define basal metabolism and explain the factors that affect basal metabolic rate.
- Summarize factors that affect energy intake and energy expenditure.

Energy Balance

Our body weight is influenced by our energy intake (calories we consume) and our energy expenditure (calories we burn during rest and physical activity). Weight can be thought of as a whole-body estimate of energy balance. Energy balance is achieved when intake of energy is equal to energy expended (Figure 12.1.1); body weight is maintained when the body is in energy balance. When you consume more calories than your body expends, you are in a positive energy balance; the excess energy will be stored as fat which typically results in weight gain. You are in negative energy balance when you consume fewer calories than your body expends; your body will need to use its stores to provide energy which typically results in weight loss. In general, weight is a good predictor of energy balance, but many other factors play a role in energy intake and energy expenditure. Some of these factors are under your control; others are not. Let us begin with the basics of energy intake and energy expenditure. Then we will consider the other factors that play a role in maintaining energy balance and hence, body weight.

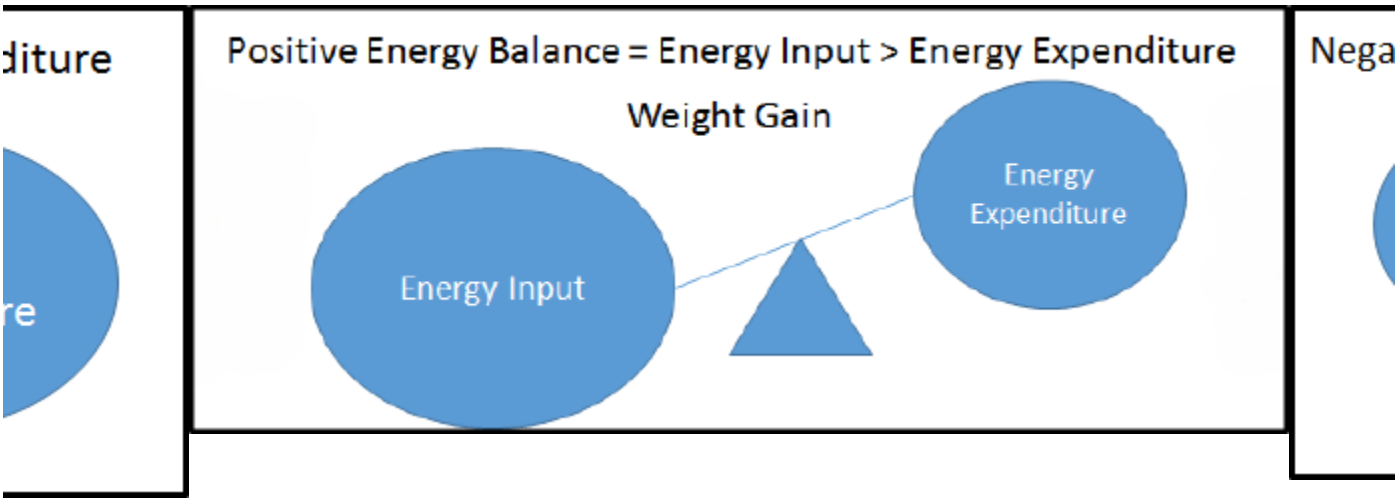


Figure 12.1.1: Energy balance (CC BY-NC-SA 2.0; Tamberly Powell)

Energy Intake

The amount of energy consumed each day comes from the foods you eat and the beverages you drink. Energy intake is measured in kilocalories, as described in Chapter 1, which are commonly referred to as calories.

Energy Expenditure

The amount of energy you expend every day includes not only the calories you burn during physical activity, but also the calories you burn while at rest (basal metabolism), and the calories you burn when you digest food (Figure 12.1.2).

Basal metabolism refers to those metabolic pathways necessary to support and maintain the body's basic functions (e.g., breathing, heartbeat, liver and kidney function) while at rest. The basal metabolic rate (BMR) is the amount of energy required by the body to conduct its basic functions at rest. The majority of energy expended daily (60-75%) is from conducting life's basic processes. BMR is dependent on body size, body composition, sex, age, nutritional status, and genetics (Table 12.1.1). People

with a larger frame size have a higher BMR simply because they have more mass. Muscle tissue burns more calories than fat tissue even while at rest, and thus the more muscle mass a person has, the higher their BMR. Since females typically have less muscle mass and a smaller frame size than men, their BMR is generally lower than men's. As we get older, muscle mass declines, and thus so does BMR. Nutritional status also affects basal metabolism. Caloric restriction, as occurs while dieting, for example, causes a decline in BMR. This is because the body attempts to maintain homeostasis and will adapt by slowing down its basic functions to offset the decrease in energy intake. Conversely, BMR increases when calorie consumption is high in an attempt to maintain homeostasis, but this increase can be overridden easily. Body temperature and thyroid hormone levels are additional determinants of BMR. An estimate of your BMR can be determined using the appropriate formula below:

- males: weight (in kg) x 1.0 x 24 hours
- females: weight (in kg) x 0.9 x 24 hours

The energy required for all enzymatic reactions that take place during food digestion and absorption of nutrients is called the "thermic effect of food" and accounts for about 5-10% of total energy expended per day.

The other energy required during the day is for physical activity. Depending on lifestyle, the energy required for this ranges between 15 and 35% of total energy expended. Of all the ways we expend energy, this is the one we have the most control over.

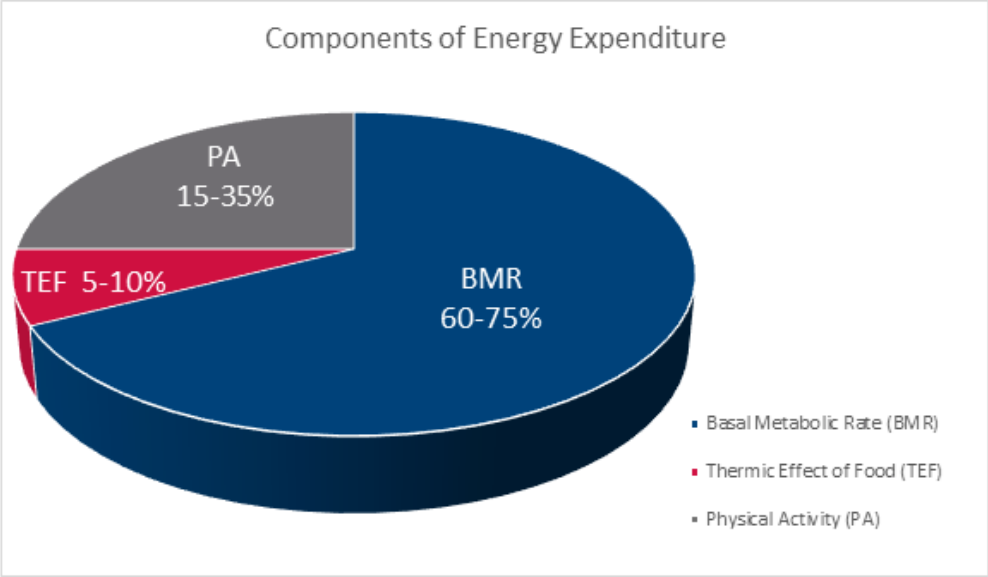


Figure 12.1.2: Energy expenditure is the sum of energy expended at rest (BMR), during digestion (TEF), and during physical activity (PA). ("Components of Energy Expenditure" by Ann Diker is licensed under CC BY 4.0)

Table 12.1.1: Factors Affecting Basal Metabolic Rate (BMR)

Factors That Increase BMR	Factors That Decrease BMR
Higher lean body mass	Lower lean body mass
Greater height	Shorter height
Younger age	Older age
Male sex	Female sex
Elevated levels of thyroid hormone	Depressed levels of thyroid hormone
Stress, fever, illness	Fasting, very low-calorie diets

Factors Affecting Energy Intake

Physiological Influences

How much we eat and what we eat is controlled not only by our own desires but is also regulated physiologically. The hypothalamus in the brain is the main control point of hunger and satiety (feeling full). It receives hormonal and neural signals that determine if you feel hungry or full. Hunger is an unpleasant sensation of feeling empty that is communicated to the brain by both mechanical and chemical signals from other parts of the body. Conversely, satiety is the sensation of feeling full, and it is also determined by mechanical and chemical signals relayed from other parts of the body.

Hunger pangs are real, and so is a “growling” stomach. When the stomach is empty, it contracts, producing the characteristic pang and “growl.” When you hear that growl, the sound is actually from air bubbles moving in the digestive tract. The stomach’s mechanical movements relay neural signals to the hypothalamus, which relays other neural signals to parts of the brain. This results in the conscious feeling of the need to eat. Alternatively, after you eat a meal, the stomach stretches and sends a neural signal to the brain, stimulating the sensation of satiety and relaying the message to stop eating. The stomach also sends out certain hormones when it is full (e.g., GLP-1, peptide YY) and others when it is empty (e.g., ghrelin). These hormones communicate to the hypothalamus and other areas of the brain either to stop eating or to find some food.

Adipose (fat) tissue also plays a role in regulating food intake. Adipose tissue produces the hormone leptin, which communicates to the hypothalamus that the body is in positive energy balance, which then causes reduced food intake. Obese people tend to have high levels of leptin in the body, but are insensitive to its effects.

Nutrients themselves also play a role in influencing food intake. After eating, blood glucose levels are high which then stimulates the release of insulin. Insulin binds to receptors in the hypothalamus to help indicate that you're full. When there are low levels of glucose in the blood, insulin is not released and therefore doesn't block the receptors in the hypothalamus.

For a review of many of these physiologic factors, watch the video below from the Khan Academy.

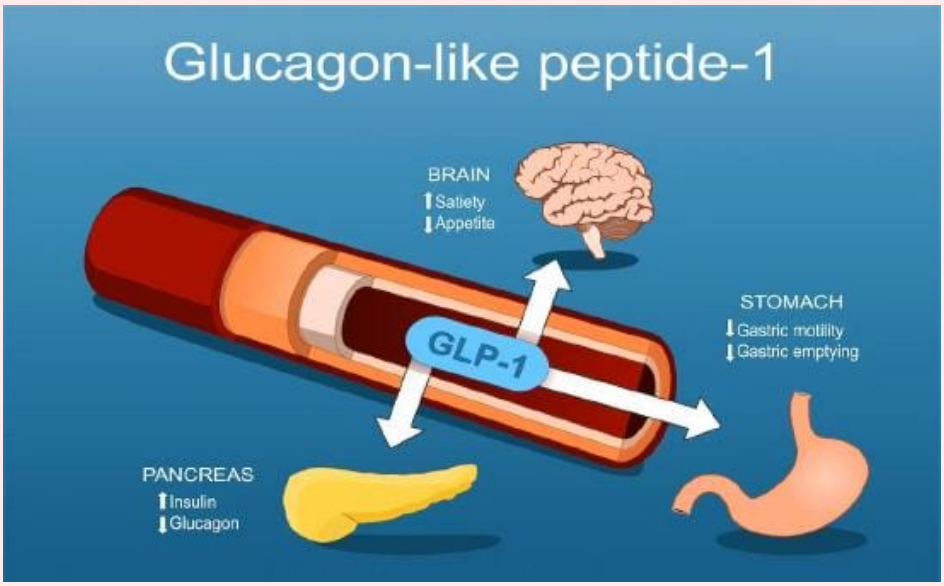
YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

"Hormone Control of Hunger" (CC BY-NC-SA 4.0 by Khan Academy)

How Do GLP-1 Medicines Work?



Glucagon-like peptide-1 (GLP-1) is a hormone that is naturally produced in the gut after eating. GLP-1 stimulates the pancreas to release insulin and inhibit glucagon, which collectively lowers blood glucose. In addition, GLP-1 slows the emptying of the stomach, which makes you feel full and reduces appetite. Lastly, GLP-1 promotes satiety via GLP-1 receptors in the brain by decreasing appetite and therefore food intake. GLP-1 weight loss drugs are medicines that mimic the GLP-1 hormone. Using a GLP-1 weight loss drug essentially supplements our natural GLP-1 hormones. As a result, GLP-1 weight loss drugs regulate blood glucose, slow stomach emptying, and promote satiety. However, there is growing evidence that these medications are associated with micronutrient deficiencies (e.g., vitamin D, iron, B-complex vitamins) due to appetite suppression, reduced food intake, and altered nutrient absorption.[1]

Genetic Influences

Genetics play a role in body fatness, weight, and food intake. Children who have been adopted typically are similar in weight and body fatness to their biological parents. Moreover, identical twins are twice as likely to be of similar weights as compared to fraternal twins. The scientific search for obesity genes is ongoing, and a few have been identified, such as the gene that encodes for leptin. However, overweight and obesity that manifests in millions of people is not likely to be attributed to one or even a few genes, but rather to the interactions of hundreds of genes with the environment.

Food Environment

The "food environment" is the food a person is surrounded by, and can provide "cues" to eat. If a person is surrounded by an abundance of tasty foods, they tend to eat more. Think about how much more you eat at buffets than at places where food options are more limited. You may have heard the term "toxic food environment." A prominent obesity researcher, Dr. Kelly Brownell, coined that term. The food environment has changed significantly in the last 100 years, and there are exponentially more highly palatable foods available now. This is one possible explanation for the increase in obesity over time.

Psychological/Behavioral Influences

When your mouth waters in response to the smell of food, you are experiencing a psychological influence on food intake. A person's perception of good-smelling and good-tasting food influences what they eat and how much they eat. Mood and emotions are also associated with food intake. For example, some people eat more when they are under a lot of stress, while others eat less.

Certain behaviors can be predictive of how much a person eats. They can play a role in how much food a person puts on their plate, how often they snack on calorie-dense, salty foods, how often they watch television or sit at a computer, and how often they

eat out.

Societal Influences

Food preferences, cultural customs, and religious practices are just a few of the societal influences that can impact energy intake. Special occasions with family or friends can lead to overeating. In addition, there tends to be easy access to high-calorie, convenient, fast food which can influence eating behavior.

Factors Affecting Energy Expenditure

Physiological and Genetic Influences

Why is it so difficult for some people to lose weight and for others to gain weight? There are several theories and factors that attempt to explain the impact of physiological and genetic influences, including:

- **Set Point Theory.** One theory is that every person has a “set point” of energy balance. This "set point" tries to maintain our weight within a narrow range by triggering changes in energy intake or expenditure to maintain body weight within the target range. Some believe that this theory provides an explanation as to why after dieting, most people return to their original weight shortly after stopping the diet.
- **Thrifty Gene Theory.** The thrifty gene theory proposes that a gene (or genes) causes people to be energetically thrifty. In theory, people with this gene expend less energy than other people and therefore may gain weight more easily and be more resistant to weight loss.
- **FTO Gene.** Although it is likely that there is no one 'obesity gene', there are some genes that have been identified, such as the fat mass and obesity (FTO) gene. The FTO gene is associated with higher levels of hunger, as well as increased intake of high-fat foods and refined starches. It's estimated that 44-65% of people have at least one copy of the FTO gene.
- **Gut Microbiome.** Several microorganisms within the gastrointestinal tract (or "gut") have been identified as related to obesity. Due to the complexity and diversity of the microorganisms within the gut (the "gut microbiome"), the mechanism by which the gut microbiome induces obesity still needs to be further studied.[2]
- **Protein Leverage Hypothesis.** This hypothesis proposes that the body has a fixed daily dietary protein target that must be reached. The hypothesis suggests that overeating may occur because our diets are proportionally higher in carbohydrate and fat (and lower in protein).
- **Drifty Gene Hypothesis.** The drifty gene hypothesis proposes that random mutation and drift in genes control the upper limit of body fatness. Individuals with "drifty genes" are prone to obesity because the genes do not control the upper limit of body fatness.
- **Age.** Daily energy expenditure changes across the human life course, reflecting differences in growth, body composition, and activity levels. In infancy and childhood, energy needs are relatively high per kilogram of body weight to support rapid growth and development. During adolescence, energy requirements peak as growth spurts and increases in lean body mass elevate total energy expenditure. In adulthood, energy needs seem to stabilize. Observed weight gain during adulthood is more strongly linked to reductions in physical activity and lifestyle factors rather than metabolic slowdown. Reductions in BMR may begin around 60 years old. Older adults typically require fewer calories, though nutrient density becomes increasingly important to maintain health and prevent loss of lean body mass.[3]

Psychological/Behavioral Influences

Sedentary behavior includes sitting, reclining, or lying down while awake. The sedentary lifestyle of many Americans contributes to their lower average energy expenditure. Simply put, the more you sit, the less energy you expend. Americans also partake in an excessive amount of screen time, which is a sedentary behavior that not only reduces energy expenditure, but also may contribute to weight gain because of the exposure to aggressive advertising campaigns for unhealthy foods.

Societal Influences

In the United States, many societal factors influence the number of calories burned in a day. Escalators, moving walkways, elevators, and cars are common modes of transportation that reduce average daily energy expenditure. Office work, high-stress jobs, and occupations requiring extended working hours are all societal pressures that reduce the time allotted for exercise. Even remote controls contribute to being less active.

Socioeconomic status is related to weight gain; people of lower economic status have higher rates of obesity and related chronic diseases than people with higher incomes.[4] One reason for this relationship is that inhabitants of low-income neighborhoods have reduced access to safe streets and parks for walking. Another is that fitness clubs are expensive and few are found in lower-income neighborhoods. In addition, some are economically forced to purchase cheap, unhealthy foods, such as those at a nearby gas station.

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Learning Objectives

- Identify ways to evaluate body weight.
- Calculate body mass index (BMI) given a particular weight and height.
- Identify weight status based on BMI.
- Describe factors that affect body composition and fat distribution.

There are many ways we can look at health and its relationship with body size, weight, and composition. When we think about body weight, it is important to remember that it's a sum of the weight from water, fat mass, fat-free mass, glycogen, and digestive system content such as what we have consumed recently and waste. And, although the terms "overweight" and "obese" are often used interchangeably, they mean different things. "Overweight" refers to having more weight than is typical for a particular height. That weight may be the result of water weight, muscle weight, or fat mass. "Obese" refers specifically to having excess body fat. In most cases, people who are overweight also have excess body fat. Obesity is classified as a disease by most major medical associations including the American Medical Association and the World Health Organization. Because a person is not defined by a disease, the proper terminology is 'person with obesity' rather than 'obese person'. This section will review three ways to evaluate body weight: body mass index (BMI), body composition, and fat distribution.

Body Mass Index (BMI)

Body mass index (BMI) is calculated using weight and height measurements and is more predictive of health risk than using weight alone. BMI measurements are used to indicate whether an individual may be underweight, normal weight, overweight, or obese. BMI is defined as the body mass (weight) divided by the square of body height, and is universally expressed in units of kg/m^2, resulting from mass in kilograms and height in meters.

$$\text{BMI} = \frac{\text{weight } (kg)}{\text{height } (m^2)}$$

There is also a calculation that uses weight in pounds (lb) and height in inches (in):

$$\text{BMI} = \frac{\text{weight } (lb)}{\text{height } (in^2)} \text{ X } 703$$

In addition, there are online BMI calculators that can be used, including those from the:

- National Heart, Lung, and Blood Institute
- Centers for Disease Control and Prevention

BMI attempts to estimate the amount of tissue mass (muscle, fat, and bone) in an individual, and then categorizes that person as underweight, normal weight, overweight, or obese based on that value. Commonly accepted BMI categories are included in Table 12.2.1.

Table 12.2.1: BMI Categories

Weight Status	BMI
Underweight	< 18.5
Normal weight	18.5–24.9
Overweight	25.0–29.9
Obese	30.0 and above

Very high and very low BMIs appear to increase a person's risk of dying (mortality). If you look at a graph of BMI as it relates to your risk of dying, it has a "J shaped curve" or a "U shaped curve" because having too low or too high of a BMI raises your risk of mortality (Figure 12.2.1). Instead, you'd like to be in the middle range of the BMI which is what they use for "normal weight".

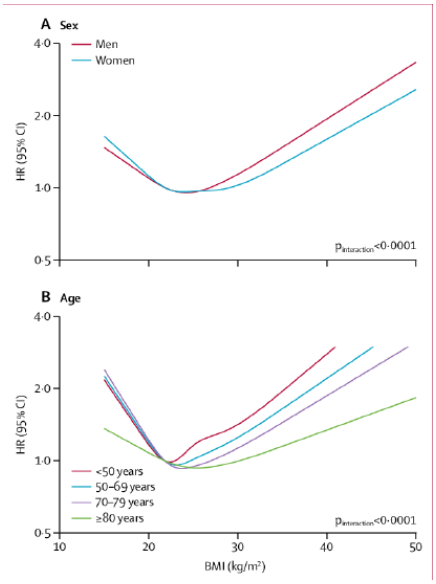


Figure 12.2.1: Mortality risk vs. BMI by sex (A) and age (B). (CC BY 4.0; Bhaskaran K, Silva I, Leon D, Douglas I, and Smeeth L via ResearchGate)

Limitations of BMI

BMI is a fairly simple measurement that was originally intended to assess populations rather than individuals. It is used by professionals as part of health assessment because it is quick and the equipment is available. However, it does not take into account fat mass or fat distribution in the body, both of which are additional predictors of disease risk. Body fat weighs less than muscle mass. Therefore, BMI can sometimes underestimate the amount of body fat in people with overweight or obesity and overestimate it in more muscular people. For instance, a muscular athlete will have more muscle mass (which is heavier than fat mass) than a couch potato of the same height. Based on their BMIs, the muscular athlete could be erroneously classified as overweight, or in the case of very muscular bodybuilders, obese and at increased health risk according to their BMI; however, this is an infrequent problem with BMI. The BMI formula does not take into consideration the effect of age or ethnicity on BMI. An older person with osteoporosis (decreased bone mass) will have a lower BMI than an older person of the same height without osteoporosis, even though the person with osteoporosis may have more fat mass. The American Medical Association (AMA) recommends avoiding BMI as a measurement due to its historical harm, use for racist exclusion, and because BMI cutoffs are based primarily on data from non-Hispanic white populations and do not consider a person's gender or ethnicity.[1] For example, BMI misclassifies those of African descent as overweight or obese (when they are not) more often than other races, and misclassifies those of Asian descent more often as normal weight when they are actually overweight. Medical experts recommend using BMI in conjunction with other indicators of health risk, such as the fat distribution measurements described below.[2] BMI also has limitations when used with pregnant and lactating women. Ultimately, BMI is a useful, inexpensive tool that is *highly correlated* with adiposity and disease risk, but additional measurements are needed to diagnose obesity and more accurately assess disease risk.

Body Composition

Having more fat mass may be indicative of disease risk, but fat mass also varies with sex, age, and physical activity level. Females have more fat mass than males typically, which is needed for reproduction. The difference in body composition of males and females is, in part, due to differences in hormone profiles. The optimal body fat percentage varies among different experts, but the NIH states that the optimal body fat percentage is 20-30% for a female and 12-20% for a male. Fat mass can be measured in a variety of ways, including:

- **Skin-fold test.** This method is perhaps the simplest and lowest-cost way to measure body composition. A health professional uses a caliper to measure the thickness of skin on the back, arm, and other parts of the body and compares it to standards to assess body fatness (see Figure 12.2.2). It is a noninvasive and fairly accurate method of measuring fat mass, but the test should be done by a trained professional using appropriate calculations based on individual demographics. Skin-fold testing is not accurate in those who have severe obesity. For other populations, the margin of error is 3-5%.
- **Underwater weighing.** This technique requires a chamber full of water big enough for the whole body to fit in. First, a person

is weighed outside the chamber and then weighed again while immersed in water. The two weights are compared to calculate body composition. Bone and muscle weigh more than water; fat weighs less than water. If the underwater weight is heavier than the "dry land" weight, it indicates a lower body fat percentage. The margin of error for underwater weighing is 1.5-2.8%.

- **Air displacement plethysmography (ADP).** This technique is based on the same principles as underwater weighing, but uses air displacement instead of water immersion. While a person sits inside an enclosed chamber (usually called a BOD POD, see Figure 12.2.2), changes in air pressure are used to determine the amount of air that is displaced in the chamber. These measurements are then translated into percent body fat. The margin of error for ADP is 2.2-2.7%.
- **Bioelectric Impedance Analysis (BIA).** This device is based on the fact that fat slows down the passage of electricity through the body. When a small amount of electricity is passed through the body, the rate at which it travels is used to determine body composition. Body fluid levels must be normal with BIA, which is a limistation, since hydration can be impacted by exercise, alcohol, and menstrual cycles. There are several types of BIA devices, including scales, hand-held, and multiple-frequency professional-grade devices (see Figure 12.2.2). The margin of error for BIA is 3.1-7.5%.[3]
- **Dual-Energy X-ray Absorptiometry (DEXA).** This technique is used to measure bone density. It can also determine fat content via the same method, which directs two low-dose x-ray beams through the body and determines the amount of energy absorbed from the beams (see Figure 12.2.2). The amount of energy absorbed is dependent on the body's content of bone, lean tissue mass, and fat mass. Using standard mathematical formulas, fat content can be accurately estimated. DEXA is considered the 'gold standard' of body composition assessment. The margin of error for DEXA is 2-3%.[4]



Figure 12.2.2: Body composition measurement methods: skin-fold test, ADP, BIA, and DEXA. (public domain, CC BY-NC 4.0; NARA & DVIDS Archive, Fortify Fitness, Medical Imaging Consultants)

Fat Distribution

Total fat mass in the body is one predictor of health; another is how the fat is distributed in the body. You may have heard that fat on the hips is better than fat in the belly—this is true. Fat can be found in different areas in the body, and it does not all act the same, meaning it differs physiologically based on location. Fat deposited in the abdominal cavity is called visceral fat; fat underneath the skin is called subcutaneous fat. Visceral fat is metabolically more active than subcutaneous fat and is a better predictor of disease risk than total fat mass. Visceral fat releases hormones and inflammatory factors that contribute to disease risk. The only tool required for measuring visceral fat is a measuring tape. Measurements typically used to determine fat distribution include:

- **Waist Circumference.** A person's waist circumference is measured at their natural waist (just above the belly button). Men with a waist circumference greater than 40 inches and women with a waist circumference greater than 35 inches are predicted to face a greater risk for chronic disease.
- **Waist-to-Height Ratio.** The waist-to-height ratio measures central adiposity. To calculate your waist-to-height ratio, use a measuring tape to measure your waist circumference and then measure your height using the same units. Next, divide the waist circumference by the height to arrive at the waist-to-height ratio. The general recommendation is to keep your waist circumference to less than half your height. A waist-to-height ratio above 0.5 is associated with a greater health risk.

- **Waist-to-Hip Ratio.** To calculate your waist-to-hip ratio, use a measuring tape to measure your waist circumference and then measure your hip circumference at its widest part. Next, divide the waist circumference by the hip circumference to arrive at the waist-to-hip ratio. Observational studies have demonstrated that people with “apple-shaped” bodies (who carry more weight around the waist/upper body) have greater risks for chronic disease than those with “pear-shaped” bodies (who carry more weight around the hips/lower body). It's thought that apple-shaped patterning causes problems with fat and carbohydrate metabolism, leading to unhealthy changes in blood cholesterol, insulin, glucose, and blood pressure. Abdominal obesity is defined by the World Health Organization (WHO) as having a waist-to-hip ratio at or above 0.90 for males and at or above 0.85 for females.[5]

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12.3: Health Risks of Overweight and Underweight

Learning Objectives

- Describe health risks associated with being overweight and underweight.
- Describe symptoms of various eating disorders.

Health Risks of Being Overweight or Obese

According to the CDC, over 40% of adults over the age of 20 are obese and over 72% of adults are either overweight or obese.[1] Overweight and obesity raise the risk for certain health problems including[2-4]:

- Type 2 diabetes
- High blood pressure
- Heart disease
- Stroke
- Sleep apnea
- Metabolic syndrome (blood pressure ≥ 130/85 mm Hg, blood glucose levels ≥ 100 mg/dL, triglycerides ≥ 150 mg/dL, HDL cholesterol < 40 mg/dL for men or < 50 mg/dL for women, too much fat around your waist)
- Depression due to weight bias and stigma
- Certain cancers (including endometrial cancer, liver cancer, kidney cancer, postmenopausal breast cancer, and colon cancer)
- Osteoarthritis
- Alzheimer's disease, dementia, and cognitive decline

Health Risks of Being Underweight

Being underweight is linked to nutritional deficiencies, 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 being underweight in America is inadequate nutrition. Other causes are wasting diseases, such as cancer, multiple sclerosis, tuberculosis, and eating disorders. Some common eating disorders include[5,6]:

- **Anorexia nervosa.** Anorexia nervosa is a potentially fatal condition characterized by undereating and excessive weight loss. People with this disorder are preoccupied with weight, dieting, calories, and food intake to a dysfunctional degree, to the point that it causes disruptions in daily activities and health. People with anorexia nervosa typically weigh themselves repeatedly, severely restrict the amount of food they eat, often exercise excessively, and/or may force themselves to vomit or use laxatives to lose weight. Symptoms of anorexia include extremely restricted eating, fear of gaining weight, and distorted body image. Signs that may develop over time include bone loss (osteopenia or osteoporosis), brittle hair and nails, constipation, low blood pressure, and multiorgan failure.
- **Bulimia nervosa.** People with bulimia nervosa have recurrent and frequent episodes of eating unusually large amounts of food and feeling a lack of control over these episodes. What separates a binge from overeating that some do from time to time is the feeling of a lack of control during a binge. This binge-eating is followed by behavior that compensates for the overeating, such as forced vomiting, excessive use of laxatives or diuretics, fasting, excessive exercise, or a combination of these behaviors. People with bulimia nervosa may be slightly underweight, normal weight, or overweight. Symptoms of bulimia include gastric reflux, severe erosion of tooth enamel, dehydration, electrolyte imbalances, and intestinal distress/irritation if laxatives are abused to compensate for binging.
- **Binge-eating disorder.** People who suffer from binge-eating disorder experience regular episodes of eating an extremely large amount of food in a short period of time. Binge eating is a compulsive behavior, and people who suffer from it typically feel it is beyond their control. The episodes of overeating are 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. Symptoms of binge-eating disorder include eating unusually large amounts of food in a specific amount of time (such as 2 hours), eating fast during binge episodes, and eating alone or in secret to avoid embarrassment.

- **Orthorexia.** Orthorexia is an unhealthy preoccupation with healthy eating. The signal that a person is not just interested in healthy eating but is obsessed with it is that their preoccupation with healthy eating interferes with their everyday life. Signs of orthorexia can include compulsively reading food labels, cutting out an increasing number of food groups (all sugar, all dairy, etc.), 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 fixation on healthy eating is taken to the extreme and can put their health at risk. Orthorexia can lead to malnutrition if a person becomes overly restrictive or starts eliminating food groups out of fear, such as limiting fruits because of the sugar content.

It is important to note that eating disorders are considered mental conditions. Treatment plans for eating disorders are tailored to individual needs and may include individual, group, and/or family psychotherapy; medical care and monitoring; nutritional counseling; and medications. The nutrition counseling portion of treatment aims to return the individual to a healthful body weight, teach normal eating patterns, and address healing their relationship with food, body, and movement.

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12.4: Recommendations for Safe and Effective Weight Loss and Weight Gain

Learning Objectives

- Identify strategies for safe and effective weight loss and weight gain.

It is important to note that intentionally altering body weight is not appropriate for individuals experiencing an eating disorder. In these cases, the primary focus would be healing one's relationship with food, body, and movement with a trusted professional team. This could look like having a specialized eating disorder team consisting of a physician, psychiatrist, therapist, registered dietitian nutritionist, and any additional specialists.

Losing Weight Safely

Strategies for losing weight safely include:

- **Set specific, measurable, and realistic goals.** Weight loss is best maintained if it is accomplished gradually. Experts recommend losing weight at a pace of 0.5 to 2 pounds per week.
- **Reasonable reductions in energy intake.** There are multiple ways to reduce energy intake. Each individual should use strategies that are realistic for their situation while keeping sustainability and long-term health in mind. Eating smaller portions is one way to accomplish reduced energy intake. Alternatively, choosing nutrient-dense foods and beverages such as fruits, vegetables, lean meats, and water in place of higher-calorie options can assist with being in energy deficit to induce weight loss.
- **Mindful eating.** Mindful eating involves being aware of hunger and satiety levels, as well as an awareness of the eating experience by limiting distractions while eating.
- **Participate in regular physical activity.** Even small amounts of activity are beneficial for weight loss. Participating in physical activity that is enjoyed is a good strategy. Members of the National Weight Control Registry who have maintained at least a 30-pound weight loss for one year or longer increased their physical activity to lose weight; the most frequently reported form of activity in that group is walking.[1]
- **Application of behavior modification techniques.** Practicing mindful eating and slowing down while eating are behavior modification techniques that can assist with weight loss. Another idea is to use smaller plates, bowls, and glasses to make food/beverage portions appear larger. Keeping healthy snacks within reach can help limit the purchase of energy-dense convenience foods. Monitoring food and calorie intake (in an app like MyFitnessPal) helps bring awareness to caloric intake.

In most scientific studies, successful weight loss is accomplished by changing the diet *and* increasing physical activity. Doing one without the other limits the amount of weight lost and the length of time that weight loss is sustained. Contrary to popular belief, weight loss is not typically a linear process but tends to follow a curvilinear process. Metabolic adaptations often make weight loss show faster during the first few days to a month, followed by a slower rate afterwards.[2] A gradual approach to weight loss is recommended, as it is more sustainable and supports overall health. This method better preserves muscle mass, maintains energy levels, supports immune function, and reduces the likelihood of binging compared to more extreme restrictive approaches.

It is important to note that the weight loss strategy needs to be individualized. Just because a strategy worked well for one person does not mean it will work for everyone. And some may need a tool such as a weight-loss medication or weight-loss surgery to be successful. Social media influencers often promote unrealistic or unhealthy weight loss approaches and sometimes insist that their approach is the only effective approach to weight loss. A registered dietitian nutritionist can help find an approach that is healthy and appropriate.

Effective Weight Gain

Guidelines for safe and effective weight gain include:

- **Choose nutrient-dense foods that are also energy-dense.** Energy-dense food options could include smoothies, milkshakes, nut butters, nuts, avocado, and dried fruit.
- **Eat 500-1,000 calories/day more than needed for weight maintenance.** Eating enough calories for weight gain can be difficult, as energy-dense foods can make a person feel full quickly. Liquid sources of calories, like smoothies, may be helpful, as they tend to be less filling.
- **Eat frequently.** Including multiple meals and snacks each day can help increase energy intake. Some individuals find it helpful to have beverages between meals (instead of with meals) to limit the impact of the beverage on satiety during the meal. Packing food to take with you can help increase calorie intake as well.
- **Avoid tobacco products.** Tobacco products depress appetite and increase metabolism.
- **Participate in regular physical activity.** Incorporate resistance training (e.g., weight lifting) to increase muscle mass.

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13: NUTRITION AND PHYSICAL ACTIVITY

13.1: Physical Fitness and Physical Activity
13.2: Fuel Sources for Physical Activity
13.3: Nutrient Needs for Physical Activity

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13.1: Physical Fitness and Physical Activity

Learning Objectives

- Differentiate between physical fitness and physical activity.
- Describe the components of physical fitness.
- List the benefits of physical activity.

Becoming physically fit and participating in physical activity can have a great impact on achieving optimal health. Physical fitness is the ability to carry out daily tasks without getting too tired and with enough leftover energy to enjoy leisure-time pursuits. Physical activity is any muscle movement that increases energy expenditure, including activity related to a person's job, transportation, leisure-time activity, and purposeful exercise. Participating in physical activity increases physical fitness.

There are multiple components of physical fitness: cardiorespiratory fitness (fitness of the heart and lungs), musculoskeletal fitness (fitness of muscles and bones), flexibility, balance, and speed. Each component offers specific health benefits, but optimal health requires including all of the components. Some forms of exercise incorporate multiple components of physical fitness. For example, riding a bicycle for 30 minutes or more builds cardiorespiratory fitness, musculoskeletal fitness, and balance. Some forms of yoga build musculoskeletal fitness, flexibility, and balance. However, addressing all of the components of physical fitness generally requires incorporating a range of activities into your regular routine.

Components of Physical Fitness

Cardiorespiratory Fitness

Cardiorespiratory fitness is the ability to perform whole-body exercises at moderate-to-vigorous intensity for an extended period of time.[1] Aerobic activities such as walking, running, jumping rope, riding a bike, and swimming help increase cardiorespiratory fitness (Figure 13.1.1). Both the *Physical Activity Guidelines for Americans* and the World Health Organization recommend at least 150 minutes (2.5 hours) to 300 minutes (5 hours) a week of moderate-intensity aerobic physical activity, or 75 minutes (1.25 hours) to 150 minutes (2.5 hours) a week of vigorous-intensity aerobic physical activity.[1,2] People who are physically active for at least 150 minutes per week have a 33% lower risk of dying early compared to those who are inactive.[1] Activity should be spread throughout the week. If this level of activity seems like too much, know that some physical activity is better than none.

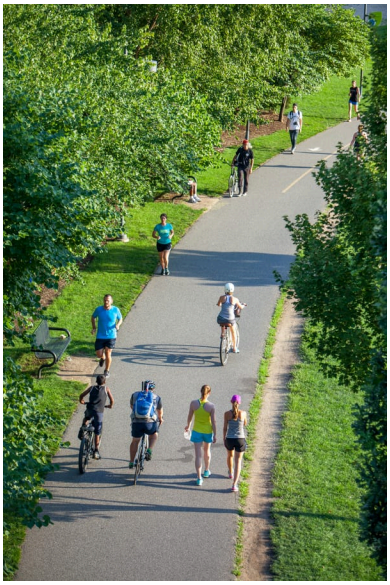


Figure 13.1.1: People walking, running, and biking on a park path. (James Lewis; Unsplash)

Aerobic physical activity can range in intensity level; for example, brisk walking is considered moderate-intensity, and running is considered vigorous-intensity. As intensity increases, heart and breathing rates increase to meet the increased demand for oxygen in working muscles. When someone continues with aerobic physical activity for weeks and months, they become more fit. As someone becomes more fit, physiological changes occur. For example, the lungs become more efficient at delivering oxygen. The heart also becomes more efficient. It does this by increasing the size of the left ventricle, which is the part of the heart that pumps blood into the aorta (the main artery leading from the heart). This increase in ventricle size allows the heart to beat fewer times during periods of rest while still pumping the same amount of blood. This also means that during exercise, more blood and oxygen are delivered to working muscles. For most adults, a resting heart rate of 60-100 beats per minute (bpm) is normal; a lower resting heart rate is associated with higher physical fitness. Resting heart rates under 60 bpm can occur with endurance-trained athletes whose bodies are more efficient at using oxygen from the blood.

Musculoskeletal Fitness

Musculoskeletal fitness is important for everyone and includes both muscle strength and muscle endurance. Musculoskeletal fitness training can involve the use of resistance machines, resistance bands, free weights (see Figure 13.1.2), or other tools. Homemade weights, such as plastic bottles filled with sand or water, can be used to work towards musculoskeletal fitness. You can also use your own body weight and do push-ups, leg squats, abdominal crunches, and other exercises to build muscles. Muscular strength is increased by lifting weights (or other resistance training) with heavier weights for fewer repetitions. Muscle endurance is typically achieved by using lighter weights for more repetitions. The *Physical Activity Guidelines for Americans* recommend strength training at least twice per week.[1]



Figure 13.1.2: Weightlifting. (UConn Rudd Center for Food Policy and Health)

As one becomes more fit, physiological changes also occur in the muscles. Exercising muscles require more fuel, so the body starts to store more fuel where it's burnt. This includes increased carbohydrate storage (as glycogen) in the muscles, and more fat storage for endurance athletes in the form of intramuscular triglycerides.

Flexibility

Flexibility is the range of motion available to your joints. Yoga, tai chi, pilates, and stretching (see Figure 13.1.3) are examples of activities that improve this element of fitness. Stretching improves your range of motion, promotes better posture, and helps you perform activities that can require greater flexibility, such as chores around the house.



Figure 13.1.3: Group exercise class. (Anupam Mahapatra; Unsplash)

Balance

Balance is the ability to maintain equilibrium while moving or while stationary.[1] Walking backward, standing on one leg, tai chi (see Figure 13.1.4), or using a balance board are examples of activities that can enhance balance. Balance tends to deteriorate with age, which can result in falls and fractures.



Figure 13.1.4: Group tai chi in the park. (CC0 1.0; Cccherry76 via Wikimedia Commons)

Speed

Speed refers to the ability to move the body quickly.[1] When first starting an activity, your speed may be slower. To reduce risk of injury, increase the speed gradually over a period of weeks or months.

Benefits of Physical Activity

Regular physical activity is one of the best things you can do to achieve optimal health. Physical activity provides a wealth of

benefits including:

- **Supporting a healthful body weight and composition.** Exercise, along with a healthy, balanced eating plan, can help you lose extra weight, maintain weight loss, or prevent excessive weight gain.
- **Reduced risk of chronic disease.** A regular routine can help to prevent or manage a wide range of conditions and concerns, such as cardiovascular disease, metabolic syndrome, type 2 diabetes, arthritis, and certain types of cancer.
- **Strong bones.** Research shows that aerobic activity and strength training can slow the loss of bone density that typically accompanies aging.
- **Mood improvement.** Aerobic activity, strength training, and more contemplative activities such as yoga, all help break cycles of worry and distraction, effectively draining tension from the body.
- **Reduced risk of depression, or limited symptoms of it.** Some people have called exercise “nature’s antidepressant,” and studies have shown that physical activity reduces the risk of and helps people cope with the symptoms of depression.
- **Cognitive skills retention.** Regular physical activity can help people maintain thinking, learning, and judgment as they age. In fact, many experts consider aerobic exercise as one of the best strategies to reduce cognitive decline.
- **Better sleep.** A good night’s sleep is essential for clear thinking, and regular exercise promotes healthy, sound sleep. It can also help you fall asleep faster and deepen your rest, promoting better mental and emotional wellbeing.

Even small changes, such as taking the stairs instead of the elevator, or parking farther away from a store can lead to a more active lifestyle and set you on the road to optimal health. An important element of a more active lifestyle is to select activities that you enjoy and can integrate into your schedule smoothly, so you can maintain them.

Physical activity is recommended for most people because it can provide significant health benefits. However, it can sometimes be too physiologically stressful for those with certain medical conditions, especially those affecting the nervous system. It also may not be appropriate for those experiencing eating disorders and it may not be feasible for those with limited physical abilities. In these situations, healing one's relationship with movement or choosing gentler forms of activity may be more appropriate to support overall well-being. Physical activity is more challenging for those with limited mobility. For those who cannot walk, there are chair exercises. For those with arthritis, activity can be painful, but appropriate activity can actually reduce the symptoms. For those with injuries that make physical activity difficult or risky, a qualified fitness professional or physical therapist can provide advice on how to adapt exercise.

Improving Your Fitness Level

A sound physical fitness program meets your personal goals; includes variety, consistency, and fun; appropriately overloads the body; and includes a warm-up and cool-down period.

Progressive overload is the idea of placing additional physical demands on the body to improve fitness. Too much physical exertion is NOT recommended. The FITT principle can be used to achieve an appropriate overload. FITT stands for:

- Frequency – the number of activity sessions per week
- Intensity – the amount of effort expended
  - Traditionally, heart rate has been used to indicate intensity
  - Maximal heart rate is estimated as 220 - your age
    - moderate-intensity physical activity: 50-70% of estimated maximal heart rate
    - vigorous-intensity physical activity: 70-85% of estimated maximal heart rate (see Table 13.1.1)
- Time of activity – how long each session lasts
- Type of activity - the range of physical activities a person can engage in to promote health and physical fitness.

Table 13.1.1: Maximal Heart Rate Chart

Age	Maximal Heart Rate	50% Maximal Heart Rate	70% Maximal Heart Rate	85% Maximal Heart Rate
20	200	100	140	170
30	190	95	133	161
40	180	90	126	153
50	170	85	119	144
60	160	80	112	136

Age	Maximal Heart Rate	50% Maximal Heart Rate	70% Maximal Heart Rate	85% Maximal Heart Rate
70	150	75	105	127
80	140	70	98	119

Self-Check Questions

Query 13.1.1

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13.2: Fuel Sources for Physical Activity

Learning Objective

- Describe the various processes used to break down macronutrients into fuels that support physical activity.

The human body uses carbohydrate, fat, and protein in food and from body stores for energy to fuel physical activity. These essential nutrients are needed regardless of the intensity of the activity you are doing. Whether you are lying down and reading a book or running a marathon, these macronutrients are always needed in the body. However, in order for these nutrients to be used as fuel for the body, their energy must be transferred into the high-energy molecule known as adenosine triphosphate (ATP; see Figure 13.2.1).

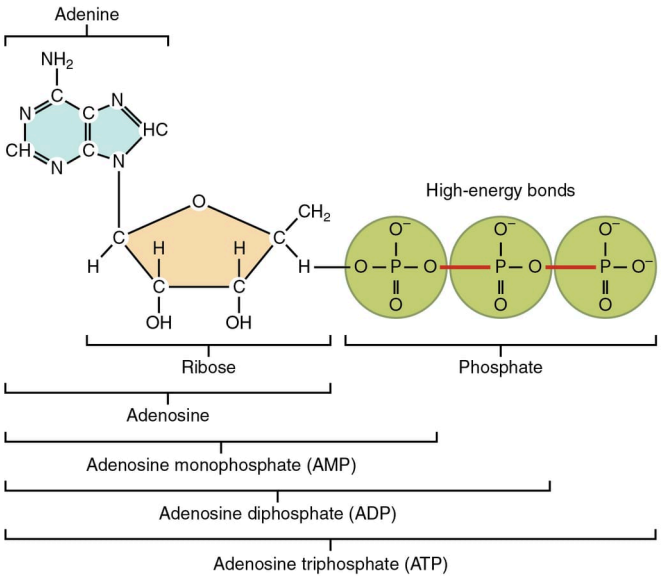


Figure 13.2.1: Structure of adenosine triphosphate (ATP). (CC BY 3.0; OpenStax College via Wikimedia Commons)

ATP is the body's immediate fuel source and can be generated through either aerobic metabolism (in the presence of oxygen) or anaerobic metabolism (without the presence of oxygen). The type of metabolism that is predominantly used during physical activity is determined by the availability of oxygen and how much carbohydrate, fat, and protein are used. For an overview of ATP and the ATP cycle that produces cellular energy, watch the following video:

YouTube Video

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Anaerobic and Aerobic Metabolism

Anaerobic metabolism occurs in the cytosol of the muscle cells. As seen in Figure 13.2.2, a small amount of ATP is produced in the cytosol without the presence of oxygen. Anaerobic metabolism uses glucose as its only source of fuel and produces pyruvate and lactic acid. Pyruvate can then be used as fuel for aerobic metabolism. Aerobic metabolism takes place in mitochondria of the

cell and is able to use carbohydrates, protein, or fat as fuel sources. Aerobic metabolism is a much slower process than anaerobic metabolism, but it can produce much more ATP and is the process by which the majority of the ATP in the body is generated.

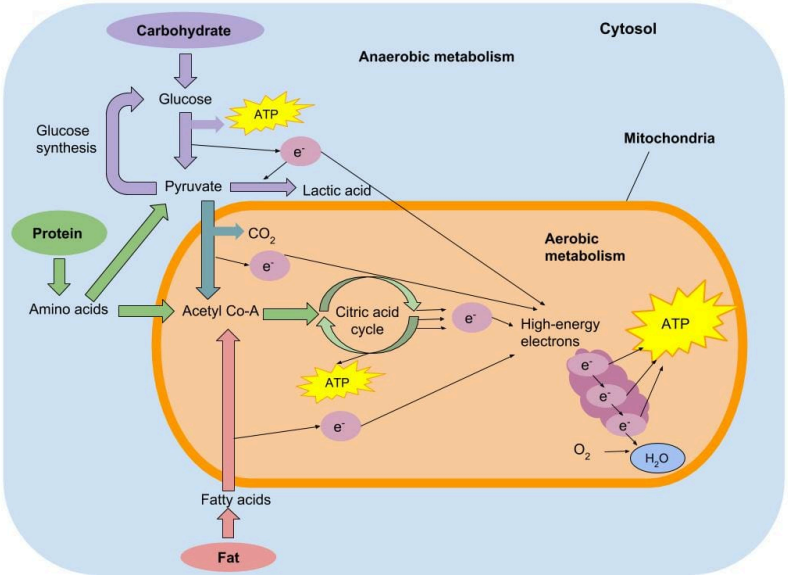


Figure 13.2.2: Anaerobic and aerobic metabolism. (CC BY 4.0; Allison Calabrese via Human Nutrition 2020 Ed [Hawaii])

Physical Activity Duration and Fuel Use

The respiratory system plays a vital role in the uptake and delivery of oxygen to muscle cells throughout the body. Oxygen is inhaled by the lungs and transferred from the lungs to the blood, where the cardiovascular system circulates the oxygen-rich blood to the muscles. The oxygen is then taken up by the muscles and can be used to generate ATP. When the body is at rest, the heart and lungs are able to supply the muscles with adequate amounts of oxygen to meet the energy needs for aerobic metabolism. However, during physical activity, your muscles need more energy and oxygen. In order to provide more oxygen to the muscle cells, your heart rate and breathing rate will increase. The amount of oxygen that is delivered to the tissues via the cardiovascular and respiratory systems during exercise depends on the duration and intensity of the activity, as well as the individual's fitness level. The energy systems used to fuel exercise depend on the duration of exercise as summarized below and in Figure 13.2.3.

- **During the first few steps of exercise**, your muscles are the first to respond to the change in activity level. Your lungs and heart do not react as quickly, and during those beginning steps, they can't yet increase the delivery of oxygen. In order for our bodies to get the energy that is needed in these beginning steps, the muscles rely on a small amount of ATP that is stored in resting muscles. The stored ATP is able to provide energy for only a few seconds before it is depleted. Once the stored ATP is just about used up, the body resorts to another high-energy molecule known as creatine phosphate to convert ADP (adenosine diphosphate) to ATP.
- **About 15 seconds into exercise,** the stored ATP and creatine phosphate are used up in the muscles. The heart and lungs have still not adapted to the increased oxygen need, so the muscles must begin to produce ATP by anaerobic metabolism (without oxygen). Anaerobic metabolism can produce ATP at a rapid pace but only uses glucose as its fuel source. The glucose is obtained from muscle glycogen. At around 30 seconds, anaerobic pathways are operating at their full capacity, but because the availability of glucose is limited, it cannot continue for a long period of time.
- **As your exercise reaches 2-3 minutes**, your heart rate and breathing rate have increased to supply more oxygen to your muscles. Aerobic metabolism is the most efficient way of producing ATP; it produces significantly more ATP for each molecule of glucose than anaerobic metabolism. Although the primary source of ATP in aerobic metabolism is carbohydrates, fatty acids and protein can also be used as fuel to generate ATP.

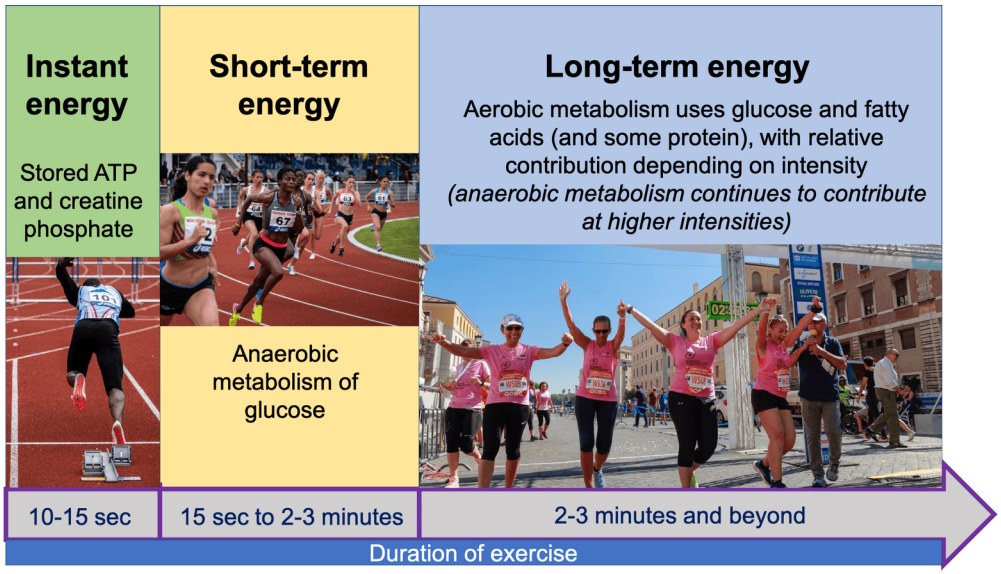


Figure 13.2.3: Energy systems used to fuel exercise of different durationse. (CC BY 4.0; Alice Callahan via Nutrition Science and Everyday Application [Callahan, Leonard, and Powell])

The fuel sources for anaerobic and aerobic metabolism will change depending on the amount of nutrients available and the type of metabolism (see Figure 13.2.4).

- **Glucose** may come from blood glucose (which is from dietary carbohydrates, liver glycogen, and glucose synthesis) or muscle glycogen. Glucose is the primary energy source for both anaerobic and aerobic metabolism.
- **Fatty acids** are stored as triglycerides in muscles, but about 90% of stored energy is found in adipose tissue. As low- to moderate-intensity exercise continues using aerobic metabolism, fatty acids become the predominant fuel source for exercising muscles.
- Although **protein** is not considered a major energy source, small amounts of amino acids are used while resting or doing an activity. The amount of amino acids used for energy metabolism increases if the total energy intake from your diet does not meet your nutrient needs or if you are involved in long-duration endurance exercise. When amino acids are broken down, and the nitrogen-containing amine group is removed, the remaining carbon molecule can be broken down into ATP via aerobic metabolism, or it can be used to make glucose. When exercise continues for many hours, amino acid use will increase as an energy source and for glucose synthesis.

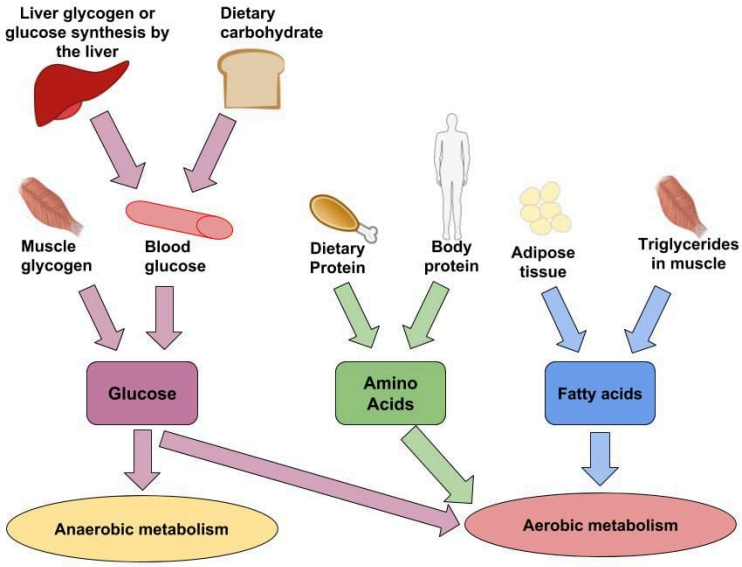


Figure 13.2.4: Fuel sources for anaerobic and aerobic metabolism. (CC BY 4.0; Allison Calabrese via Human Nutrition 2020 Ed [Hawaii])

Physical Activity Intensity and Fuel Use

Exercise intensity determines the contribution of different fuel sources used for ATP production (see Table 13.2.1. Both anaerobic and aerobic metabolism combine during exercise to ensure that the muscles are equipped with enough ATP to carry out the demands placed on them. The contribution from each type of metabolism depends on the intensity of an activity. During low-intensity activities, aerobic metabolism is used to supply enough ATP to muscles. However, during high-intensity activities, more ATP is needed, so the muscles must rely on both anaerobic and aerobic metabolism to meet the body's demands.

Table 13.2.1: Preferred Fuels for Activities of Varying Intensities and Durations

Activity Intensity	Activity Duration	Preferred Fuel	Oxygen Needed?	Activity Example
Very High	30 seconds - 3 minutes	Glucose	No (anaerobic metabolism)	Sprinting
High	3 - 20 minutes	Glucose	Yes (aerobic metabolism)	Jogging
Low to Moderate	> 20 minutes	Fatty Acids	Yes (aerobic metabolism)	Walking

For most daily activities, including exercise, we use a mixture of carbohydrate and fat for energy (see Figure 13.2.5). At rest and lower exercise intensities, we rely more on fat as a fuel source. During low-intensity activities, the body will use aerobic metabolism because it is more efficient and produces larger amounts of ATP. As exercise intensity increases, we rely more on carbohydrate (glucose) for energy. Proteins (amino acids) are used minimally as a fuel source for exercise (about 3-6%, if needed).

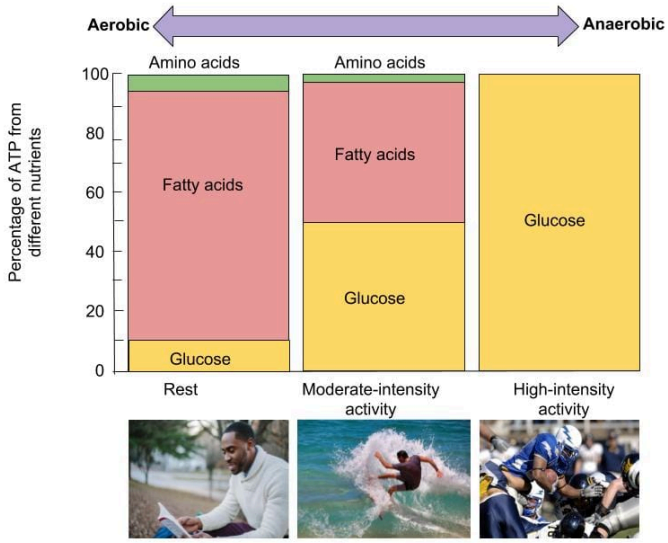
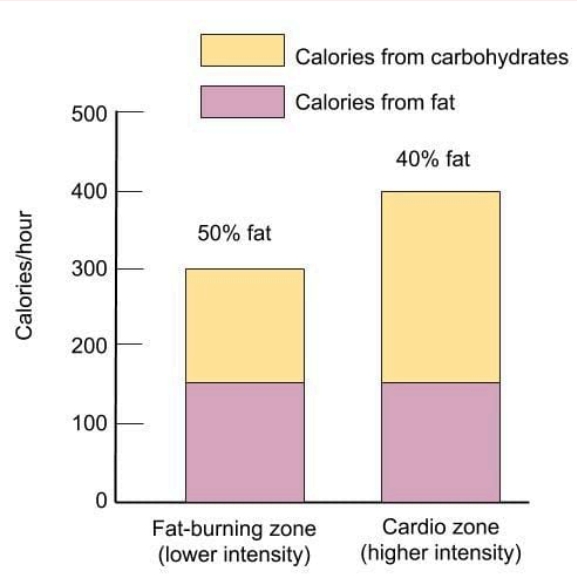


Figure 13.2.5: Fuel sources used during various exercise intensities. (CC BY 4.0; Allison Calabrese via Human Nutrition 2020 Ed [Hawaii])

Does Working Out in the "Fat-Burning" Zone Burn More Fat?



Many people think that to lose body fat, they should exercise at a lower intensity so that fat is the primary fuel source. The fat-burning zone is typically a low-intensity aerobic activity that keeps your heart rate between 60-69% of your maximum heart rate. The cardio zone, on the other hand, is a high-intensity aerobic activity that keeps the heart rate between 70-85% of your maximum heart rate. So, which zone do you burn the most fat in? Technically, your body burns a higher percentage of calories from fat during a low-intensity aerobic activity. When you begin a low-intensity activity, about 50% of the calories burned come from fat, whereas in the cardio zone only 40% come from fat. However, this isn't the whole story. High-intensity activity burns more total calories per minute. At this higher rate of energy expenditure, you can burn just as much or more total fat and more total calories as during a lower-intensity activity. If weight loss is the goal, high-intensity activities will burn more total calories, helping to shift to negative energy balance, and will promote a greater level of fitness. However, the best exercise program is one that is enjoyable, sustainable, and safe. If someone is just starting out, it's wise to begin with low- to moderate-intensity activities and work their way up from there.

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Self-Check Questions

Query 13.2.1

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13.3: Nutrient Needs for Physical Activity

Learning Objective

- Describe how nutrient needs for energy, macronutrients and micronutrients may change in response to an increase in physical activity.

Nutrition is essential to performance during all types of physical activity. The foods consumed in your diet are used to provide the body with enough energy to fuel an activity regardless of the intensity of activity. Let's look at how physical activity affects nutrient needs.

Macronutrients

As activity increases, macronutrient intake may need to increase in order to supply the body with enough energy. However, the proportion of calories from each macronutrient (the AMDR) stays the same as the recommendations for the general population. The recommended diet includes:

- 45-65% of calories (kcal) from carbohydrates. To optimize muscle glycogen stores, carbohydrate intake of 6-10 g/kg body weight is often recommended, depending on the intensity and duration of the physical activity. However, more carbohydrates may be needed to support vigorous exercise or endurance exercise. When choosing carbohydrate-rich foods, athletes should focus most of their carbohydrate intake on fiber-rich, less-processed whole grains, fruits, and vegetables. In addition to adequate quantity, the timing of carbohydrate intake is key. Consuming complex carbohydrates 1-3 hours before a workout may improve performance. Athletes should strive to consume carbohydrate-dense foods in the first few hours after finishing exercise to replenish glycogen stores effectively. The one time a refined or simple carbohydrate may be beneficial is right after a workout. It can help replenish glycogen stores and, when consumed with a protein source, increase muscle protein synthesis. Endurance athletes sometimes use a strategy called carbohydrate loading. It involves altering exercise duration and carbohydrate intake to maximize muscle glycogen storage. However, carbohydrate loading does not always increase performance. Downsides may include water retention, diarrhea, and a heavy, sluggish feeling.
- 20-35% kcal from fat and less than 10% of total kcal as saturated fat. Fat intakes below 20% of energy intake will reduce the availability of fat-soluble vitamins and essential fatty acids (e.g., omega-3 fatty acids).
- 10-35% kcal from protein. Protein intakes range from 1.2-2.0 g/kg body weight.[1] Recommended ranges for various types of athletes can be seen in Table 13.3.1. The majority of athletes, not to mention Americans, consume enough protein from food (so protein supplements are usually not necessary).

Table 13.3.1: Recommended Protein Intake for Various Athletes

Level of Activity	Recommended Daily Protein Intake[2,3]
Sedentary Adults	0.8-1.2 g/kg
Recreational Athletes	1.0-1.4 g/kg
Elite Endurance Athletes	1.5-.1.8g/kg
Strength/Power Athletes	1.4-2.0 g/kg

Micronutrients

The requirements for some vitamins and minerals may be altered in athletes. Adequate intake of these nutrients can be met with a healthy diet and typically do not require supplementation.

- B vitamins - involved in energy metabolism
- Calcium - role in muscle contraction and bone health
- Iron - integral to oxygen transport and energy production

Fluids

Regular exercise increases our need for fluids. The average person needs approximately 2 liters of fluid daily to remain hydrated. However, it is much more accurate to determine hydration needs based on a person's weight. One common formula recommends 30ml (1 ounce) of fluid for every kg of weight. For example, a 135 lb person is 61.36 kg (135/2.2 = 61.36kg) would have a daily fluid requirement of 1840ml, or 1.84 liters (61.36kg x 30ml = 1840ml). This baseline fluid requirement doesn't consider sweat loss during activity. During exercise, heat is dissipated through sweat. Minerals are also lost in sweat during exercise, with sodium being the greatest. Sports drinks that supply fluid, sodium, and carbohydrates were created to prevent dehydration during exercise and are recommended when activities last beyond one hour. Commercial sports drinks provide 30-80 grams of carbohydrates and 400-800 mg of sodium per liter (7-19 g carbohydrate and 95-190 mg sodium per 8 fluid ounces). As a general rule, it is recommended to consume a liter of fluid per hour during prolonged exercise greater than an hour.

After exercising, it is recommended to consume 1.5L of fluid per kg of weight loss, or 24 ounces for each pound lost. Sports drinks work very well to rehydrate athletes post-exercise, but again, are only necessary if the exercise is over 1 hour in length. To determine weight loss, simply weigh yourself before and after the exercise to pinpoint how much fluid is required to return to normal body weight. Once weight loss is established from a few exercise bouts, it is not necessary to weigh before and after each exercise session. Finding a pre- and post-exercise fluid routine will highly benefit an athlete's hydration status.

Additional hydration recommendations include:

- Drink fluids before, during, and after exercise.
- Consume enough fluid to maintain body weight. Avoid losing more than 2-3% of body weight; even fluid loss of 1% of body weight can impair performance.
- Training in hot environments requires careful attention to fluid intake – dehydration is a serious threat.
- Do not rely on thirst as an indicator of hydration status. A pale-yellow color and odorless urine indicate proper hydration. Alternatively, if you pinch the skin on the back of the hand and it doesn't snap back quickly, that's a sign of dehydration.
- Water is appropriate for most activities less than one hour in duration.
- Sports beverages that supply fluid, sodium, and carbohydrates are recommended when activities last beyond one hour.

Homemade Sports Drink



To make your own low-cost sports drink that delivers a similar nutrient profile as commercial sports drinks, try the simple recipe below. The recipe makes 1 liter (approximately 4 cups).

- 1/4 cup sugar
- 1/4 teaspoon salt
- 1/4 cup hot water

- 1/4 cup orange juice (or other 100% juice)
- 3 1/2 cups cold water

In a pitcher, dissolve the sugar and salt in the hot water. Add the juice and cold water. Stir and chill.

Nutrition Information (per cup):

- Calories: 55
- Carbohydrate: 14 g
- Sodium: 154 mg

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14: LIFECYCLE NUTRITION

14.1: Pregnancy and Nutrition

14.2: Infancy and Nutrition

14.3: Nutrition for Toddlers and Children

14.4: Nutrition During Adolescence

14.5: Older Adults and Nutrition

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14.1: Pregnancy and Nutrition

Learning Objective

- Describe nutrition-related considerations during pregnancy.

It is crucial to consume healthy foods at every phase of life. Good nutrition is vital for any pregnancy and begins in the months before conception. All parents-to-be should consider their eating habits; a sedentary lifestyle and a diet low in fresh fruits and vegetables may affect fertility. Including nutrient-dense food choices not only helps an expectant parent remain healthy but also impacts the development of the fetus and ensures that the baby thrives in infancy and beyond. During pregnancy, there is an increased need for certain nutrients. If these nutritional needs are not met, infants could suffer from low birth weight (a birth weight less than 5.5 pounds or 2,500 grams), among other developmental problems. Therefore, it is crucial to make careful dietary choices before and during pregnancy.

Physiology of Pregnancy

For medical purposes, pregnancy is measured from the first day of a person's last menstrual period until childbirth, and typically lasts 38-42 weeks. Pregnancy is divided into trimesters, with each trimester lasting 13-14 weeks. At conception, a sperm cell fertilizes an egg cell, creating a zygote. The zygote implants itself in the uterine wall and rapidly divides into multiple cells to become an embryo. The embryo develops organs, limb buds, and facial features. At week 8, the embryo transitions to being called a fetus. One important development during the first trimester is the development of the placenta, which is responsible for oxygen, nutrient, and waste exchange between the mom and the fetus via the umbilical cord (see Figure 14.1.1).

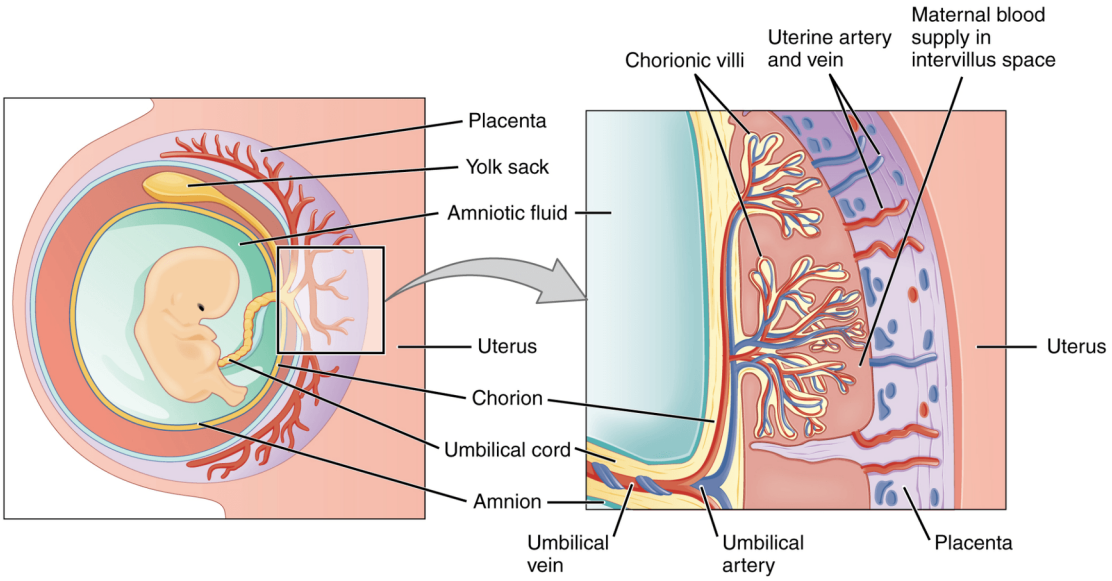


Figure 14.1.1: Cross-section of the placenta showing that the maternal and fetal bloodstreams do not mix. Nutrients, gases, and waste products diffuse between them. (CC BY 4.0; OpenStax Anatomy and Physiology)

Major changes occur in the early weeks of pregnancy, often before a person even knows they are pregnant. During this period, adequate nutrition supports cell division, tissue differentiation, and organ development. Embryos are extremely vulnerable to teratogens during this time; exposure to teratogens or inadequate nutrition can cause major structural and/or functional birth defects (see Figure 14.1.2).

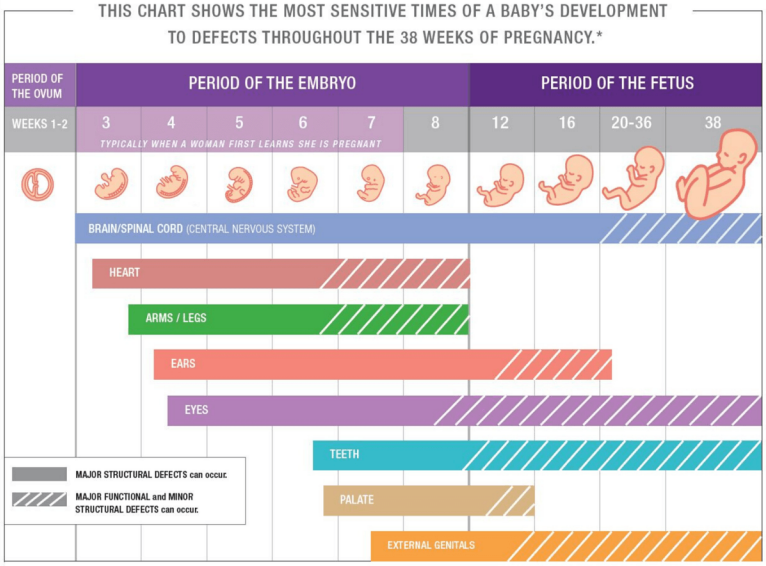


Figure 14.1.2: Critical periods of development. (MotherToBaby)

A pregnancy may happen unexpectedly. Therefore, it is important for all people who have the potential to get pregnant and are of childbearing age to get 400 micrograms of folate per day prior to pregnancy and 600 micrograms per day during pregnancy. Folate, which is also known as folic acid, is crucial for the production of DNA and RNA and the synthesis of cells. A deficiency can cause macrocytic anemia (the development of abnormally large red blood cells) during pregnancy. It can also have a profound effect on the unborn baby. Typically, folate intake has the greatest impact during the first eight weeks of pregnancy, when the neural tube closes. The neural tube develops into the fetus's central nervous system (including the brain and spinal cord), and adequate folate reduces the risk of brain abnormalities or neural tube defects. This vital nutrient also supports the spinal cord and its protective coverings. Inadequate folate can result in birth defects, such as spina bifida, which is the failure of the spinal column to close (Figure 14.1.3). Leafy green vegetables (such as spinach and kale) and legumes/beans (such as lentils) are good sources of folate. Additionally, since 1998, food manufacturers have been required to add folate to cereals and other grain products. The required addition of folate has helped reduce the number of neural tube defects and was an important solution, especially since many people don't know that they're pregnant until after the neural tube closes.

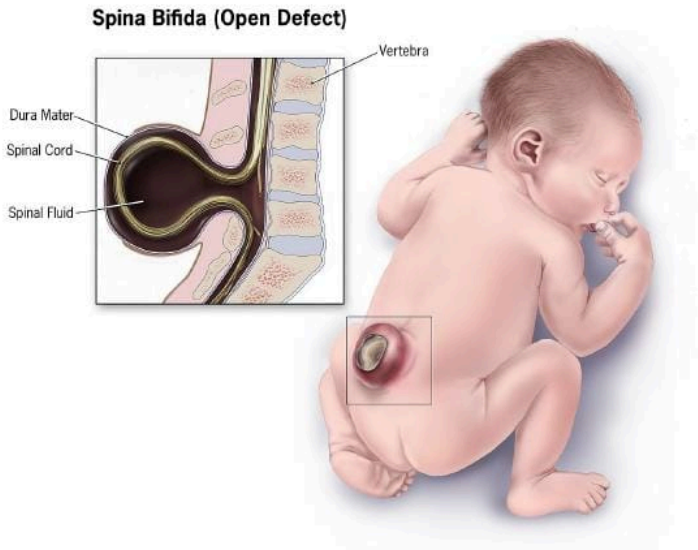


Figure 14.1.3: Spina bifida is a neural-tube defect that can have severe health consequences. (CC0; by Centers for Disease Control and Prevention via Wikimedia Commons)

Weight Gain during Pregnancy

During pregnancy, the body changes in many ways. One of the most notable and significant changes is weight gain. If a pregnant person does not gain enough weight, their unborn baby will be at risk. Poor weight gain, especially in the third trimester, could result not only in low birth weight, but also infant mortality and intellectual disabilities. Therefore, it is vital for a pregnant person to maintain a healthy weight. The amount of weight that should be gained during pregnancy is based on their pre-pregnancy body mass index (BMI). See Table 14.1.1 for the Institute of Medicine (IOM) recommendations.

Table 14.1.1: Body Mass Index and Pregnancy[1]

Prepregnancy BMI	Weight Category	Recommended Weight Gain
Below 18.5	Underweight	28–40 pounds
18.5–24.9	Normal weight	25–35 pounds
25.0–29.9	Overweight	15–25 pounds
30.0 and above	Obese	11–20 pounds

A pre-pregnancy weight below or above the normal weight range can lead to different complications. Pregnant people with a pre-pregnancy BMI below 18.5 are at higher risk of a premature birth and delivering a low birth weight infant.[2] Those with a pre-pregnancy BMI above 30 have an increased risk for gestational diabetes, preeclampsia (high blood pressure during pregnancy), cesarean delivery, and macrosomia (larger baby than normal).[3] Therefore, it is optimal to have a BMI in the normal range prior to pregnancy.

During the first trimester, pregnant people generally gain 3-5 pounds. During the 2nd and 3rd trimesters, gaining about 1 pound a week is considered healthful. Some of the new weight is due to the growth of the fetus, while some is due to changes in the parent's body that support the pregnancy. For example, the placenta supplies nutrients to the fetus and removes waste products; the amniotic sac contains fluids that surround and cushion the fetus. The approximate distribution of weight gained during pregnancy can be seen in Figure 14.1.4. Those who are pregnant with more than one fetus are advised to gain even more weight to ensure the health of their unborn babies.

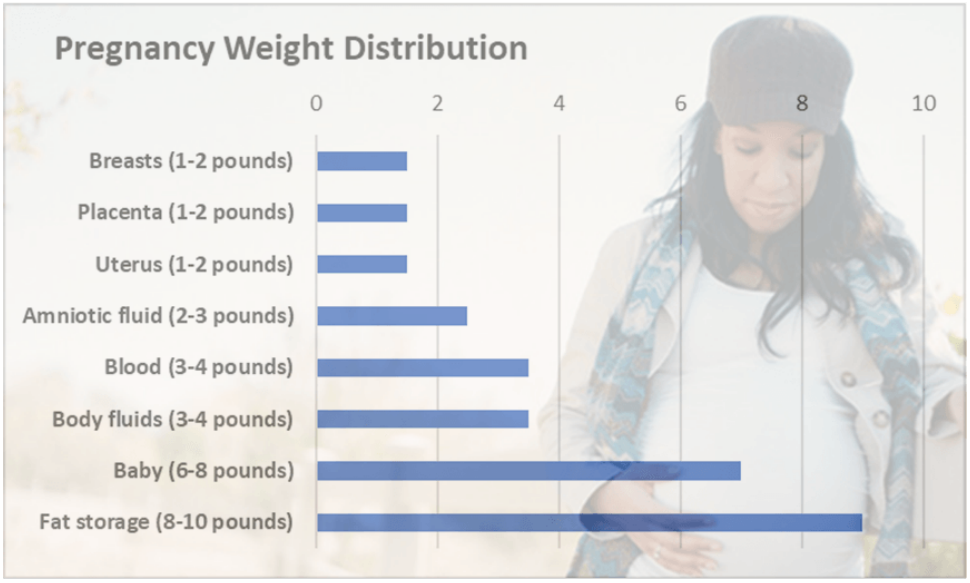


Figure 14.1.4: Pregnancy Weight Distribution (background image: CC BY-NC-ND 2.0; Andreanna Arambula via flickr)

Preterm babies are born before 38 weeks and may be low-birth-weight or very-low-birth-weight babies. In addition, an undernourished mother is more likely to give birth to a low-birth-weight baby. Low birth weight and very low birth weight babies are at increased risk of infections, learning disabilities, impaired physical development, and death in the first year of life.

- Low birth weight: any baby born weighing less than 5.5 pounds

- Very low birth weight: any baby born weighing less than 3.3 pounds

Weight Loss after Pregnancy

During labor, some of the weight gained during pregnancy is lost with the delivery of the child. In the following weeks, the birthing parent continues to shed weight as they lose accumulated fluids and their blood volume returns to normal. Those who gain a healthy amount of weight and participate in regular physical activity during their pregnancies also have an easier time shedding weight post-pregnancy. However, people who gain more weight than needed for a pregnancy typically retain that excess weight as body fat, which can lead to complications such as high blood pressure or type 2 diabetes in future pregnancies or later in life.

Nutritional Requirements During Pregnancy

As a pregnant person's body changes, so do their nutritional needs. Pregnant people must consume more calories and nutrients in the 2nd and 3rd trimesters than non-pregnant adults. However, the average recommended daily caloric intake can vary depending on activity level and the person's pre-pregnancy weight. Choosing nutrient-dense foods helps ensure nutrient needs during pregnancy are met. It is also standard to take prenatal supplements during pregnancy to ensure adequate intake of the needed micronutrients.

Energy

During the first trimester, a pregnant person has the same energy requirements as normal and should consume the same number of calories as usual. However, as the pregnancy progresses, caloric intake must increase. During the 2nd and 3rd trimesters, caloric needs increase by 350-450 calories per day. This is partly due to an increase in metabolism, which rises during pregnancy and contributes to increased energy needs. These increased needs can easily be met by consuming more nutrient-dense foods. For example, an additional 350 calories could include a large banana (about 120 calories), a cup of low-fat plain yogurt (about 170 calories), and a slice of whole-wheat toast (about 60 calories).

Carbohydrates

The recommended daily allowance, or RDA, of carbohydrates during pregnancy is about 175-265 grams per day to fuel fetal brain development. The best nutrient-dense carbohydrate food sources include whole-grain breads and cereals, brown rice, root vegetables, legumes, and fruits. These and other unrefined carbohydrates provide nutrients, phytochemicals, antioxidants, and fiber. These foods also help to build the placenta and supply energy for the growth of the unborn baby. Ideally, a pregnant person should eat 28 grams of dietary fiber per day. Insoluble fiber (from whole grains, fruits, vegetables, and beans) acts as a natural laxative, which softens stools and speeds the elimination of waste material through the colon to prevent constipation. Soluble fiber (found in oats, barley, fruits, vegetables, and beans) has little effect on the intestines; however, it helps lower blood cholesterol levels and regulate blood glucose.

Protein

During pregnancy, extra protein is needed for the synthesis of new tissues. Protein builds muscle and other tissues, enzymes, antibodies, and hormones in both the birthing parent and the unborn baby. Additional protein also supports increased blood volume and the production of amniotic fluid. The RDA for protein during pregnancy is 1.1 grams per kilogram per day, which is about 25 grams above the normal recommendation. However, in most instances, there is no need to make an effort to increase protein intake as long as the pregnant person has a normal appetite, because even non-pregnant people in the U.S. typically eat that much protein. Protein should be derived from healthy sources, such as lean meats, legumes, nuts, seeds, eggs, and fish. Low-fat dairy products also provide protein, along with calcium and other nutrients.

Fat

During pregnancy, fats should make up 20-35% of daily calories. A very low-fat diet is not recommended during pregnancy since it would be hard to meet the needs of essential fatty acids and fat-soluble vitamins. Recommendations for omega-3 and omega-6 essential fatty acids increase during pregnancy. These essential fatty acids are important during pregnancy because they support the baby's brain and eye development. In particular, the brain depends on omega-3 and omega-6 fatty acids for

function, structure, and growth. Docosahexaenoic acid (DHA; an omega-3 fatty acid) and arachidonic acid (ARA; an omega-6 fatty acid) have been linked to enhanced brain growth and eye development. Good sources of DHA include oily fish such as salmon, sardines, anchovies, and mackerel. Good sources of ARA include meat, fish, and poultry. Additional sources of omega-3 and omega-6 fats can be found in Chapter 5.

Vitamins and Minerals

Pregnancy requires certain conditionally essential nutrients, which are nutrients that are required in higher amounts only under special conditions, such as stress, illness, or aging. The daily requirements change with the onset of a pregnancy. Taking a daily prenatal supplement or multivitamin helps to meet many nutritional needs. However, many of these requirements can be fulfilled with a nutrient-dense diet. Table 14.1.2 compares the normal levels of several vitamins and minerals to the levels needed during pregnancy. It's important to note that during pregnancy, the DRI for nearly all vitamins and minerals increases.

Table 14.1.2: Recommended Nutrient Intakes during Pregnancy[4]

Nutrient	Non-pregnancy Recommendation	Recommendation during Pregnancy	Importance
Vitamin A (mcg)	700	770	Forms healthy skin and eyesight; helps with bone growth
Vitamin B_6 (mg)	1.3	1.9	Helps form red blood cells; helps the body metabolize nutrients
Vitamin B_{12} (mcg)	2.4	2.6	Maintains nervous system; helps form red blood cells and DNA
Vitamin C (mg)	75	85	Promotes healthy gums, teeth, bones
Vitamin D (mcg)	15	15	Supports fetal bone development
Calcium (mg)	1,000	1,000	Supports fetal bone development
Folate (mcg)	400	600	Helps prevent neural tube defects; supports growth and development of fetus and placenta
Iron (mg)	18	27	Helps red blood cells deliver oxygen to fetus
Magnesium (mg)	320	360	Supports fetal bone development
Phosphorus (mg)	700	700	Supports fetal bone development
Zinc (mg)	8	11	Helps cell development and protein synthesis

Iron and folate are two nutrients that are commonly supplemented during pregnancy. It's almost impossible to obtain adequate amounts of iron from only food sources. During the 3rd trimester, the fetus stores iron for use during the first few months after birth. Therefore, even if a pregnant person consumes a healthy diet, there is still typically a need to take an iron supplement. Folate needs increase during pregnancy to 600 micrograms to prevent neural tube defects, assist with cell division, and help produce the extra blood a pregnant body requires. However, it's important to avoid exceeding vitamin or mineral recommendations. Taking megadose supplements can lead to excessive amounts of certain micronutrients, such as vitamin A and zinc, which may produce toxic effects that can also result in birth defects.

Guide to Eating during Pregnancy

While pregnant people have an increased need for energy, vitamins, and minerals, energy increases are proportionally less than other macronutrient and micronutrient increases. So, nutrient-dense foods, which have a higher proportion of macronutrients and micronutrients relative to calories, are essential to a healthy diet during pregnancy. Examples of nutrient-dense foods include

fruits, vegetables, whole grains, legumes (beans), reduced-fat dairy, and lean meats. Those who are pregnant should be able to meet almost all of their increased needs with a nutrient-dense diet. However, a prenatal supplement should be taken to ensure an adequate intake of iron and folate.

Foods to Avoid

Some substances can harm a growing fetus; therefore, it is vital to avoid them throughout a pregnancy. Some substances are so detrimental that they should be avoided even if there's a suspicion of being pregnant. For example, consumption of alcoholic beverages can result in fetal alcohol syndrome (discussed in Chapter 7) and lead to learning and attention deficits, heart defects, and abnormal facial features. Alcohol enters the unborn baby via the umbilical cord and can slow fetal growth, damage the brain, or even result in miscarriage. The effects of alcohol are most severe in the first trimester, when the organs are developing. As a result, there is no safe amount of alcohol that a pregnant person can consume.

Caffeine is a stimulant that crosses the placenta and reaches the fetus. Caffeine may increase the risk of miscarriage and low birth weight. Pregnant people should limit caffeine intake, which is found not only in coffee but also in tea, sodas, chocolate, and energy drinks. Current recommendations suggest limiting caffeine to less than 200 milligrams a day (the amount in approximately 12 ounces of brewed coffee).[5]

Foodborne Illness

For both the birthing parent and the fetus, foodborne illness can cause major health problems. For example, the foodborne illness caused by the bacteria *Listeria monocytogenes* can cause preterm labor or miscarriages. Those who are pregnant are more likely to become infected with this disease, which is known as listeriosis, than non-pregnant, healthy adults.[6] Foods more likely to contain the bacteria are unpasteurized dairy products, especially soft cheeses, and also smoked seafood, hot dogs, paté, cold cuts, and uncooked meats. To avoid consuming contaminated foods, people who are pregnant or breastfeeding should take the following measures:

- Thoroughly rinse fruits and vegetables before eating them
- Keep cooked and ready-to-eat food separate from raw meat, poultry, and seafood
- Store food at 40° F (4° C) or below in the refrigerator and at 0° F (–18° C) in the freezer
- Refrigerate perishables, prepared food, or leftovers within two hours of preparation or eating
- Clean the refrigerator regularly and wipe up any spills right away
- Check the expiration dates of stored food once per week

You will learn more about foodborne illness and its consequences in the next chapter.

Food Contaminants

It is always important to avoid consuming contaminated food. This is especially true during pregnancy. Heavy metal contaminants, particularly mercury, lead, and cadmium, pose risks to those who are pregnant. Some fish contain high levels of mercury. As a result, there are guidelines related to fish intake during pregnancy. Pregnant people can eat fish, ideally 8 to 12 ounces of a variety of seafood per week, from choices that are lower in mercury. Figure 14.1.5 includes good and best choices of seafood that are lower in mercury. In addition, the figure identifies fish with high mercury levels, such as shark, swordfish, tilefish, marlin, orange roughy, bigeye tuna, and king mackerel that should be avoided.



Figure 14.1.5: Best choices, good choices, and choices of fish to avoid during pregnancy.

Physical Activity during Pregnancy

Physical activity during pregnancy is recommended in the *Physical Activity Guidelines for Americans*. People should do at least 150 minutes (2 hours and 30 minutes) of moderate-intensity aerobic activity a week during pregnancy and the postpartum period. Preferably, aerobic activity should be spread throughout the week. People who habitually engaged in vigorous-intensity aerobic activity or who were physically active before pregnancy can continue these activities during pregnancy and the postpartum period.[7] Physical activity during pregnancy reduces the risk of gestational diabetes, preeclampsia, preterm birth, and large for gestational age infants. In addition, physical activity can enhance mood, reduce lower back pain and shorten labor.

Common Discomforts during Pregnancy

Pregnancy can lead to certain discomforts, from back strain to swollen ankles. A pregnant person is likely to experience constipation because increased hormone levels can slow digestion and relax muscles in the bowels. Constipation and pressure from growth of the uterus can result in hemorrhoids, which are another common discomfort. Getting mild to moderate exercise and drinking enough fluids can help prevent both conditions. Also, eating a high-fiber diet softens the stools and reduces the pressure on hemorrhoids.

Heartburn (gastroesophageal reflux) can occur during the early months of pregnancy due to an increase in the hormone progesterone, and during the later months due to the expanding size of the fetus, which limits stomach contraction. Avoiding foods that cause heartburn and remaining upright for an hour after meals can help pregnant people avoid heartburn. In addition, it can be helpful to drink fluids between meals, instead of with food.

Other common complaints can include leg cramps and bloating. Regular exercise can help to alleviate these discomforts. Many pregnant people develop gastrointestinal issues, such as nausea and vomiting. Many also experience food cravings and aversions. All of these can impact a pregnant person's nutritional intake and it is important to protect against adverse effects.

Nausea and Vomiting

Nausea and vomiting are gastrointestinal issues that strike many pregnant people, typically in the first trimester. Nausea tends to occur more frequently than vomiting. These conditions are often referred to as "morning sickness," although that's something of a misnomer because nausea and vomiting can occur all day long, although it is often the worst in the first part of the day.

Increased levels of hormones may cause nausea and vomiting. Nausea usually subsides after 16 weeks, possibly because the body becomes adjusted to higher hormone levels.

It can be useful for those who are pregnant to keep a food diary to discover which foods trigger nausea, so they can avoid them in the future. Other tips to help avoid or treat nausea and vomiting include the following:

- Avoid spicy foods
- Avoid strong or unusual odors
- Eat dry cereal, toast, or crackers
- Eat frequent, small meals
- Consume more unrefined carbohydrates
- Get moderate aerobic exercise
- Drink ginger tea, which aids in stomach upset
- Seek fresh air when a bout of nausea comes on

A severe form of nausea and vomiting is a condition known as hyperemesis gravidarum. It is marked by prolonged vomiting, which can result in dehydration and require hospitalization.

Food Cravings and Aversions

Food aversions and cravings do not have a major impact unless food choices are extremely limited. Some common food aversions include meat, eggs, milk, and spicy foods. During pregnancy, it is not harmful to indulge in the occasional craving, such as the desire for chocolate or ice cream. A medical disorder known as pica is willingly consuming foods with little or no nutritive value, such as dirt, clay, or soap. In some places, this is a culturally accepted practice. However, it can be harmful if these substances take the place of nutritious foods or contain toxins.

Complications during Pregnancy

Different complications may arise during the course of a pregnancy. These complications include certain medical conditions that could greatly impact a pregnancy if left untreated, such as gestational hypertension and gestational diabetes, which have diet and nutrition implications.

Gestational Hypertension

Gestational hypertension is a condition of high blood pressure during the second half of pregnancy. First-time birthing parents are at a greater risk, along with those who have parents or siblings who had gestational hypertension, those carrying multiple fetuses, those with a prior history of high blood pressure or kidney disease, and people who are overweight or obese when they become pregnant.

Hypertension can prevent the placenta from getting enough blood, which would result in the baby getting less oxygen and nutrients. This can result in low birth weight, although most people with gestational hypertension can still deliver a healthy baby if the condition is detected and treated early. Some risk factors can be controlled, such as diet, while others cannot, such as family history. If left untreated, gestational hypertension can lead to a serious complication called preeclampsia. This disorder is marked by elevated blood pressure and protein in the urine and is associated with swelling (edema) and unexplained rapid weight gain. To prevent preeclampsia, the World Health Organization recommends increasing calcium intake for pregnant people consuming diets low in calcium and administering a low dosage of aspirin (75 milligrams), among other interventions.[8]

Gestational Diabetes

Approximately 9% of pregnant people suffer from a condition known as gestational diabetes,[9] which is abnormal glucose tolerance during pregnancy. The body becomes resistant to the hormone insulin, which enables cells to transport glucose from the blood. Gestational diabetes is usually tested for and diagnosed near the end of the 2nd trimester, although it is possible for the condition to develop later into a pregnancy. Signs and symptoms of this disease include extreme hunger, thirst, or fatigue. If blood sugar levels are not properly monitored and treated, the baby might gain too much weight and require a cesarean delivery. Diet and regular physical activity can help to manage this condition. Most patients who suffer from gestational diabetes also require daily insulin injections to boost the absorption of glucose from the bloodstream and promote the storage of glucose in the form of glycogen in liver and muscle cells. Gestational diabetes usually resolves after childbirth, although some people who suffer from this condition develop Type 2 diabetes later in life, particularly if they are overweight.

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14.2: Infancy and Nutrition

Learning Objectives

- Describe nutrition-related considerations during infancy.
- Outline feeding recommendations for infants, including benefits/challenges of breastfeeding and introduction of solid foods.

Diet and nutrition have a major impact on a child's development from infancy into the adolescent years. A healthy diet not only affects growth, but also immunity, intellectual capabilities, and emotional well-being. It's important to ensure that children receive an adequate amount of needed nutrients to provide a strong foundation for the rest of their lives.

Infancy (Birth to Age One)

Healthy infants grow steadily, but not always at an even pace. For example, during the first year of life, length/height increases by 50%, while weight triples. Physicians and other health professionals plot length/height, weight, and head circumference on growth charts to track an infant's development process. These growth charts allow for tracking trends over time and comparisons to a population of other healthy infants. Growth charts may provide warnings that a child has a medical problem or is malnourished. Insufficient weight or length/height gain during infancy may indicate a condition known as failure-to-thrive (FTT), which is characterized by poor growth. Some causes include poverty, lack of enough food, inappropriate foods, and excessive fruit juice.

Nutritional Requirements

Requirements for macronutrients and micronutrients on a per-kilogram basis are higher during infancy than at any other stage in the human life cycle. These needs are affected by the rapid cell division that occurs during growth, which requires energy and protein, along with nutrients involved in DNA synthesis. Infants are entirely dependent on parents and caregivers to meet these needs. For almost all infants 6 months or younger, human milk is the best source to fulfill nutritional requirements. An infant may require feedings 8-12 times a day or more in the beginning. Typically, after about 6 months, infants can gradually begin to consume solid foods to help meet nutrient needs.

Energy

Energy needs relative to size are much greater in infants than in adults; infant energy needs are high to support rapid growth. An infant needs about 40-50 calories per pound of body weight per day.[1] How often an infant wants to eat will also change over time due to growth spurts, which typically occur at about 2 weeks and 6 weeks of age, and again at about 3 months and 6 months of age.

Macronutrients

Dietary recommendations for infants are different from recommendations for adults. About 40-50% of an infant's calorie intake should come from fat. A high-fat diet is necessary to encourage the development of neural pathways in the brain and other parts of the body. Infants 0-6 months of age need approximately 9 grams of protein per day; infants 7-12 months need 11 grams of protein per day to support growth. Because infants' kidneys are still immature, having too much protein makes it difficult for the kidneys to process and excrete excess nitrogen; therefore, no more than 20% of an infant's calories should come from protein. Carbohydrate recommendations are set at 60 grams per day for infants 0-6 months old and 95 grams per day for infants 7-12 months old. These levels reflect the lactose content of human milk. Almost all of the carbohydrate in human milk is lactose, which infants digest and tolerate well.

Micronutrients

Almost all of the nutrients that infants require can be met if they consume an adequate amount of human milk or formula. There

are a few exceptions, though. Human milk is low in vitamin D, which is needed for calcium absorption and building bone, among other things. Therefore, infants and children consuming human milk often need to take a vitamin D supplement in the form of drops. Human milk is not high in iron, but the iron in human milk is well absorbed by infants. After 4-6 months, however, an infant needs an additional source of iron other than human milk; the source of iron typically comes from solid foods that are introduced. For formula-fed infants, supplementation depends on the particular formula being used; for example, many formulas are fortified with iron, so iron supplementation would not be needed when using iron-fortified formula.

Fluids

Infants have a high fluid needs; 1.5 milliliters per kilocalorie consumed compared to 1.0 milliliters per kilocalorie consumed for adults. This is because children have larger body surface area per unit of body weight and a reduced capacity for perspiration. Therefore, they are at greater risk of dehydration. However, parents or other caregivers can meet an infant's fluid needs with human milk or formula. As solid foods are introduced, parents and caregivers must make sure that infants continue to drink fluids (human milk or formula) throughout the day.

Breastfeeding

When a breastfeeding infant suckles at the breast, a nerve impulse is sent to the pituitary gland to release the hormone oxytocin. Oxytocin helps move milk from the alveoli to the lactiferous ducts, collect in the lactiferous sinuses, and ultimately release into the baby's mouth through nipple pores (Figure 14.2.1).

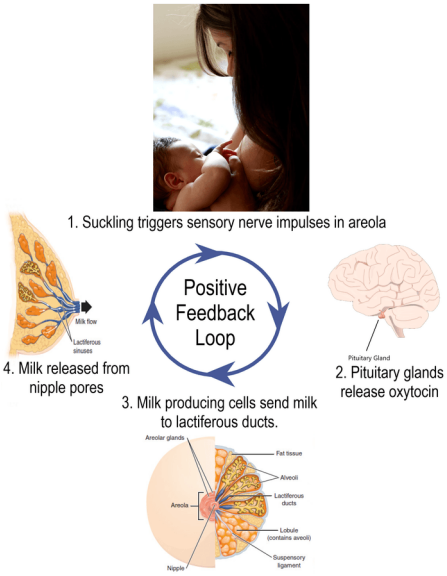


Figure 14.2.1: Lactation positive feedback loop. (CC BY-SA 4.0; by Christinelmiller)

After the birth of the baby, nutritional needs must be met to ensure that the infant not only survives, but thrives from infancy into childhood. Breastfeeding provides the fuel a newborn needs for rapid growth and development. As a result, the World Health Organization (WHO) and the American Academy of Pediatrics (AAP) recommend that breastfeeding be done exclusively for the first 6 months of an infant's life.[2,3]

Lactation

Lactation is the process that makes breastfeeding possible, and is the synthesis and secretion of human milk. Early in a pregnancy, mammary glands begin to prepare for milk production. Hormones play a major role in this, particularly during the second and third trimesters. At that point, levels of the hormone prolactin increase to stimulate the growth of the milk duct system, which initiates and maintains milk production. Levels of the hormone oxytocin also rise to promote the release of human milk when the infant suckles at the breast. However, levels of the hormone progesterone need to decrease for successful milk production, because progesterone inhibits milk secretion. Shortly after birth, the delivery/removal of the placenta triggers a fall in progesterone levels, which activates lactation.

Caloric and fluid intake must be adjusted to make breastfeeding possible. The Estimated Energy Requirement (EER) is 330 additional calories (beyond pre-pregnancy needs) during the first six months of lactation and 400 additional calories during the second 6 months of lactation. The energy needed to support breastfeeding comes from both increased food/beverage intake and from stored fat. For example, it's estimated that milk production requires 700-800 calories per day. During the first 6 months after a baby is born, 330 of those calories would come from increased intake, and 370-470 calories would come from the birthing parent's fat stores that built up during pregnancy. This helps explain why breastfeeding may promote weight loss after pregnancy. Those who are lactating should also drink 3.8 liters of liquids per day (about 16 cups) to maintain milk production.[4] As is the case during pregnancy, the DRI for nearly all vitamins and minerals increases for those who are breastfeeding their babies. Table 14.2.1 compares the recommended vitamins and minerals during lactation to the levels during non-pregnancy and pregnancy.

Table 14.2.1: Recommended Nutrient Intakes during Lactation[4]

Nutrient	Recommendations during Non-pregnancy	Recommendations during Pregnancy	Recommendations during Lactation
Vitamin A (mcg)	700	770	1,300
Vitamin B_6 (mg)	1.5	1.9	2.0
Vitamin B_{12} (mcg)	2.4	2.6	2.8
Vitamin C (mg)	75	85	120
Vitamin D (mcg)	15	15	15
Vitamin E (mg)	15	15	19
Calcium (mg)	1,000	1,000	1,000
Folate (mcg)	400	600	500
Iron (mg)	18	27	9
Magnesium (mg)	320	360	320
Niacin (B_3) (mg)	14	18	17
Phosphorus (mg)	700	700	700
Riboflavin (B_2) (mg)	1.1	1.4	1.6
Thiamin (B_1) (mg)	1.1	1.4	1.4
Zinc (mg)	8	11	12

Calcium requirements do not change during breastfeeding because of more efficient absorption (which is the case during pregnancy, too). However, the reasons for this differ. During pregnancy, there is enhanced absorption within the gastrointestinal tract. During lactation, there is enhanced retention by the kidneys.

Components of Human Milk

Human milk provides adequate nutrition for infants, and it also helps protect newborns from disease. In addition, human milk is rich in cholesterol, which is needed for brain development. It is helpful to know the different types and components of human milk, along with the nutrients they provide that enable an infant to survive and thrive. The components of human milk include:

- **Colostrum.** Colostrum is the first milk produced; it is a fairly thick, yellow/creamy-colored liquid. This protein-rich liquid fulfills an infant's nutrient needs during the first few days. Although low in volume, colostrum is packed with concentrated nutrition for newborns. Colostrum is high in fat-soluble vitamins, minerals, and immunoglobulins (antibodies). Immunoglobulins pass from the lactating parent to the infant via human milk; this provides passive immunity for the newborn and protects the baby from bacterial and viral diseases.[5]
- **Transitional Milk.** Around 2-4 days after birth, transitional milk is produced. Transitional milk is a creamy liquid that lasts

for approximately 2 weeks and includes high levels of fat, lactose, and water-soluble vitamins. It also contains more calories than colostrum. When production of transitional milk begins, there is typically a noticeable change in the volume and type of liquid secreted from the breasts as well as an increase in the weight and size of the breasts.[5]

- **Mature Milk.** Mature milk is the type of human milk that is produced after the first 2 weeks. About 90% of mature milk is water, which helps an infant remain hydrated. The other 10% contains carbohydrates, proteins, and fats, which support energy and growth. Similar to cow's milk, the main carbohydrate of mature milk is lactose. Human milk contains vital fatty acids, such as docosahexaenoic acid (DHA) and arachidonic acid (ARA). Lactalbumin is the major protein found in human milk. In terms of protein, human milk contains more whey than casein (which is the reverse of cow's milk). Whey is much easier for infants to digest than casein. There are two types of mature milk, which, combined, ensure that a baby receives adequate nutrients to grow and develop properly:
  - Foremilk occurs at the beginning of a breastfeeding session and includes water, vitamins, and protein.
  - Hind-milk occurs after the initial release of milk and contains higher levels of fat, which is necessary for weight gain.[5]

In addition, human milk provides adequate vitamins and minerals. Although absolute amounts of some micronutrients are low, they are more efficiently absorbed by infants. Other essential components include digestive enzymes that help a baby digest the human milk.

Diet and Milk Quality

Diet can have a major impact on milk production and quality. As during pregnancy, those who are lactating should avoid illegal substances and cigarettes. Some legal drugs and herbal products can be harmful as well, so it is helpful to discuss them with a health care provider. Some people who are lactating may need to avoid certain things, such as spicy foods, that can produce gas in sensitive infants. Lactating people can drink alcohol, though they must avoid breastfeeding until the alcohol has completely cleared from their milk. Typically, this takes 2-3 hours for a standard drink (12 ounces of beer, 5 ounces of wine, or 1.5 ounces of liquor), depending on the person's body weight.[6]

Benefits of Breastfeeding

Several benefits of breastfeeding are listed in Table 14.2.2. Human milk contains immunoglobulins, enzymes, immune factors, and white blood cells. As a result, breastfeeding boosts the baby's immune system and lowers the incidence of diarrhea, along with respiratory diseases, gastrointestinal problems, and ear infections. Babies fed human milk are also less likely to develop asthma and allergies, and breastfeeding lowers the risk of sudden infant death syndrome (SIDS). In addition, human milk is a rich source of microbes that have the potential to influence infant health; for example, human milk encourages the growth of healthy bacteria in an infant's intestinal tract.[7]

Table 14.2.2: Benefits of Breastfeeding[8]

Breastfed babies have a lower risk of:	Birthing parents who breastfeed their child(ren) have a lower risk of:
Asthma	Breast cancer
Obesity	Ovarian cancer
Type 1 diabetes	Type 2 diabetes
Severe lower respiratory disease	High blood pressure
Acute otitis media (ear infections)	
Sudden infant death syndrome (SIDS)	
Gastrointestinal infections (diarrhea/vomiting)	

Breastfeeding has a number of other important benefits. It is easier for babies to digest human milk than formula. Formula contains proteins made from cow's milk that require an adjustment period for infant digestive systems. Breastfeeding is more sustainable and results in less plastic waste and other trash. Breastfeeding can also save families money because it does not incur the same cost as purchasing formula. Other benefits include that human milk does not have to be mixed, heated, or prepared - it is always at the right temperature.

Some initiatives related to feeding infants human milk include:

- The Baby-Friendly Hospital Initiative, which assists hospitals in giving parents and caregivers information, confidence, and skills necessary to successfully initiate and continue breastfeeding. Hospitals with the Baby-Friendly® designation successfully implement the Ten Steps to Successful Breastfeeding and follow the International Code of Marketing of Breast Milk Substitutes. While Baby-Friendly® hospitals encourage breastfeeding, formula is provided in cases where patients have a medical indication or have made an informed decision to use formula.[9]
- Human milk banks (e.g., the Human Milk Banking Association of North America) provide access to human milk through support of breastfeeding and use of pasteurized donor human milk.

Barriers to Breastfeeding

Although human milk is ideal for almost all infants, there are some challenges that people may face when starting and continuing to breastfeed their infants. These obstacles include painful engorgement or fullness in the breasts, sore and tender nipples, lack of comfort or confidence in public, and lack of accommodation to breastfeed or express milk in the workplace. One of the first challenges faced is learning the correct technique for breastfeeding. It may take a little time for the lactating person to help their baby properly latch on to the nipple. Improper latching can result in inadequate intake, which could slow growth and development. However, International Board Certified Lactation Consultants (IBCLCs) are health care professionals trained to help people learn the proper technique. Additional barriers include social concerns, such as breastfeeding in public and conflicts with the breastfeeding parent's employment. Education, the length of maternity leave, and laws to protect public breastfeeding, among other measures, can all help facilitate breastfeeding for many lactating people and their newborns.

Contraindications to Breastfeeding

Although there are numerous benefits to breastfeeding, in some cases, there are also risks that must be considered. In the developed world, someone with HIV should not breastfeed, because the infection can be transmitted through human milk. This is typically not an issue, as there is access to infant formula that is a safe alternative to human milk. However, in developing nations where HIV infection rates are high and acceptable infant formula can be difficult to come by, many newborns would be deprived of the nutrients they need to develop and grow. As a result, the WHO recommends that people living with HIV in the developing world should feed their infants human milk while taking antiretroviral medications to lower the risk of transmission.[10]

Formula Feeding

For parents and caregivers who choose to formula feed, infant formula provides a balance of nutrients. However, not all formulas are the same, and there are important considerations that parents and caregivers must weigh. Standard formulas use cow's milk as a base. They have 20 calories per fluid ounce, similar to human milk, with vitamins and minerals added. Soy-based formulas are usually given to infants who develop diarrhea, constipation, vomiting, colic, or abdominal pain, or to infants with a cow's milk protein allergy. Hypoallergenic protein hydrolysate formulas are usually given to infants who are allergic to cow's milk and soy protein. This type of formula uses hydrolyzed protein, meaning that the protein is broken down into amino acids and small peptides, making it easier to digest. Preterm infant formulas are given to low-birth-weight infants if human milk is unavailable. Preterm infant formulas have 24 calories per fluid ounce and are given until the infant reaches a desired weight.

Infant formula comes in three basic types:

1. Powder that requires mixing with water. This is the least expensive type of formula.
2. Concentrates, which are liquids that must be diluted with water. This type is slightly more expensive.
3. Ready-to-use liquids that can be poured directly into bottles. This is the most expensive type of formula. However, it requires the least amount of preparation.

When preparing formula, parents and caregivers should carefully follow the safety guidelines, since an infant has an immature immune system. All equipment used in formula preparation should be sterilized. Prepared, unused formula should be refrigerated to prevent bacterial growth. Parents and caregivers should avoid using contaminated water to mix formula to prevent foodborne illnesses. Follow the instructions for powdered and concentrated formula carefully—formula that is over-diluted will not provide adequate calories and protein, while over-concentrated formula provides too much protein and too little water, which can impair kidney function.

Introducing Solid Foods

Infants should be breastfed or formula fed exclusively for the first 6 months of life. Infants should not consume solid foods before 6 months because solid foods do not contain the right nutrient mix that infants need. Also, eating solid foods may mean drinking less human milk or formula. If that occurs, an infant may not consume the right quantities of various nutrients. If parents or caregivers try to feed an infant who is too young or not ready, the infant's tongue will push the food out, which is called the extrusion reflex. The extrusion reflex begins to lessen around 4-6 months of age. Other developmental milestones that indicate readiness for solid foods include the infant's ability to hold up their head, sit up, open their mouth to signal readiness to eat, and move food from the front of the mouth to the back, where it can be safely swallowed.

Solid baby foods can be purchased commercially or prepared from food at home using a food processor, blender, food mill, or grinder. Usually, an iron-fortified infant cereal is the first solid food introduced to an infant (around the age of 6 months) as it is easy to digest and rarely causes an allergic response. Introducing an iron-fortified infant cereal at this time is also advantageous to prevent anemia in the infant; infants are born with an iron supply that lasts approximately 6 months. By 9-12 months of age, infants are able to chew soft foods and can eat solids that are well-chopped or mashed.

Learning to Self-Feed

With the introduction of solid foods, young children begin to learn how to handle food and how to feed themselves. Initially, infants use their whole hand to pick up items (this is known as the palmar grasp). They can lift larger items, but picking up smaller pieces of food is difficult. Between 8 and 12 months of age, infants develop a pincer grasp, which uses fingers to pick up objects. After the age of 1, children slowly begin to use utensils to handle their food. Unbreakable dishes and cups are essential, since very young children may play with them or throw them when they become bored with their food.

Feeding Problems during Infancy

Parents and caregivers should be mindful of certain diet-related problems that may arise during infancy. Heating an infant’s food presents a risk of accidental injury or burns, which may occur if the food is heated unevenly or excessively. Keep in mind that an infant cannot communicate that the food is too hot. Some foods and beverages are not safe for infants, including:

- **Honey and corn syrup.** These may contain spores of *Clostridium botulinum,* which is a bacteria that can produce a poisonous toxin in an infant’s intestines and cause the foodborne illness botulism. Botulism can be fatal. After the age of 1, it is safe to give a child honey or corn syrup because their digestive tract is mature enough to kill the bacteria.
- **Foods that can cause choking.** Certain foods are choking hazards, including foods with skins or foods that are very small, such as grapes. Other examples of potential choking hazards include raw carrots and apples, raisins, and hard candy. Parents and caregivers should never leave a baby alone at mealtime, because an infant can accidentally choke on pieces of food that are too big or have not been adequately chewed.
- **Cow's milk, goat's milk, and plant-based milk alternatives.** These milks do not have the appropriate mix of nutrients to meet an infant's needs and can be difficult for an infant to digest. These milks tend to have too much protein and too few carbohydrates for an infant. Offering these milks after the age of 1 is ok.

Food Allergies

Delaying the introduction of solid foods until the age of 6 months reduces the risk of developing food allergies. It is also recommended to introduce only one new food at a time to help identify allergic responses or food intolerances. One of the most common allergies in infants is to proteins in cow's milk-based formulas. Other common food allergens that can appear just before or after the first year include peanut, egg white, and wheat allergies. Symptoms may include rash, hives, diarrhea, constipation, bloating, blood in the stool, and vomiting.

Early Childhood Caries

Primary teeth are at risk for a disorder known as early childhood caries (cavities) from human milk, formula, juice, or other drinks fed through a bottle for prolonged periods of time. Liquids can build up in a baby’s mouth, and the natural or added sugars lead to tooth decay. Early childhood caries is caused not only by the kinds of liquids given to an infant, but also by the frequency and length of time that fluids are given. Giving a child a bottle of juice or other sweet liquids several times each day, or letting a baby

suck on a bottle longer than a mealtime, either when awake or asleep, can also cause early childhood caries. Providing beverages in a cup starting around 8 months of age and no longer using a bottle after 18 months of age are strategies to prevent early childhood caries from overuse of a bottle.

Gastroesophageal Reflux

Small amounts of spitting up during a feeding is normal. However, there is cause for concern if it is too difficult to feed an infant due to gastroesophageal reflux. This condition occurs when stomach muscles open at the wrong times and allow milk or food to go back up into the esophagus. Symptoms of gastroesophageal reflux in infants include severe spitting up, projectile vomiting, arching of the back as though in pain, refusal to eat or pulling away from the breast during feedings, gagging or problems with swallowing, and slow weight gain. For most infants, making adjustments in feeding practices addresses the issue. For example, a parent can feed their baby in an upright position, wait at least an hour after eating for play time, burp more often, or give a child smaller, more frequent feedings.

Dehydration

Dehydration can result from diarrhea, vomiting, or inadequate fluid intake and is an extremely dangerous situation for infants. Treatment includes providing fluids and electrolytes.

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14.3: Nutrition for Toddlers and Children

Learning Objectives

- Describe nutrition-related considerations for toddlers and children.
- Outline feeding recommendations for toddlers and children, including the division of responsibility.

The toddler stage (ages 1-3) includes growing independence and changes in nutrient requirements. Their physical growth slows compared to the progress they made as infants. However, toddlers experience enormous intellectual, emotional, and social changes. During this stage, the diet shifts from breastfeeding or formula feeding to solid foods and healthy beverages. Children (ages 4-8) grow consistently, but at a slower rate than infants and toddlers. A healthy diet facilitates the physical and mental development during toddlerhood and childhood. Both stages can also pose interesting challenges for parents and caregivers, as toddlers and children learn how to eat on their own and begin to develop personal preferences.

Energy and Macronutrients

The energy requirements for toddlers and children vary based on sex, growth rate, and level of physical activity. Because toddlers and children have small stomachs, they require small, frequent, nutrient-dense snacks and meals to meet energy needs. Examples of nutrient-dense foods for toddlers and children include avocado, eggs, full-fat dairy, fatty fish, nut butters, fruits, vegetables with dip or hummus, and whole grains. One way to estimate serving sizes for toddlers and children is to offer 1 tablespoon for each year of life. For example, a serving of fruit or vegetables for a 2-year-old would be 2 tablespoons, while a 4-year-old would be given 4 tablespoons (1/4 cup). Carbohydrate recommendations include eating complex carbohydrates for energy needs. While 100% juice can be a source of nutrients, the American Academy of Pediatrics (AAP) recommends limiting consumption of fruit juice to 4 ounces (1/2 cup) per day or less for toddlers, 1/2-3/4 cup for children ages 4-6, and 1 cup for children ages 7-18.[1] The AAP also recommends whole fruit in place of fruit juice to help with fiber intake.[1] Toddlers and children have a high need for protein (1.05 g/kg for toddlers; 0.95 g/kg for children)[2] to support muscle growth and development. The AMDR for total fat is 30-40% of calories for toddlers and 25-35% of calories for children; these ranges help transition from the higher fat intake required during infancy while also including essential fatty acids that are vital for brain and nervous system development.[2]

Micronutrients

Recommendations for many vitamins and minerals increase during toddlerhood and childhood. These nutrient needs can typically be met with a balanced diet that incorporates a variety of foods from each food group, with a few exceptions. Nutrients of concern include:

- **Vitamin D.** Toddlers and children need 15 micrograms of vitamin D per day to support bone health.[3] Fish (e.g., salmon, tuna) and vitamin D-fortified foods (e.g., dairy, orange juice, cereals) can help meet this need. However, toddlers and children who do not get enough of this micronutrient should receive a supplement.
- **Calcium.** Calcium is needed for toddlers and children to build optimal bone mass. Toddlers need 700 mg of calcium per day; children need 1,000 mg of calcium per day.[3] Dairy products and calcium-fortified beverages are good sources of calcium. In alignment with total fat recommendations, whole-fat dairy may be given starting at age 1; reduced-fat dairy may be given starting at age 2.
- **Iron.** Iron-deficiency anemia is the most common nutrient deficiency in young children due in part to low dietary intake and poor bioavailability of iron in plant-based foods. Iron-deficiency anemia causes several problems, including weakness, pale skin, shortness of breath, and irritability. It can also result in intellectual, behavioral, or motor problems. Iron-deficiency anemia can occur as toddlers are weaned from iron-rich foods, such as breast milk and iron-fortified formula. Inclusion of iron-rich foods, including lean meats, beans, seafood, and iron-enriched or iron-fortified foods (e.g., cereal) can help prevent iron-deficiency anemia.

Division of Responsibility

The gold standard in feeding toddlers and children is called the Division of Responsibility, designed by Ellyn Satter, a registered dietitian. According to the Division of Responsibility, feeding is a responsibility that is split between the parent/caregiver and the toddler/child:

- Parents and caregivers are responsible for *what* toddlers and children eat, *when* they eat, and *where* they eat.
- Toddlers and children are responsible for *how much* food they eat and *whether* they eat.

Parent/caregiver responsibilities in feeding include:

- selecting and preparing food
- providing regular meals and snacks (3 meals and 2-3 snacks per day is recommended)
- making eating times pleasant
- showing toddlers/children, by example, how to behave at mealtime
- being considerate of food preferences without catering to likes and dislikes
- offering only water between meals and snack times (no other foods or beverages)
- letting toddlers/children grow up to get bodies that are right for them[4]

For additional information on the Division of Responsibility, watch the following video:

YouTube Video

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View this YouTube Video online

Nutrition-Related Concerns for Toddlers and Children

High-Risk Choking Foods

Certain foods (that tend to be small and round) are difficult for toddlers and young children to manage and pose a high risk of choking, including:

- Hot dogs
- Nuts and seeds
- Chunks of meat or cheese
- Whole grapes
- Hard, gooey, or sticky candy
- Popcorn
- Chunks of peanut butter
- Raw vegetables
- Raisins
- Chewing gum
- Marshmallows

Food Neophobia and "Picky Eaters"

Toddlers and children are often picky about what they want to eat, and they are beginning to develop food preferences. Toddlers and children may reject new or unfamiliar foods (food neophobia), but it's helpful to know that food preferences take time to develop. Tips to help when encountering food neophobia and picky eaters include:

- Follow the Division of Responsibility outlined above
- Offer new foods alongside familiar foods
- Offer new foods repeatedly without applying pressure to eat them - it can take 10 or more times of tasting a food before the food is accepted
- Provide a choice between two different nutrient-dense food options (e.g., "Would you like applesauce or banana slices as your snack?")
- Include children in food planning and preparation (e.g., selecting items from a list at the grocery store, tearing lettuce for a salad)

Food Jags

For weeks, toddlers or children may go on a food jag and eat one or two preferred foods—and nothing else. It is important to understand that preferences will be inconsistent as a toddler or child develops eating habits. This is one way that toddlers and children can assert their individuality and independence. However, parents and caregivers should be concerned if the same food jag persists for several months, instead of several weeks. Options for addressing this problem include rotating acceptable foods while continuing to offer a variety of nutrient-dense foods, remaining low-key to avoid exacerbating the problem, and discussing the issue with a pediatrician. In addition, toddlers and children should not be forced to eat foods that they do not want. It is important to remember that food jags do not typically have a long-term effect on health, and are usually temporary situations that will resolve themselves.

Food Allergies and Food Intolerances

Approximately 8% of children have a food allergy; the most common food allergies in children are to peanuts, milk, and shellfish.[5] Although nearly any food can trigger an allergic reaction, the following nine foods cause the majority of reactions: milk, egg, peanuts, soy, wheat, tree nuts, shellfish, fish, and sesame.[6] An allergy occurs when a protein in food triggers an immune response, which results in the release of antibodies, histamine, and other defenders that attack foreign bodies. Possible symptoms include itchy skin, hives, abdominal pain, vomiting, diarrhea, and nausea. Symptoms usually develop within minutes to hours after consuming a food allergen. Anaphylaxis is a life-threatening reaction that results in difficulty breathing, swelling in the mouth and throat, decreased blood pressure, shock, or even death. A dose of the drug epinephrine is often administered via an “EpiPen” to treat a person who goes into anaphylactic shock.

Some children experience a food intolerance, which does not involve an immune response. A food intolerance is marked by unpleasant symptoms (e.g., gas, bloating, diarrhea, stomach pain) that occur after consuming certain foods. Lactose intolerance is one example. Children who suffer from this condition experience an adverse reaction to the lactose in milk products. It is a result of the small intestine’s inability to produce enough of the enzyme lactase, which is produced by the small intestine. Symptoms of lactose intolerance usually affect the GI tract and can include bloating, abdominal pain, gas, nausea, and diarrhea. An intolerance is best managed by making dietary changes and avoiding any foods that trigger the reaction.

For a review of food allergies vs. food intolerances, watch the following video:

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

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Lead Toxicity

There is a danger of lead toxicity, or lead poisoning, among children. Lead is found in plumbing in old homes, in lead-based paint, and occasionally in the soil. Contaminated food and water can increase exposure and result in hazardous lead levels in the blood. Children under age six are especially vulnerable. They may consume items tainted with lead, such as chipped, lead-

based paint. Lead is indestructible, and once it has been ingested, it is difficult for the human body to alter or remove it. It can quietly build up in the body for months, or even years, before the onset of symptoms. Lead toxicity can damage the brain and central nervous system, resulting in impaired thinking, reasoning, and perception. Fortunately, lead toxicity is highly preventable. It involves identifying potential hazards, such as lead paint and pipes, and removing them before children are exposed to them.

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14.4: Nutrition During Adolescence

Learning Objective

- Describe nutrition-related considerations during adolescence.

Puberty is the beginning of adolescence. The onset of puberty brings several changes, including the development of reproductive organs, the onset of menstruation in females, growth spurts, and changes in body composition. Adolescent females typically experience an increase in body fat; adolescent males typically experience greater bone and muscle development. All of these changes must be supported with adequate intake and healthy food choices.

Energy and Macronutrients

The energy requirements for adolescents differ according to sex, growth, and activity level. Nutrient needs are greater in adolescence than at any other time in the life cycle, except during pregnancy. Food choices should focus on nutrient-dense foods instead of empty-calorie foods to support adequate nutrient intake and a healthy body weight. The AMDR for carbohydrates is 45-65% of daily calories; inclusion of whole-grain food choices such as whole-grain bread, corn tortillas, oats, and brown rice are recommended to help meet fiber recommendations for this group. The AMDR for protein is 10-30% of daily calories; lean protein options such as lean meat, poultry, fish, beans, nuts, and seeds are excellent ways to meet needs during adolescence. The AMDR for fat is 25-35% of daily calories; the focus should be on unsaturated plant fats to prevent chronic diseases.

Micronutrients

Key vitamins and minerals needed during adolescence include calcium, iron, vitamin A, and vitamin D. Almost all of these needs should be met with dietary choices, not supplements (iron is an exception since it is hard to get enough iron from food during this stage of life).

- **Calcium:** Adequate calcium intake is essential for building bone and preventing osteoporosis later in life. The calcium recommendation is 1,300 milligrams for both adolescent males and females. Low-fat dairy, almonds, chickpeas, and green leafy vegetables are good sources of calcium. It can also be helpful for adolescents to consume products fortified with calcium, such as breakfast cereals, calcium-fortified soy milk, and calcium-fortified orange juice, to reach the recommended intake.
- **Iron:** Iron supports the development of lean body mass during adolescence. In addition, adolescent females need sufficient iron intake once menstruation starts. Good sources of iron include lean meat, seafood, beans, and fortified foods. Including a vitamin C source (e.g., orange juice, peppers) when eating iron-containing foods can increase iron absorption.
- **Vitamin A:** Vitamin A is critical to support the rapid development and growth that happens during adolescence. Adequate fruit and vegetable intake meets vitamin A needs.
- **Vitamin D:** Vitamin D is required for calcium absorption, making it a critical nutrient for building bone mass during adolescence. Fatty fish and fortified foods (e.g., dairy, orange juice) are good sources of vitamin D.

Nutrition-Related Concerns for Adolescents

Eating Disorders and Disordered Eating

Eating disorders involve extreme behaviors related to food and exercise. They encompass a group of conditions marked by undereating or overeating, as discussed in Chapter 12. It's estimated that 9% of the U.S. population will have an eating disorder in their lifetime, with females being twice as likely as males.[1] Additionally, 22% of children and adolescents worldwide show disordered eating patterns.[2] Because eating disorders and disordered eating often lead to malnourishment, adolescents with these conditions are deprived of the critical nutrients needed for the development and growth that happens during this life stage. It is important to note that eating disorders are considered mental conditions. Treatment includes cognitive, behavioral, and nutritional therapy. The nutrition counseling portion of treatment aims to return the individual to a healthful body weight, teach

normal eating patterns, and address healing their relationship with food, body, and movement.

Obesity

Adolescents need adequate caloric intake for growth, and it is important not to impose restrictive diets. However, exceeding caloric requirements regularly can lead to obesity, which has become a major problem in the United States. According to a national survey, over 22% of adolescents have obesity.[3]

There are several reasons behind the obesity problem, including:

- larger portion sizes
- increased consumption of sugary beverages
- limited access to nutrient-rich foods
- increased access to fast foods and vending machines
- insufficient physical activity and a sedentary lifestyle
- lack of sleep
- community factors (safe environment for physical activity, affordability of healthy food options)
- media messages encouraging the consumption of unhealthy foods

Adolescents who suffer from obesity are more likely to become overweight or obese adults. Obesity has a profound effect on self-esteem, energy, and activity level. In addition, it is a major risk factor for many diseases later in life, including high blood pressure, heart disease, Type 2 diabetes, sleep apnea, joint problems, and certain cancers.[4]

A percentile for body mass index (BMI) specific to age and sex is used to determine if an adolescent is overweight or obese. An adolescent with a BMI higher than that of 85% of U.S. adolescents of the same age and sex would be classified as overweight. If BMI is higher than that of 95% of U.S. adolescents of the same age and sex, the adolescent would be classified as obese. Strategies to combat adolescent overweight and obesity include:

- limiting energy-dense, nutrient-poor snack foods
- increasing fruit and vegetable intake
- encouraging 60 minutes or more of physical activity through fun activities each day
- limiting sedentary activities such as watching television, playing video games, or surfing the internet
- limiting sugar-sweetened beverages

Initially, the goal is not weight loss, but rather allowing height to catch up with weight as the adolescent continues to grow. In situations where there is limited improvement after 3-6 months with lifestyle interventions like the ones noted above, weight loss programs and medications may be pursued.[5]

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14.5: Older Adults and Nutrition

Learning Objectives

- Describe nutrition-related considerations during older adulthood.

Definitions of older adulthood vary, but generally include those who are 65 and older.[1] Older adults may face a variety of nutritional issues and health challenges. For example, immune function declines, short-term memory issues might arise, and slight reductions in height may occur. Other changes include a decline in hormone production (e.g., testosterone, estrogen, growth hormone), muscle mass, and strength. In addition, the heart has to work harder because each pump is not as efficient as it used to be; kidneys are not as effective in excreting metabolic products such as sodium, acid, and potassium, which can alter water balance and increase the risk for over- or under-hydration; and there is lower efficiency in the absorption of vitamins and minerals. Many older adults suffer from serious health conditions, such as cardiovascular disease and cancer. Being either underweight or overweight is also a major concern for older adults. However, older adults can remain in relatively good health and continue to be active. Good nutrition is often the key to maintaining health later in life. In addition, the fitness and nutritional choices made earlier in life set the stage for continued health. Older adults should continue to consume nutrient-dense foods and remain physically active. However, deficiencies are more common after age 60, primarily due to reduced intake or malabsorption. The loss of mobility among frail, homebound older adults also impacts their access to healthy, diverse foods.

Energy and Macronutrients

Due to reductions in lean body mass and metabolic rate, older adults require less energy than younger adults. The decrease in physical activity that is typical of older adults also influences nutritional requirements. Older adults should try to include unrefined carbohydrates, such as whole grains and brown rice. Fiber is especially important in preventing constipation and diverticulitis, and may also reduce the risk of colon cancer. Protein intake should be maintained at or above the RDA (0.8g/kg body weight) to help protect lean body mass; healthy options can include plant proteins and/or lean animal proteins. Healthy fats, such as unsaturated and omega-3 fatty acids, are part of any good diet.

Micronutrients

An increase in certain vitamins and minerals can help maintain health during older adulthood. A few nutrient changes to note include:

- **Calcium:** To slow bone loss, the recommendations for calcium increase from 1,000 mg/day to 1,200 mg/day for men over 70 and women.
- **Vitamin D:** To help protect bones, vitamin D recommendations increase from 15 to 20 micrograms per day for men and women over the age of 70.
- **Vitamin B_6:** To help lower levels of homocysteine and protect against cardiovascular disease, recommendations rise to 1.7 milligrams per day for older men and 1.5 milligrams per day for older women.
- **Vitamin B_{12}:** Stomach acid is critical for the absorption of vitamin B_{12}. As adults age, the production of stomach acid can decrease, which can lead to a vitamin B_{12} deficiency. Vitamin B_{12} also works with folate and vitamin B_6 to reduce cardiovascular disease risk. Individuals consuming a vegan diet or older than 50 years of age are advised to eat foods fortified with vitamin B_{12}, take vitamin B_{12} supplements, or receive vitamin B_{12} injections.
- **Iron:** For older adult women, higher iron levels are no longer needed postmenopause, and recommendations decrease to 8 milligrams per day.

Nutrition-Related Concerns for Older Adults

Dietary choices can help improve health and address some of the nutritional concerns that many older adults face. In addition, there are specific concerns related to nutrition that affect adults in their later years. They include medical problems, such as disability and disease, which can impact diet and activity level. For example, dental problems can lead to difficulties with chewing

and swallowing, which in turn can make it hard to maintain a healthy diet. The use of dentures or the preparation of pureed or chopped foods can help solve this problem. There is also a decreased thirst response in the elderly, and the kidneys have a decreased ability to concentrate urine, both of which can lead to dehydration.

Sensory Issues

Around 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 older adults lose the ability to distinguish between salty, sour, sweet, and bitter flavors. This can make food seem less appealing and decrease appetite. An intake of foods high in sugar and sodium can increase due to an inability to discern those tastes. The sense of smell also decreases, which impacts attitudes toward food. Sensory issues may also affect digestion because the taste and smell of food stimulate the secretion of digestive enzymes in the mouth, stomach, and pancreas.

Gastrointestinal Problems

A number of gastrointestinal issues can affect food intake and digestion among older adults. Saliva production decreases with age, which affects chewing, swallowing, and taste. Digestive secretions decline later in life as well, which can lead to atrophic gastritis (inflammation of the lining of the stomach). This interferes with the absorption of some vitamins and minerals (such as vitamin B_{12}). Reduction of the digestive enzyme lactase results in a decreased tolerance for dairy products. Slower gastrointestinal motility can result in more constipation, gas, and bloating. Slower gastrointestinal motility can also result from low fluid intake, decreased physical activity, and a diet low in fiber, fruits, and vegetables.

Dysphagia

Some older adults have difficulty getting adequate nutrition because of the disorder dysphagia, which impairs the ability to swallow. Any damage to the parts of the brain that control swallowing can result in dysphagia. Therefore, stroke and dementia are two common causes of dysphagia. 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 a more successful and safe swallowing process. 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 patients with dysphagia.

Obesity

Similar to other life stages, obesity is a concern for older adults. Being overweight or obese increases the risk for potentially fatal conditions that can afflict older adults, particularly cardiovascular disease and type 2 diabetes. Obesity also contributes to 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 as well as fat, which can exacerbate the loss of muscle mass due to aging. Although weight loss among older adults 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 older adults, 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 older adults leads to a higher risk for immune deficiency, frequent falls, muscle loss, and cognitive deficits. Decreased intake may be due to a variety of reasons, including disability, a lack of motivation to eat, or skipping meals. Nutrition interventions should focus primarily on a healthy diet. Remedies can include increasing meal frequency and adding healthy, high-calorie foods (e.g., nuts, avocados, dried fruits) to the diet. Liquid supplements between meals may also help improve caloric intake.

Vision Problems

Many older people suffer from vision problems and vision loss. Age-related macular degeneration (see Figure 14.5.1) is an eye disease that can blur the sharp, central vision you need for activities like reading, driving, and cooking; it is the leading cause of vision loss for older adults.[2] This disorder can make food planning and preparation extremely difficult; people who suffer from it often must depend on caregivers for their meals. Self-feeding also may be difficult if an older adult cannot see his or her

food clearly. Friends and family members can help older adults with shopping and cooking. Food-assistance programs for older adults (such as Meals on Wheels) can also be helpful. Diet may help prevent macular degeneration. Consuming colorful fruits and vegetables increases the intake of lutein and zeaxanthin, two antioxidants that are associated with eye health.[3] Lutein and zeaxanthin are found in green, leafy vegetables such as spinach, kale, and collard greens.



Figure 14.5.1: Normal vision vs. vision with macular degeneration. (CC BY-NC 4.0; Henry Eye Clinic)

Neurological Conditions

Older adults who suffer from dementia may experience memory loss, agitation, and delusions. Experts suggest that more than 6 million Americans, most of them age 65 or older, suffer from Alzheimer's, which is the most common form of dementia.[5] These conditions can have serious effects on diet and nutrition as a person increasingly becomes incapable of caring for himself or herself, which includes the inability to buy and prepare food and to self-feed.

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15: FOOD SAFETY, TECHNOLOGY, SECURITY, AND SUSTAINABILITY

15.1: Foodborne Illness and Food Safety
15.2: Food Technology
15.3: Food Security
15.4: Food Sustainability

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15.1: Foodborne Illness and Food Safety

Learning Objectives

- Identify groups at risk for foodborne illness.
- Describe the major types of foodborne illness.
- Identify various causes of food contamination.
- Describe steps to prevent foodborne illness.
- Identify federal agencies that regulate food.

Foodborne illness is a serious threat to health. Sometimes called “food poisoning,” foodborne illness is a common public health problem that can result from exposure to a pathogen or a toxin in food or beverages. Raw foods, such as seafood, produce, and meats, can all be contaminated during harvest (or slaughter for meats), processing, packaging, or during distribution. For all kinds of food, contamination also can occur during preparation and cooking in a home kitchen or in 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. The CDC estimates that 48 million Americans get sick from a foodborne illness each year.[1] Foodborne illness can range from mild stomach upset to severe symptoms, or even death.

At-Risk Groups

No one is immune to consuming contaminated food. But whether you become seriously ill depends on the microorganism, the amount you have consumed, and your overall health. In addition, some groups have a higher risk than others for developing severe complications from foodborne illness, including:

- young children
- elderly people
- pregnant people
- people with compromised immune systems from medical conditions, such as diabetes, liver disease, kidney disease, organ transplants, or HIV/AIDS, or from receiving chemotherapy or radiation treatment

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.

Major Types of Foodborne Illness

Foodborne illnesses are classified as either food infections or food intoxications. The difference depends on the agent that causes the condition. Microbes, such as bacteria, cause food infections, while toxins, such as the kind produced by molds, cause food intoxications. Different diseases manifest in different ways, so signs and symptoms can vary with the source of contamination. The microbe or toxin enters the body through the gastrointestinal tract, and as a result, common symptoms include diarrhea, nausea, and abdominal pain. Additional symptoms may include vomiting, dehydration, lightheadedness, and rapid heartbeat. More severe complications can include a high fever, diarrhea that lasts more than three days, prolonged vomiting, bloody stools, and signs of shock.

One of the biggest misconceptions about foodborne illness is that it is always triggered by the last meal that a person ate. However, it may take several days or more before the onset of symptoms. If you develop a foodborne illness, you should rest and drink plenty of fluids.

Food Infection

Food infections are caused by consuming food or beverages contaminated with bacteria, viruses, or parasites. The infection

then grows inside the body and becomes the source of symptoms (e.g., diarrhea, vomiting). Bacteria, one of the most common agents of food infection, are single-celled microorganisms (also called microbes) 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. To reproduce within food, microorganisms require the following conditions:

- **Temperature.** Microorganisms multiply more rapidly when the temperature is between 40°F and 140°F, which is called the danger zone (see Figure 15.1.1).
- **Water.** Many microorganisms require a high moisture content to multiply. Fresh fruits and vegetables have the highest moisture content.
- **Oxygen.** Most microorganisms need oxygen to grow and multiply, but a few are anaerobic (do not need oxygen to grow).
- **Acidity (pH) Level.** Most microorganisms grow best in a slightly acidic to neutral environment (around 4.6-7.0 on the pH scale).

Food Intoxication

Food intoxications are caused by microorganisms that secrete toxins (harmful chemicals) that bind to cells in the body and cause a variety of symptoms. Toxins are categorized as:

- **Enterotoxins.** Enterotoxins affect the gastrointestinal system and cause symptoms such as abdominal cramping, diarrhea, and vomiting.
- **Neurotoxins.** Neurotoxins affect the nervous system and can cause neurological damage or paralysis. For example, *Clostridium botulinum* produces a toxin that blocks nerve transmissions to muscle cells. *Clostridium botulinum* can grow in an oxygen-free environment. It can be present in honey, so honey should not be given to infants.

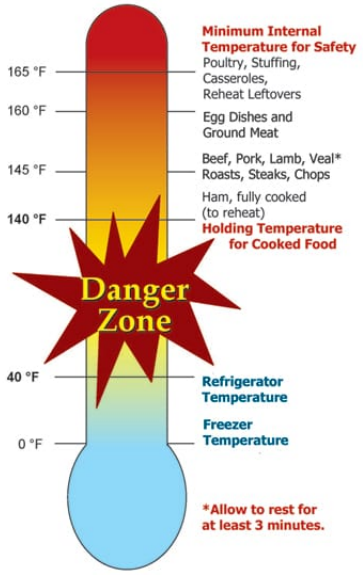


Figure 15.1.1: Danger Zone and Minimum Internal Temperatures. (CC0 1.0; Food Safety and Inspection Service, USDA)

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 this section, we will focus on several causes of food contamination, including bacteria, viruses, parasites, and mold toxins.

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 do not destroy the bacteria completely. The microbes can reactivate when the food is taken out and thawed. Table 15.1.1 lists the symptoms, when symptoms begin, and common food sources for several bacteria that cause foodborne illness.

Table 15.1.1: Bacteria that Cause Foodborne Illness[1,2]

Bacteria	Timeframe for onset of symptoms	Symptoms	Common food sources
Campylobacter	2-5 days	bloody diarrhea, stomach cramps, fever	raw or undercooked poultry, unpasteurized milk, contaminated water
Clostridium botulinum	18-36 hours	blurred vision, slurred speech, difficulty swallowing or breathing, muscle weakness, paralysis	improperly canned or fermented food, honey
Clostridium perfringens	6 - 24 hours	diarrhea, stomach cramps	beef or poultry; gravies
Escherichia coli (E. coli)	3-4 days	severe stomach cramps, bloody diarrhea, vomiting	raw or undercooked beef, unpasteurized milk or juice, raw vegetables (such as lettuce or sprouts), contaminated water
Listeria monocytogenes	2 weeks	fever, muscle aches, headache, stiff neck, confusion	queso fresco and other soft cheeses, raw sprouts, melons, hot dogs, deli meats, smoked seafood, unpasteurized milk
Salmonella	6 hours - 6 days	diarrhea, fever, stomach cramps, vomiting	raw or undercooked chicken or turkey; eggs; unpasteurized milk or juice
Staphylococcus aureus (Staph)	30 minutes - 8 hours	nausea, vomiting, stomach cramps, diarrhea	foods that are handled without workers washing hands; foods not cooked after handling (such as sliced meats, sandwiches, pastries)
Vibrio	within 24 hours	watery diarrhea, nausea, stomach cramps, vomiting, fever, chills	raw or undercooked shellfish (particularly oysters)

Viruses

Viruses are another type of pathogen that can lead to food infections; however, they are less prominent than bacteria.

- The most common form of contamination from handled foods is the norovirus. You can get norovirus from having direct contact with an infected person, consuming contaminated food/water, or touching contaminated surfaces then putting your unwashed hands in your mouth. The norovirus is very contagious (part of the reason for this is that the virus is able to survive on surfaces for weeks); symptoms include vomiting and diarrhea that typically develop 12-48 hours after being exposed to the virus.[3]
- Hepatitis A is another food-contaminating virus. 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 1 month after exposure. At first, symptoms include loss of appetite, nausea, vomiting, and fever. Additional symptoms, including jaundice and darkened urine, can appear 3-10 days later. Severe cases of hepatitis A can result in liver damage and death.

Parasites

Food-contaminating parasites are microscopic organisms that simultaneously derive benefit from and harm their host. The most common parasites that cause foodborne illness are helminths and protozoa.

- Helminths are multicellular worms (e.g., tapeworms and roundworms). Helminths reproduce by releasing eggs; animals may consume the eggs, which then develop into larvae that can survive even after the animal is killed. Eating raw or undercooked meat can lead to ingesting the larvae. Thorough cooking destroys the larvae.

- Protozoa are single-celled organisms. There are several different types of protozoa (e.g., *Toxoplasma gondii* or *Giardia*). People typically become infected after eating undercooked, contaminated meat or from drinking contaminated water.

Prions

Prions are animal proteins that misfold and become infectious. Prions go on to destroy normal proteins to the point that nerve tissues lose their function, leading to neurological disease (known as variant Creutzfeldt-Jakob disease) and eventually death.

Mold Toxins

Warm, humid, or damp conditions encourage mold to grow on food. Molds are microscopic fungi that live on animals and plants. Under a microscope, molds look like slender mushrooms. They have stalks with spores that form at the ends. The spores give molds their color, allow the mold to reproduce, and can be transported by air, water, or insects. Molds also have root-like threads that may grow deep into food and be difficult to see. The threads are very deep when a food shows heavy mold growth. Foods that contain mold may also have bacteria growing alongside it.

Some molds, like the kind found in blue cheese, are desirable in foods, while other molds can be dangerous. The spores of some molds can cause allergic reactions and respiratory problems. In the right conditions, a few molds produce mycotoxins, which are natural, poisonous substances that can make you sick if they are consumed. Mycotoxins are contained in and around mold threads, and in some cases, may have spread throughout the food.

Can You Cut Mold Off Food?



It depends.

Generally, if you see mold on food, your best bet is to throw the food away, clean the area where the food was stored, and check nearby items the moldy food might have touched for contamination. Foods that have a high moisture content (e.g., lunch meats, leftovers, soft cheeses, yogurt, soft fruits and vegetables, bread) can be contaminated beyond what you see, so cutting/scooping out the mold may not get rid of mold threads or any bacteria growing along with the mold.

However, it is ok to cut off the mold on some foods. Cut off at least 1 inch around and below the mold spot in hard cheeses (e.g., parmesan, aged cheddar, aged gouda) and firm fruits and vegetables (e.g., cabbage, bell peppers, carrots, apples) prior to eating the food. Make sure to keep the knife out of the mold itself to prevent contaminating other parts of the food.[4]

Preventing Foodborne Illness

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:[5]

- **Clean.** Wash hands thoroughly with warm, soapy water for at least 20 seconds before preparing food and every time after handling raw foods. Clean surfaces often and wash utensils after each use. Wash fruits and vegetables (even if you plan to peel them).
- **Separate.** Don't cross-contaminate food during preparation and storage. Use separate cutting boards for produce and for meat, poultry, seafood, and eggs. Store food products separately in the refrigerator.
- **Cook.** Heat food to proper temperatures. Use a food thermometer to check the temperature of food while it is cooking. It can be helpful to check a cooking temperature chart. If food is not served immediately after cooking, keep food hot (140°F or above) after it has been cooked.
- **Chill.** Refrigerate any leftovers within 2 hours. Make sure your refrigerator is set to 40°F or below and your freezer is set to 0°F or below. Never thaw or marinate food on the counter; it's best to thaw or marinate food in the refrigerator to prevent bacteria growth. Know when to keep food and when to throw it out by checking a safe storage time chart. It is helpful to label leftovers with the date the food was made to help track when the leftovers should be thrown out.

For a review of food safety and tips you can use while shopping and at home, watch the following video from the U.S. Food and Drug Administration (FDA):

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

Food Regulation

Food regulatory agencies work to protect the consumer and ensure the safety of our food. Food regulation is divided among different agencies, primarily the Food and Drug Administration (FDA) and the United States Department of Agriculture (USDA). 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, while the USDA is in charge of the eggs once they are out of their shells.

The Food and Drug Administration (FDA)

The FDA enforces the safety of domestic and imported foods. It also monitors supplements, food labels, claims that corporations make about the benefits of products, and pharmaceutical drugs. Sometimes, the FDA must recall contaminated foods and remove them from the market to protect public health. Recalls are almost always voluntary and often are requested by companies after a problem has been discovered. In rare cases, the FDA will request a recall. But no matter what triggers the removal of a product, the FDA's role is to oversee the strategy and assess the adequacy and effectiveness of the recall.

The United States Department of Agriculture (USDA)

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. The USDA also assures food safety, and in particular oversees the regulation of meat, poultry, and processed egg products.

The Environmental Protection Agency (EPA)

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. The agency conducts environmental assessment, education, research,

and regulation. The EPA also works to prevent pollution and protect natural resources. Two of its many regulatory practices in the area of agriculture include overseeing water quality and the use of pesticides.

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15.2: Food Technology

Learning Objectives

- Describe various food preservation techniques.
- Identify food additives and their uses.
- Discuss the pros and cons of genetic modification.
- Discuss food residues.

Food technology is the application of food science to develop, preserve, process, package, and distribute food products.[1] In this section we'll cover several topics related to food technology including food preservation, food additives, genetic modification, and food residues.

Food Preservation

Food preservation includes the handling or treating of food to prevent or slow down spoilage. Preservation guards against foodborne illnesses and also protects the flavor, color, moisture content, or nutritive value of food. There are many different ways to preserve food. Some methods that have been practiced for generations include curing, smoking, pickling, drying, salting, fermenting, canning, freezing, and refrigeration. Others methods include:

- **Pasteurization.** This technique exposes the food/beverage to high heat for a short period of time. This method is effective in killing microorganisms that may cause spoilage or foodborne illness. Since the food/beverage is only exposed for a short amount of time (typically less than 20 seconds), taste and quality are not impacted.
- **Aseptic packaging.** Food and beverages are first sterilized using ultra-high temperatures, then cooled and placed in sterile containers that are then sealed.
- **Modified atmosphere packaging.** The oxygen in a package of food (e.g., meat, fish, fruits, vegetables) is replaced with nitrogen or carbon dioxide to prevent chemical reactions that spoil food and slow growth of bacteria that require oxygen.
- **Irradiation.** This process involves treating food with ionizing radiation, which kills the bacteria and parasites that cause toxicity and disease. Irradiated food must be labeled with a Radura symbol (see Figure 15.2.1).



Figure 15.2.1: Radura symbol used for irradiated food in US. (CC0; by United States Department of Agriculture, Food Safety and Inspection Service via Wikimedia Commons)

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 used to enhance the food in some way. Some control acidity and alkalinity, while others enhance the color or flavor of food. Some additives stabilize food and keep it from breaking down, while others add body or texture. Currently, there are more than 3,000 food additives used in the United States. Table 15.2.1 lists some common food

additives and their uses.

Table 15.2.1*: Food Additives*[2,3]

Additive	Uses
Beta-carotene	Adds color to food
Citric acid	Increases tartness to prevent food from becoming rancid
Dextrin	Thickens gravies, sauces, and baking mixes
Gelatin	Stabilizes, thickens, or adds texture to food
Modified food starch	Keeps ingredients from separating and prevents lumps
Monosodium glutamate (MSG)	Enhances flavor in a variety of foods
Pectin	Gives candies and jams a gel-like texture
Polysorbates	Blends oil and water and keeps them from separating
Soy lecithin	Emulsifies and stabilizes chocolate, margarine, and other items
Sulfites	Prevent discoloration in dried fruits
Xanthan gum	Thickens, emulsifies, and stabilizes dairy products and dressings

The FDA works to protect the public from potentially dangerous additives. Passed in 1958, the Food Additives Amendment states that a manufacturer is responsible for demonstrating the safety of an additive before it can be approved. The Delaney Clause that was added to this legislation prohibits the approval of any additive found to cause cancer in animals or humans. However, most additives are considered to be “Generally Recognized as Safe” (GRAS), an FDA designation for food additives that experts consider safe for consumption. Additives on the GRAS list do not need prior review/approval from the FDA when they are added to foods. Examples of items on the GRAS list include citric acid, gelatin, lecithin, salt, and vinegar.

Food additives are typically included in the processing stage to improve the quality and consistency of a product. Many additives also make items more “shelf stable,” meaning they will last a lot longer on store shelves and can generate more profit for store owners. Additives can also help to prevent spoilage that results from changes in temperature, damage during distribution, and other adverse conditions. In addition, food additives can protect consumers from exposure to rancid products and foodborne illnesses.

Food additives aren’t always beneficial, however. Some substances have been associated with certain diseases if consumed in large amounts. For example, the FDA estimates that sulfites can cause allergic reactions in 1% of the general population and in 5% of asthmatics. Similarly, the additive monosodium glutamate (MSG) may cause headaches, nausea, weakness, difficulty breathing, rapid heartbeat, and chest pain in some individuals.

Bioengineering / Genetic Modification

Bioengineering, also known as genetic modification, is the process of changing an organism (plant or animal) by manipulating its genetic material. Examples of genetic modification include selective breeding and recombinant DNA technology. The result is a plant or animal with desirable characteristics (for example, a crop that has improved resistance to pesticides, disease, and/or drought). Foods that have undergone genetic modification (GM) using recombinant DNA technology are referred to as genetically modified organisms (GMOs). In the United States, most of the soybean, corn, sugarbeet, and canola crops are genetically modified.[4] Food products that are bioengineered or contain a bioengineered ingredient must include a disclosure on the package or label (see Figures 15.2.2*a* and 15.2.2*b* for examples).



Figure 15.2.2*a*: Bioengineered Text Disclosure (CC BY 4.0; Ann Diker



Figure 15.2.2*b*: Bioengineered Symbol (CC0 1.0; USDA)

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 modification has improved productivity for farmers (e.g., faster growing crops that use less water and produce higher yields), it has also stirred up debate about consumer safety and environmental protection. Possible side effects related to the consumption of GM foods include an increase in allergenicity, or tendencies to provoke allergic reactions. There is also some concern related to the possible transfer of the genes used to create genetically engineered foods from plants to people. This could influence human health if antibiotic-resistant genes are transferred to the consumer. Therefore, the World Health Organization (WHO) and other groups have encouraged the use of genetic engineering without antibiotic-resistance genes. There are also concerns that GMO crops will lead to a lack of biodiversity and growth of superweeds that have a tolerance to herbicides. Genetically modified plants may adversely affect the environment as well and could lead to the contamination of conventional crops.[5]

Food Residues

Food residues are chemicals that remain on foods after cleaning and processing. Two food residues of concern include persistent organic pollutants and pesticides.

Persistent Organic Pollutants (POPs)

Persistent organic pollutants (POPs) are chemicals that are released into the environment through improper waste disposal and emissions from industry, agriculture, and automobiles. Once in the soil or water, these POPs can persist (continue to exist) for years or decades and potentially cause problems if the pollutants are absorbed and accumulate in plants or animals. For example, fish that swim in polluted waters can contain significant amounts of pollutants that can be passed on to consumers that eat those fish.

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, older homes with lead-based paint, 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 (e.g., swordfish, shark, king mackerel, tilefish) 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.

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 strawberries, spinach, kale, grapes, and peaches; foods that contain the lowest levels of pesticide residue include avocados, sweet corn, pineapples, onions, and papaya.[6]

In some 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.

Some consumers choose to reduce their exposure to pesticides by purchasing organic produce. Organic foods are grown or produced without synthetic pesticides or fertilizer. Organic farmers may rely on alternatives to synthetic pesticide use including crop rotation, natural pesticides, and planting nonfood crops nearby to lure pests away. Foods that are labeled organic must meet the following definitions:

- **Organic.** Products that contain at least 95% organically produced ingredients (by weight), excluding water and salt. Non-organic ingredients cannot make up more than 5% of the combined total ingredients. Products that meet this definition can display the USDA Organic Seal (Figure 15.2.3).
- **Made with organic ingredients.** Products that contain at least 70% organic ingredients; these products *cannot* display the organic seal.



Figure 15.2.3: USDA Organic Seal (CC0; by United States Department of Agriculture via Wikimedia Commons)

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15.3: Food Security

Learning Objectives

- Describe food security and the various levels of food insecurity.
- Identify groups at risk of food insecurity.
- Describe various food assistance programs that seek to mitigate hunger in the United States.

Adequate food intake that meets nutritional requirements is essential to achieve a healthy, productive lifestyle. However, millions of people in the U.S. go hungry and are malnourished each year due to a recurring and involuntary lack of food. Measurements related to this lack of food are often stated in terms of food security and food insecurity.

Food Security and Food Insecurity

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, some U.S. households experience food insecurity at certain points during the year, which means their access to food is limited due to a lack of money or other resources. Figure 15.3.1 shows the food security status of U.S. households during 2024, including:

- **Food secure households.** These households had access, at all times, to enough food for an active, healthy life for all household members. Throughout 2024, 86.3% of U.S. households were food secure.
- **Food-insecure households.** At times during the year, these households were uncertain of having, or unable to acquire, enough food to meet the needs of all their members because they had insufficient money or other resources for food. Throughout 2024, 13.7% of U.S. households were food insecure. Food-insecure households are further categorized as:
  - **Low food security households.** These food-insecure households obtained enough food to avoid substantially disrupting their eating patterns or reducing food intake by using a variety of coping strategies, such as eating less-varied diets, participating in Federal food assistance programs, or getting emergency food from community food pantries. During 2024, 8.3% of U.S. households had low food security.
  - **Very low food security households.** In these food-insecure households, normal eating patterns of one or more household members were disrupted, and food intake was reduced at times during the year because they had insufficient money or other resources for food. About 5.4% of U.S. households had very low food security at some time during 2024.

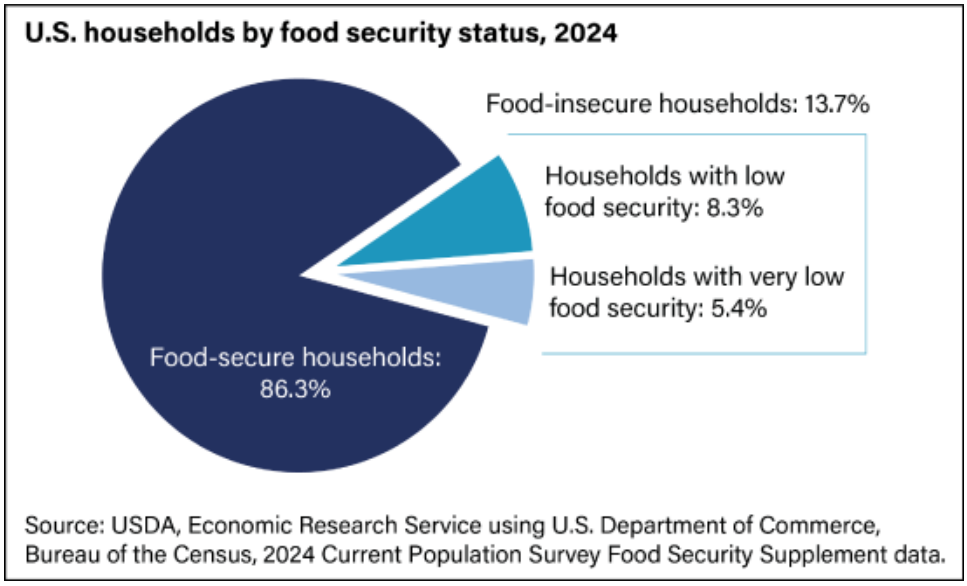


Figure 15.3.1: Food security status of U.S. households. (CC0; by United States Department of Agriculture, Economic Research Service)

At-Risk Groups

Groups at risk for food insecurity include:

- Households with children
- Women or men living alone
- Black, non-Hispanic households
- Hispanic households
- Families consisting of single mothers or single fathers and their children
- Rural areas
- Households in the southern U.S.
- Low-income households with incomes below 185% of the poverty guideline (the poverty guideline was $33,000 for a family of four in 2026)[1]

Figure 15.3.2 illustrates the higher rates of food insecurity for two of these at-risk groups - Black households and Hispanic households.

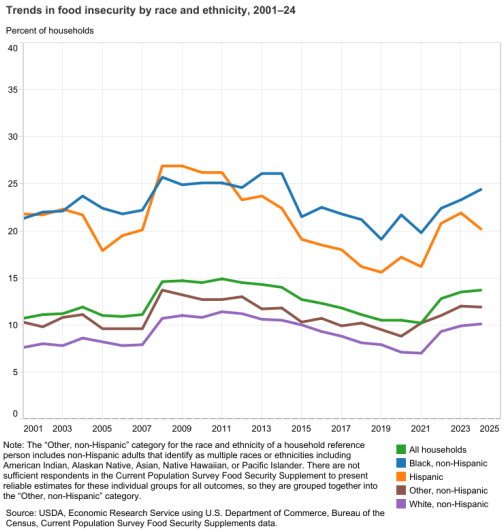


Figure 15.3.2: Food insecurity trends by race and ethnicity. (CC0; by USDA Economic Research Service)

Food Assistance Programs

The federal government has established several programs to alleviate hunger and ensure that many low-income families receive the nutrition needed to live a healthy life. Eligibility for these programs is often based on income and household size (e.g., income must be at or below 130%, 185%, or 200% of the federal poverty guideline, depending on the program). Programs include:

- **Supplemental Nutrition Assistance Program.** With over 42 million participants,[2] the Supplemental Nutrition Assistance Program (SNAP) provides monthly benefits for low-income households to purchase approved food items at authorized stores. Clients qualify for the program based on available household income, assets, and certain basic expenses. 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.
- **Special Supplemental Nutrition Program for Women, Infants, and Children.** The Special Supplemental Nutrition Program for Women, Infants and Children (WIC) serves nearly 7 million participants by providing food packages to pregnant and breastfeeding women, infants, and children up to age five, to promote adequate intake for healthy growth and development.[3] Most state WIC programs provide vouchers that participants use to acquire supplemental packages at authorized stores.
- **National School Lunch Program.** The National School Lunch Program serves over 22 million participants, and the School Breakfast Program serves approximately 13 million participants.[4] These programs provide nutritionally balanced, low-cost or

free breakfasts and/or lunches to children each school day.

- **Child and Adult Care Food Program.** The Child and Adult Care Food Program serves nearly 5 million participants by offering meals and snacks at child care centers, daycare homes, adult day care centers, and afterschool care programs.[4]
- **Summer Food Service Program.** The Summer Food Service Program provides free meals and snacks at schools, parks, and other neighborhood locations to nearly 3 million children during summer break.[4]

Other Forms of Assistance

Other forms of assistance include locally operated charitable organizations, such as food banks and food pantries, which acquire food from local manufacturers, retailers, farmers, and community members to give to low-income individuals and families. Neighborhood soup kitchens provide meals to the homeless and other people in need. These and other organizations are run by nonprofit groups, as well as religious institutions, to provide an additional safety net for those in need of food.

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15.4: Food Sustainability

Learning Objectives

- Identify food-related practices that positively impact food system sustainability.

Sustainability is the ability to meet basic needs (now and in the future) without undermining natural resources and environmental quality. The term relates to the goal of achieving a world that meets the needs of its present inhabitants while preserving resources for future generations. It includes agricultural practices and processes, along with the choices that consumers make when they shop for their food. Ideally, sustainable practices include methods that are healthy, conserve the environment, protect livestock, respect food industry workers, provide fair wages to farmers, and support farming communities. When a practice or a process is sustainable, it can be maintained for decades or even centuries to come.

We often notice the monetary cost of food when we purchase it. However, there are other costs as well, including the economic, social, and environmental costs that impact the sustainability of the entire food system. Individuals interested in eating more sustainably can consider the suggested solutions and sustainable alternatives provided by the University of Michigan's Center for Sustainable Systems[1]:

- **Eat less meat.** Meat-based diets use more energy to produce and are associated with more greenhouse gas emissions than vegetarian diets.
- **Reduce waste.** Much of household food waste is due to spoilage. Prevent food from going bad by buying smaller amounts, planning meals, and sticking to shopping lists. For foods that have a "use by" best if used by" or "sell by" date, those dates do not refer to the safety of the food - they indicate when the food will be at its best quality; avoid waste by looking for signs of spoilage in addition to the date on the product.
- **Eat organic.** Organic farms don't use chemicals that require large amounts of energy to produce, pollute soil and water, and cause human health impacts.
- **Eat local.** Transportation accounts for approximately 14% of the total energy used in the US food system. Eating locally grown food and consolidating shopping trips can reduce this impact. Community Supported Agriculture and Farmers' Markets are two ways to support local food systems.

Concerns exist about contaminants in our food supply and the sustainability of our oceans. One concern involves microplastics - tiny pieces of plastic material that may enter our food and water. More research is needed to fully understand the impact of microplastics on the environment and our health, but current strategies focus on reducing plastic waste to limit the release of microplastics (see Figure 15.4.1).[2,3]



Figure 15.4.1: Reducing plastic waste. (eufic.org)

Another concern is related to the sustainability of our oceans and seafood. The Monterey Bay Aquarium's video below includes information about seafood selection to avoid contaminants and to eat sustainably.

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

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"Make Better Seafood Choices" by Seafood Watch

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GLOSSARY

A

Acceptable Macronutrient Distribution Range (AMDR) | The recommended range of intake for energy-yielding macronutrients (carbohydrates, protein, and fat). It is expressed as percentages of total daily calorie intake sufficient to provide total adequate energy needs. Staying within the AMDR is associated with reducing the risks for developing chronic disease.

added sugars | Sugars, and other sweeteners (e.g., high-fructose corn syrup, honey, maple syrup, and molasses), that are added to food, whether it be at the table, in cooking, or in processing.

adequate | Sufficient for a goal or purpose. In nutrition, it is used to signify a diet that provides all nutrients, fiber, and energy in amounts sufficient to maintaining good health and body weight.

Adequate Intake (AI) | The average nutrient level consumed daily by the average healthy population that is assumed to be adequate to meet this population's needs. If the scientific data is insufficient to establish an Estimated Average Requirement (EAR), the AI is established based on the data available. The AI serves as a nutrient-intake goal.

adipose tissue | Fatty tissue in the body that consists of masses of fat-storing cells.

adolescence | The period of the human life cycle, between the ages of 14-18 years old, nutritionally speaking.

aerobic | Requires oxygen.

age-related macular degeneration (AMD) | The progressive loss of central vision with age, resulting from damage to the macula (the center of the retina).

albumin | A butterfly-shaped protein that plays a role in fluid balance, acid-base balance, and the transport of biological molecules.

alcohol | In chemistry, alcohol refers to organic compounds that have an -OH group attached as a side group. In alcoholic beverages, the alcohol that is being consumed is ethanol.

alpha-linolenic acid | An essential fatty acid found in leafy greens and some nuts.

amino acids | The building blocks of proteins. Simple organic compounds composed of carbon, oxygen, hydrogen, and nitrogen.

amphiphilic | A compound that has both water-loving and fat-loving properties.

anabolism | The metabolic pathways that use energy to build larger molecules from smaller ones.

anaerobic | The absence of oxygen.

anaphylaxis | A life-threatening, extreme immune response to a food allergen. Anaphylaxis can result in difficulty breathing, swelling in the mouth and throat, decreased blood pressure, shock, and death.

anorexia nervosa | A psychiatric illness in which a person obsesses over their weight, and losing weight by refusing to eat. It results in extreme nutrient inadequacy and, eventually, organ malfunction.

anorexia of aging | A condition that elderly people can get that is characterized by poor food intake.

antibodies | Proteins in the blood that protect against unwanted intruders (such as bacteria or viruses) in the body.

antioxidant | Any molecule that protects cells from the damage caused by free radicals. Antioxidants can block free radicals from stealing electrons.

appetite | A psychological desire for food or drink.

arachidonic acid (ARA) | An omega-6 essential fatty acid that is a precursor tot the synthesis of eicosanoids. It is a polyunsaturated fatty acid that is in found in animal cells.

atherosclerosis | Disease that is characterized by the deposition of plaques and fatty material in the walls of the body's artery, vein and blood vessel network.

atoms | The basic building blocks of all matter, living and nonliving.

atrophic gastritis | Inflammation of the stomach.

B

balanced diet | A diet that provides the appropriate quantities and proportions of foods needed to maintain health. In a balanced diet, foods rich in one nutrient leave room for foods that are rich in other nutrients.

basal metabolic rate (BMR) | The number of calories being burned while performing basic life-sustaining functions.

basal metabolism | Metabolic pathways necessary to support and maintain the basic functions of the body (e.g. breathing, heartbeat, liver, and

kidney function) while at rest.

bile | A fluid secreted by the liver to help with the absorption and digestion of fats.

binge-eating disorder | A nonpsychiatric disorder characterized by periodic losses of control over eating. The periods of excessive overeating are not followed by fasting or purging. People who have this disorder are often overweight or obese.

bioavailability | the proportion of a nutrient that is absorbed and used by the body

Blood Alcohol Concentration (BAC) | A measurement of the alcohol level in the blood stream, used to determine if an individual is legally intoxicated and/or driving while impaired.

Body Mass Index (BMI) | A measurement that is based on one's height and weight. It is indicative of obesity and overweight and is a more comprehensive measurement of body fat than just weight alone.

bone remodeling | The process in which bone tissue is broken down and rebuilt in the same location to create more mature bone tissue.

bone resorption | The process in which osteoclasts secrete hydrogen ions to make the bone tissue more acidic and dissolve the minerals in the bone tissue matrix.

bulimia | A psychiatric illness characterized by frequent episodes of eating large amounts of food followed by purging.

C

caffeine | A chemical stimulant, also known as xanthine. It is found in the seeds, leaves, and fruits of many plants, where it acts as a natural pesticide. It is the most widely consume psychoactive substance, as it is found primarily in coffee and tea.

calcitonin | A hormone, secreted by the thyroid, that aids in the maintenance of blood calcium levels by decreasing calcium levels when necessary. It has the opposite effect of calcitriol and parathyroid hormone.

calcium | The most abundant mineral in mineralized bone tissue. Good dietary sources of calcium are dairy products and many vegetables with low oxalate content, such as kale, collard greens, and okra.

calorie | A unit of energy. A calorie is equivalent to the amount of energy needed to increase the temperature of 1 gram of water by 1 degree Celsius.

carbohydrates | Organic molecules composed of carbon, hydrogen, and oxygen. There are two basic forms: simple sugars and complex sugars.

cardiorespiratory endurance | The cardiovascular system’s ability to deliver oxygen and nutrients efficiently to fuel physical activity.

cardiovascular disease | A disease of the heart or blood vessels.

catabolism | All metabolic processes involved in breaking down molecules, which releases energy.

celiac disease | An autoimmune disorder in which the small intestine has an abnormal reaction with gluten.

cell theory | Cells are the most basic building units of life, all living things are composed of cells, and new cells are made from preexisting cells, which divide into two.

cellular respiration | The process by which organisms combine oxygen with the stored chemical energy in nutrients to produce cellular energy.

central nervous system | Neurons form the core of the central nervous system, which consists of the brain, spinal cord, and other nerve bundles. The main function of the central nervous system is to sense changes in the external environment and create a reaction to them.

chemical energy | Potential energy that is stored in the bonds of chemical compounds.

chylomicron | Chylomicron clusters form when lipids are combined with carrier proteins in the cells of the intestinal lining. Chylomicron is a vehicle of transport for fats throughout the watery environment of the body to the liver and other tissues.

chyme | An acidic fluid that moves from the stomach to the small intestine. It consists of gastric juices and partially digested foods.

circulatory system | Consists of the heart, blood, and blood vessels. The main functions of this system are to transport nutrients to all cells and transport waste from all cells.

cis fatty acid | A fatty acid with the hydrogen atoms bonded to the same side of the carbon chain.

coenzymes | Organic compounds required by many enzymes for catalytic activity.

cofactors | Minerals that make up part of enzymes required for converting a substrate to an end-product.

collagen | A strong, fibrous protein typically found in skin and other connective tissues.

complementary foods | A combination of foods that when consumed together (though not necessarily at the same time) contain all nine essential amino acids at adequate levels.

complete protein | Foods that contain all nine of the essential amino acids.

concentration | The amount of particles in a set volume of water.

conditionally essential | Nutrients that are required in higher amounts only under special conditions, such as pregnancy, growth, stress, illness, or aging.

cortical bone | Dense, strong bone that surrounds trabecular bone tissue. Also called compact bone.

D

dehydration | Water loss from the body without adequate replacement.

dementia | A disorder of the nervous system characterized by changes in the normal activity of the brain. It can be marked by memory disorders, personality changes, and altered reasoning.

denaturation | The physical changes that can modify the molecular structure of a protein under abnormal conditions.

dietary fiber | Polysaccharides that are highly branched, typically only found in plants, and not digested by the body.

Dietary Reference Intakes (DRIs) | A set of nutrient recommendations that includes the Estimated Average Requirement (EAR), Recommended Dietary Allowance (RDA), Adequate Intake (AI), Tolerable Upper Intake Level (UL), Chronic Disease Risk Reduction Intake (CDRR), and Acceptable Macronutrient Distribution Range (AMDR).

diglyceride | A product of lipid digestion, consisting of a glycerol molecule that has two fatty acids attached.

disaccharide | Two monosaccharides joined together. The most common disaccharides are sucrose, lactose, and maltose.

disease | Any abnormal condition that affects the health of an organism and is characterized by specific signs and symptoms.

diuretic | A substance or drug that increases urine production.

diverticulitis | Inflammation of the diverticulum, or the out-pockets in the lining of the colon. Symptoms include lower abdominal pain, nausea, and alternating between constipation and diarrhea.

docosahexaenoic acid (DHA) | An omega-3 fatty acid that is especially important for brain growth and development in infants. Sources of DHA include cold-water fish, dairy, and eggs.

dual energy X-ray absorptiometry (DEXA) | An imaging test performed to measure bone density. The procedure involves two X-ray beams passing through a person to calculate the amount of calcified tissue in grams per unit area of bone.

E

eating disorder | A behavioral condition that involves extreme attitudes and behaviors toward food and nutrition. These disorders are characterized by overeating or under eating, and include anorexia nervosa, binge-eating disorder, and bulimia nervosa.

edema | Swelling caused by excess fluid trapped in your body's tissues.

eicosanoids | Compounds derived from polyunsaturated fatty acids that control several body functions.

eicosapentaenoic acid (EPA) | An omega-3 fatty acid that is made from linolenic acid; it is most commonly found in fish.

electrolyte | A substance that contains ions. Examples of electrolytes include sodium and potassium.

embolism | Blood vessel obstruction caused by a mass, such as a detached blood clot or other foreign body, that circulates in the bloodstream.

emulsifier | A compound that stabilizes emulsions by allowing two immiscible liquids to combine without separation.

energy | The quantity of work a particular system can perform.

energy balance | When energy intake is equal to energy expended.

energy drinks | Beverages containing extremely high levels of caffeine.

energy metabolism | The metabolic pathways that release or store energy.

enzymes | Proteins that conduct a specific chemical reaction in order to transform substrates into a product.

epidemiological studies | Scientific investigations that define frequency, distribution, and patterns of health events in a population.

erythrocyte | Red blood cell.

essential amino acids | Amino acids that cannot be made by the body and must come from the diet.

essential fatty acids | Fatty acids that the body cannot synthesize in adequate amounts and must be supplied through the diet.

Estimated Average Requirement (EAR) | Average daily nutrient intake levels estimated to meet the needs of 50% of the target population. It is used in nutrition research and policy-making. EARs form the basis for which RDA values are set.

Estimated Energy Requirement (EER) | Energy intake values that have been established to preserve energy balance in healthy adults of a specific age, sex, weight, and height, and category of physical activity concurrent with good health.

estrogen | Primary female reproductive hormone.

exchange reaction | A chemical reaction in which anions and cations of the reactants exchange their positions in the products.

extrusion reflex | An involuntary reflex that causes infants to push food out of their mouths with their tongues to avoid choking.

F

failure-to-thrive (FTT) | A condition in children, characterized by inadequate growth or weight gain due to any cause.

fatty acids | Organic compounds that have a carboxylic acid (-COOH) group on one end and a methyl group (-CH3) on the other end.

fermentable sugars | Sugars such as glucose, fructose, and maltose that are easily metabolized by bacteria in a process known as fermentation.

fetus | An unborn baby.

flexibility | Capability of joints to move in a wide range of motion.

fluoride | A mineral that blocks tooth decay and is part of mineralized bone tissue. The primary dietary source is fluoridated water.

food additives | Natural or man-made substances added to food during processing to improve it's appearance, quality, and/or preservation.

food allergy | After eating certain kinds of food, the immune system reacts shortly thereafter producing symptoms such as digestive troubles, swollen airways, hives, or possible death.

food desert | A location that provides little to no access to affordable nutritious foods.

food infections | Foodborne illness caused by bacteria, viruses, or parasites.

food insecurity | The situation of not having continual access to sufficient, safe, and nutritious food to achieve an active, healthy lifestyle.

food intoxications | Foodborne illness caused by natural toxins or harmful chemicals.

food jag | A behavior exhibited by a young child who insists upon eating the same foods over and over again.

food security | The situation of having adequate access to food and ability to consume enough nutrients to achieve a healthy lifestyle.

foodborne illness | An illness caused by consuming contaminated food or drinks.

free radical | A molecule that has one or more unpaired electrons, making it highly reactive and unstable.

G

gastroesophageal reflux | A disorder that occurs when stomach acid rises into the esophagus.

gastroesophageal reflux disease (GERD) | A persistent form of acid reflux, in which acidic contents of the stomach leak backward into the esophagus and cause irritation more than two times per week.

gestation | The process of carrying in the uterus; the time spent in the uterus between conception and birth.

gestational diabetes | A metabolic condition characterized by elevated glucose levels in the blood during pregnancy.

gestational hypertension | High blood pressure during pregnancy.

glucagon | A hormone produced by the pancreas that controls glucose levels in the blood.

gluconeogenesis | A metabolic pathway that results in the formation of new glucose molecules in the body.

glycemic index (GI) | A measurement that ranks foods containing carbohydrates, based on their effects on blood-sugar levels.

glycogen | A highly branched macromolecule consisting of thousands of glucose monomers held together by chemical bonds.

glycogenesis | process of converting excess glucose into glycogen for storage

glycogenolysis | process of converting glycogen into glucose

glycolysis | The first stage of glucose breakdown; a ten-step enzymatic process that splits glucose into two three-carbon molecules and yields two molecules of ATP.

H

hard water | Water that has a high amount of dissolved minerals (particularly calcium and magnesium).

heat capacity | The amount of heat needed to raise the temperature of the body by one degree Celsius.

heat stroke | Failure of the body's temperature-regulating mechanism when exposed to excessively high temperatures; a condition caused by the body overheating.

hemoglobin | A protein that transports oxygen in the blood.

high-density lipoprotein (HDL) | High-density lipoproteins are also known as "good cholesterol." They contain a high percentage of protein and a low percentage of cholesterol. They collect and transport excess cholesterol and return it to the liver to be reused or excreted.

hindmilk | High-fat, high-calorie breast milk that the baby receives towards the end of a feeding.

homocysteine | An amino acid produced by the body.

hormones | Biological molecules transported in the blood that regulate cellular processes in other tissues.

hunger | The physiological feeling of discomfort or weakness caused by a lack of food.

hyperkalemia | Elevated potassium levels in the blood.

hyperlipidemia | Excessive fat, or lipids, in the blood.

hypertension | Abnormally high blood pressure. The force of the blood against the arterial walls is strong enough that it could lead to heart disease or other health issues.

hypoglycemia | Lower than normal levels of glucose in the blood.

hyponatremia | Lower than normal level of sodium in the blood.

I

immune system | The immune system is made up of several different types of white blood cells and other components that act as barricades to foreign invaders. The functions of the immune system are to barricade, seek, recruit, attack, and destroy foreign invaders, such as bacteria and viruses.

immunoglobulins | Proteins produced by plasma cells that function as antibodies.

inorganic | Not consisting of or deriving from living matter. In chemistry, it refers to any compound that does not contain carbon.

insensible water loss | The amount of body fluid that is lost daily and not easily measured.

insulin | A hormone produced by the pancreas that regulates the amount of glucose in the blood.

interventional clinical trial studies | Scientific investigations in which a variable is changed between groups of people.

intrinsic factor | A protein produced by the stomach that increases vitamin B12 absorption in the intestines.

iron-deficiency anemia | A condition that develops from having insufficient iron levels in the body, resulting in fewer and smaller red blood cells containing lower amounts of hemoglobin. Signs and symptoms include fatigue, weakness, pale skin, shortness of breath, dizziness, swollen and sore tongue, and abnormal heart rate.

irradiation | The use of radiation on foods for sterilization and the removal of harmful bacteria or pathogens.

irritable bowel syndrome (IBS) | A disorder characterized by muscle spasms in the colon that result in abdominal pain, bloating, constipation, and/or diarrhea. There is no permanent structural damage to the large intestine.

J

jaundice | A condition characterized by yellow discoloration of the skin or whites of the eyes.

K

ketoacidosis | A condition where high levels of ketones in the body cause the blood to become more acidic.

ketones | Acidic organic compounds that are a byproduct of fat metabolism; typically produced when the body uses fat as an energy source instead of glucose.

kilocalorie (Calorie) | A unit of energy. It is the amount of heat, that is generated by a macronutrient, to raise the temperature of 1 kilogram of water by 1 degree Celsius. Kilocalories are listed on the Nutrition Facts label as "Calories".

kwashiorkor | A syndrome of severe protein and micronutrient deficiency, characterized by swelling (edema) of the feet and abdomen, poor skin health, growth retardation, low muscle mass, and liver malfunction.

L

lactation | The medical term for the process of producing and secreting breast milk.

lactose intolerance | The inability to digest lactose, caused by a deficiency of the enzyme lactase.

leukocytes | White blood cells that play a role in the body's immune system; they help the body fight infections and diseases.

life cycle | The span of a human life, which includes different stages such as infancy, childhood, adolescence, adulthood, and older age.

lifestyle | The way in which a person lives. The components of lifestyle are dietary habits, physical activity levels, recreational drug use, and sleeping patterns, which all play a role in health and impact nutrition.

linoleic acid | An omega-6 fatty acid that is essential for human health.

lipase | A pancreatic enzyme that is responsible for the breakdown of fats in food so that they can be absorbed.

lipids | A family of organic compounds composed of carbon, hydrogen, and oxygen. They are insoluble in water. The three main types of lipids are triglycerides, phospholipids, and sterols.

lipoprotein | A group of proteins that transport fats in the body.

low-density lipoprotein (LDL) | Low-density lipoproteins are also known as "bad cholesterol." They contain high concentrations of

triacylglycerols and low concentrations of proteins. They are responsible for delivering cholesterol to the tissues in the body.

M

macronutrients | Nutrients that are needed in large amounts. Includes carbohydrates, lipids, proteins, and water.

magnesium | A mineral that is involved in nerve signaling, healthy bone building, and muscle contractions. Dietary sources of magnesium include meat, fish, dairy products, whole grains, nuts, chocolate, and coffee.

marasmus | A syndrome of severe protein and energy deficiency, characterized by emaciation, poor skin health, and growth retardation.

mechanical breakdown | Chewing, followed by muscular contractions in the esophagus, stomach and small intestines to break down food and transport it to the rest of the digestive system.

metabolic syndrome | A medical condition in which people have three or more risk factors for Type 2 diabetes and cardiovascular disease.

metabolism | The chemical reactions in the body's cells that change food into energy.

metastasis | Spread of cancerous cells from an original location to one or more new sites within the body.

micelles | Lipid molecules that arrange themselves in a sphere.

micronutrients | Nutrients (including vitamins and minerals) needed in small amounts for normal growth and development.

moderation | Eating only as much as the body needs. Not eating to the extremes, neither too much nor too little.

monoglyceride | A product of lipid digestion, consisting of a glycerol molecule with one fatty acid attached.

monosaccharide | The simplest unit of a carbohydrate. The most common monosaccharides are glucose, fructose, and galactose.

morbidity | The condition of suffering from a disease or medical condition.

mortality | death

motility | movement

muscle endurance | The muscle's ability to perform repetitive movements for a lengthy period of time.

muscular system | The organ system that includes skeletal muscle, smooth muscle, and cardiac muscle. This system is responsible for mobility and stability.

mutual supplementation | The process of combining two or more incomplete protein sources to make a complete protein.

mycotoxins | Natural, poisonous substances produced by certain molds and mushrooms that can cause foodborne illness.

N

non-nutrients | Substances absorbed from food that are not strictly required by the body to function.

nonessential amino acid | Amino acids that are produced by the body.

nutrient | Substances that are required for the body that must be obtained from the diet to aid in growth and maintenance of life.

nutrient-dense | Foods that are high in nutrients (vitamins, minerals, complex carbohydrates, lean protein, and healthy fats), but relatively low in calories.

Nutrition Facts label | Found on most packaged foods. Contains information such as amounts of calories, sugar, fat, vitamins, minerals, etc. Compares the amounts of nutrients in the food to the recommended intake values - these are reported as percent DV. Ingredients are also listed on the label.

nutritional science | The investigation of how an organism is nourished, and how this nourishment affects personal, population, and planetary health.

nutritionist | Health-care professionals who work in the field of nutrition, but do not have the credentials to be Registered Dietitian Nutritionists (RD/RDN).

O

obese | Having excess body fat (BMI greater than 30 for adults; BMI at the 95th percentile or higher for children and teens).

oligosaccharide | A carbohydrate that is a chain of a few (3-10) monosaccharides.

organ | A group of tissues arranged in a specific manner to support a common function.

organ systems | Two or more organs that work together to support a specific physiological function.

organelles | A structural or functional unit in a cell that is constructed from several macromolecules bonded together.

organic | Relating to or derived from living matter. In chemistry, it refers to any compound that contains carbon. When used to describe food and/or farming practices, it refers to food grown or produced without synthetic pesticides or fertilizer.

organism | A complete living system that is capable of conducting all basic life processes.

osmosis | The movement of water through a selectively permeable membrane to the area that has more solutes.

osteoblast | A cell that helps build bone.

osteoclast | A cell that helps break down bone.

osteocytes | Star-shaped cells that are the most abundant cell type in bone tissue.

osteoid | Bone tissue that is not mineralized.

osteomalacia | Similar to rickets, this disease involves softening and weakening of the bones in adults due to a lack of vitamin D or a problem metabolizing the vitamin.

osteopenia | Lower than normal bone mass.

overweight | Having excess weight (BMI of 25.0-29.9 for adults; BMI from the 85th to less than the 95th percentile for children and teens).

oxidation | The interaction between oxygen molecules and all the different substances they may contact. Can be more precisely defined as the loss of at least one electron when two or more substances interact and these substances may or may not include oxygen.

oxidative stress | An imbalance in any cell, tissue, or organ between the amount of free radicals and the capabilities of its detoxifying and repair systems.

P

pancreatic amylase | Enzyme secreted by the pancreas that breaks down carbohydrates in the small intestine by breaking the glycosidic bonds between monomers.

peak bone mass | The greatest amount of bone mass that a person reaches during their lifetime.

pepsin | An enzyme secreted by stomach that breaks the peptide bonds between amino acids to produce shorter protein fragments.

peptide bond | The chemical bond that connects amino acids.

percent Daily Value (%DV) | The percentage of how much the nutrient in a serving contributes to the Daily Value based on a 2,000-calorie diet.

peristalsis | Waves of smooth muscle contraction that propel food down the digestive tract.

persistent organic pollutants (POPs) | Hazardous organic compounds that are resistant to biodegradation and can have an adverse effect on human and environmental health.

pesticide | A substance used for destroying insects or other organisms.

phospholipids | Lipids that have a glycerol backbone attached to two fatty acids and a phosphate group.

phosphorus | A mineral that makes up a substantial part of mineralized bone tissue. The dietary sources are meat, fish, and dairy products, as well as processed foods, and cola beverages.

physical activity | Any bodily movement that is produced by the skeletal muscles that requires energy.

physical fitness | The ability of the body systems to work together efficiently to promote good health and strength.

phytochemicals | Nonessential plant compounds considered to have a beneficial impact on human health.

pincer grasp | A grip that involves picking up an object with the thumb and index finger.

platelets | Fragments of cells that, when stimulated by blood vessel injury, rush to the site of injury to help form blood clots to stop bleeding at the wound site.

point of unsaturation | The place on a molecule where additional hydrogen atoms can attach; typically indicates the place where there is a double bond between two carbon atoms.

polysaccharides | A long chain of monosaccharides that may be branched or not branched.

polyunsaturated fatty acid | A fatty acid that contains two or more double bonds (points of unsaturation).

prebiotics | Specialized plant fibers that act as food for "good" bacteria.

prediabetes | A metabolic condition in which people have moderately high glucose levels, but do not meet the criteria for diagnosis as a diabetic.

preeclampsia | A possible complication of pregnancy marked by elevated blood pressure and high levels of protein in the urine.

preventive nutrition | The use of dietary practices to reduce disease and promote health and well-being.

probiotics | Living strains of bacteria that add to the population of "good" bacteria in the digestive system.

prolactin | A hormone produced by the pituitary gland that causes the breasts to grow and make milk during and after pregnancy.

proteases | Enzymes that break down proteins.

protein turnover | The processes of continually breaking down proteins and building new ones.

proteins | Macromolecules composed of amino acids.

R

randomized clinical interventional trial studies | Scientific investigations in which there is a control group and experimental group to help determine a causal relationship.

Recommended Dietary Allowances (RDA) | Nutrient-intake goals designed to meet the requirements of 97-98% of the target group for a given nutrient.

risk factor | A variable that increases the chance of developing a disease or adverse outcome.

S

satiety | The sensation of feeling full; determined by mechanical and chemical signals relayed from the periphery.

scientific method | The process of inquiry that involves making an observation, coming up with a hypothesis, conducting a test of that hypothesis, evaluating results, gathering more supporting evidence, and coming up with a conclusion.

sedentary behavior | Activity that requires less than 1.5 times the amount of energy expended while at rest (examples include sitting, reclining, or lying down while awake).

socioeconomic status | A measurement dependent on three variables; income, occupation, and education.

soluble fiber | Fiber that attracts water and turns to gel, which slows digestion. Soluble fiber is readily fermented in the colon by bacteria into gases and waste byproducts.

solute | Any dissolved substance in a fluid.

solvent | A substance in which other materials dissolve.

subsidies | Federal funding given to an agricultural producer to provide assistance and support.

sugar alcohols | Carbohydrates that occur naturally in some fruits and vegetables; however they are industrially synthesized by yeast and other microbes for use as food additives.

supplements | Vitamins, minerals, and herbs which are taken in addition to your regular diet to promote healthy body functions or to target specific body parts.

T

T-score | How much a result differs from the average. In bone density tests, it compares the patient's bone density to the average peak bone density of a healthy 30-year-old population of the same sex.

taste threshold | Minimum concentration at which taste sensitivity to a food or substance can be perceived.

teratogens | Substances that can cause birth defects or abnormalities in developing embryos or fetuses.

tissues | A group of cells that share a common structure and function and that work together.

Tolerable Upper Intake Levels (UL) | The highest average daily nutrient-intake level at which a nutrient can be consumed before it poses a risk of toxicity.

trabecular bone | Porous bone that forms the inner structure of the bone. Also called spongy bone.

trace mineral | Nutrients that we need to consume in amounts less than 100 milligrams per day.

trans fatty acid | A fatty acid that has hydrogens attached on opposite sides of the carbon chain.

transamination | The process of transferring an amine group from one molecule to another, typically to form new amino acids.

transcription | The process of copying a segment of DNA into RNA.

translation | The process of converting a sequence of a messenger RNA (mRNA) molecule to a sequence of amino acids during protein synthesis.

triacylglycerols | The most common type of fat in the body, composed of one glycerol molecule and three fatty acid molecules. Also called triglycerides.

triglycerides | The most common type of fat in the body, composed of one glycerol molecule and three fatty acid molecules. Also called triacylglycerols.

Type 1 diabetes | A metabolic disease in which cells in the pancreas are killed by an abnormal response of the immune system, causing a lack of insulin in the body.

Type 2 diabetes | A metabolic disease of insulin insufficiency; also caused by muscle, liver, and fat cells no longer responding to the insulin in the body.

V

variety | Consuming an abundance of foods from different food groups on a regular basis.

very low-density lipoprotein (VLDL) | Lipoproteins that are formed in the liver and released in the bloodstream. VLDL carries triglycerides to target tissues.

visceral fat | The fat that is stored within the abdominal cavity.

vitamin D | Both a vitamin and a hormone, vitamin D plays an essential role in maintaining calcium homeostasis. A deficiency in vitamin D compromises bone health.

vitamin K | A vitamin that acts as a coenzyme that modifies proteins important for bone health. The dietary sources are green vegetables such as broccoli, cabbage, kale, parsley, spinach, and lettuce.

W

waist-to-hip ratio | A comparison of waist size to hip size. It is calculated by dividing the waist circumference by the hip circumference.

water-soluble | Able to be dissolved in water.

wellness | Achieving balance and integration of aspects that affect quality of life, including physical, mental, emotional, social, environmental, and spiritual dimensions.

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