INTRODUCTION TO NUTRITION



Ann Diker
Metropolitan State University of Denver



Introduction to Nutrition

This text is disseminated via the Open Education Resource (OER) LibreTexts Project (https://LibreTexts.org) and like the thousands of other texts available within this powerful platform, it is freely available for reading, printing, and "consuming."

The LibreTexts mission is to bring together students, faculty, and scholars in a collaborative effort to provide an accessible, and comprehensive platform that empowers our community to develop, curate, adapt, and adopt openly licensed resources and technologies; through these efforts we can reduce the financial burden born from traditional educational resource costs, ensuring education is more accessible for students and communities worldwide.

Most, but not all, pages in the library have licenses that may allow individuals to make changes, save, and print this book. Carefully consult the applicable license(s) before pursuing such effects. Instructors can adopt existing LibreTexts texts or Remix them to quickly build course-specific resources to meet the needs of their students. Unlike traditional textbooks, LibreTexts' web based origins allow powerful integration of advanced features and new technologies to support learning.



LibreTexts is the adaptable, user-friendly non-profit open education resource platform that educators trust for creating, customizing, and sharing accessible, interactive textbooks, adaptive homework, and ancillary materials. We collaborate with individuals and organizations to champion open education initiatives, support institutional publishing programs, drive curriculum development projects, and more.

The LibreTexts libraries are Powered by NICE CXone Expert and was supported by the Department of Education Open Textbook Pilot Project, the California Education Learning Lab, the UC Davis Office of the Provost, the UC Davis Library, the California State University Affordable Learning Solutions Program, and Merlot. This material is based upon work supported by the National Science Foundation under Grant No. 1246120, 1525057, and 1413739.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation nor the US Department of Education.

Have questions or comments? For information about adoptions or adaptions contact info@LibreTexts.org or visit our main website at https://LibreTexts.org.

This text was compiled on 06/07/2026

TABLE OF CONTENTS

Licensing

1: Foundational Concepts

- 1.1: Defining Nutrition, Health, and Disease
- 1.2: Overview of Nutrients and Calories
- 1.3: The Broad Role of Nutritional Science
- 1.4: Nutrition and the Media

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: Dietary Supplements
- 2.6: Understanding Food Labels
- 2.7: Understanding Portion Sizes
- 2.8: Is Alcohol Part of a Healthy Diet?

3: Digestion

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

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

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

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
- 6.6: Vegetarian and Vegan Diets

7: Nutrients Important for Fluid and Electrolyte Balance

- 7.1: Overview of Fluid and Electrolyte Balance
- 7.2: Functions of Water
- 7.3: Regulation of Water Balance
- 7.4: Electrolytes
- 7.5: Understanding Dehydration and Heat Illnesses

8: Nutrients Important for Antioxidant Activity and Vision

- 8.1: Introduction to Free Radicals and Antioxidants
- 8.2: Antioxidant Nutrients
- 8.3: Vitamin A and Vision
- 8.4: Cancer

9: Nutrients Important for Bone Health

- 9.1: Bone Structure and Function
- 9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D
- 9.3: Other Essential Micronutrients for Bone Health
- 9.4: Osteoporosis

10: Nutrients Important for Metabolism and Blood Function

- 10.1: Overview of Blood and Metabolism
- 10.2: Vitamins Important for Metabolism and Blood Function
- 10.3: Minerals Important for Metabolism and Blood Function

11: Energy Balance

- 11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution
- 11.2: Balancing Energy Intake with Energy Output
- 11.3: Physical Fitness and Physical Activity
- 11.4: Fuel and Nutrient Needs for Physical Activity
- 11.5: Health Risks of Overweight and Underweight
- 11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain

12: Lifecycle Nutrition: Pregnancy to the Toddler Years

- 12.1: Pregnancy and Nutrition
- 12.2: Infancy and Nutrition
- 12.3: Nutrition in the Toddler Years

13: Lifecycle Nutrition: Childhood to Late Adulthood

- 13.1: Childhood and Nutrition
- 13.2: Early Adolescence and Nutrition
- 13.3: Older Adolescence and Nutrition
- 13.4: Young Adulthood and Nutrition
- 13.5: Middle Age and Nutrition
- 13.6: Older Adults and Nutrition

14: Food Safety, Technology, Security, and Sustainability

- 14.1: Foodborne Illness and Food Safety
- 14.2: Food Technology
- 14.3: Food Security
- 14.4: Food Sustainability

Index

Glossary

Detailed Licensing

Licensing

*A detailed breakdown of this resource's licensing can be found in **Back Matter/Detailed Licensing**.*

CHAPTER OVERVIEW

1: Foundational Concepts

1.1: Defining Nutrition, Health, and Disease
1.2: Overview of Nutrients and Calories
1.3: The Broad Role of Nutritional Science
1.4: Nutrition and the Media

This page titled 1: Foundational Concepts is shared under a CC BY-NC-SA 4.0 license and was authored, remixed, and/or curated by Ann Diker.

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 super models 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, and includes the study of how nourishment affects personal health, population health, and planetary health. Nutrition science includes a wide spectrum of disciplines such as biology, physiology, immunology, biochemistry, education, psychology, sustainability, and sociology. Without adequate nutrition the human body does not function optimally, and severe nutritional inadequacy can lead to disease and even death. Nutrition is a relatively new discipline of science. Early research in nutrition focused on nutrient 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).

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, to think clearly, to communicate, to hope, to dream, to go to school, to gain knowledge, to go to work, to earn a living, and to do all of the things that you like to do are dependent upon one factor—your health. Good health means you are able to function normally and work hard to achieve your goals in life. 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."

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, leading 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 eating too much of certain foods is linked to chronic diseases. We now know that diet-related conditions and diseases include hypertension (high blood pressure), obesity, Type 2 diabetes, cardiovascular disease, some cancers, and osteoporosis. These diet-related conditions and diseases are some of the biggest killers of Americans. For example, research indicates that unhealthy diets accounted for 529,299 deaths in 2016, with 84% of those deaths due to cardiovascular diseases.[1] The Dietary Guidelines for Americans [2], 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 at first to many people. However, creative cooks can adapt healthy foods to meet most peoples’ taste.
- **Economics.** Access to fresh fruits and vegetables may be 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.** The media greatly influences food choice by persuading consumers to eat certain foods.
- **Social factors.** Any school lunchroom observer can testify to the impact of peer pressure on eating habits, and this influence lasts through adulthood. People make food choices based on how they see others and want others to see them. For example, individuals can purchase cheap and fast pizzas or opt for high-end versions at fancy restaurants.
- **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.

Key Takeaways

- Nutrition science is the investigation of how an organism is nourished, and includes how nourishment affects personal health, population health, and planetary health.
- Health is a state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity.
- Disease is defined as any abnormal condition that affects the health of an organism, and is characterized by specific signs and symptoms.
- Diet-related conditions and diseases include obesity, Type 2 diabetes, cardiovascular disease, some cancers, and osteoporosis.
- Good nutrition provides a mechanism to promote health and prevent disease.
- The *Dietary Guidelines for Americans* aim to promote health and prevent disease by outlining ways to improve your overall eating patterns.
- Numerous factors other than nutrition influence food choices.

References

1. The US Burden of Disease Collaborators. The State of US Health, 1990-2016: Burden of Diseases, Injuries, and Risk Factors Among US States. *JAMA.* 2018;319(14):1444–1472. doi:10.1001/jama.2018.0158.

2. *U.S. Department of Agriculture and U.S. Department of Health and Human Services. Dietary Guidelines for Americans, 2020-2025. 9th Edition. December 2020. Available at DietaryGuidelines.gov.* Accessed May 9, 2025.

This page titled 1.1: Defining Nutrition, Health, and Disease is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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 diet, since the human body does not synthesize them, or does not synthesize them in large enough amounts for human health. Nutrients are used for many body functions such as growing, moving your muscles, repairing tissues and much more! 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

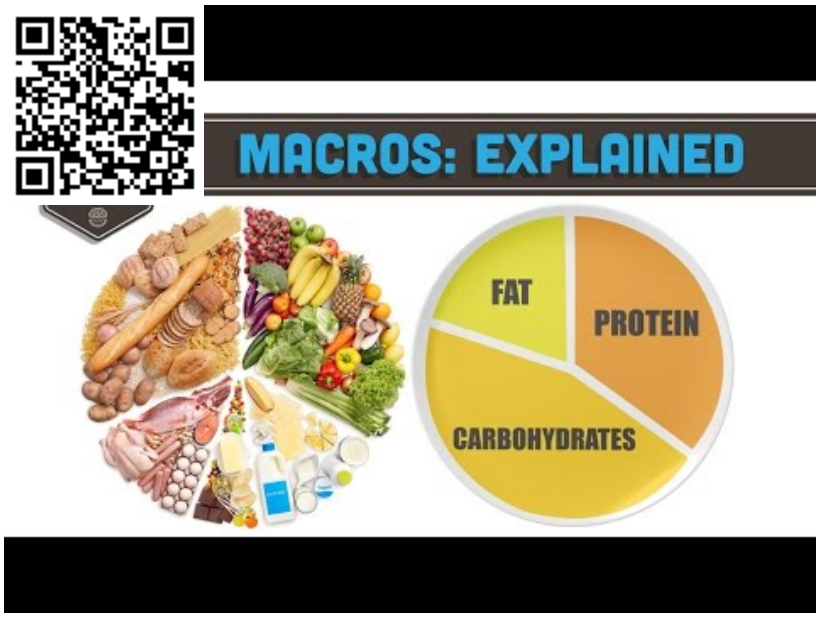
Nutrient	Organic vs. Inorganic	Functions
Carbohydrates	Organic	• Provide a ready source of energy for the body (sometimes referred to as the preferred source of energy for the body). • Provide structural constituents for the formation of cells.
Lipids (Fats)	Organic	• Provide stored energy for the body. • Function as structural components of cells. • Function as signaling molecules for proper cellular communication. • Provide insulation to vital organs. • Helps 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 macronutrients (and you can also read more about macronutrients below the video):



"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 7.

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 7-10.

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:



"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

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



"What is a Calorie?" by Emma Bryce

Key Takeaways

- Foods contain nutrients that are essential for our bodies to function.
- Four of the classes of nutrients required for bodily function are needed in large amounts. They are carbohydrates, lipids, proteins, and water, and are referred to as macronutrients.
- Two of the classes of nutrients are needed in lesser amounts, but are still essential for bodily function. They are vitamins and minerals.
- The "energy yielding" nutrients are carbohydrates, lipids (fats), and proteins. Carbohydrates provide 4 calories for every gram we consume; fats provide 9 calories for every gram we consume; and proteins provide 4 calories for every gram we consume.

This page titled 1.2: Overview of Nutrients and Calories is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

1.3: The Broad Role of Nutritional Science

Learning Objectives

- Describe the scientific method.
- Identify various types of scientific studies.

The Scientific Method

Similar to the method by which a police detective finally charges a criminal with a crime, nutritional scientists discover the health effects of food and its nutrients by first making an observation. Once observations are made, they come up with a hypothesis, test their hypothesis, and then interpret the results. After this, they gather additional evidence from multiple sources and finally come up with a conclusion on whether the food suspect fits the claim. This organized process of inquiry used in forensic science, nutritional science, and every other science is called the scientific method.

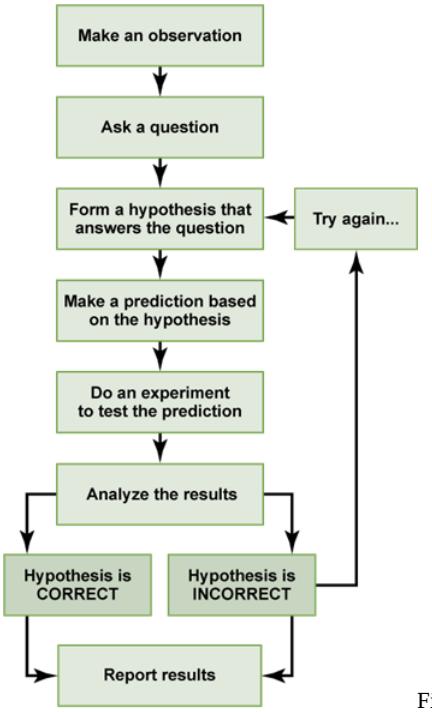


Figure 1.3.1: Steps of the scientific method (CNX OpenStax / CC BY creativecommons.org/licenses/by/4.0)

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. The researcher makes an observation and description of an event.
    - 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. The researcher proposes a hypothesis (educated guess) to explain why the event occurs.
    - A hypothesis is also referred to as a research 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. The researcher develops an experiment that will test the hypothesis.
    - An experiment is a scientific study that tests the hypothesis.
    - 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).
  - Scientists compare the 2 groups by plotting variables on a graph.
    - Independent variable
      - *controlled* by the researcher
      - plotted on the horizontal axis (x axis)
      - example: the number of apples eaten per day
    - Dependent variable
      - not controlled by the researcher
      - *observed* or *measured* by the researcher
      - plotted on the vertical axis (y axis)
      - also called the outcome variable
      - example: the number of doctor visits
- Researcher 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. 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 an alternate hypothesis may be proposed and tested.
   - If the data support the original hypothesis, then a conclusion is drawn. More experiments are typically conducted to further test and confirm support for the hypothesis.
   - If multiple experiments consistently support the hypothesis, then the hypothesis becomes more widely accepted in the scientific community.

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.

- **Observation.** Eating seaweed is a cure for goiter, a gross enlargement of the thyroid gland in the neck.
- **Hypothesis.** In 1813, Swiss physician Jean-Francois Coindet hypothesized that the seaweed contained iodine and he could use just iodine instead of seaweed to treat his patients.
- **Experimental test.** Coindet administered iodine tincture orally to his patients with goiter.
- **Interpret results.** Coindet’s iodine treatment was successful.
- **Gathering more evidence.** Many other physicians contributed to the research on iodine deficiency and goiter.
- **Hypothesis.** French chemist 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).
- **Experimental test.** In the late 1860s the program, “The stamping-out of goiter,” started with people in several villages in France being given iodine tablets.
- **Results.** The program was effective and 80 percent of goitrous children were cured.
- **Hypothesis.** In 1918, Swiss doctor Bayard proposed iodizing salt as a good way to treat areas endemic with goiter.

- **Experimental test.** Iodized salt was transported by mules to a small village at the base of the Matterhorn where more than 75 percent of school children were goitrous. It was given to families to use for six months.
- **Results.** The iodized salt was beneficial in treating goiter in this remote population.
- **Experimental test.** Physician David Marine conducted the first experiment of treating goiter with iodized salt in America in Akron, Ohio.
- **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 the scourge of goiterism. Today more than 70 percent of American households use iodized salt and many other countries have followed the same public health strategy to reduce the health consequences of iodine deficiency.

Evidence-Based Approach to Nutrition

It took 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 USDA and HHS, which are departments of the US federal government. The USDA and HHS websites are great tools for discovering ways to optimize health; however, it is important to gather nutrition information from multiple resources as there are often differences in opinion among various scientists and public health organizations. While the latest *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. For example, the Harvard School of Public Health (HSPH) feels the government falls short by being "too lax on refined grains." The guidelines recommend getting at least *half* of grains from whole grains—according to the HSPH this still leaves too much consumption of refined grains.

Types of Scientific Studies

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

Epidemiological Studies

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

Epidemiological studies are used to examine and evaluate public health. 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 between two things happening but NOT whether one factor CAUSED the other. Epidemiological studies may give us ideas but those ideas need clinical trials to figure out what the patterns mean.

Clinical Trials

Interventional clinical trial studies are scientific investigations in which a variable is changed between groups of people. When well done, this type of study allows one to determine causal relationships. An example of an interventional clinical trial is a study in

Spain that is investigating the effect of a the Mediterranean diet on prevention of cardiovascular diseases. There are many studies that are part of the Prevention with Mediterranean Diet (PREDIMED) trials. In one study[4], 7,447 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 clinical interventional trial studies are:

- those studies that include a sufficient number of participants;
- those that include a control group, which does not receive the intervention, to which you can compare the people who receive the intervention being tested;
- those in which the subjects are randomized into the 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.
- ideally, neither the researchers nor the participants will 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 interventional trial studies are powerful tools to provide supporting evidence for a particular relationship and are considered the “gold standard” of scientific studies. However, from their limitations it is clear that epidemiological studies complement interventional clinical trial studies and both are necessary to construct strong foundations of scientific evidence for health promotion and disease prevention.

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.)

Laboratory Studies

Other scientific studies used to provide supporting evidence for a hypothesis include laboratory studies conducted on animals or cells. An advantage of this type of study is that they typically do not cost as much as human studies and they require less time to conduct. 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.

Evolving Science

Science is always moving forward, albeit sometimes slowly. 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 to accumulate before incorporating some change in our diet.

One of the newest areas in the realm of nutritional science is the scientific discipline of nutritional genetics, also called nutrigenomics. Genes are part of DNA and contain the genetic information that make up all our traits. Genes are codes for proteins and when they are turned “on” or “off,” they change how the body works. While we know that health is defined as more than just the absence of disease, there are currently very few accurate genetic markers of good health. Rather, there are many more genetic markers for disease. However, science is evolving and nutritional genetics aims to identify what nutrients to eat to “turn on” healthy genes and “turn off” genes that cause disease. Eventually this field could progress to the point that a person’s diet can be tailored to their genetics. Thus, your DNA could someday determine your optimal diet!

Key Takeaways

- The scientific method is an organized process of inquiry used in nutritional science.
- The scientific method is part of the overall evidence-based approach to designing nutritional guidelines that are based on facts.
- There are different types of scientific studies—epidemiological studies, randomized clinical interventional trial studies, and laboratory animal and cell studies—which all provide different, complementary lines of evidence.
- It takes time to build scientific evidence that culminates as a commonly accepted conclusion.
- Agreement of experts across multiple scientific disciplines is a necessity for recommending dietary changes to improve health and help to prevent disease.
- Science is always evolving as more and more information is collected.

References

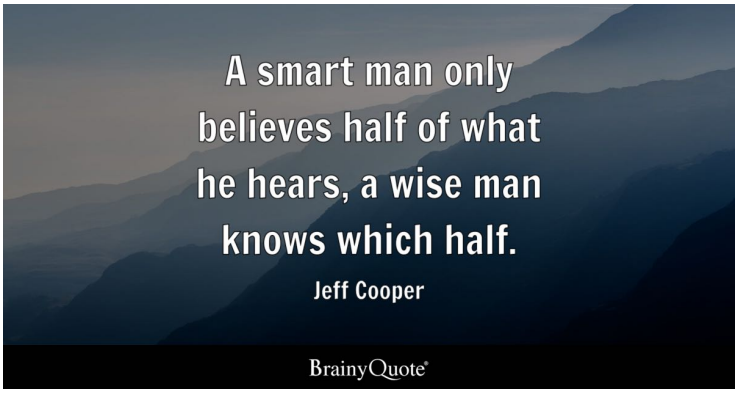
1. Zimmerman MB. Research on iodine deficiency and goiter in the 19th and early 20th centuries. *J Nutr.* 2008;138(11):2060–63.
2. Carpenter KJ. David Marine and the problem of goiter. *J Nutr.* 2005;135(4):675–80.
3. Framingham Heart Study. History of the Framingham Heart Study. Accessed May 9, 2025.
4. Estruch E, Ros E, Salas-Salvado J, et al; PREDIMED Study Investigators. Primary prevention of cardiovascular disease with a Mediterranean diet supplemented with extra-virgin olive oil or nuts. *N Engl J Med.* 2018;378:e34.

This page titled 1.3: The Broad Role of Nutritional Science is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

1.4: Nutrition and the Media

Learning Objectives

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



"Jeff Cooper Quotes" by Jeff Cooper

With access to information just a click away on the internet, it can be easy to be misled if you don't know where to go for reliable nutrition information.

Using Eyes of Discernment

“New study shows that margarine contributes to arterial plaque.” “Asian study reveals that two cups of coffee per day can have detrimental effects on the nervous system.” How do you react when you read news of this nature? Do you boycott margarine and coffee? When reading nutrition-related claims, articles, websites, or advertisements always remember that one study does not substantiate a fact. One study neither proves nor disproves anything. Readers who may be looking for complex answers to nutritional dilemmas can quickly misconstrue such statements and be led down a path of misinformation. Listed below are ways that you can develop discerning eyes when reading nutritional news.

1. The scientific study under discussion should be published in a peer-reviewed journal. Examples of peer-reviewed journals include the *Journal of Nutrition*, the *Journal of the Academy of Nutrition and Dietetics*, and the *International Journal of Behavioral Nutrition and Physical Activity*. 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).
2. The report should disclose the methods used by the researcher(s). Did the study last for three or thirty weeks? Were there ten or one hundred participants? What did the participants actually do? Did the researcher(s) observe the results themselves or did they rely on self reports from program participants? Generally speaking, studies that last longer and have more participants are considered to be more credible. Studies where participant results are directly observed by researchers are considered to have used higher quality research methods.
3. Who were the subjects of this study? Humans or animals? If human, are any traits/characteristics noted? You may realize you have more in common with certain program participants and can use that as a basis to decide if the study applies to you.
4. Credible reports often disseminate new findings in the context of previous research. A single study on its own gives you very limited information, but if a body of literature supports a finding, it gives you more confidence in it.
5. Peer-reviewed articles deliver a broad perspective and are inclusive of findings of many studies on the exact same subject.
6. How recent is the study? Studies that have been conducted within the past 5 years may have information that expands on older information on the subject.
7. When reading such news, ask yourself, “Is this making sense?” Even if coffee does adversely affect the nervous system, do you drink enough of it to see any negative effects? Remember, if a headline professes a new remedy for a nutrition-related topic, it may well be a research-supported piece of news, but more often than not it is a sensational story designed to catch the attention

of an unsuspecting consumer. Track down the original journal article to see if it really supports the conclusions being drawn in the news report.
8. Who conducted the study and who paid for it? If the researchers or funders will profit from certain results then there could be a conflict of interest and results may need to be replicated by other research that doesn't have any conflicts of interest.

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

1. Who sponsors the website? Look at the website extension (.com, .edu, .gov, .org); typically .com websites are considered less credible than websites with other extensions.
2. What is the overall intent/purpose of the website? Are you being sold something at this website? Or, is the intent to educate the reader?
3. Are author names and credentials disclosed? If so, do the authors have the educational background and/or expertise required for the topic?
4. Is an editorial board identified? Are experts reviewing the content of the website for accuracy and currency?
5. Does the website use a lot of testimonials? Or, is it based on reputable research studies that followed the scientific method?
6. Does the site contain links to other credible informational websites? Even better, does it reference peer-reviewed journal articles? If so, do those journal articles actually back up the claims being made on the website?
7. How often is the website updated?
8. Does the website charge a fee?

Trustworthy Sources

Groups that provide reputable nutrition information include:

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

For more information, watch this video about "Who Is A Dietitian?"



"Nutrition Diversity" by MSU Denver

Questionable credentials include:

- nutritionist (there is no definition or law regulating the term)
- certified clinical nutritionist (CCN)
- certified nutritionist (CN)
- certified nutrition consultant (CNC)

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

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

Additional reliable sources that advocate good nutrition to promote health and prevent disease using evidence-based science are listed below in Table 1.4.1.

Table 1.4.1: Web Resources for Nutrition and Health

Reliable Sources for Nutrition and Health
Governmental
USDA Center for Nutrition Policy and Promotion
Food and Drug Administration
Healthy People
Office of Disease Prevention and Health Promotion
Office of Dietary Supplements
International
World Health Organization
Food and Agricultural Organization of the United Nations
Nongovernmental
Harvard School of Public Health
Mayo Clinic
Linus Pauling Institute
American Society for Nutrition
American Medical Association
American Diabetes Association
American Institute for Cancer Research
American Heart Association

Key Takeaways

- When reading nutrition-related claims, articles, websites, or advertisements always remember that one study does not substantiate a fact. One study neither proves nor disproves anything.
- Reliable nutritional news will be based upon solid scientific evidence, supported by multiple studies, and published in peer-reviewed journals.
- Critically review websites to ensure the information comes from a credible and trustworthy source.

This page titled 1.4: Nutrition and the Media is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

CHAPTER OVERVIEW

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: Dietary Supplements
2.6: Understanding Food Labels
2.7: Understanding Portion Sizes
2.8: Is Alcohol Part of a Healthy Diet?

This page titled 2: Achieving a Healthy Diet is shared under a CC BY-NC-SA 4.0 license and was authored, remixed, and/or curated by Ann Diker.

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, saturated and trans fats, all of which are associated with the development of diseases such as atherosclerosis, heart disease, stroke, cancer, obesity, high cholesterol, diabetes, and other illnesses. A balanced diet is a mix of food from the different food groups (vegetables, legumes, fruits, grains, protein foods, and dairy).

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, 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: a 1 oz. bag of potato chips vs. 2 medium carrots and 1/4 cup hummus. Both snacks are 150-160 calories. The carrots and hummus are higher in protein, fiber, 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. Some additional examples of alternatives to move to a more nutrient-dense diet are included in Table 2.1.1 below.

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
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

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.

Key Takeaways

- A healthful diet is adequate in providing enough nutrients and calories, is balanced so that one nutrient is not consumed at the expense of another, contains nutrient-dense foods and beverages, is moderate in unwanted constituents, and draws from a variety of nutritious foods.

References

Chapter cover photo "Healthy Diet" by davis.steve32 is licensed under CC BY 2.0.

This page titled 2.1: What is a Healthy Diet? is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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 11.

Key Takeaways

- The *Dietary Guidelines for Americans* are based on evolving scientific evidence and are updated every five years.
- The goal of the *Dietary Guidelines for Americans* is to provide evidence-based guidance on what to eat and drink to support health and reduce chronic disease.
- A healthy dietary pattern stays within calorie limits and includes a variety of protein, dairy, vegetables, fruits, healthy fats, and whole grains.
- A healthy dietary pattern limits highly processed foods, added sugars, refined carbohydrates, saturated fat, sodium, and alcoholic beverages.

References

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.

This page titled 2.2: Understanding the Dietary Guidelines is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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.

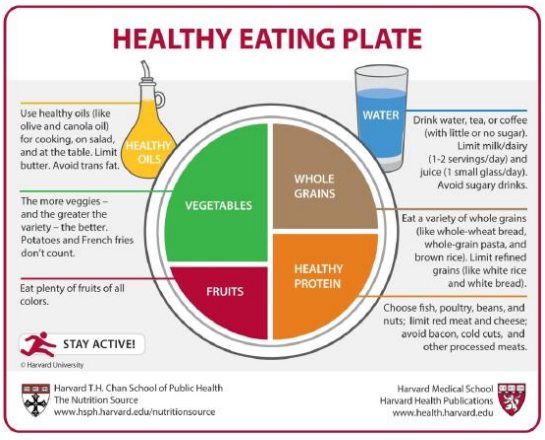


Figure 2.3.2: Harvard Healthy Eating Plate graphic ("Healthy Eating Plate" by Harvard University, Copyright © 2011, Harvard University.)

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	2,300mg (1,500mg lowers blood pressure even further)	
Nuts, seeds, dry beans, and peas		4-5
Sweets		5 or less

Key Takeaways

- There are a variety of food patterns available to help design a healthy diet.
- The New Pyramid encourages the inclusion of nutrient-dense protein, dairy, healthy fats, vegetables, fruits, and whole grains in a healthy diet while also limiting highly processed foods, added sugars, and refined carbohydrates.
- The Harvard Healthy Eating Plate also promotes vegetables, fruits, and whole grains. It also provides guidance related to healthy protein options, oil consumption, and encouraging water as a beverage while limiting milk/dairy, juice, and sugary drinks.
- The DASH Eating Plan can be used to lower blood pressure and emphasizes nutrient-dense whole grains, fruits, vegetables, low-fat dairy, and lean proteins.

References

1. Healthy Eating Plate vs. USDA's My Plate. The Nutrition Source. hsph.harvard.edu. Accessed May 9, 2025.
2. DASH Eating Plan. National Heart, Lung, and Blood Institute (NHLBI). nhlbi.nih.gov. Accessed May 9, 2025.

This page titled 2.3: Tools to Help Design a Healthy Diet is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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]

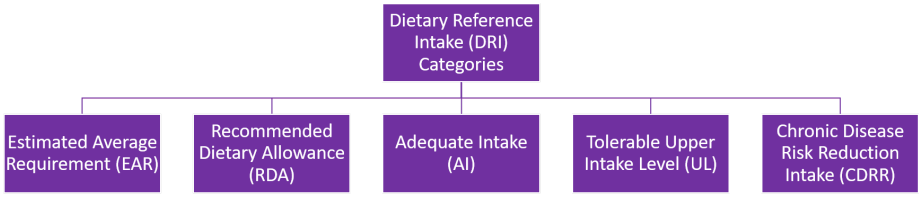


Figure 2.4.1: The DRIs include five reference values for micronutrients, the Estimated Average Requirement (EAR), Recommended Dietary Allowance (RDA), Adequate Intake (AI), Tolerable Upper Intake Level (UL), and Chronic Disease Risk Reduction Intake (CDRR). ("Dietary Reference Intake (DRI) Categories"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

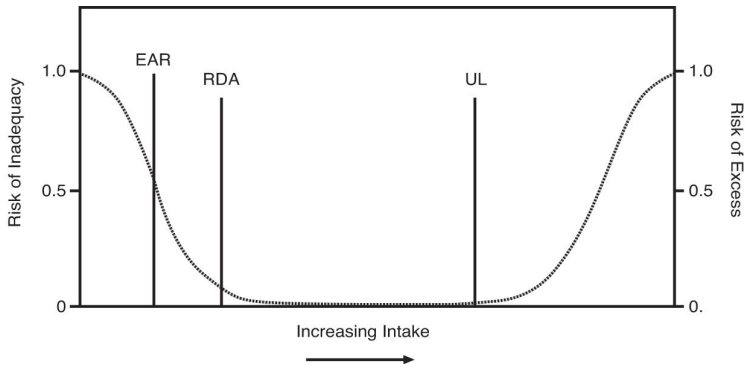


Figure 2.4.2: DRI Graph. This graph illustrates the risks of nutrient inadequacy and nutrient excess as we move from a low intake of a nutrient to a high intake. Starting on the left side of the graph, you can see that when you have a very low intake of a nutrient, your risk of nutrient deficiency (inadequacy) is high. As your nutrient intake increases, the chances that you will be deficient in that nutrient decrease. The point at which 50 percent of the population meets their nutrient needs is the EAR, and the point at which 97 to 98 percent of the population meets their needs is the RDA. The UL is the highest level at which you can consume a nutrient without it being too much—as nutrient intake increases beyond the UL, the risk of health problems resulting from that nutrient increases. ("DRI Graph" by Institute of Medicine, Copyright © 2012, National Academy of Sciences.)

Estimated Energy Requirement (EER)

The Estimated Energy Requirement (EER) is the average dietary energy (kcal) 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 kcals). 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

Key Takeaways

- Nutrient-intake recommendations set for healthy people living in the United States and Canada are known as Dietary Reference Intakes (DRIs).
- The DRIs includes the EAR, RDA, AI, UL, and CDRR for micronutrients, the EER for energy/calorie requirements, and the AMDR ranges for energy-yielding macronutrients. The DRIs provide a set of standards for researchers and government policy-makers, and specifies nutrient consumption guidelines for individuals.

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; 2002.

This page titled 2.4: Understanding Dietary Reference Intakes (DRIs) is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

2.5: Dietary Supplements

Learning Objectives

- Understand what dietary supplements are and when they are needed.
- Explain the safety and regulations 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.

Because the global supplement market is worth over $177 billion, it is easy to assume that most adults take some sort of dietary supplement 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.

Typically speaking, nutrients from foods are best absorbed and are complimented by additional nutrients in the foods themselves. 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 efficacy 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 2.5.1) offer voluntary seals of approval if a product passes the organization's quality tests for potency and the product is free of harmful contaminants. The seals do not ensure safety or effectiveness of the product.



Figure 2.5.1: 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.

Key Takeaways

- Dietary supplements are beneficial for preventing and treating nutrient deficiencies.
- The impact of a dietary supplement on currently used medications and/or supplements should be considered prior to new supplement use.
- The FDA is the regulatory agency that oversees the safety and efficacy of dietary supplements in the marketplace.

References

1. Dictionary.com. *Supplement*. Accessed May 9, 2025.
2. U.S. Food & Drug Administration. *Dietary Supplements*. Accessed May 9, 2025.
3. Grand View Research. *Dietary Supplements Market Size, Share & Trends Analysis Report by Ingredient (Vitamins, Minerals, Probiotics), By Form (Capsules, Gummies, Liquids), By End User, By Application, By Type, By Distribution Channel, By Region, and Segment Forecasts, 2024 – 2030*. Accessed May 9, 2025.
4. Council for Responsible Nutrition. *Dietary Supplement Health & Education Act (DSHEA)*. Accessed May 9, 2025.

Contributors

Metropolitan State University of Denver Nutrition Department: Marci Steiner

This page titled 2.5: Dietary Supplements is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

2.6: 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 eight 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 DRIs in planning your nutrient intakes can make you better equipped to select the right foods the next time you go to the supermarket.

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:

- Name and address of the manufacturer, packager, or distributor
- 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
- 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 (peanuts, tree nuts, milk, wheat, eggs, soy, fish, shellfish)
- Nutrition information (also known as the Nutrition Facts label)

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

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.

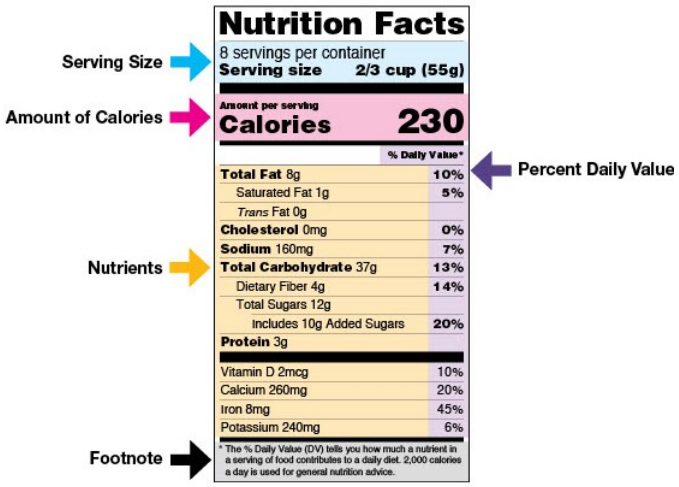


Figure 2.6.1: The Nutrition Facts label ("Nutrition Facts Label" by U.S. Food and Drug Administration)

% 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 2.6.1, 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, or sodium, 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.

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 2.6.1 for some examples.[3]

Table 2.6.1: 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

Term	Explanation
Light/lite	Contains ⅓ fewer calories or 50% less fat; if more than half of calories come from fat, then fat content must be reduced by 50% or more
Organic	Contains 95% organic ingredients

Health Claims

Often we hear news of a particular nutrient or food product that contributes to our health or may prevent disease. 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. Prior to the passage of the Nutrition Labeling and Education Act of 1990 products that made such claims were categorized as drugs and not food.

All health claims must be substantiated by scientific evidence in order for it to be approved and put on a food label. To avoid having companies making false claims, laws also regulate how health claims are presented on food packaging. In addition to the claim being backed up by scientific evidence, it may never claim to cure or treat the disease. For a detailed list of approved health claims, visit the FDA's list of authorized health claims.

Qualified Health Claims

While health claims must be backed up by *significant* scientific evidence, qualified health claims have *credible* evidence, which is not as definitive as with health claims. The evidence may suggest that the food or nutrient is beneficial. Wording for this type of claim may look like this: “Consuming EPA and DHA combined may reduce the risk of CHD (coronary heart disease) by lowering blood pressure. However, FDA has concluded that the evidence is inconsistent and inconclusive. One serving of [name of the food or dietary supplement] provides [x] gram(s) of EPA and DHA.".[4]

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]

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.[5] 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.

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.

Key Takeaways

- The Nutrition Labeling and Education Act of 1990 made it a law that foods sold in the United States have a food label that provides the accurate contents of nutrients within them.

- The Nutrition Facts label gives information on the amount of servings per container, the amount of calories per serving, and the amounts of certain nutrients.
- The %DV is the percentage of the amount of the nutrient in the food in relationship to its recommended intake. It is a guide to help you determine if a food is a good or poor source of nutrients.
- To keep companies from making false claims, the FDA provides regulation for food manufacturers in putting labels on packages that promote health. Allergens must also be listed on food labels.
- Enrichment involves adding nutrients to restore those that were lost during processing; fortification involves adding nutrients that didn't originally exist in the food.

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.
3. US Food and Drug Administration. *Food Labeling Guide*. Last updated January 2013. Accessed May 9, 2025.
4. FDA Announces New Qualified Health Claims for EPA and DHA Omega-3 Consumption and the Risk of Hypertension and Coronary Heart Disease. fda.gov. Accessed May 9, 2025.
5. Frequently Asked Questions: Food Allergen Labeling Guidance for Industry. fda.gov. Accessed May 9, 2025.

This page titled 2.6: Understanding Food Labels is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

2.7: 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 2.7.1, 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.

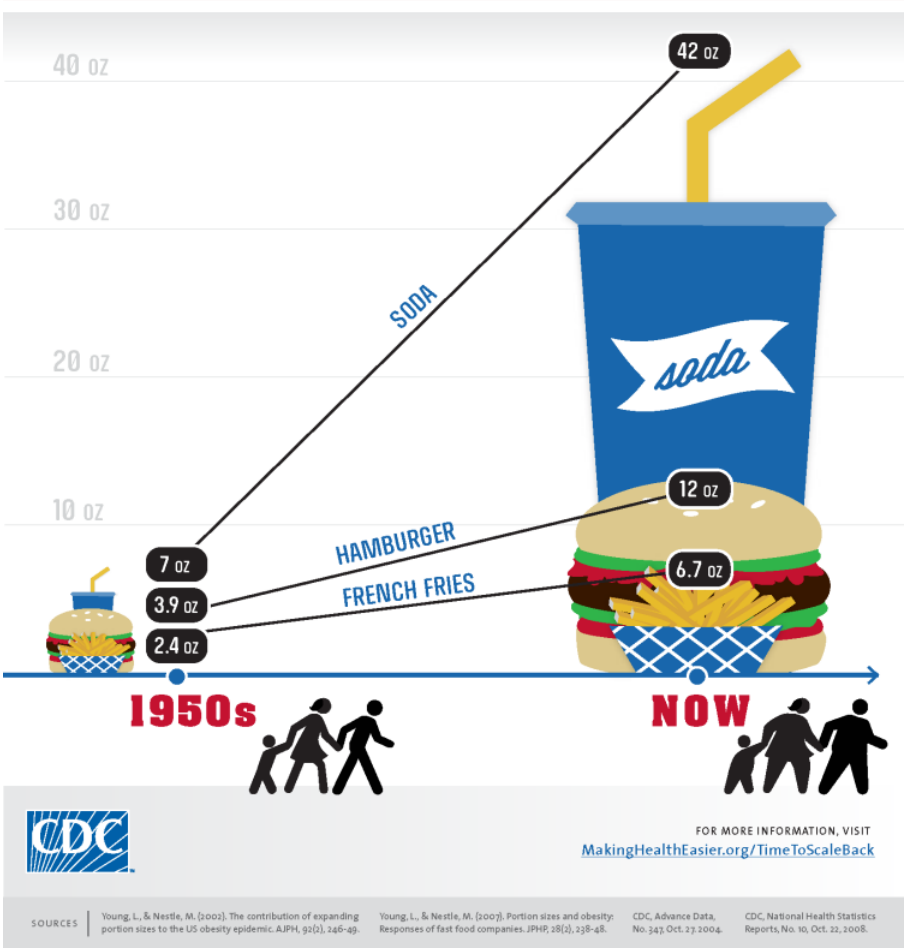
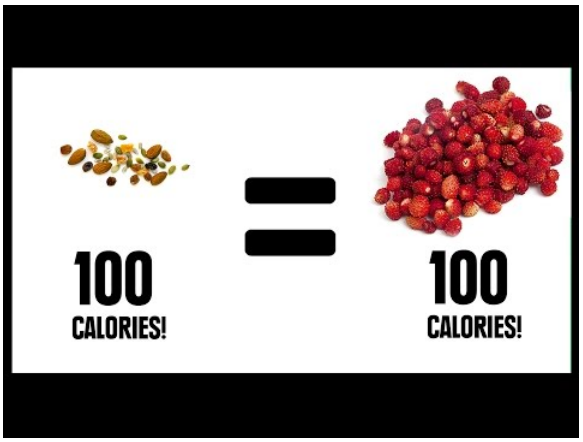


Figure 2.7.1: Fast food portion sizes over time ("The New (Ab)Normal" by CDC Division of Nutrition, Physical Activity, and Obesity)

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

A sedentary lifestyle can make it difficult to expend enough calories during normal daily activities. Take the Portion Distortion Quiz to compare portions from the past to today's portions. The answers to the quiz include examples of the amount of physical activity required to burn off the extra calories provided by today's portions.

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 2.7.1 for some examples.[1]

Table 2.7.1: 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
1 ounce	golf ball		nuts, cheese
3 ounces	deck of cards	average-sized palm of a hand	fish, chicken, beef, other meats

Amount	Object Comparison	Hand Comparison	Appropriate portion size for:
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!

Key Takeaways

- Judging portion sizes can be done using your hand or household objects in comparison.
- Multiple strategies can be used to help manage portion sizes when eating away from home.

References

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

This page titled 2.7: Understanding Portion Sizes is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

2.8: Is Alcohol Part of a Healthy Diet?

Learning Objectives

- Identify recommendations for alcohol intake.
- Describe the health benefits and health risks associated with alcohol consumption.

When considering total calorie intake, it is important to consider alcohol. Alcohol is not a nutrient, but it does contain calories – 7 kcal/g. Calories come from alcohol itself, but also from the other ingredients that are often included in alcoholic drinks, such as juices and mixers.

Recommendations[1,2]

It is not recommended for any non-drinker to start drinking alcohol. For those who do drink, drinking less is always better than drinking more. 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 2.8.1, one drink is equal to:

- 12 fluid ounces of regular beer (5% alcohol)
- 8-10 fluid ounces of malt liquor (7% alcohol)
- 5 fluid ounces of table wine (12% alcohol)
- 1.5 fluid ounces of 80-proof distilled spirits (40% alcohol)

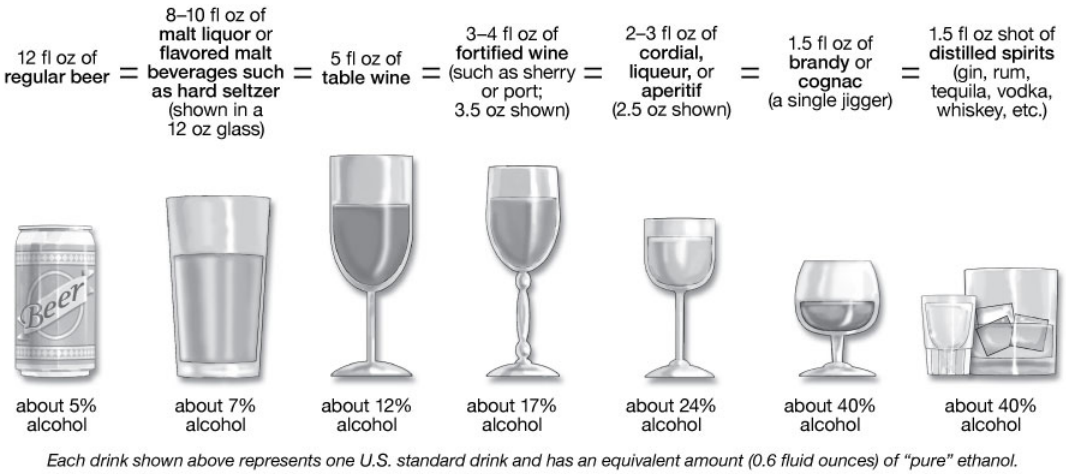


Figure 2.8.1: Examples of one standard drink. (public domain; National Institutes of Health)

Alcohol Metabolism[4]

The only effective way to avoid alcohol toxicity is to give the liver enough time to metabolize the alcohol that has been consumed. 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.

The majority of the alcohol consumed is metabolized by the liver. 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. The remaining circulating alcohol (85-98% of what was consumed) is metabolized by the liver.

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.

Blood Alcohol Concentration[5] (BAC) is used to measure the amount of alcohol in the bloodstream. It can be affected by the amount of alcohol consumed, a person's weight, sex, drinking patterns, and genetics. The legal BAC limit is 0.08. This is the level that is considered illegal and unsafe to drive, because at this level, a person loses coordination, balance, speech, reaction times, and so on.

Impact of Alcohol on Health

Drinking alcohol in moderation can be beneficial for some things like appetite improvement, as well as stress and anxiety reduction. However, these benefits can be sought out by means other than alcohol. With that being said it is not recommended to encourage a non-drinker to start drinking alcohol, when the risks can far outweigh those benefits. Heavy drinking is related to an increased risk of death from all causes.[2]

Short-term health risks associated with drinking alcohol include:

- Motor vehicle crashes
- Violence including homicide, suicide, sexual assault, intimate partner violence, etc.
- Alcohol poisoning
- Risky sexual behaviors such as unprotected sex, sex with multiple partners which can lead to STDs or unplanned pregnancies
- Miscarriage, stillbirth, or fetal alcohol syndrome[6]

Long-term health risks associated with drinking alcohol include:

- Cancer: Moderate to heavy alcohol consumption can significantly increase the risk of head and neck cancers, esophageal cancer, liver cancer, breast cancer, and colorectal cancer[7].
- Heart Disease[8]: Heavy drinking is linked to high blood pressure, heart failure, and stroke. Alcohol consumption can also lead to obesity and diseases associated with obesity.
- Liver Disease[9]: Although not every drinker will die from liver problems, many do. This is because the liver plays a major role in filtering in the body. The liver can become extremely stressed by alcohol abuse.
- Learning and memory problems (such as dementia and poor school performance), mental health problems (depression and anxiety), social problems (lost productivity, family problems, unemployment), alcohol use disorders and alcohol dependence[6]

Alcohol and Pregnancy[9]

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; this is known as Fetal Alcohol Syndrome. It is recommended to stop drinking alcohol 4-6 weeks before conception, if hoping to become pregnant. Alcohol consumption during the 1st trimester of pregnancy can lead to physical damage of developing organs and tissues. During the 2nd trimester, it can increase the risk of spontaneous abortion. During the 3rd trimester, both body and brain growth problems can develop in the baby. Fetal Alcohol Syndrome can have many impacts on the baby including:

- Poor growth in the womb and after birth

- Decreased muscle tone
- Poor coordination
- Delayed developmental milestones

Chronic alcoholism during pregnancy can lead to multiple issues including small head circumference, narrow or receding forehead, flattened nasal bridge, short or upturned nose, underdeveloped jaw, receding chin, extra skin folds on eyelids, drooping eyelids, downward slant of eyes, short-sightedness, inability to focus, uneven or poorly formed ears, and absence of the groove in the upper lip.

Alcohol and Breastfeeding[10]

The safest option is for breastfeeding moms to avoid drinking alcohol. If a breastfeeding mother participates in heavy alcohol consumption, the infant can have issues with growth, development and sleeping patterns. After consuming alcohol, it can be found in breastmilk for 2-3 hours. The more alcohol that is consumed, the longer it will be found in the breastmilk.

Key Takeaways

- There is no reason for people who do not drink alcohol to start drinking. For those who choose to drink alcohol, moderate alcohol intake is defined as 2 drinks or less per day (for men) or 1 drink or less per day (for women).
- 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.
- Drinking alcohol in moderation can be beneficial for some things, but the short-term and long-term health risks associated with drinking alcohol can outweigh the benefits.
- During pregnancy, there is no safe level of alcohol consumption.
- The safest option during breastfeeding is to avoid drinking alcohol because it can be found in breastmilk for 2-3 hours after consuming alcohol.

References

1. 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.
2. National Academies of Sciences, Engineering, and Medicine. Review of Evidence on Alcohol and Health. The National Academies Press; 2025. Accessed January 7, 2026.
3. Alcohol's Effects on Health. niaaa.nih.gov. Accessed January 7, 2026.
4. Alcohol Metabolism. University of Hawaii at Manoa. Accessed May 9, 2025.
5. Monico, N. Blood Alcohol Concentration Levels and How They Affect the Body. American Addiction Centers. Accessed May 9, 2025.
6. Alcohol Use and Your Health. cdc.gov. Accessed May 9, 2025.
7. Alcohol and Cancer Risk. cancer.gov. Accessed May 9, 2025.
8. Alcohol and Heart Health: Separating Fact from Fiction. Johns Hopkins Medicine. Accessed May 9, 2025.
9. Pros and Cons of Drinking Alcohol. Foundations of Nutrition (Byerly). Accessed May 9, 2025.
10. Alcohol. cdc.gov. Accessed May 9, 2025.

Contributors

Metropolitan State University of Denver Nutrition Department: Lauren Groth and Marci Steiner

This page titled 2.8: Is Alcohol Part of a Healthy Diet? is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

CHAPTER OVERVIEW

3: Digestion

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

This page titled 3: Digestion is shared under a CC BY-NC-SA 4.0 license and was authored, remixed, and/or curated by Ann Diker.

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.

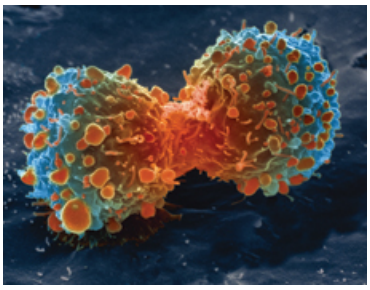


Figure 3.1.1: One cell divides into two, which begins the creation of millions of more cells that ultimately become you. (Public Domain; National Institutes of Health).

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

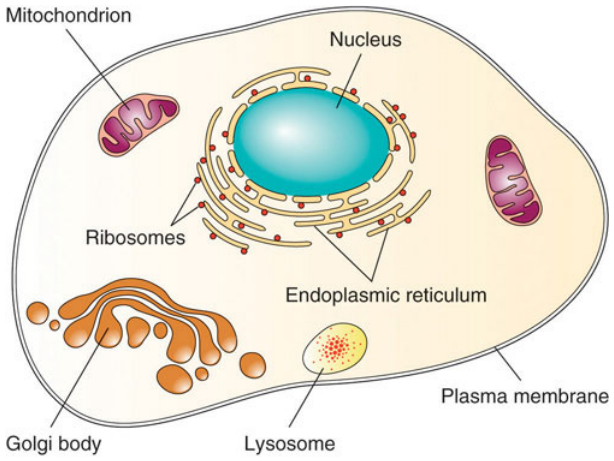
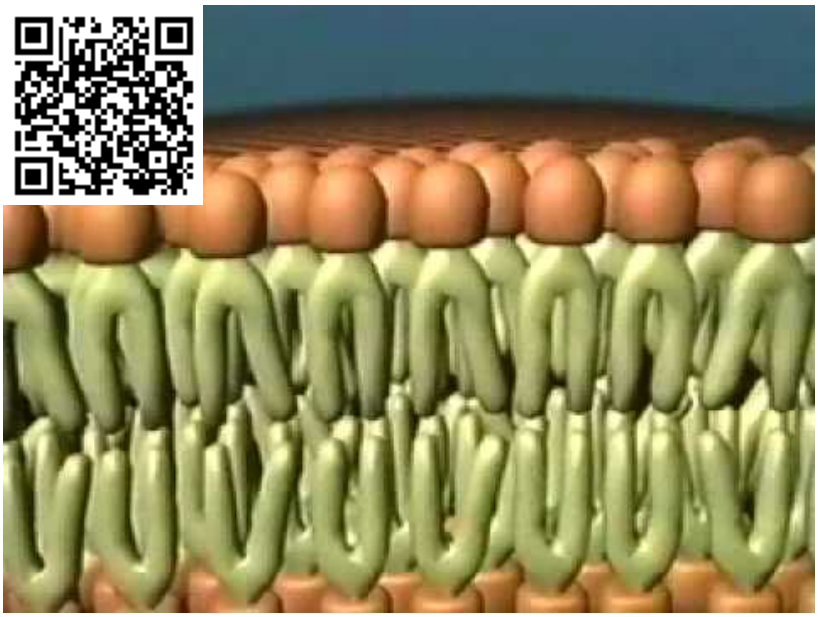


Figure 3.1.2: The components of a cell.

As seen in (Figure 3.1.2), all of the organelles are anchored 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.



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

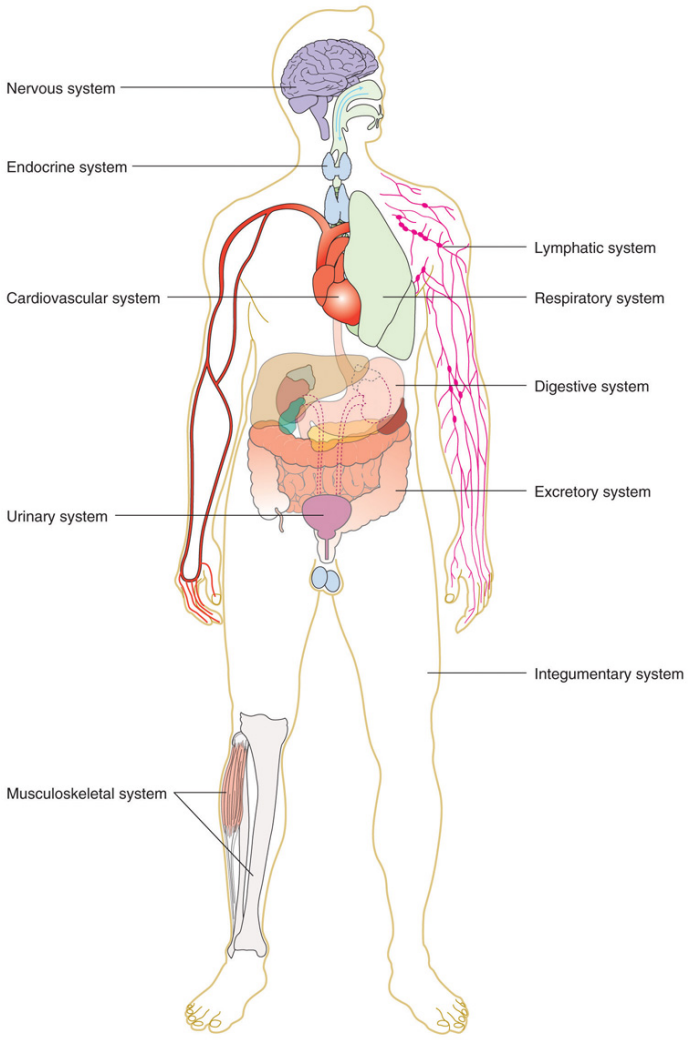


Figure 3.1.3: Organ systems in the human body, (© Networkgraphics)

An Organism Requires Energy and Nutrient Input

Energy is required in order to build molecules into larger macromolecules, and to turn macromolecules into organelles and cells, and then turn those into tissues, organs, and organ systems, and finally into an organism. Proper nutrition provides the necessary nutrients to make the energy that supports life's processes. Your body builds new macromolecules from the nutrients in food.

Nutrient and Energy Flow

Energy is stored in a nutrient's chemical bonds. As seen in Figure 3.1.4, energy comes from sunlight, which plants capture and (via photosynthesis) use this energy to transform carbon dioxide (CO_2) in the air into sugar (glucose). When the bonds in the glucose molecules are broken, energy is released. Bacteria, plants, and animals (including humans) harvest the energy in glucose via a biological process called cellular respiration. In this process the chemical energy of glucose is transformed into cellular energy in the form of adenosine triphosphate (ATP). Cellular respiration requires oxygen which is provided as a waste product of photosynthesis. The waste products of cellular respiration are carbon dioxide (CO_2) and water, which plants use to conduct photosynthesis again. Thus, energy is constantly cycling between plants and animals.

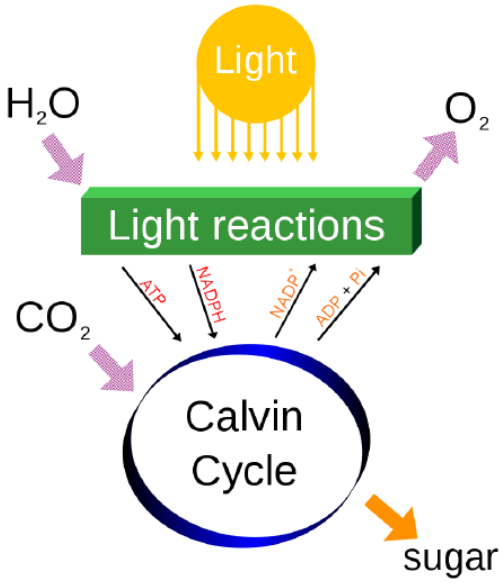


Figure 3.1.4: Overview of photosynthesis. (CC BY-SA 4.0; Daniel Mayer via Wikimedia Commons)

In this section, we have learned that all life is composed of cells capable of transforming small organic molecules into energy. How do complex organisms such as humans convert the large macromolecules in the foods that we eat into molecules that can be used by cells to make cellular energy? In the next section, we will discuss the physiological process of digestion to answer this question.

Key Takeaways

- The cell is the basic structural and functional unit of life. Cells are independent, single-celled organisms that take in nutrients, excrete waste, detect and respond to their environment, move, breathe, grow, and reproduce. The macromolecules (carbohydrates, proteins, lipids, and nucleic acids) make up all of the structural and functional units of cells.
- In complex organisms, cells are organized into five levels so that an organism can conduct all basic processes associated with life.
- There are eleven organ systems in the human body that work together to support life, all of which require nutrient input.
- Energy is constantly cycling between plants and animals.

References

Chapter cover photo "Cute Digestive System" by Bentlie is licensed under CC BY-NC-ND 3.0.

This page titled 3.1: Human Body Organization is shared under a CC BY-NC-SA 4.0 license and was authored, remixed, and/or curated by Ann Diker.

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.

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.



"Hormone Control of Hunger" by khanacademymedicine

This page titled 3.2: Hunger vs. Appetite is shared under a CC BY-NC-SA 4.0 license and was authored, remixed, and/or curated by Ann Diker.

3.3: Digestion and Absorption

Learning Objectives

- Identify the major 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.

Digestion and Absorption Overview

The food we eat undergoes three processes:

- Digestion: the process by which foods are broken down into molecules
- Absorption: the process of taking the products of digestion (molecules) across the gastrointestinal (GI) tract walls and into circulation
- Elimination: the process by which 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 protein (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.

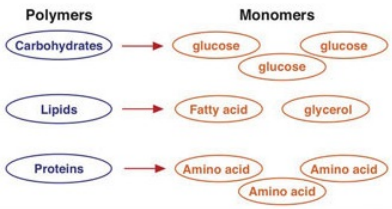


Figure 3.3.1: The Digestion Process. Digestion converts the food we eat into smaller particles, which will be processed into energy or used as building blocks. (CC BY-NC-SA 4.0; LibreTexts An Introduction to Nutrition (Zimmerman))

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 of digestion, mechanical and chemical breakdown of food, 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 with mastication (chewing) in the mouth. Teeth crush and grind large food particles, while 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.

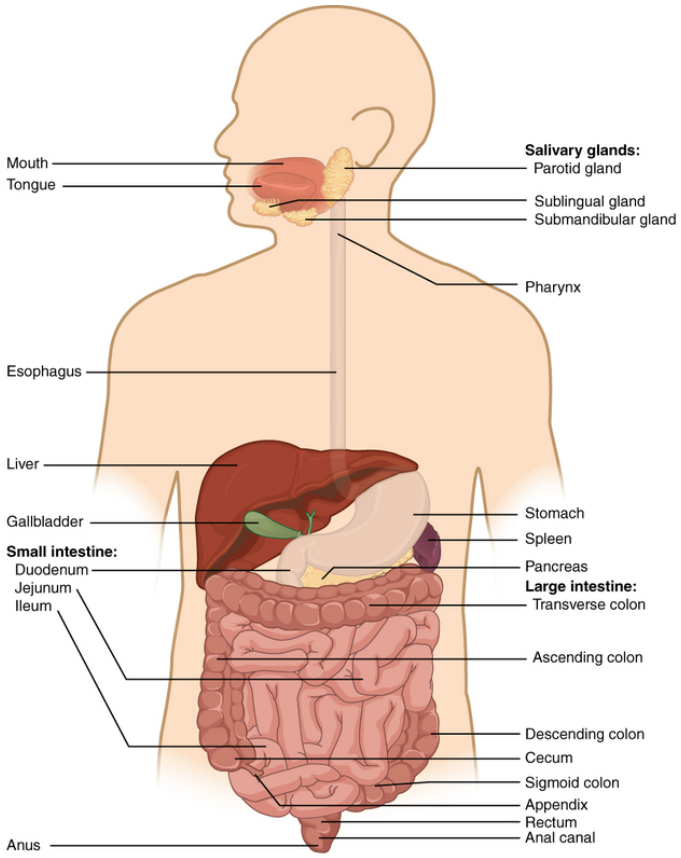


Figure 3.3.2: Components of the Digestive System. All digestive organs play integral roles in the life-sustaining process of digestion. (CC BY 4.0; OpenStax Anatomy and Physiology)

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.

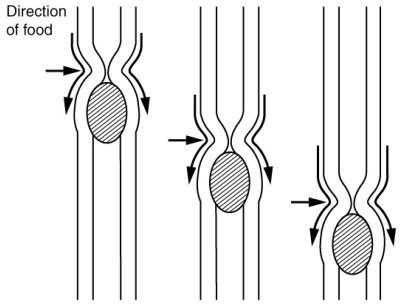


Figure 3.3.3: Peristalsis. Peristalsis moves food through the digestive tract with alternating waves of muscle contraction and relaxation. (CC BY 4.0; OpenStax Anatomy and Physiology)

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 first part), the jejunum (the middle), and the ileum (the last part). 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 sloshes 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 first 25 centimeters of the small intestine. 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 in the remaining length of the small intestine, or ileum (> 5 meters). The small intestine is perfectly structured for maximizing nutrient absorption. Its surface area is greater than 200 square meters, which is about the size of a tennis court. The surface area of the small intestine increases by 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" (see Figure 3.3.5). 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.

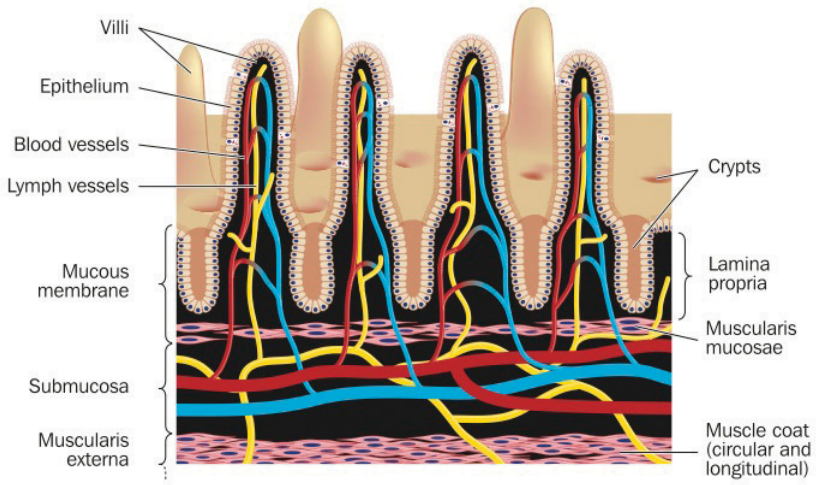


Figure 3.3.4: The way the small intestine is structured gives it a huge surface area to maximize nutrient absorption. The surface area is increased by folds, villi, and microvilli. Digested nutrients are absorbed into either capillaries or lymphatic vessels contained within each microvilli. (© Shutterstock)

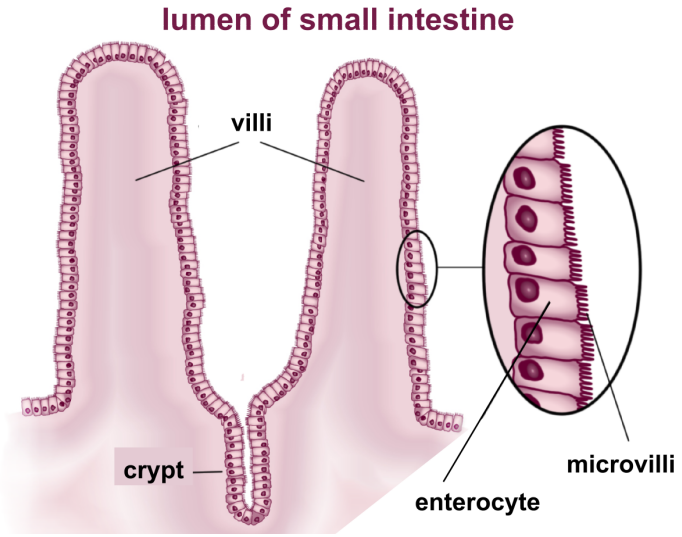


Figure 3.3.5: Drawing showing the relationship between villi and microvilli of the small intestine. The luminal surface of the enterocytes have microvilli (1 micrometer long) while the cell layer itself is folded to form villi (0.5-1.6 millimeters long) and crypts. Both serve to increase the total absorption surface of the intestine. (CC BY-SA 4.0; BallenaBlanca via Wikimedia Commons)

Large Intestine

The process of digestion is fairly efficient. Any food that is still incompletely broken down (usually less than ten percent of food consumed) and the food's indigestible fiber content 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 three to six hours in the small intestine, and about sixteen hours in the large intestine, the digestion process enters step four, which is the elimination of indigestible food as feces. Feces contain indigestible food and gut bacteria (almost 50 percent 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 major functions of the digestive tract that you learned about above.

Table 3.3.1: Functions of the Digestive Organs

Organ	Major Functions
Mouth	• Ingests food • Chews and mixes food • Begins chemical breakdown of carbohydrates • Moves food into the esophagus • Begins breakdown of lipids via lingual lipase
Esophagus	• Propels food to the stomach
Stomach	• Mixes and churns food with gastric juices to form chyme • Begins chemical breakdown of proteins • Releases food into the duodenum as chyme • Absorbs some fat-soluble substances (for example, alcohol, aspirin)
Small intestine	• Mixes chyme with digestive juices • Propels food at a rate slow enough for digestion and absorption • Absorbs breakdown products of carbohydrates, proteins, lipids, and nucleic acids, along with vitamins, minerals, and water • Performs physical digestion via segmentation
Accessory organs	• Liver: produces bile salts, which emulsify lipids, aiding their digestion and absorption • Gallbladder: stores, concentrates, and releases bile • Pancreas: produces digestive enzymes and bicarbonate
Large intestine	• Further breaks down food residues • Absorbs most residual water, electrolytes, and vitamins produced by bacteria within the large intestine • Propels feces toward rectum • Eliminates feces

Key Takeaways

- The role of the digestive system is to breakdown the complex macromolecules (carbohydrates, fats, and proteins) from food into simple absorbable components (glucose, fatty acids, and amino acids) to be processed into energy or used as building blocks by different cells throughout the body.
- The major organs of the digestive system include the mouth, esophagus, stomach, small intestine, and large intestine (or colon).
- There are four steps in the digestion process: ingestion, the mechanical and chemical breakdown of food, nutrient absorption, and elimination of indigestible food.
- The mechanical breakdown of food occurs via muscular contractions called peristalsis and segmentation. Enzymes secreted by the salivary glands, stomach, pancreas, and small intestine accomplish the chemical breakdown of food. Additionally, bile emulsifies fats.

This page titled 3.3: Digestion and Absorption is shared under a CC BY-NC-SA 4.0 license and was authored, remixed, and/or curated by Ann Diker.

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.

Diarrhea

Diarrhea is defined as the frequent passage of loose, watery stools. 'Frequent passage' means more than three times in one day.

Contributing factors

Typical causes of diarrhea include:

- infection of the digestive tract
- stress
- certain foods/beverages
- reaction to medication

Treatment

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.

Contributing factors

Factors that contribute to constipation can include:

- travel
- change in diet
- certain medications

Treatment

Common suggestions for relief of constipation include:

- increasing fluid intake
- increasing fiber intake
- 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.

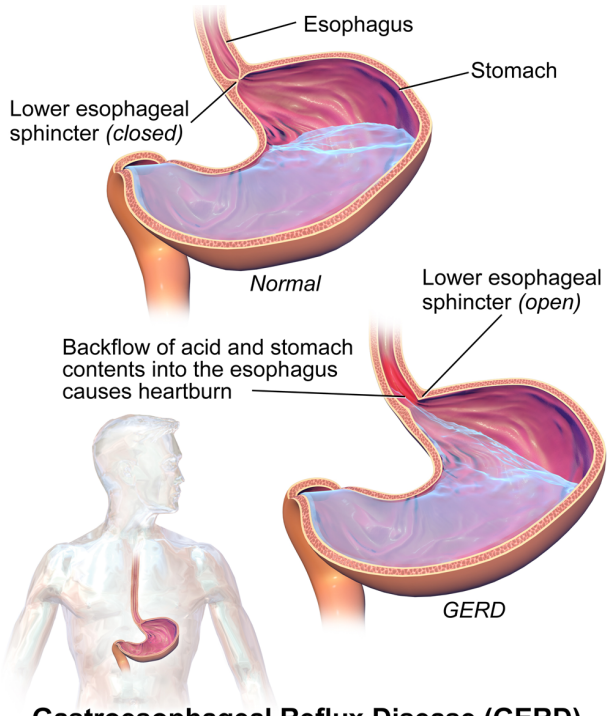


Figure 3.4.1: Gastroesophageal Reflux Disease (GERD). (CC BY-SA 4.0, BruceBlaus via Wikimedia Commons)

Contributing factors

The exact causes of GERD are unknown. However, some contributing factors include:

- overweight/obesity
- pregnancy
- cigarette smoking
- certain foods/beverages (e.g., spicy foods, chocolate, fried foods, tomato-based foods, caffeine, alcohol)

Treatment

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.

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.

Contributing factors

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
- Prolonged use of nonsteroidal anti-inflammatory drugs (NSAIDs) such as ibuprofen (Advil) and naproxen sodium (Aleve)

Treatment

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).

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).

Contributing Factors

The precise cause of IBS isn't known, but factors that appear to play a role include:

- stress
- severe infections
- certain foods/beverages (e.g., wheat, dairy products, citrus fruits, beans, fatty foods, coffee, alcohol)

Treatment

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. While celiac disease is a serious illness, many people avoid gluten, but may not fully understand what gluten is, as seen in the following Jimmy Kimmel segment.



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 deficiences can lead to osteoporosis, a disease in which bones become brittle.

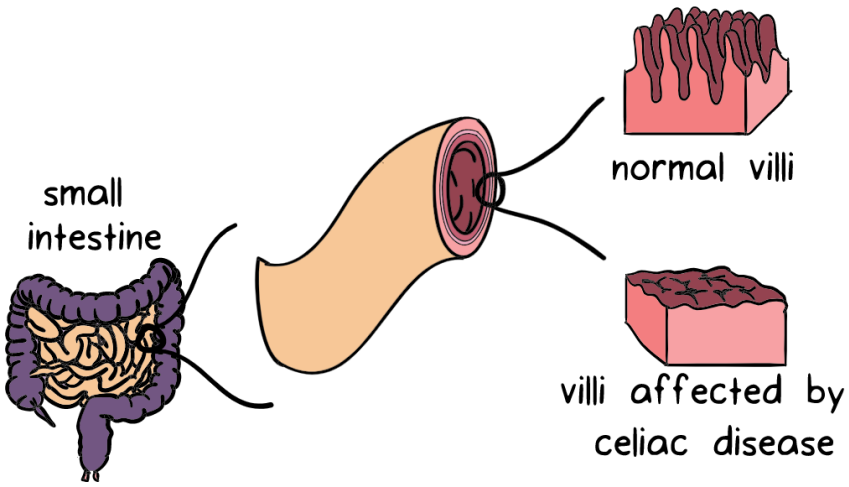


Figure 3.4.2: Normal villi of the small intestine compared to damaged villi affected by celiac disease. (khanacadamy.org)

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
- Difficulty breathing
- Hives
- Stomach cramps

- Diarrhea
- Vomiting
- Drop in blood pressure
- Loss of consciousness
- 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

Key Takeaways

- Certain disorders and diseases can cause an inadequate intake and absorption of nutrients simulating the health consequences of an unbalanced diet.

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.

This page titled 3.4: Disorders That Can Compromise Health is shared under a CC BY-NC-SA 4.0 license and was authored, remixed, and/or curated by Ann Diker.

CHAPTER OVERVIEW

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

Template:HideTOC

This page titled 4: Carbohydrates is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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

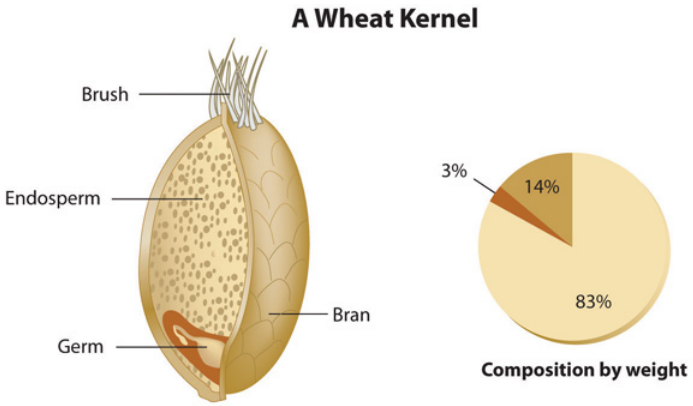
Many people think that we should avoid carbohydrates in the diet, but this important macronutrient is essential and needed in abundance. Carbohydrates are composed of carbon, hydrogen, and oxygen. The most abundant carbohydrate is glucose which is produced by plants through photosynthesis; water, carbon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

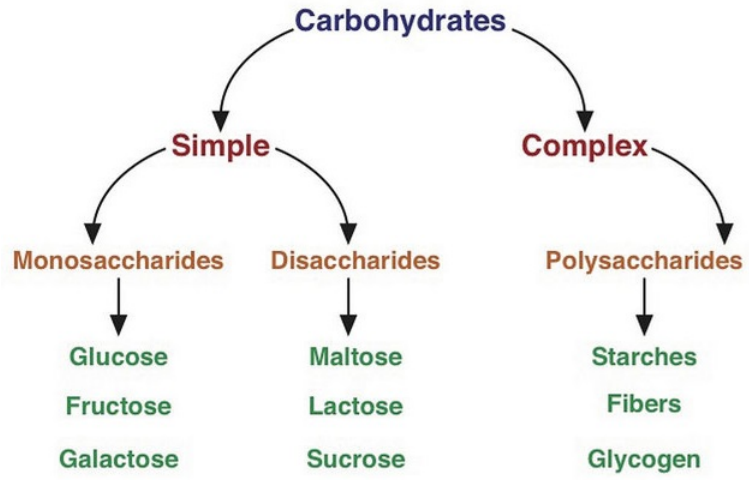


Figure 4.1.2: Carbohydrate Classification Scheme. Carbohydrates are broken down into "simple" and "complex" carbohydrates. These subgroups are further categorized into mono-, di-, and polysaccharides.

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; 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, twelve hydrogen, and six oxygen. 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.

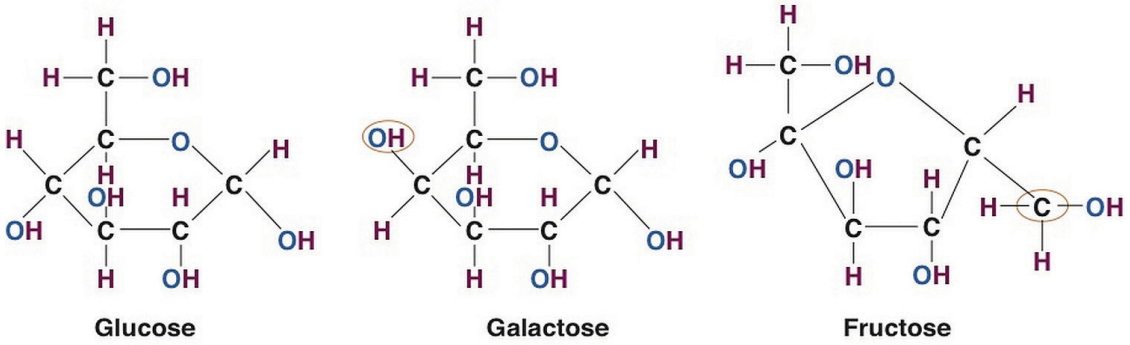


Figure 4.1.3: Structures of the three most common monosaccharides: glucose, galactose, and fructose. Circled areas indicate the structural differences between the three molecules.

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 the 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. 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.

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 4.1.4). 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 4.1.4). 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.

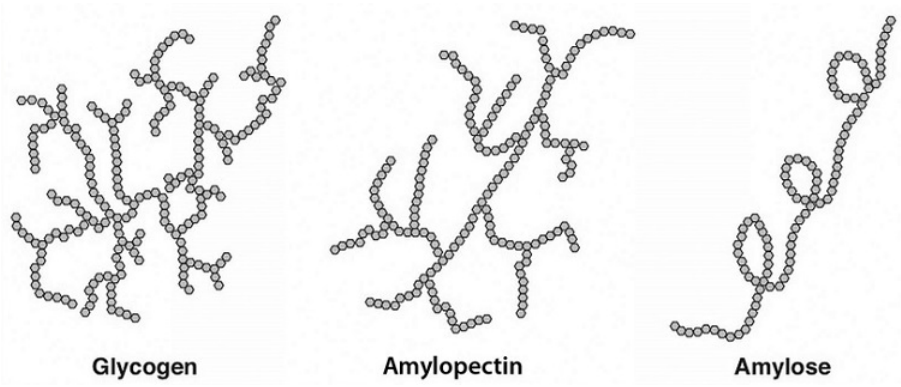


Figure 4.1.4: Structures of the plant starches (amylose and amylopectin) and glycogen

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.



Key Takeaways

- Carbohydrates are broadly classified into two subgroups, simple and complex carbohydrates.
- Simple carbohydrates include monosaccharides (glucose, galactose, and fructose) and disaccharides (sucrose, lactose, and maltose).
- Complex carbohydrates include the following polysaccharides: starch (amylose and amylopectin), glycogen, and fiber.
- Fiber-rich foods help reduce the risk of heart disease and diabetes and promote regular bowel movements.
- Glucose is the most important monosaccharide in human nutrition; it is the body's preferred fuel source.

This page titled 4.1: Introduction to Carbohydrates is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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. Only 12.2% of adults meet the daily fruit recommendation; only 9.3% meet the daily vegetable recommendation.[1] The recommendation for grains is that at least 50% of the grains we eat should be whole grains. According to a recent National Center for Health Statistics Data Brief, Americans consume ~16% of their grains as whole grains.[2] However, research indicates that consuming higher amounts of dietary fiber decreases the risk for Type 2 diabetes, and cardiovascular disease.[3,4]

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[5] (fiber binds cancer-causing substances and speeds elimination from colon)
  - diverticulosis (bulging pockets that can form in the wall of the colon; see Figure 4.2.1) and diverticulitis (inflamed bulging pockets)

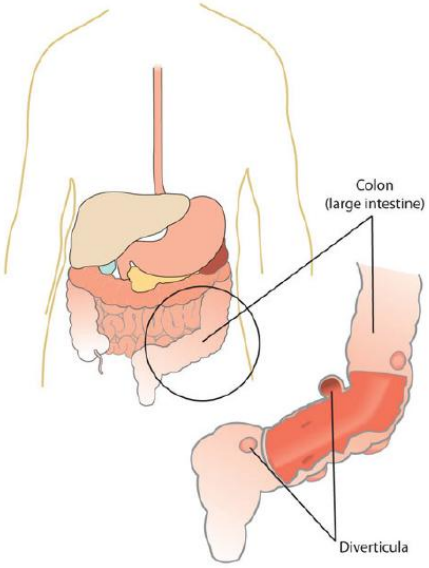


Figure 4.2.1: Diverticulosis (CC BY-NC-SA 4.0; LibreTexts An Introduction to Nutrition (Zimmerman))

Most Americans eat only half the recommended amount of fiber. People interested in increasing their fiber intake can include more whole grains, vegetables, fruits, nuts, and legumes in their diet. Increasing fluid intake as you increase your fiber intake is also important to prevent constipation.

Key Takeaways

- Fruits, vegetables, and whole grains contribute fiber to our diets.
- Consuming higher amounts of fiber can benefit blood glucose control, weight management, heart health, and colon health.

References

1. Lee-Kwan SH, Moore LV, Blanck HM, Harris DM, Galuska D. Disparities in State-Specific Adult Fruit and Vegetable Consumption — United States, 2015. MMWR Morb Mortal Wkly Rep 2017;66:1241–1247.
2. Ahluwalia N, Herrick KA, Terry AL, Hughes JP. Contribution of whole grains to total grains intake among adults aged 20 and over: United States, 2013–2016. NCHS Data Brief, no 341. Hyattsville, MD: National Center for Health Statistics. 2019.
3. Reynolds AN, Akerman AP, Mann J. Dietary fibre and whole grains in diabetes management: Systematic review and meta-analyses. *PLoS Med*. 2020;17(3):e1003053. Published 2020 Mar 6. doi:10.1371/journal.pmed.1003053.
4. McRae MP. Dietary Fiber Is Beneficial for the Prevention of Cardiovascular Disease: An Umbrella Review of Meta-analyses. *J Chiropr Med*. 2017;16(4):289-299. doi:10.1016/j.jcm.2017.05.005.
5. Gianfredi V, Salvatori T, Villarini M, Moretti M, Nucci D, Realdon S. Is dietary fibre truly protective against colon cancer? A systematic review and meta-analysis. *Int J Food Sci Nutr*. 2018;69(8):904-915. doi:10.1080/09637486.2018.1446917.

This page titled 4.2: Benefits of Fiber is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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.

From the Mouth to the Stomach

The mechanical and chemical digestion of carbohydrates begins in the mouth. Chewing, also known as mastication, crumbles the carbohydrate foods into smaller and smaller pieces. The salivary glands in the 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 five percent of starches are broken down in the mouth. 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.

From the Stomach to the Small Intestine

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 starts again the breakdown of dextrins into shorter and shorter carbohydrate chains. Additionally, enzymes are secreted by the intestinal cells that line the villi. These enzymes, known collectively as 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.

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: Going to the Blood Stream

The cells in the small intestine have membranes that contain many transport proteins in order to get the monosaccharides and other nutrients into the blood where they can be distributed to the rest of the body (see Figure 4.3.1). The first organ to receive glucose, fructose, and galactose is the liver. The liver takes them up and converts galactose to glucose, breaks fructose into even smaller carbon-containing units, and either stores glucose as glycogen or exports it back to the blood. How much glucose the liver exports to the blood is under hormonal control and you will soon discover that even the glucose itself regulates its concentrations in the blood.

If needed for energy, glucose is released from the liver to the bloodstream, and on to cells that need it. Excess glucose is converted to glycogen in the liver and muscles and stored in those organs. The glycogen stored in the liver maintains blood glucose between meals; muscle glycogen provides immediate energy to the muscle during exercise. Enzymes in the liver and muscles combine glucose molecules to form glycogen through a process known as glycogenesis. Stored glycogen can be broken down into glucose when needed through glycogenolysis ("-lysis" = break down). Once the storage capacity of the liver and muscles is reached, excess glucose is stored as fat.

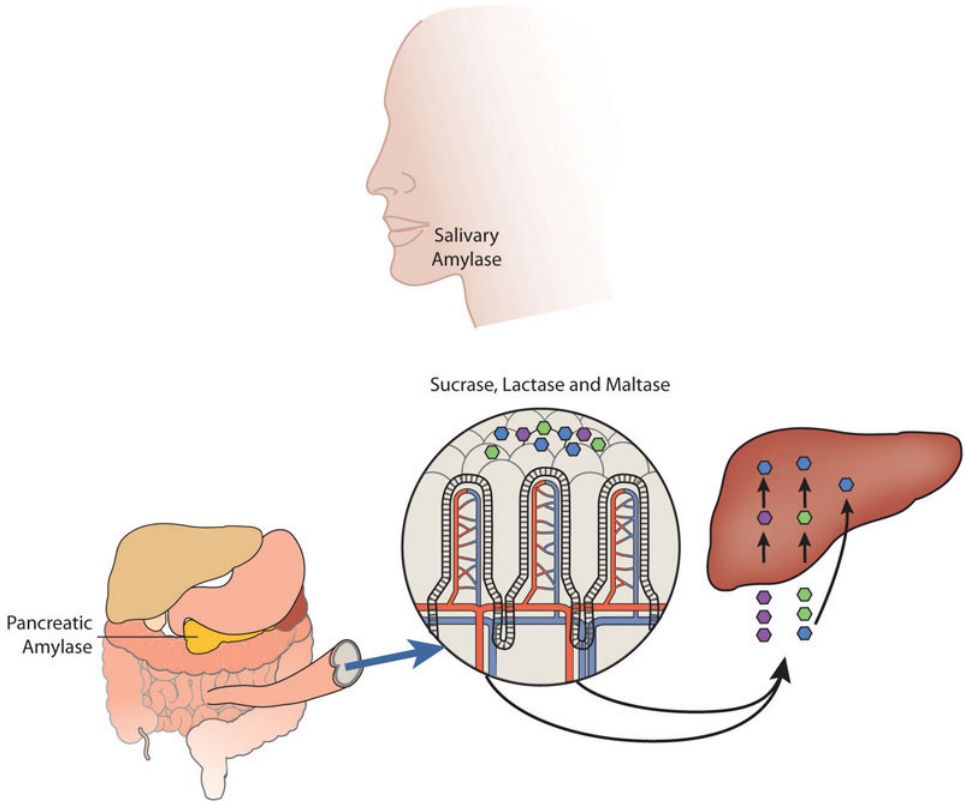


Figure 4.3.1: Carbohydrate digestion begins in the mouth and is most extensive in the small intestine. The resultant monosaccharides are absorbed into the bloodstream and transported to the liver. (CC BY-NC-SA 4.0; LibreTexts An Introduction to Nutrition (Zimmerman))

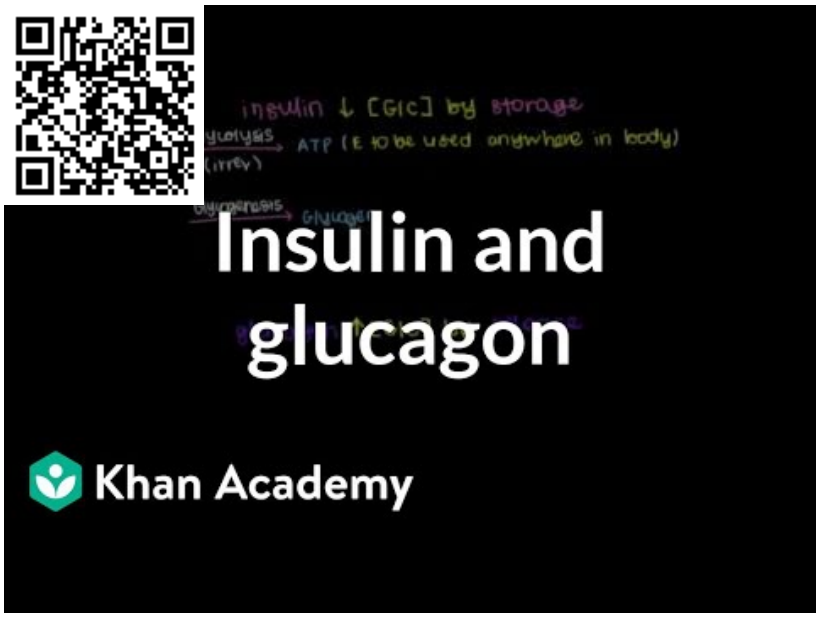
Maintaining Blood Glucose Levels: The Pancreas and Liver

Glucose levels in the blood are tightly controlled, as having either too much or too little glucose in the blood can have health consequences. Glucose regulates its levels in the blood via a process called negative feedback. An everyday example of negative feedback is in your oven because it contains a thermostat. When you set the temperature to 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. 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. Glycogen levels do not take long to reach their physiological limit and when this happens excess glucose will be converted to fat.

Insulin has an opposing hormone called glucagon. As the time after a meal increases, glucose levels decrease in the blood. 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 (the break down of glycogen into glucose) 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.



"Insulin and Glucagon" by khanacademymedicine

Leftover Carbohydrates: The Large Intestine

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

Key Takeaways

- Carbohydrate digestion begins in the mouth with the mechanical action of chewing and the chemical action of salivary amylase. Carbohydrates are not chemically broken down in the stomach, but rather in the small intestine. Pancreatic amylase and the disaccharidases finish the chemical breakdown of digestible carbohydrates.
- The monosaccharides are absorbed into the bloodstream and delivered to the liver.
- Blood glucose levels are regulated by two hormones: insulin and glucagon.
- Some of the indigestible carbohydrates are digested by bacteria in the large intestine.

References

1. Definitions and Facts for Lactose Intolerance. niddk.nih.gov. Accessed May 13, 2025.

This page titled 4.3: Digestion and Absorption of Carbohydrates is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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 percent of the glucose entering the body from digestion is redistributed (by the liver) back into the blood for use by other tissues. Cells that require energy remove the glucose from the blood with a transport protein in their membranes. The energy from glucose comes from the chemical bonds between the carbon atoms. Sunlight energy was required to produce these high-energy bonds in the process of photosynthesis. Cells in our bodies break these bonds and capture the energy to perform cellular respiration. Cellular respiration is basically a controlled burning of glucose versus an uncontrolled burning. A cell uses many chemical reactions in multiple enzymatic steps to slow the release of energy (no explosion) and more efficiently capture the energy held within the chemical bonds in glucose.

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).

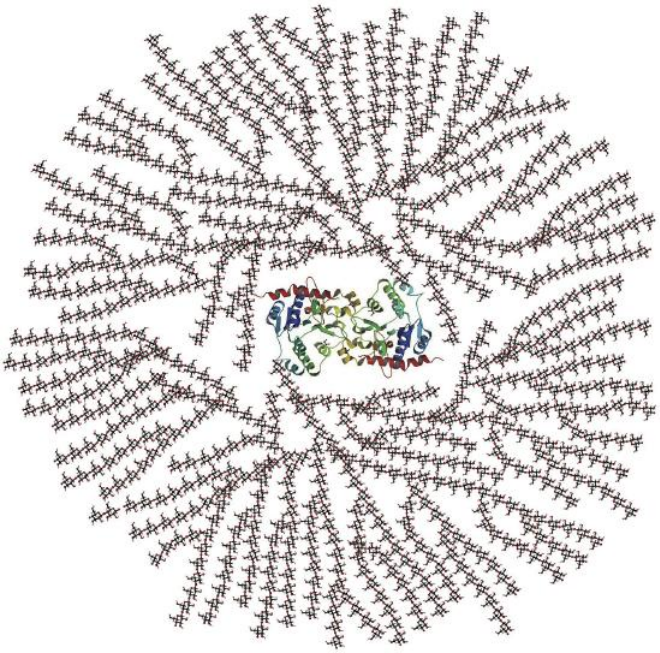


Figure 4.4.1:The structure of glycogen enables its rapid mobilization into free glucose to power cells.

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 sets in because it takes longer to transform the chemical energy in fatty acids and proteins to usable energy than glucose. After prolonged exercise, glycogen is gone and muscles must rely more on lipids and proteins as an energy

source. Athletes can increase their glycogen reserve modestly 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 destruction 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 destruction 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.

Key Takeaways

- The four primary functions of carbohydrates in the body are to provide energy, store energy, spare protein, and prevent ketosis.
- Glucose energy is stored as glycogen, with the majority of it in the muscle and liver. The liver uses its glycogen reserve as a way to keep blood-glucose levels within a narrow range between meal times.
- The presence of adequate glucose in the body spares the breakdown of proteins from being used to make glucose needed by the body.
- Adequate glucose also prevents ketosis which can make the blood too acidic.

References

1. Batch JT, Lamsal SP, Adkins M, Sultan S, Ramirez MN. Advantages and Disadvantages of the Ketogenic Diet: A Review Article. *Cureus*. 2020;12(8):e9639. Accessed May 13, 2025.
2. Food and Nutrition Board of the Institute of Medicine. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids.* Washington, DC: National Academies Press; 2002.

This page titled 4.4: Functions of Carbohydrates is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

4.5: Carbohydrate Recommendations

Learning Objectives

- Identify the Acceptable Macronutrient Distribution Range for carbohydrates.
- Identify the Adequate Intake for fiber.
- Identify the recommended intake of added sugars.

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). 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; 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 USDA Dietary Guidelines recommend that less than 10% of total calories consumed should come from added sugars. The Food and Nutrition Board has also set the Adequate Intake (AI) for dietary fiber at 14 grams for every 1,000 calories consumed. This translates into an AI of 38 grams for men and 25 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
Added Sugars			< 10
Fiber (adults 50 or younger)	38 (men), 25 (women)		
Fiber (adults 51 or older)	30 (men), 21 (women)		

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. 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.[1,2] 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.

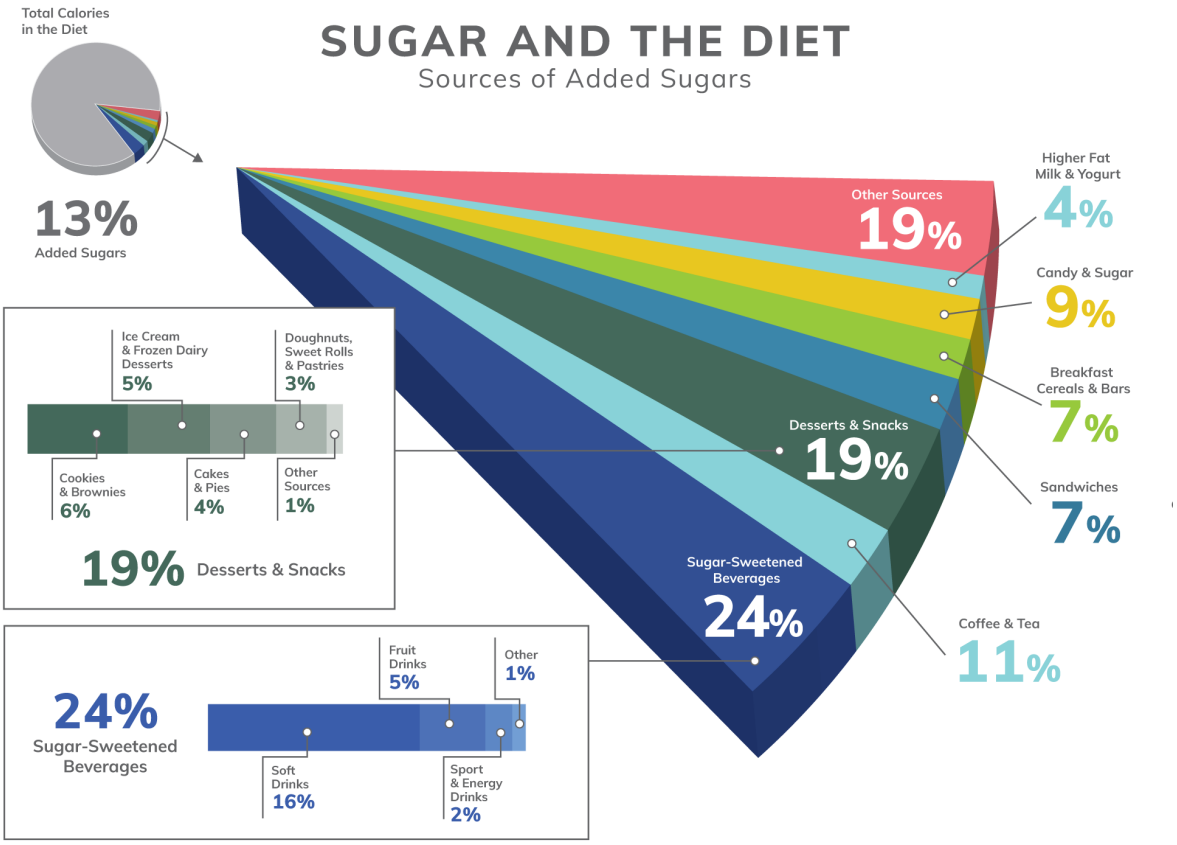


Figure 4.5.1: Sources of Added Sugar in the Diet ("Sugar and the Diet: Sources of Added Sugars" by The Sugar Association)

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.

Key Takeaways

- The Recommended Dietary Allowance (RDA) of carbohydrates for children and adults is 130 grams per day. This is the average minimum amount the brain requires to function properly. The Acceptable Macronutrient Distribution Range (AMDR) for total carbohydrates is 45-65%.
- Health recommendations include limiting added sugar intake to less than 10% of total calories.
- The Adequate Intake (AI) for fiber is 25 grams per day for women and 38 grams per day for men.
- Carbohydrates are contained in all five food groups: grains, fruits, vegetables, proteins (in beans and some processed meats) and dairy products.

References

1. Imamura F, O'Connor L, Ye Z, et al. Consumption of sugar sweetened beverages, artificially sweetened beverages, and fruit juice and incidence of type 2 diabetes: systematic review, meta-analysis, and estimation of population attributable fraction. *British Journal of Sports Medicine* 2016;50:496-504.
2. Malik VS, Li Y, Pan A, et al. Long-term consumption of sugar-sweetened and artificially sweetened beverages and risk of mortality in US adults. *Circulation* 2019;139:2113-2125.

This page titled 4.5: Carbohydrate Recommendations is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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 three diseases in America. It affects millions of people and causes tens of thousands of deaths each year. It has been estimated that by 2050, 1 in 3 American adults will have diabetes, which is closely related to the obesity epidemic in the U.S. Poorly treated or untreated diabetes has many serious side effects including kidney failure, blindness, limb loss and 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 regulate blood glucose levels. The most common complication is hyperglycemia (elevated 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. There are three different 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. Its onset typically occurs before the age of thirty. 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 inject insulin under the skin. Before this treatment was discovered, people with Type 1 diabetes died rapidly after disease onset. Death was the result of extremely high blood-glucose levels affecting brain function and leading to coma and death.

A person with Type 1 diabetes usually has a rapid onset of symptoms that include hunger, excessive thirst, excessive urination, and rapid weight loss (see Figure 4.6.1). 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 who have Type 1 diabetes must adhere to a strict diet to prevent the development of serious complications. Type 1 diabetics are advised to consume a diet low in the types of carbohydrates that rapidly spike glucose levels (high glycemic index foods), to count the carbohydrates they eat, to consume healthy-carbohydrate foods, to eat small meals frequently, and to inject appropriate amounts of insulin based on the amount of carbohydrates eaten. These guidelines are aimed at preventing large fluctuations in blood glucose.

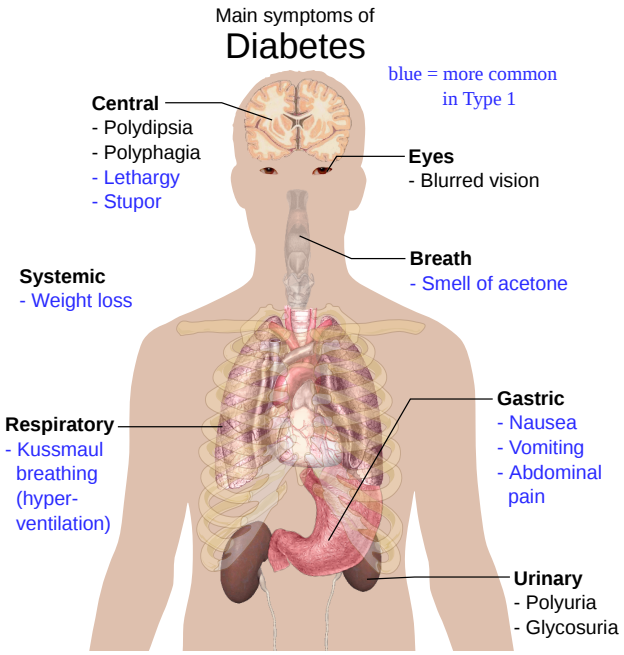


Figure 4.6.1: Overview of the symptoms of diabetes in the main systems of the body. (Public domain; Mikael Häggström)

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 (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 is more 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. 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 be treated with insulin injections. 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.

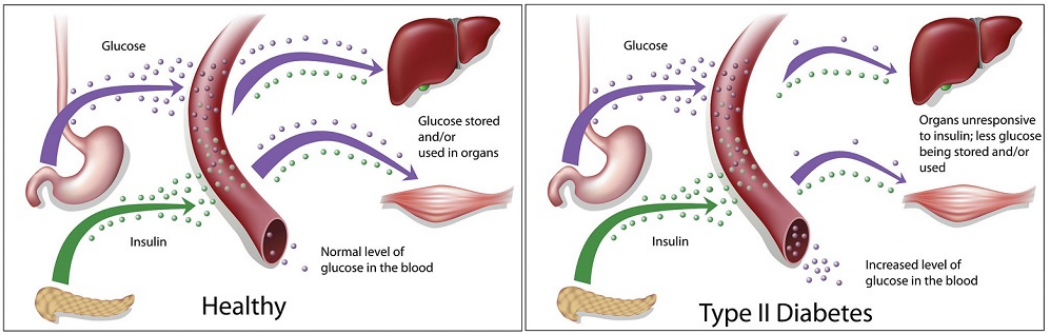


Figure 4.6.2: Type 2 diabetes is a metabolic disease characterized by high blood-glucose levels. © Shutterstock

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 for 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.[1] The IDF estimates that 20-25% of adults worldwide have metabolic syndrome and people with metabolic syndrome are 5 times more likely to develop Type 2 diabetes.[1]

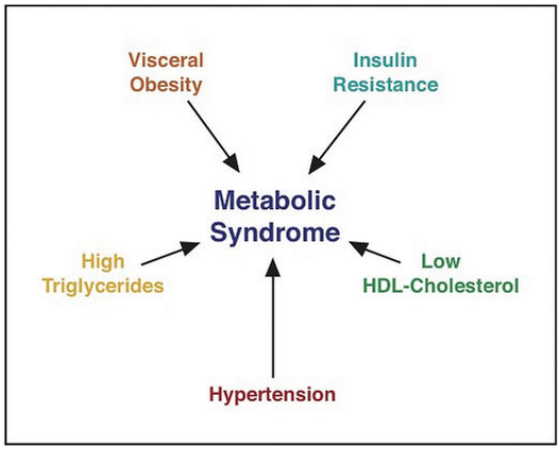


Figure 4.6.3: Metabolic Syndrome consists of a combination of risk factors that increases the chances for chronic disease. (CC BY-NC-SA 4.0; LibreTexts An Introduction to Nutrition (Zimmerman))

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. One out of every three adults in the United States have prediabetes.[2] 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.[3] 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.

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.[4] 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 insulin injections as soon as they are diagnosed (Figure 4.6.4).

Type 2 diabetics may require oral medications and insulin injections to maintain blood glucose levels in the target range. The symptoms of high blood glucose, also called hyperglycemia, are difficult to recognize, diminish in the course of diabetes, and are mostly not apparent until levels become very high. The symptoms are increased thirst and frequent urination.

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 injecting too much insulin or injecting 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 people are sensitive to the intake of sugars, refined starches, and high glycemic index foods. Individuals with reactive hypoglycemia have some symptoms of hypoglycemia. Symptoms are caused by a higher than normal increase in blood insulin levels. This rapidly decreases blood glucose levels to a level below what is required for proper brain function.



Figure 4.6.4: Insulin syringe and pen. (CC-SA-BY-3.0; BruceBlaus)

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.[5]

Key Takeaways

- Diabetes is a disease of insulin deficiency and glucose excess. Like other diseases, genetics, nutrition, environment, and lifestyle are all involved in determining a person's risk for developing diabetes.
- Type 1 diabetes is treated with insulin injections. However, insulin injections do not cure the disease, and diabetics can suffer many disease complications. Diabetes complications can be relieved by strictly managing blood glucose levels, adhering to a healthy diet, and increasing physical activity.
- The front-line approach for treating Type 2 diabetes includes eating a healthy diet and increasing physical activity.
- The long-term health consequences of diabetes are severe and result from chronically high glucose concentrations in the blood and other metabolic abnormalities such as high blood lipid levels.

References

1. IDF Consensus Worldwide Definition of the Metabolic Syndrome.idf.org. www.idf.org/e-library/consensus-statements/60-idfconsensus-worldwide-definitionof-the-metabolic-syndrome.html. Updated May 4, 2017. Accessed June 13, 2020.
2. Insulin Resistance and Prediabetes. niddk.nih.gov. Accessed May 13, 2025.
3. Definition and Facts of Gestational Diabetes. niddk.nih.gov. Accessed May 13, 2025.
4. Emerging Risk Factors Collaboration, Sarwar N, Gao P, et al. Diabetes mellitus, fasting blood glucose concentration, and risk of vascular disease: a collaborative meta-analysis of 102 prospective studies [published correction appears in Lancet. 2010 Sep 18;376(9745):958. Hillage, H L [corrected to Hillege, H L]]. *Lancet*. 2010;375(9733):2215-2222. doi:10.1016/S0140-6736(10)60484-9.
5. What Is the National DPP? cdc.gov. Accessed May 13, 2025.

This page titled 4.6: Looking Closely at Diabetes is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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 it. (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 percent 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 carginogenic 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 incorporates 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

Sweeteners with Trade Name	Calories	Source/Origin	Consumer Recommendations	Controversial Issues
Aspartame • NutraSweet • Equal	4 kcal/g	Composed of two amino acids (phenylalanine + aspartic acid) + methanol. 200 times sweeter than sucrose.	ADI: 50 mg/kg body weight = 16 12 oz. diet soft drinks for adults. Cannot be used in products requiring cooking. People with PKU should not consume aspartame.	Children have potential to reach ADI if consuming many beverages, desserts, frozen desserts, and gums containing aspartame routinely.
Saccharin • Sweet ‘n’ Low	0 kcal/g	Discovered in 1878. The basic substance is benzoic sulfinide. 300 times sweeter than sucrose.	ADI: 5 mg/kg body weight. Can be used in cooking.	• In the 1970s, high doses of saccharin were associated with bladder cancer in laboratory animals. In 1977, FDA proposed banning saccharin from use in food • protest launched by consumer & interest groups • warning label listed on products about saccharin and cancer risk in animals until 2001 when studies concluded that it did not cause cancer in humans

Sweeteners with Trade Name	Calories	Source/Origin	Consumer Recommendations	Controversial Issues
Acesulfame K • Sunnett • Sweet One	0 kcal/g	Discovered in 1967. Composed of an organic salt, potassium (K). Structure is very similar to saccharin. Acesulfame K is not solely sold in stores; it is often blended with another sweetener when sold under a brand name (e.g., Sweet One). It passes through the body unchanged which means it does not provide energy. 200 times sweeter than sucrose.	ADI: 15 mg/kg body weight. Body cannot digest it. Can be used in cooking.	
Sucralose • Splenda	3.31 kcal/g	First discovered in 1976. Approved for use in 1998 in the United States and in 1991 in Canada. Derived from sucrose in which three of its hydroxyl (OH) groups are replaced by chlorine (Cl−). 600 times sweeter than sucrose.	ADI: 5 mg/kg body weight. Can be used in cooking.	
Stevioside • Stevia • Sweet Leaf	N/A	Derived from stevia plant found in South America. 200-400 times sweeter than sucrose.[1]	Considered to be a dietary supplement and approved not as an additive, but as a dietary supplement.	Used sparingly, stevia may do little harm, but FDA could not approve extensive use of this sweetener due to concerns regarding its effect on reproduction, gastrointestinal microbial imbalance, and energy metabolism.
Siraitia grosvenorii • Monk fruit	N/A	Siraitia grosvenorii comes from a small green melon native to southern China. 100-250 times sweeter than sucrose.[1]	ADI: not specified[1]	
Sugar Alcohols • Sorbitol • Xylitol • Mannitol	1.6–2.6 kcal/g	Sorbitol is derived from glucose.	Less likely to cause tooth decay than sucrose.	May cause diarrhea and gastrointestinal distress if consumed in large amounts.

Key Takeaways

- Sugar substitutes have replaced added sugars in many foods and beverages due to the potential health consequences of consuming too many added sugars.
- Chewing gum with artificial sweeteners is the only proven way that artificial sweeteners promote oral health.
- The most common side effect of consuming products containing sugar substitutes is gastrointestinal upset, a result of their incomplete digestion.
- Prior to introducing any new artificial sweetener into foods it is rigorously tested and must be legally approved by the FDA.

References

1. United States Food and Drug Administration. fda.gov. Aspartame and Other Sweeteners in Food. Accessed May 13, 2025.
2. Toews I, Lohner S, Küllenberg de Gaudry D, Sommer H, Meerpohl JJ. Association between intake of non-sugar sweeteners and health outcomes: systematic review and meta-analyses of randomised and non-randomised controlled trials and observational studies. *BMJ*. 2019;364:k4718. doi:10.1136/bmj.k4718.
3. National Cancer Institute. cancer.gov. Artificial Sweeteners and Cancer. Accessed May 13, 2025.
4. World Health Organization. Aspartame hazard and risk assessment results released. Accessed May 13, 2025.

Contributors

Metropolitan State University of Denver Nutrition Department: Gabriel J. Duran de Casaus and Dr. Jerald Foote

This page titled 4.7: Sugar Substitutes is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

CHAPTER OVERVIEW

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

Template:HideTOC

This page titled 5: Lipids is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

5.1: Introduction to Lipids

Learning Objectives

- Describe the three types of lipids.
- Compare and contrast the structure of the following types of fats:
  - triacylglycerols (including saturated, monounsaturated, polyunsaturated, *cis*, *trans*, omega-3, and omega-6 fatty acids)
  - phospholipids
  - sterols

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. Composed of fats and oils, 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 triacylglycerols, phospholipids, and sterols (Figure 5.1.1).

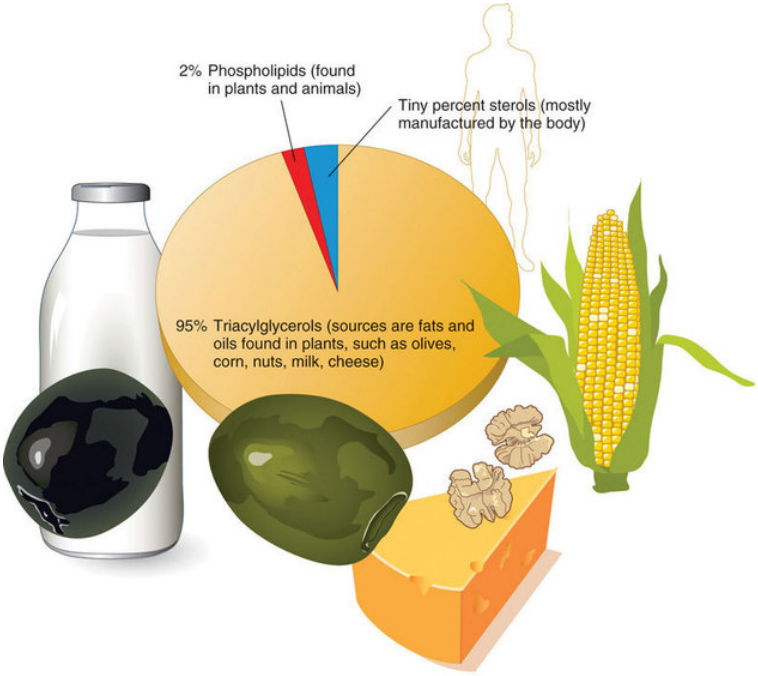


Figure 5.1.1: Types of Lipids (CC BY-NC-SA 4.0; LibreTexts An Introduction to Nutrition (Zimmerman))

Triacylglycerols

Triacylglycerols (also known as triglycerides) make up more than 95 percent of lipids in the diet and are commonly found in fried foods, vegetable oil, butter, whole milk, cheese, cream cheese, and some meats. Naturally occurring triacylglycerols are found in many foods, including avocados, olives, corn, and nuts. We commonly call the triacylglycerols in our food “fats” and “oils.” Lipids have two main forms - fats, which are solid at room temperature, and oils, which are generally liquid at room temperature. As with most fats, triacylglycerols do not dissolve in water. The terms fats, oils, and triacylglycerols are often used interchangeably. In this chapter when we use the word fat, we are referring to triacylglycerols.

Triacylglycerols (triglycerides) are the most common type of fat eaten and stored in the body. The types of fatty acids in our diet directly correlate to the types of fatty acids that are stored in our body.

Fatty acids and glycerol are the building blocks of triacylglycerols. To form a triacylglycerol, a glycerol molecule is joined by three fatty acid chains (Figure 5.1.2). Glycerol is a 3-carbon alcohol that is the backbone of a triacylglycerol; various fatty acids attach to the glycerol backbone.

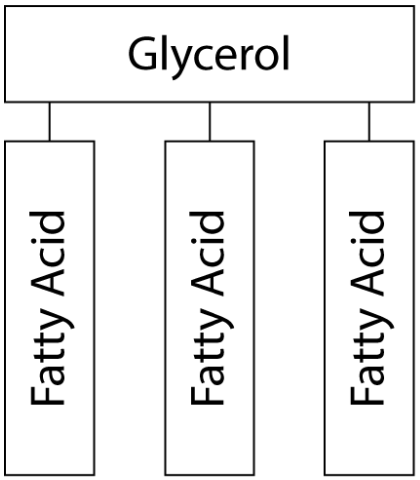


Figure 5.1.2: Structure of a triglyceride. (CC BY-SA 4.0; Sarah Greenwood via Wikimedia Commons)

Fatty Acids

Fatty acids determine if the compound is solid or liquid at room temperature. Fatty acids consist of a carboxyl group (−COOH) group on one end of a carbon chain and a methyl group ($-CH_3$) on the other end (Figure 5.1.3). Fatty acids can differ from one another in three important ways—carbon chain length, degree of saturation, and shape.

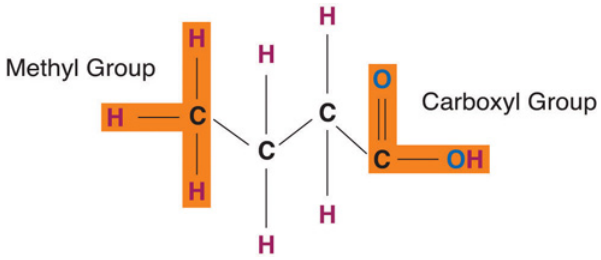


Figure 5.1.3: Structure of a fatty acid (CC BY-NC-SA 4.0; LibreTexts An Introduction to Nutrition (Zimmerman))

Carbon Chain Length

Fatty acids have different chain lengths and different compositions. The length of the carbon chain determines the method of digestion, absorption, and transport in the body. Foods have fatty acids with chain lengths between four and twenty-four 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.

Degree of Saturation

Fatty acid chains are held together by carbon atoms that attach to each other and to hydrogen atoms. The term *saturation* refers to whether or not a fatty acid chain is filled (or “saturated”) to capacity with hydrogen atoms. If each available carbon bond holds a hydrogen atom it's a saturated fatty acid chain (Figure 5.1.4). All of the carbon atoms in a saturated fatty acid chain are bonded through single bonds. The structure 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 animal fats, 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. Unsaturated fatty acids do not stack together well and are liquid at room temperature. 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 5.1.4). Any fatty acid that has only one double bond is a monounsaturated fatty acid, an example of which is olive oil (75 percent of its fat is monounsaturated). Monounsaturated fats help regulate blood cholesterol levels, thereby reducing the risk for heart disease and stroke. A polyunsaturated fatty acid is a fatty acid with two or more double bonds or two or more points of unsaturation. Soybean oil contains high amounts of polyunsaturated fatty acids. Both monounsaturated fats and polyunsaturated fats provide nutrition that is essential for normal cell development.

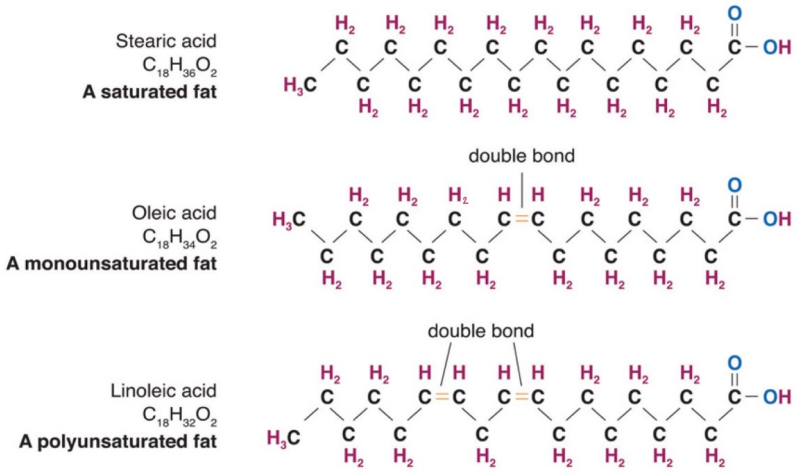


Figure 5.1.4: Chemical structure of saturated, monounsaturated, and polyunsaturated fats (CC BY-NC-SA 4.0; Lauren Groth)

Foods that have a high percentage of saturated fatty acids tend to be solid at room temperature. Examples of foods high in saturated fats include chocolate and meat. Foods rich in unsaturated fatty acids, such as olive oil, tend to be liquid at room temperature.

Shape

The introduction of a carbon double bond in a carbon chain, as in an unsaturated fatty acid, can result in different structures for the same fatty acid composition. When the hydrogen atoms are bonded to the same side of the carbon chain, it is called a *cis* fatty acid (Figure 5.1.5). Because the hydrogen atoms are on the same side, the carbon chain has a bent structure. Naturally occurring fatty acids usually have a *cis* configuration.

In a *trans* fatty acid, the hydrogen atoms are attached on opposite sides of the carbon chain (Figure 5.1.5). 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. Dietary Guidelines recommend keeping *trans* fat intake as low as possible. 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.

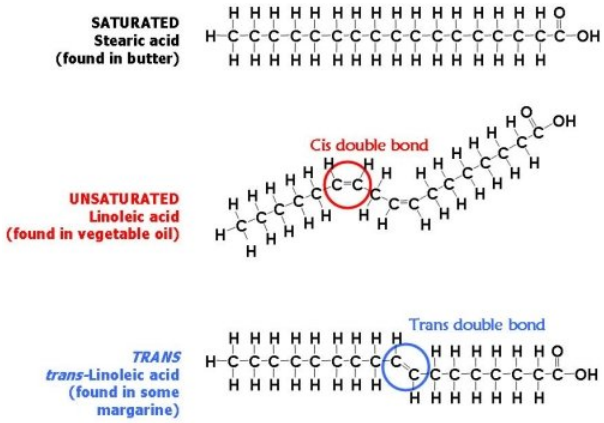


Figure 5.1.5: Cis vs trans fatty acid configurations. (Salway J. *Medical Biochemistry at a Glance*. Blackwell Publishing; 2006:144.)

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 (for example, olive oil) whereas saturated fats tend to be solid at room temperature (for example, butter). Avocados are rich in unsaturated fats. Most vegetable and fish oils contain high quantities of polyunsaturated fats. Olive oil and canola oil are also rich in monounsaturated fats. However, not all oils are unsaturated - tropical oils like palm oil and coconut oil are liquid at room temperature yet high in saturated fat. *Trans* fat 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.

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 food. These fatty acids are known as nonessential fatty acids. However, there are some fatty acids that the body cannot synthesize and these are called essential fatty acids. 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 (methyl) end of the chain. Omega-3 and omega-6 fatty acids are precursors to important compounds called eicosanoids. Eicosanoids are powerful hormones that control many other hormones and important body functions, such as the central nervous system and the immune system. Eicosanoids derived from omega-6 fatty acids are known to increase blood pressure, immune response, and inflammation. In contrast, eicosanoids derived from omega-3 fatty acids are known to have heart-healthy effects. Given the contrasting effects of the omega-3 and omega-6 fatty acids, a proper dietary balance between the two must be achieved to ensure optimal health benefits.

Alpha-linolenic acid (an omega-3 fatty acid) is found in leafy greens, hemp, flax, soy, walnuts, and canola oil. Other important omega-3 fatty acids, such as EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid) are found in fatty fish (e.g., salmon, tuna). Linoleic acid (an omega-6 fatty acid) is found in vegetable and nut oils. Because these essential fatty acids are easily accessible, essential fatty acid deficiency is extremely rare.

Phospholipids

Phospholipids make up only about 2 percent of dietary lipids. They are water-soluble and are found in both plants and animals. Phospholipids are crucial for building the protective barrier, or membrane, around your body's cells. 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 throughout the bloodstream.

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

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, honey, and mustard) 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.

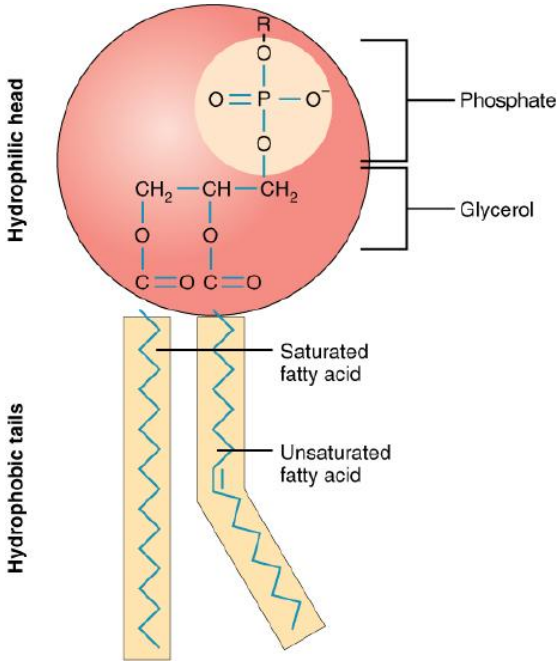


Figure 5.1.6: Phospholipid Structure (CC BY 4.0; OpenStax via Wikimedia Commons)

Sterols

Sterols are the least common 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 triacylglycerols and phospholipids. Most sterols do not contain any fatty acids but rather are multi-ring structures. They are complex molecules that contain interlinking rings of carbon atoms, with side chains of carbon, hydrogen, and oxygen attached. Cholesterol is the best-known sterol because of its role in heart disease. It forms a large part of the plaque that narrows the arteries in atherosclerosis. 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.

Key Takeaways

- Lipids include triacylglycerols, phospholipids, and sterols; triacylglycerols are the most common lipid in food and in the body.
- Three fatty acids combine with one glycerol to make a triacylglycerol, the body’s storage form of fat.
- The carbon chain in fatty acids can be saturated (filled with hydrogen), monounsaturated (with one point of unsaturation and possessing one carbon-carbon double bond), or polyunsaturated (with more than one point of unsaturation and possessing two or more double-carbon bonds).
- The structure and length of a fatty acid determines whether it is solid or liquid at room temperature.
- *Trans* fatty acids have been associated with increased risk for heart disease because of the way they negatively impact blood cholesterol levels.
- Essential fatty acids cannot be synthesized by the body and must be included in the diet. Omega-3 and omega-6 fatty acids have opposing functions and must be consumed in proper balance to promote health.
- Phospholipids are diglycerides with a phosphate group in place of the third fatty-acid chain.

- Sterols contain a multi-ring structure. Cholesterol serves important body functions such as vitamin D and hormone synthesis and is important in cell membrane structure.

References

1. US Food and Drug Administration. *Food Labeling Guide*. Last updated January 2013. Accessed May 13, 2025.

This page titled 5.1: Introduction to Lipids is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

5.2: Digestion and Absorption of Lipids

Learning Objectives

- Summarize the steps in lipid digestion and absorption.
- Explain how lipids are used for energy and stored in the body.

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

From the Mouth to the Stomach

Remember that the building blocks of lipids are triacyglycerols and phospholipids, here we will discuss how they are digested and absorbed. The first step in the digestion of triacylglycerols and phospholipids begins in the mouth as lipids encounter saliva. Next, the physical action of chewing coupled with the action of emulsifiers enables the digestive enzymes to do their tasks. The enzyme lingual lipase, along with a small amount of phospholipid as an emulsifier, initiates the process of digestion (Figure 5.2.1). These actions cause the fats to become more accessible to the digestive enzymes. As a result, the fats become tiny droplets and separate from the watery components.

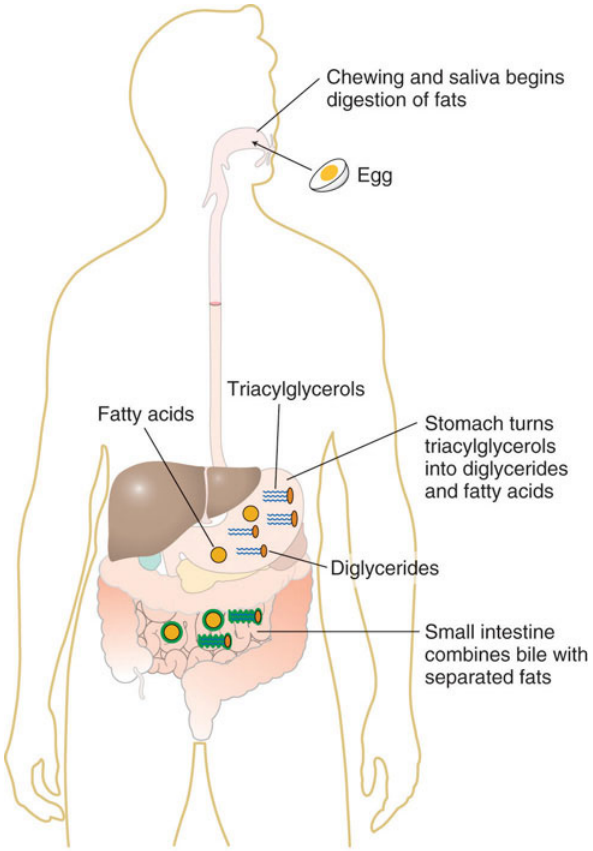


Figure 5.2.1: Lipid Digestion (CC BY-NC-SA 4.0; LibreTexts An Introduction to Nutrition (Zimmerman))

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

Going to the Bloodstream

Fats are not digested and absorbed easily because they are insoluble in water. However, with the help of bile (from the liver) and digestive enzymes (from the pancreas), lipid digestion takes place in the small intestine. In fact, the majority of lipid digestion takes

place in the small intestine. Micelles transport the end products of lipid digestion (free fatty acids and monoglycerides) to the digestive tract lining for absorption. As stomach contents enter the small intestine, the digestive system sets out to manage a small hurdle, namely, to combine the separated fats with its own watery fluids. The solution to this hurdle is bile. Bile 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, lecithin, and substances derived from cholesterol so it acts as an emulsifier. It attracts and holds on to fat while it is simultaneously attracted to and held on to by water. Emulsification increases the surface area of lipids making them more accessible to the digestive enzymes (Figure 5.2.2a).

Once the stomach contents have been emulsified, fat-breaking enzymes (known as lipases) work on the triacylglycerols and diglycerides to sever fatty acids from their glycerol foundations. As pancreatic lipase enters the small intestine, it breaks down the fats into free fatty acids and monoglycerides. Yet again, another hurdle presents itself. How will the fats pass through the watery layer of mucous that coats the absorptive lining of the digestive tract? As before, the answer is bile. Bile salts envelop the fatty acids and monoglycerides to form micelles. Micelles have a fatty acid core with a water-soluble exterior (Figure 5.2.2b). This allows efficient transportation to the intestinal microvillus. Here, the fat components are released and disseminated into the cells of the digestive tract lining.

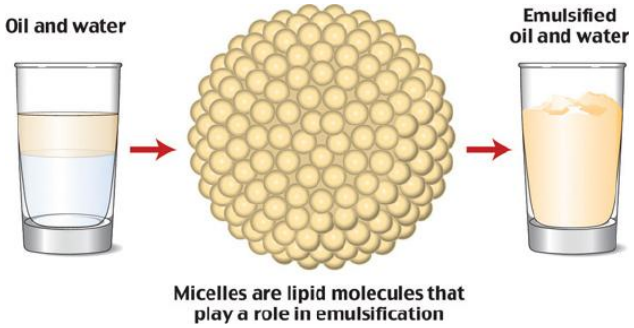


Figure 5.2.2a: Emulsification helps fats travel in the body's watery environment. (CC BY-NC-SA 4.0; LibreTexts An Introduction to Nutrition (Zimmerman))

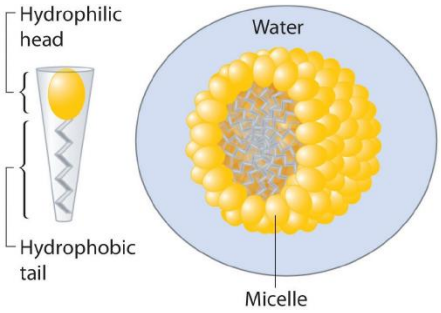


Figure 5.2.2b: Micelle structure (CC BY-NC-SA 3.0; Principles of General Chemistry)

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 triacylglycerols. Triacylglycerols, cholesterol, and phospholipids form lipoproteins when joined with a protein carrier. Lipoproteins have an inner core that is primarily made up of triacylglycerols and cholesterol esters (a cholesterol ester is a cholesterol linked to a fatty acid). The outer envelope is made of phospholipids interspersed with proteins and cholesterol (Figure 5.2.3a).

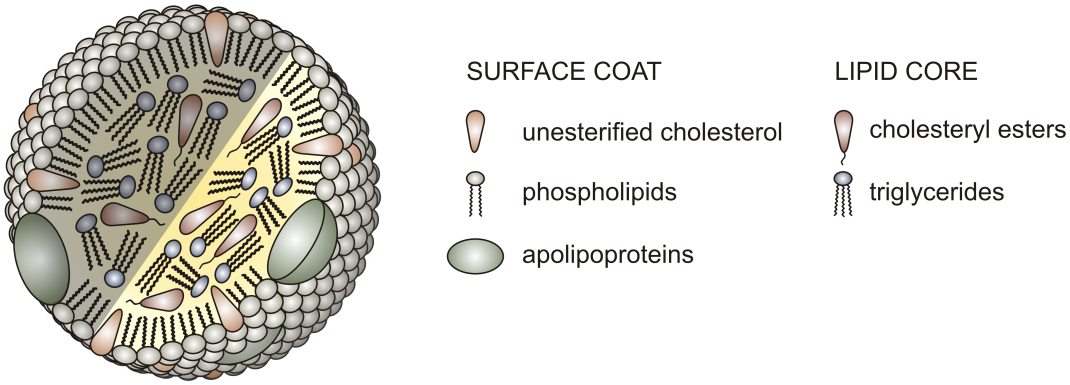


Figure 5.2.3*a*: Lipoprotein structure (CC BY-SA 3.0; Antisense)

A chylomicron (Figure 5.2.3*b*) is a large 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. Short- and medium-chain fatty acids are absorbed more quickly since they are not arranged into chylomicrons.

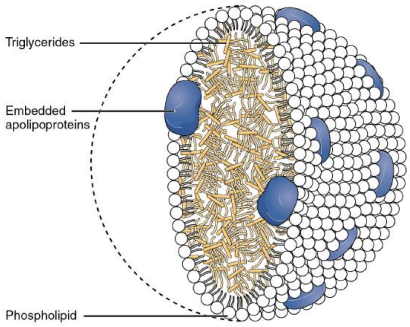


Figure 5.2.3*b*: Chylomicron structure (CC BY 3.0; OpenStax)

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

Storing and Using Body Fat

Adipose (fat) tissue is the body's storage system for extra calories/fuel. 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 is returned to the liver, where it is converted into triacylglycerols and then stored as fat.

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

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

Key Takeaways

- In the stomach fat is separated from other food substances. In the small intestines bile emulsifies fats while enzymes digest them. The intestinal cells absorb the fats.
- Long-chain fatty acids form a large lipoprotein structure called a chylomicron that transports fats through the lymph system.
- Chylomicrons are formed in the intestinal cells and carry lipids from the digestive tract into circulation.
- Cholesterol absorption is hindered by foods high in fiber.
- When energy supplies are low the body utilizes its stored fat reserves for energy.

This page titled 5.2: Digestion and Absorption of Lipids is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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

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. Fat is used for energy during exercise, especially after glycogen is depleted. 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.

Regulating and Signaling

Lipids are part of the cell membrane structure which helps maintain cell membrane fluidity and flexibility. Triacylglycerols 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. Triacylglycerols 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).

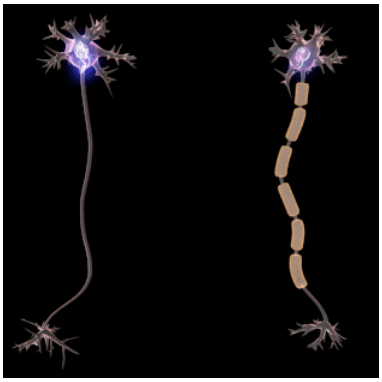


Figure 5.3.1: Lipids serve as signaling molecules; they are catalysts of electrical impulse activity within the brain. Nerve response in myelinated neurons (right) propagate faster than in unmyelinated neurons (left). Myelin is a mixture of proteins and phospholipids that insulates nerves. The myelin 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. 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.

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. Other essential nutrients, such as essential fatty acids, are constituents of the fats themselves and serve as building blocks of a cell.

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.

When the body has used all of its calories from carbohydrates (which can occur after just twenty minutes of exercise), it initiates fat usage. A professional swimmer must consume large amounts of food energy to meet the demands of swimming long distances, so eating fat-rich foods makes sense. In contrast, if a person who leads a sedentary lifestyle eats the same fat-rich foods, they will likely get more fat calories than their body requires.

Smell, Taste, Texture, and Satiety

Fat contains dissolved compounds that contribute to mouth-watering aromas and flavors. Fat also adds texture to food and helps keep baked foods moist. Fats contribute to smooth, creamy, moist, tender, and crispy textures of various foods. Frying foods locks in flavor and lessens cooking time.

Fat plays another valuable role in nutrition. Fat contributes to satiety, or the sensation of fullness. Fats take longer to digest than carbohydrates or protein because fats move slower through the digestive tract, thus promoting an overall sense of fullness. Oftentimes before the feeling of fullness arrives, people overindulge in fat-rich foods, finding the delectable taste irresistible. Indeed, the very things that make fat-rich foods attractive also make them a hindrance to maintaining a healthful diet.

Key Takeaways

- Excess energy from food is stored as adipose tissue in the body.
- Fats within the body are critical for storing energy, maintaining body temperature, cushioning vital organs, regulating hormones, transmitting nerve impulses, and transporting fat-soluble nutrients.
- Fats in food provide a condensed energy source, enhance the texture and flavor of food, and promote satiety.

This page titled 5.3: Functions of Lipids is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

- **5.3: How Lipids Work** by Anonymous is licensed CC BY-NC-SA 3.0.

5.4: Lipid/Fat Recommendations

Learning Objectives

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

Recommended Fat Intake

Table 5.4.1 includes the Acceptable Macronutrient Distribution Range (AMDR) recommendations for adults for the various types of lipids/fats.

Table 5.4.1: Acceptable Macronutrient Distribution Range (AMDR) for Lipids

Lipid Type	AMDR (% of total calories)
Total Fat	20–35
Saturated Fat	< 10
Trans Fat	minimize (less than 1%)
Cholesterol	minimize
Omega-3 Fatty Acids (alpha-linolenic acid)	0.6-1.2
Omega-6 Fatty Acids (linoleic acid)	5-10

Sources of Fats

Food may contain visible fats and/or hidden fats. Visible fats are fats we knowingly add to foods such as butter, cream, mayonnaise, and dressings. Hidden fats are added to processed and prepared foods to improve taste and texture. Examples of hidden fats include marbling in meat, regular-fat dairy products, and fried foods.

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 78% monounsaturated fat, 8% polyunsaturated fat, and 14% saturated fat.[1] Olive oil is considered to be a monounsaturated fat because it is made up of mostly monounsaturated fat. 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. The *Dietary Guidelines* recommend consuming as little dietary cholesterol as possible. Our body makes cholesterol, so we don't have to worry about getting it from food.

Table 5.4.2: Common Food Sources of Various Fats

Lipid Type	Common Sources
Saturated Fat	animal products, dairy products, palm and coconut oils, and cocoa butter
Trans Fat	stick/tub margarines, fast foods, commercial baked goods, some snack foods
Cholesterol	animal products, liver, eggs, dairy products
Monounsaturated Fat	nuts (almonds, cashews, pecans, peanuts, and walnuts) and nut products, avocados, extra virgin olive oil, sesame oil, high oleic safflower oil, sunflower oil, and canola oil
Polyunsaturated Fat	nuts (walnuts, hazelnuts, pecans, almonds, and peanuts), soybean oil, corn oil, safflower oil, flaxseed oil, canola oil, and fish (trout, herring, and salmon)

Lipid Type	Common Sources
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)

Key Takeaways

- The recommended fat intake for adults is 20–35% of your total caloric intake. Saturated fat should be less than 10% of your total caloric intake and *trans* fat should be less than 1% of total caloric intake.
- Nuts, seeds, whole grains, legumes, and vegetable oil such as soybean, canola, and flaxseed are excellent sources of monounsaturated and polyunsaturated fats.

References

1. Extra Virgin Olive Oil. FoodData Central. usda.gov. Accessed May 13, 2025.

This page titled 5.4: Lipid/Fat Recommendations is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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). Lipoproteins are characterized by size, density, and composition; the various lipoproteins are described in more detail below.

Major Lipoproteins

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

- VLDLs. Very low-density lipoproteins are made in the liver from remnants of chylomicrons and transport triacylglycerols from the liver to various tissues in the body. As the VLDLs travel through the circulatory system, lipoprotein lipase strips the VLDL of triacylglycerols. As triacylglycerol removal persists, the VLDLs become intermediate-density lipoproteins.
- IDLs. Intermediate-density lipoproteins transport a variety of fats and cholesterol in the bloodstream and are a little under half triacylglycerol in composition. While traveling in the bloodstream, cholesterol is gained from other lipoproteins while circulating enzymes strip its phospholipid component. When IDLs return to the liver, they are transformed into low-density lipoprotein.
- LDLs. Low-density lipoproteins are commonly known as “bad cholesterol”. LDLs carry cholesterol and other lipids from the liver to tissues throughout the body. LDLs are comprised of very small amounts of triacylglycerols, and contain over 50% cholesterol and cholesterol esters. As the LDLs deliver cholesterol and other lipids to the cells, each cell’s surface has receptor systems specifically designed to bind with LDLs. Circulating LDLs in the bloodstream bind to these LDL receptors and are brought into the cell. Once inside the cell, the LDL is taken apart and its cholesterol is released. A deficiency of these LDL receptors will leave a high quantity of cholesterol traveling in the bloodstream, which can lead to heart disease or atherosclerosis. Diets rich in saturated fats limit the number of LDL receptors and thus leave cholesterol in the bloodstream that could be deposited in arteries and block blood flow.
- HDLs. High-density lipoproteins are responsible for carrying cholesterol out of the bloodstream and into the liver, where it is either reused or removed from the body with bile. HDLs have a very large protein composition coupled with low cholesterol content compared to the other lipoproteins. Hence, these high-density lipoproteins are commonly called “good cholesterol.”

Contrasting LDL and HDL

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

- **LDL/HDL composition**. LDL is approximately 25% protein and 75% cholesterol and other fats. LDL is bigger (yet lighter) and richer in cholesterol than HDL. HDL is 50% protein and 50% cholesterol and other fats. HDL is smaller, more dense, and richer in protein.
- **LDL/HDL function**. LDLs carry cholesterol into cells for normal usage, but LDLs can also deposit cholesterol into the walls of blood vessels, which can lead to harmful disease. HDLs scavenge excess cholesterol from the cells, tissues, and blood vessels and deliver these back to the liver, where these are either reused or excreted.
- **LDL/HDL and inflammation**. LDLs carry lipids that are pro-inflammatory and may contribute to heart disease. HDLs transport lipids that are anti-inflammatory and may reduce the occurrence of heart disease.
- **LDL/HDL warnings**. High LDL values warn of increased health risks for heart disease, while high HDL values indicate a reduced risk for heart disease.
- **Oxidized LDL**. LDLs become more dangerous when oxidized. Oxidation is defined as the loss of electrons between two substances via a chemical reaction. If LDL oxidation occurs, the oxidized LDL is left unstable. Oxidized LDL can speed up the

process of plaque formation in the arteries. It is believed to hasten the deposition of cholesterol into the arterial walls and to induce a chronic inflammatory effect throughout the body's vast network of vessels. This activity promotes atherosclerosis and significantly increases risks for heart attack or stroke.

Blood Cholesterol Recommendations

Desirable blood cholesterol levels for total cholesterol, LDL cholesterol, and HDL cholesterol are included in Table 5.5.1.[1] More specifically, when looking at individual lipid profiles, a low amount of LDL and a high amount of HDL prevents excess buildup of cholesterol in the arteries and wards off potential health hazards. In other words, elevated LDL blood lipid profiles indicate an increased risk of heart attack, while elevated HDL blood lipid profiles indicate a reduced risk.

Table 5.5.1: Blood Cholesterol Classifications

Cholesterol Type	Category	mg/dL (milligrams per deciliter)
Total Cholesterol	Desirable Borderline High High	less than 200 200-239 240 or higher
LDL Cholesterol	Optimal Above Optimal Borderline High High Very High	less than 100 100-129 130-159 160-189 190 or higher
HDL Cholesterol	High Low	60 or higher (considered protective) less than 40

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 avoiding *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 fats accumulate along their inner walls and form plaques (Figure 5.5.1). 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.

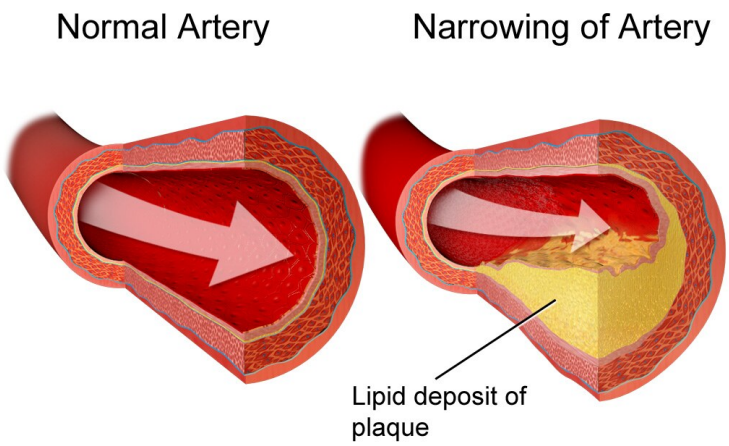


Figure 5.5.1: Illustration comparing a normal blood vessel and partially blocked vessel due to atherosclerotic plaque build-up. Plaque formation along arterial walls impedes blood flow and can create a thrombus, or stationary blood clot. (CC BY 3.0; Blausen.com staff (2014). "Medical gallery of Blausen 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 stable 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.

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 5.5.2).

Table 5.5.2: 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.	• **Cigarette smoking.** 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.** High levels of blood cholesterol can increase the risk. A high level of low-density lipoprotein (LDL), or the "bad" cholesterol, is a common contributing factor. However, a low level of high-density lipoprotein (HDL), or "good" cholesterol, can also promote atherosclerosis.

Steps to Reducing Heart Disease Risk

Diet and nutrition 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 blood cholesterol 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.

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 Table 5.5.3.[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.

Table 5.5.3: Blood Pressure Categories

Blood Pressure Category	Systolic mm Hg (upper number)	Diastolic mm Hg (lower number)
Normal	less than 120 *and*	less than 80
Elevated	120-129 *and*	less than 80
High Blood Pressure (Hypertension) - Stage 1	130-139 *or*	80-89
High Blood Pressure (Hypertension) - Stage 2	140 or higher *or*	90 or higher
Hypertensive Crisis (consult your doctor immediately)	higher than 180 *and/or*	higher than 120

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.

Key Takeaways

- Some of the major lipoproteins are VLDL, IDL, LDL, and HDL.
- VLDL delivers triacylglycerols and other lipids to the body’s tissues and slowly becomes IDL. The liver uses IDL to create LDL, the main transporter of cholesterol.
- LDL, or “bad” cholesterol, has low protein composition and high cholesterol content. High levels of LDL have been shown to increase the risks for heart disease.
- HDL or “good’’ cholesterol has a larger proportion of protein and a small cholesterol composition. HDL scavenges excess cholesterol and returns it to the liver for reuse or disposal. A high level of HDL reduces the risk for heart disease.
- It is important to maintain a healthy lipid profile within recommended values in order to minimize the risk of heart disease.
- Heart disease risk factors include age, family history, obesity, physical inactivity, and undesirable blood cholesterol levels.
- Limiting saturated and *trans* fat intake while also increasing dietary fiber intake can help reduce heart disease risk.
- High blood pressure is a risk factor for heart disease.

References

1. National Cholesterol Education Program. ATP III Guidelines At-A-Glance Quick Desk Reference. Accessed May 13, 2025.
2. Prevention and Treatment of High Cholesterol (Hyperlipidemia). Accessed May 13, 2025.
3. Heart Disease. FastStats - Heart Disease. cdc.gov. Accessed May 13, 2025.
4. High Blood Pressure Facts. cdc.gov. Accessed May 13, 2025.
5. Understanding Blood Pressure Readings. heart.org. Accessed May 13, 2025.

This page titled 5.5: Understanding Blood Cholesterol and Heart Disease is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

CHAPTER OVERVIEW

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
6.6: Vegetarian and Vegan Diets

Template:HideTOC

This page titled 6: Proteins is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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 commonly 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 side chain (R), a hydrogen (H), a nitrogen-containing *amino* group (NH_2), and a carboxylic *acid* group (COOH) — hence the name “amino acid”. Amino acids differ from each other by which specific side chain (R) is bonded to the carbon center. The side chain of an amino acid can be as simple as one hydrogen bonded to the carbon center (glycine; Figure 6.1.2*a*) or more complex like leucine (Figure 6.1.2*b*).

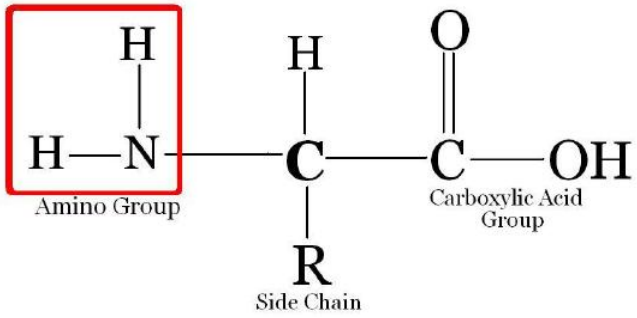


Figure 6.1.1: Amino Acid Structure. (CC BY 3.0; by Tyagi.anuj via Wikimedia Commons)

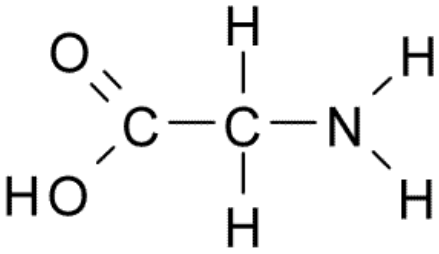


Figure 6.1.2a: Chemical structure of glycine. (CC BY-SA 3.0; by Borb via Wikimedia Commons)

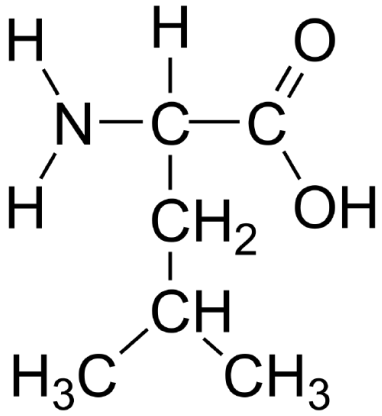


Figure 6.1.2b: Chemical structure of leucine. (CC0 1.0; by Hbf878 via Wikimedia Commons)

Essential and Nonessential Amino Acids

There are twenty 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). 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.

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*

*Conditionally essential

Essential	Nonessential
	Serine
	Tyrosine*
*Conditionally essential	

Building Proteins with Amino Acids (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 6.1.3). 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.

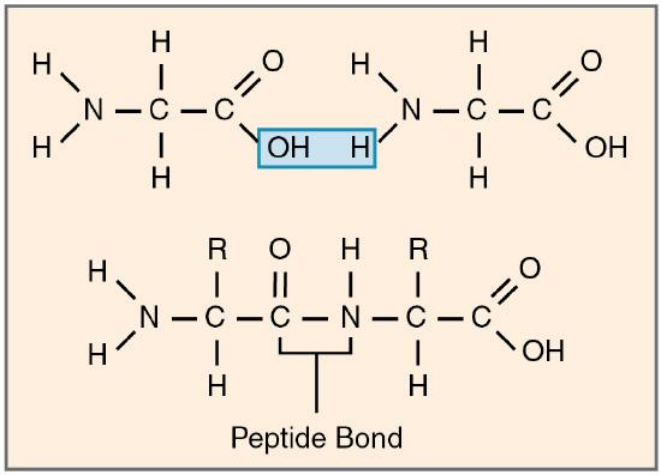


Figure 6.1.3: Connecting amino acids with peptide bonds builds proteins. (CC BY 3.0; by OpenStax College - Anatomy & Physiology)

Each protein in the human body differs in its amino acid sequence. Genes regulate amino acid bonding (a gene is a section of DNA that acts as a template for protein synthesis). Protein synthesis also involves transcription and translation.

- Transcription: messenger RNA (mRNA) copies (transcribes) information from DNA in the nucleus and carries that information to ribosomes in the cytoplasm
- Translation: information from the mRNA is converted (translated) into a growing strand of amino acids that bind together to form a specific protein

Existing proteins can be broken down to provide amino acids for new protein synthesis. The newly synthesized protein is structured to perform a particular function in a cell. The 3-D protein shape (tertiary structure) 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.

Protein synthesis can 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.

Key Takeaways

- Amino acids are the building blocks of proteins. The structure of amino acids include a central carbon atom, a hydrogen atom, an *amino* group, a carboxylic *acid* group, and a side chain.
- Some amino acids are nonessential in the diet because the body can synthesize them, and some are essential in the diet because the body cannot make them.
- Proteins are chains of amino acids held together by peptide bonds.

References

Chapter cover photo "Protein-rich Foods" by Smastronardo is licensed under CC BY-SA 4.0

This page titled 6.1: Introduction to Proteins is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

- **Current page** by Ann Diker is licensed CC BY-NC-SA 3.0.
- **5.4: Lipid/Fat Recommendations** by Ann Diker is licensed CC BY-NC-SA 3.0.

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 circulatory system.

From the Mouth to the Stomach

The first step in protein digestion involves chewing. 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. 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.

From the Stomach to the Small Intestine

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. 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 6.2.1). 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 percent of the protein ingested does not get broken down further than the amino acid monomers.

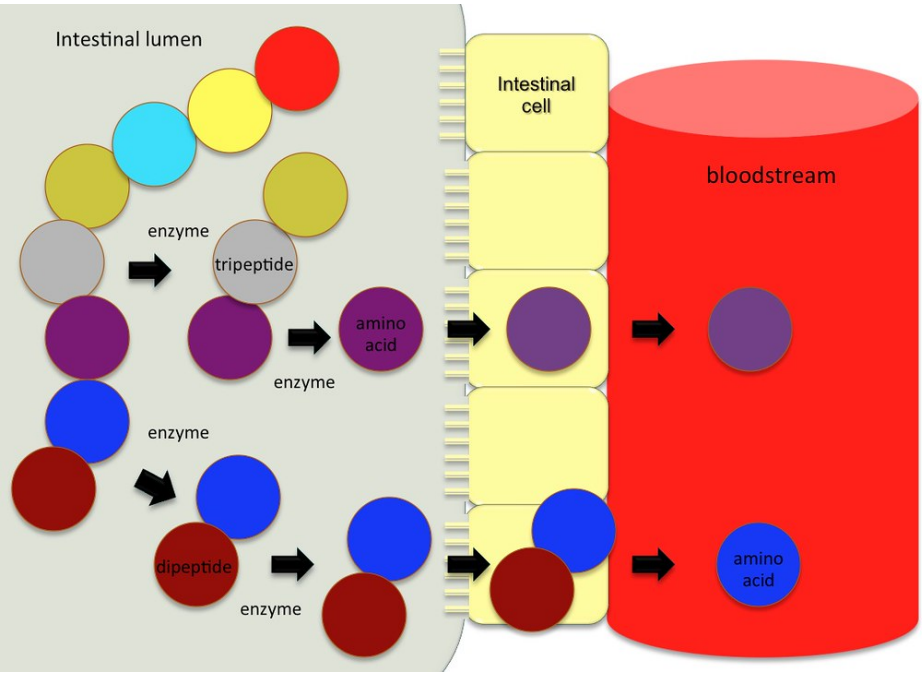


Figure 6.2.1: Once proteins are digested into dipeptides, tripeptides, and amino acids, they are absorbed into the intestinal cells and then enter the bloodstream as amino acids. (CC BY-NC-SA 2.0; by Nutritional Doublethink via Flickr)

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." 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 one percent of total body-protein content. Thus, the body does not store protein as it does with carbohydrates (as glycogen in the muscles and liver) and lipids (as triglycerides in adipose tissue).

Key Takeaways

- Mechanical digestion of protein begins in the mouth and continues in the stomach and small intestine.
- Chemical digestion of protein begins in the stomach and ends in the small intestine.
- The body recycles amino acids to make more proteins.

This page titled 6.2: Digestion and Absorption of Proteins is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

6.3: Functions of Protein

Learning Objectives

- Describe the various functions of protein in the body.

Proteins build muscle and all body tissues. It is a crucial role of the proteins to provide the structure of virtually all body tissues. Some proteins have other "jobs" to do. In other words, they are not part of the body structure, but have specific tasks to perform such as acting as transporter, antibodies, enzymes and more. You have already learned about some of these important proteins. When you learned about diabetes you studied the hormones insulin and glucagon. These are examples of two protein molecules that act as hormones with very specific and important "jobs" relative to carbohydrate metabolism.

Enzymes

Some proteins function as enzymes. Enzymes are proteins that conduct specific chemical reactions. An enzyme's job is to provide a site for a chemical reaction and to lower the amount of energy and time it takes for that chemical reaction to happen (Figure 6.3.1). This is why enzymes are sometimes called catalysts. On average, more than one hundred chemical reactions occur in cells every single second and most of them require enzymes. The liver alone contains over one thousand enzyme systems. Enzymes are specific and will use only particular substrates (or substances in Figure 6.3.1) that fit into their active site, similar to the way a lock can be opened only with a specific key. Nearly every chemical reaction requires a specific enzyme. Fortunately, an enzyme can fulfill its role as a catalyst over and over again, although eventually it is destroyed and rebuilt. All bodily functions, including the breakdown of nutrients in the stomach and small intestine, the transformation of nutrients into molecules a cell can use, and building all macromolecules, including protein itself, involve enzymes.

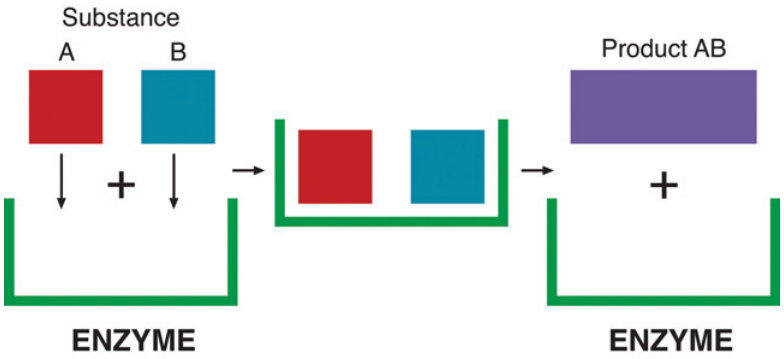


Figure 6.3.1: Enzymes are proteins. An enzyme's job is to provide a site for substances to chemically react and form a product and decrease the amount of energy and time it takes for this to happen. (CC BY-NC-SA 4.0; LibreTexts An Introduction to Nutrition (Zimmerman))

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. Other examples of hormones made from proteins include glucagon, melatonin, and thyroid hormone.

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 from an area of high concentration to one of a low concentration (you can find additional information about these concepts and images that review the concepts in Chapter 7). As a result, water moves toward areas that have higher concentrations of other solutes, such as proteins and 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 it can cause 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.

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 act as buffers and release hydrogen (H^+) into the blood if it gets too basic. Proteins 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 a role in nutrient transport. 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 6.3.2).

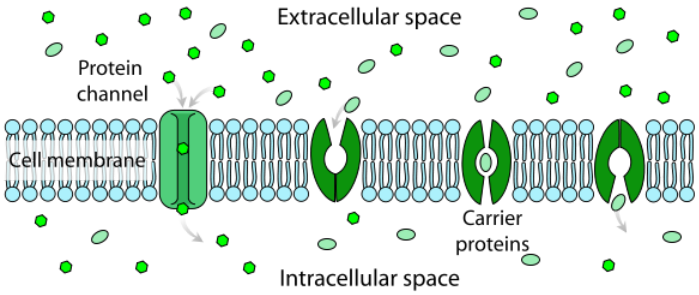


Figure 6.3.2: Molecules move in and out of cells through transport proteins, which are either channels or carriers. Facilitated diffusion in the cell membrane, showing ion channels (left) and carrier proteins (three on the right). (CC0; by LadyofHats via Wikimedia Commons)

.

Antibodies

Our immune system is designed to attack and destroy foreign substances. When a foreign substance attacks the body, the immune system produces antibodies (Figure 6.3.3) to defend against it. Antibodies are special proteins that recognize a unique molecule on harmful bacteria and viruses known as an antigen. Antibodies bind to the antigen and destroy it. Antibodies also trigger other factors in the immune system to seek and destroy unwanted intruders.

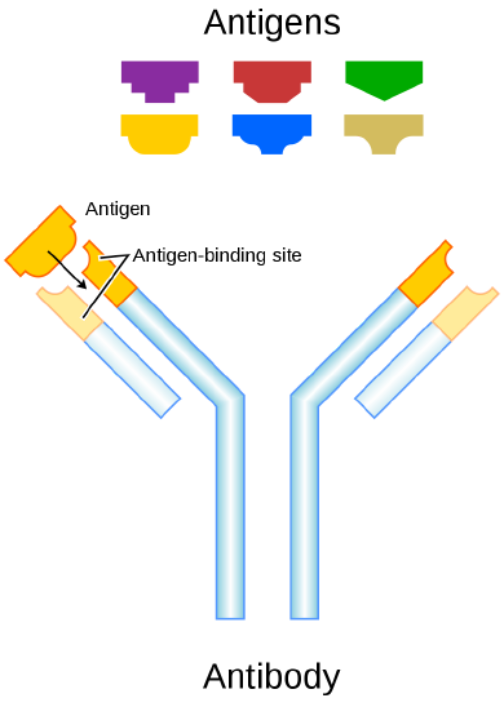


Figure 6.3.3: Antibodies are proteins that surround and attack foreign substances by attaching to antigens on the surface of the foreign substance. Each antibody binds to a specific antigen; an interaction similar to a lock and key. (public domain; by Fvasconcellos via Wikimedia Commons)

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) 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.

Key Takeaways

- Proteins have multiple functions, including: acting as enzymes and hormones, maintaining proper fluid and acid-base balance, providing nutrient transport, making antibodies, enabling wound healing and tissue regeneration, and providing energy when carbohydrate and fat intake is inadequate.
- Without adequate intake of protein containing all the essential amino acids, protein functions will be impaired.

This page titled 6.3: Functions of Protein is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

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.
- Describe various vegetarian diets.

How Much Protein Does a Person Need in Their Diet?

The Recommended Dietary Allowance (RDA) for protein is 0.8 grams of protein per kilogram of body weight. The Acceptable Macronutrient Distribution Range (AMDR) for protein is 10-35% of total calories. Although the RDA is the same for all non-pregnant and non-lactating adults, there is a growing body of evidence that this number is inadequate to meet the needs of some athletes.[1]

Using the information above, how much protein does a 150 pound sedentary adult need? 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 weigh in kilograms by the appropriate RDA (68.2 kg x 0.8 grams/kg = 55 grams protein per day)

Most Americans meet or exceed the RDA for protein.

Protein Input = Protein Used by the Body + Protein Excreted

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

$$(\text{Weight in lbs.} \div 2.2\ \text{kg/lb}) \times 0.8\ \text{g/kg}$$

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 6.4.1). 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 6.4.1: 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 6.4.2. 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 6.4.2: Mutual Supplementation Combinations

Foods	Lacking Amino Acids	Complementary Food	Complementary Menu
Legumes	Methionine, tryptophan	Grains, nuts, and seeds	Hummus and whole-wheat pita
Grains	Lysine, isoleucine, threonine	Legumes	Cornbread and kidney bean chili
Nuts and seeds	Lysine, isoleucine	Legumes	Stir-fried tofu with cashews

Key Takeaways

- The RDA set for protein for adults is 0.8 grams per kilogram of body weight and represents the amount of protein in the diet required to balance the protein that is used up by the body and that is excreted.
- Protein-containing foods include meat, seafood, poultry, eggs, soy, beans, peas, nuts, and seeds.
- Most animal-based proteins are complete protein sources and most plant-based proteins are incomplete protein sources.

References

1. Nutrition and Athletic Performance. *Medicine & Science in Sports & Exercise.* 2016;48(3):543-568. doi: 10.1249/MSS.0000000000000852.

This page titled 6.4: Protein Recommendations is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

6.5: Diseases Involving Proteins

Learning Objectives

- 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.

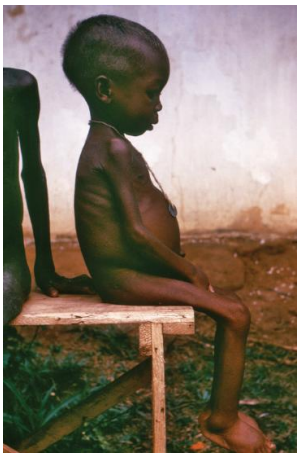


Figure 6.5.1: Kwashiorkor is a disease brought on by a severe dietary protein deficiency. Symptoms include edema of legs and feet, light-colored, thinning hair, anemia, a pot-belly, and shiny skin. (public domain; by Dr. Lyle Conrad via cdc.gov)

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 children below the age of one 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 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

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. 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.

Key Takeaways

- Protein deficiency can cause swelling, fatigue, skin problems, irritability, muscle wasting, and eventual death from infection.
- The long-term health consequences of high-protein diets have not been adequately studied.

References

1. Shams-White MM, Chung M, Du M, et al. Dietary protein and bone health: a systematic review and meta-analysis from the National Osteoporosis Foundation. *Am J Clin Nutr*. 2017;105(6):1528-1543. doi:10.3945/ajcn.116.145110.
2. Groenendijk I, den Boeft L, van Loon LJC, de Groot LCPGM. High Versus low Dietary Protein Intake and Bone Health in Older Adults: a Systematic Review and Meta-Analysis. *Comput Struct Biotechnol J*. 2019;17:1101-1112. Published 2019 Jul 22. doi:10.1016/j.csbj.2019.07.005.

This page titled 6.5: Diseases Involving Proteins is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

6.6: Vegetarian and Vegan Diets

Some people wonder if vegetarians and vegans get enough protein in their diet. People who follow vegetarian or vegan diets can meet their protein requirements with high-quality plant-based protein sources. Those consuming some animal products as part of their vegetarian diet can easily meet their protein requirements by consuming adequate amounts of these foods.

Vegetarian and Vegan Diets

Vegetarianism is the practice of restricting the diet to food substances of plant origin, including vegetables, fruits, grains, and nuts. 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, 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 diet.

This page titled 6.6: Vegetarian and Vegan Diets is shared under a CC BY-NC-SA 4.0 license and was authored, remixed, and/or curated by Ann Diker.

CHAPTER OVERVIEW

7: Nutrients Important for Fluid and Electrolyte Balance

7.1: Overview of Fluid and Electrolyte Balance
7.2: Functions of Water
7.3: Regulation of Water Balance
7.4: Electrolytes
7.5: Understanding Dehydration and Heat Illnesses

Template:HideTOC

Thumbnail: Tap water (CC BY-SA 3.0; Benutzer:Alex Anlicker via Wikipedia)

This page titled 7: Nutrients Important for Fluid and Electrolyte Balance is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

7.1: Overview of Fluid and Electrolyte Balance

Learning Objectives

- Describe body fluid including intracellular and extracellular fluids.
- 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 eighties 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 7.1.1). 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).

Although water makes up the largest percentage of body volume, it is not actually pure water but rather a mixture of cells, proteins, glucose, lipoproteins, electrolytes, and other substances. Electrolytes are substances that, when dissolved in water, disassociate 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.

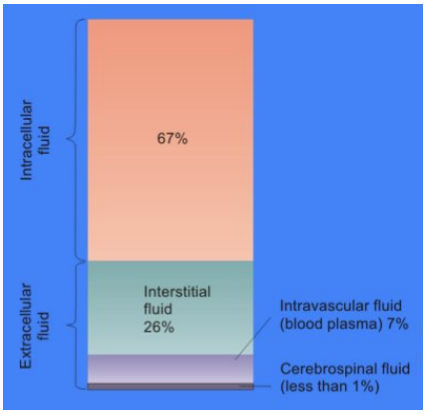


Figure 7.1.1: The components of body fluid. (CC BY 3.0; by Welcome1To1The1Jungle via Wikimedia Commons)

Osmoregulation

One of the essential homeostatic functions of the body is to maintain fluid balance and the differences in solute composition between cells and their surrounding environment. Osmoregulation is the control of fluid balance and composition in the body. The processes involved keep fluids from becoming too dilute or too concentrated. Fluid compartments are separated by selectively permeable membranes, which allow some things, such as water, to move through while other substances require special transport proteins, channels, and often energy to move through the membranes. The movement of water between fluid compartments happens by osmosis (Figure 7.1.2), which is simply the movement of water through a selectively permeable membrane from an area where water is highly concentrated to an area where water is not as concentrated. Water is never transported actively; that is, it

never takes energy for water to move between compartments. Although cells do not directly control water movement, they do control movement of electrolytes and other solutes and thus indirectly regulate water movement by controlling where there will be regions of high and low concentrations.

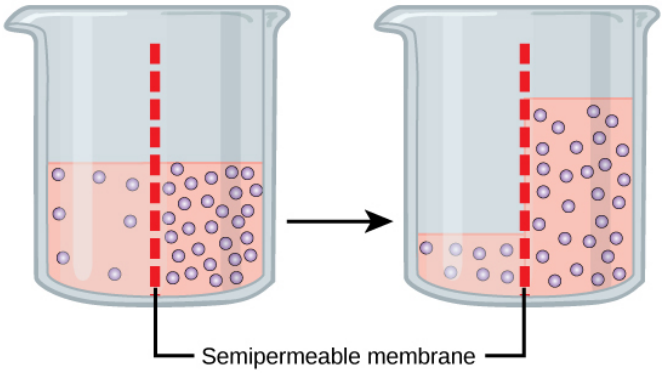


Figure 7.1.2: In osmosis, water always moves from an area of higher concentration (of water) to an area of lower concentration (of water). (CC BY 4.0; by OpenStax Concepts of Biology)

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 water balance a cell controls the movement of electrolytes to keep the total number of dissolved particles the same inside and outside of the cell. Even though the total number of dissolved substances is the same inside and outside a cell, the composition of the fluids can differ. For example, sodium exists in extracellular fluid at fourteen times the concentration as compared to that inside a cell.

If a cell is placed in a solution that contains fewer dissolved particles (known as a hypotonic solution) than the cell itself, water moves into the cell, causing it to swell (Figure 7.1.3). Alternatively, if a cell is placed in a solution that is more concentrated (known as a hypertonic solution) water moves out of the cell, causing it to shrink. Cells keep their water volume constant by pumping electrolytes in and out in an effort to balance the concentrations of dissolved particles on either side of their membranes. When a solution contains an equal concentration of dissolved particles on either side of the membrane, it is known as an isotonic solution.

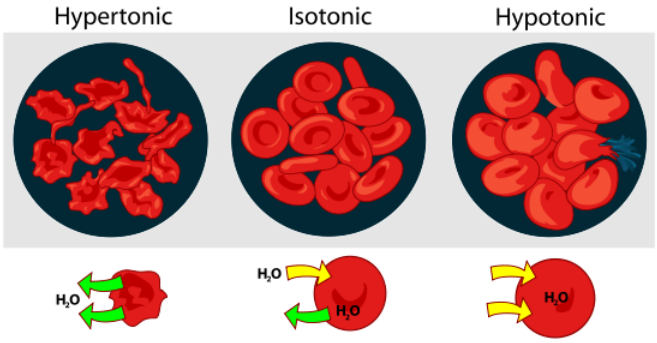


Figure 7.1.3: Cells maintain water volume by actively controlling electrolyte concentrations. (CC0; by LadyofHats via Wikimedia Commons)

Key Takeaways

- Body fluid is the liquid portion of our cells and tissues.
- In the human body, body fluid is composed of intracellular fluid and extracellular fluid.
- Movement of water is regulated by controlling the movement of electrolytes between fluid compartments.
- The movement of water between fluid compartments happens by the process of osmosis.
- Water is never transported actively; that is, it never takes special proteins and energy for water to move between compartments, it simply flows from an area of high concentration to an area where its concentration is lower.
- To maintain water balance, a cell controls the movement of electrolytes to keep the total number of dissolved particles the same inside and outside the cell.

This page titled 7.1: Overview of Fluid and Electrolyte Balance is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

7.2: 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. Molecules dissolve in water because of the hydrogen and oxygen molecules ability to loosely bond with other molecules. Molecules of water (H_2O) surround substances, suspending them in a sea of water molecules. The solvent action of water allows for substances to be more readily transported. 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 dissolved in the watery surrounding of blood to be transported to cells to support basic functions or are removed from cells to prevent waste build-up and toxicity.

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

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 alot 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 7.2.1). 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 erect hairs and shiver and to endocrine glands like the thyroid to

secrete hormones capable of ramping up metabolism. These actions increase heat conservation and stimulate its production in the body in response to cooling temperatures.

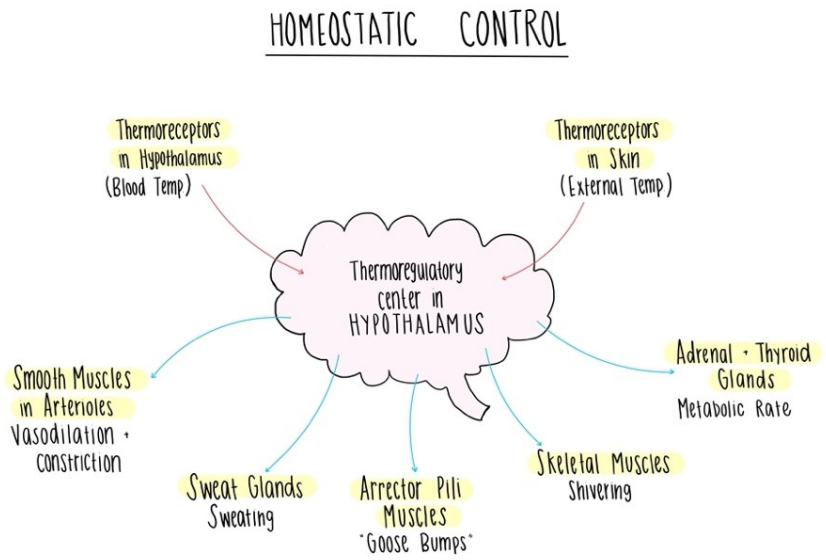


Figure 7.2.1: Thermoregulation is the ability of an organism to maintain body temperature despite changing environmental temperatures. (CC BY 4.0; by Lauren Groth)

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 causing them to dilate so that more blood flows to the body's periphery. Once on the skin, extra heat exits the body via perspiration (sweat), which is 98 to 99 percent 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.

Key Takeaways

- Uses of water 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 has been termed the "universal solvent" because more substances dissolve in it than any other fluid. Blood is the primary transport fluid in the body.
- Water serves as a medium for chemical reactions.
- Water, as a component of body fluids, acts as a lubricant and shock absorber.
- Water is good at storing heat and buffers the body against extreme variations in temperature.

This page titled 7.2: Functions of Water is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

7.3: 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. One estimate of the body's total water intake and output can be seen in Table 7.3.1.

Table 7.3.1: Water Balance

Water Intake	Water Output
Fluids: 1,200 ml/day	Insensible: 800 ml/day
Foods: 1,000 ml/day	Urine: 1,500 ml/day
Metabolism: 300 ml/day	Feces: 200 ml/day
TOTAL INTAKE: 2,500 ml/day	**TOTAL OUTPUT: 2,500 ml/day**

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 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 percent of total water intake comes from solid foods.[1] Even foods that seem dry (like crackers, cereal, bread, and other grains) still contain some water. 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.

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

Thirst Mechanism - One Way to Increase Water Intake

Thirst is a regulatory mechanism to increase water input. 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 input and contribute toward fluid balance and composition in the body. The "thirst center" is contained within the hypothalamus. 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. 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 input. Fluid intake is controlled primarily by conscious eating and drinking habits. For example, you might have a habit of drinking a beverage with meals.

Water Output

The kidneys are the organ primarily responsible for maintaining fluid balance. They constantly help maintain fluid balance by either excreting or retaining the fluid we consume. As shown in Table 7.3.1, 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
- Environmental conditions
- Pregnancy and breastfeeding
- Diuretics (increase fluid loss via urine), including:
  - certain medications
  - alcohol

Key Takeaways

- When the body is in 'water balance', the intake and output of water are equal.
- 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 amount of water a person should consume everyday is variable and should be based on the climate a person lives in, as well as their age, physical activity level, and kidney function.
- Thirst results from a complex interaction of hormones and nervous system responses that coordinate to achieve fluid balance and composition in the body.
- Water output consists of both insensible and sensible water loss.

References

1. Panel on Dietary Reference Intakes for Electrolytes and Water. *Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate*. Washington, DC: The National Academies of Science, Engineering, and Medicine; 2005. Accessed May 17, 2025.

This page titled 7.3: Regulation of Water Balance is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

7.4: 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 sources of sodium, chloride, potassium, and phosphorus

Electrolytes

Electrolytes are mineral salts dissolved in water, 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

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

Functions of 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. Electrolytes also help nerves respond to stimuli. The movement of sodium (Na^+) into the nerve cell generates an electrical impulse. The cell membrane returns to its normal electrical state through the release of potassium (K^+) to the outside of the cell. In addition, electrolytes signal our muscles to contract. The movement of calcium (Ca^{2+}) into a muscle cell stimulates the muscle to contract. The Ca^{2+} is pumped back out of the cell after the muscle contraction.

Although electrolytes are important for these functions, these nutrients provide other functions as well as we'll see below.

Sodium

Sodium is a major extracellular cation (positively-charged ion) that is water soluble. In contrast to many minerals, sodium absorption in the small intestine is extremely efficient and in a healthy individual, 90-95% is excreted by the kidneys, the remainder in the feces and sweat. Very little sodium is required in the diet because the kidneys actively reabsorb sodium. Kidney reabsorption of sodium is hormonally controlled, allowing for a relatively constant sodium concentration in the blood.

Functions of Sodium

Sodium is essential for maintaining fluid balance while also assisting with nutrient transport across the cell membrane. The sodium-potassium pumps in the cell's membrane continuously pump sodium ions out of the cell (Figure 7.4.1) to establish a high concentration of positive ions on the outside of the cell (this is also called a chemical gradient). When glucose is transported into a cell, a different transport protein, called the sodium-glucose symporter, uses the sodium gradient to power glucose movement into the cell. Sodium and glucose both move into the cell. Water passively follows the sodium. To restore balance, the sodium-potassium pump transfers sodium back to the extracellular fluid and water follows. Every cycle of the sodium-potassium pump involves the movement of three sodium ions out of a cell, in exchange for two potassium ions into a cell (Figure 7.4.1). To maintain charge neutrality on the outside of cells every positively-charged sodium ion is followed by a negatively-charged chloride ion. Every cycle of the pump costs one molecule of ATP (adenosine triphosphate). The constant work of the sodium-potassium pump maintains the solute equilibrium and consequently, water distribution between intracellular and extracellular fluids.

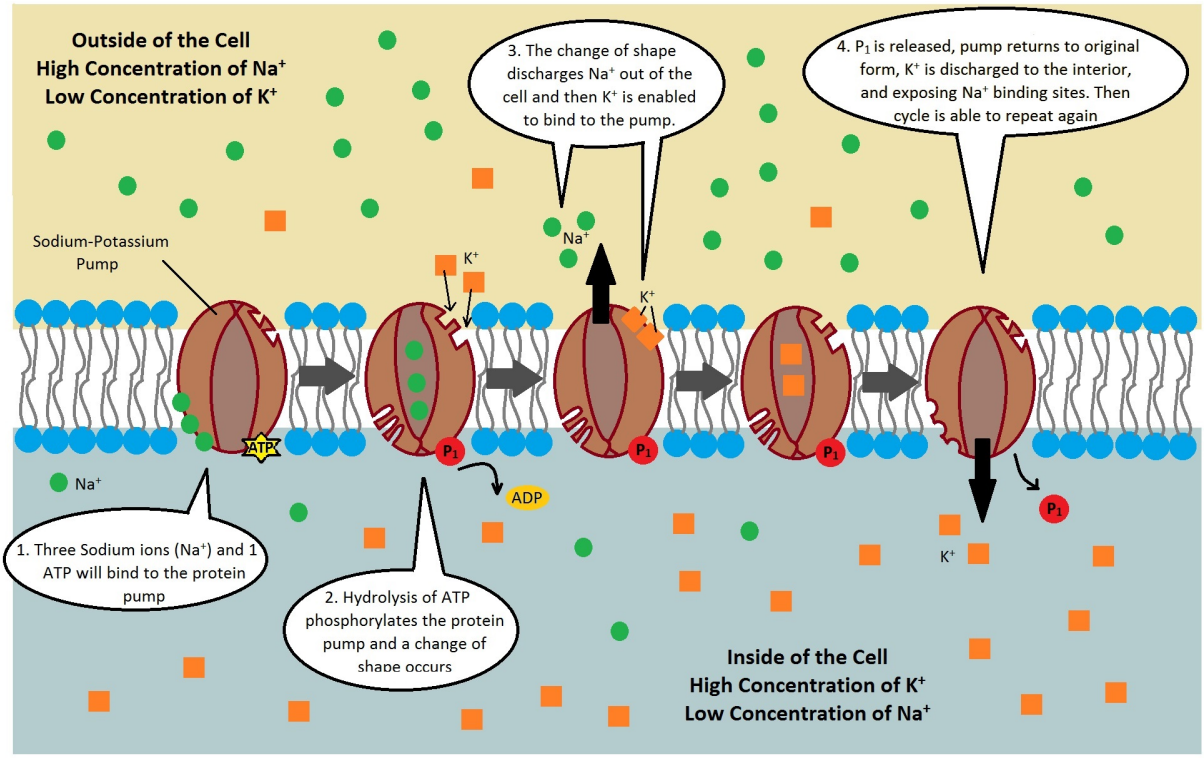


FIGURE: The Sodium-Potassium Pump

Figure 7.4.1: The sodium-potassium pump is the primary mechanism for cells to maintain water balance between themselves and their surrounding environment. (CC BY-SA 4.0; by Clod94 via Wikimedia Commons)

The unequal movement of the positively charged sodium and potassium ions makes intracellular fluid more negatively charged than the extracellular fluid. This charge gradient is another source of energy that a cell uses to perform work related to nerve transmission and muscle contraction. Nerve impulse transmission results from the transport of sodium cations into a nerve cell, which creates a charge difference (or voltage) between the nerve cell and its extracellular environment. Similar to how a current moves along a wire, a sodium current moves along a nerve cell. Stimulating a muscle contraction also involves the movement of sodium ions as well as other ion movements. For a muscle to contract, a nerve impulse travels to a muscle. The movement of the sodium current in the nerve communicates to the muscle by releasing the neurotransmitter, acetylcholine. Acetylcholine signals sodium channels in the muscle to open and sodium rushes in, creating another current that travels along the muscle eventually culminating in 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 is essential for nutrient absorption in the small intestine and also for nutrient reabsorption in the kidney. Amino acids, glucose, and water must make their way from the small intestine to the blood. To do so they pass through intestinal cells on their way to the blood. The transport of nutrients through intestinal cells is facilitated by the sodium-potassium pump, which by moving sodium out of the cell, creates a higher sodium concentration outside of the cell (requiring ATP).

Sodium Imbalances

Sweating is a homeostatic mechanism for maintaining body temperature, which influences fluid and electrolyte balance. Sweat is mostly water but also contains some electrolytes, mostly sodium and chloride. Under normal environmental conditions (i.e., not hot, humid days) water and sodium loss through sweat are negligible but is highly variable among individuals. It is estimated that sixty 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 vomiting, sweating, and

diarrhea may also cause hyponatremia. The symptoms of hyponatremia, also called water intoxication since it is often the root cause, include nausea, muscle cramps, confusion, dizziness, and in severe cases, 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 on a very low sodium diet due to special diets. These types of diets are used to treat kidney disease, hypertension, and heart disease. Excessive vomiting, for example, bulimia nervosa, or excessive diarrhea can also cause a loss of sodium resulting in hyponatremia.

On the other end of the spectrum is a condition know 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 high blood pressure (hypertension).

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 7.4.1).[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.

Table 7.4.1: Dietary Reference Intakes for Sodium[1]

Tolerable Upper Intake Level (mg/day)	Arsenic Guidance Value (mg/day)	Chronic Disease Risk Reduction Intake (CDRR)

. ND = not determined

Infants (10 to 6 months)	ND
Infants (7 to 12 months)	ND

. ND = not determined

Children (1–3 years)	ND	Reduce intakes if above 1,200 mg/day
Children (4–8 years)	ND	Reduce intakes if above 1,500 mg/day

. ND = not determined

Children (1–3 years)	Reduce intakes if above 1,800 mg/day
Adolescents (4–18 years)	Reduce intakes if above 2,300 mg/day

. ND = not determined

Adults (≥ 50 years)	Reduce intakes if above 2,300 mg/day
Adults (≥ 70 years)	Reduce intakes if above 2,300 mg/day

. ND = not determined

Adults (19 years and older)	Reduce intakes if above 2,300 mg/day

. ND = not determined

Sources of Sodium

Most sodium in the typical American diet comes from processed and prepared foods, including restaurant foods (Figure 7.4.2). 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 dietary intake in a typical diet.

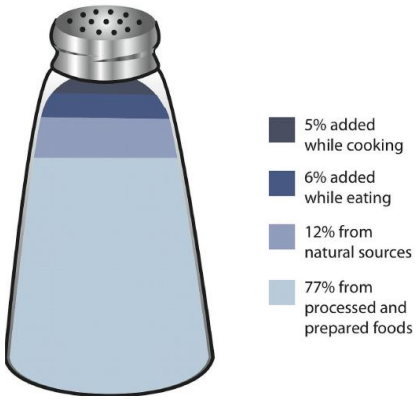


Figure 7.4.2: Dietary Sources of Sodium (CC BY-NC-SA 4.0; LibreTexts An Introduction to Nutrition (Zimmerman))

The Nutrition Facts label displays the amount of sodium (in milligrams) per serving of the food in question (Figure 7.4.3). 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 7.4.2).[2]

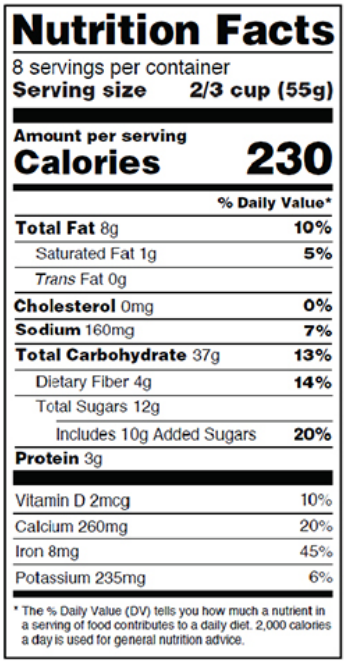


Figure 7.4.3: Sodium levels in milligrams is a required listing on a nutrition facts label. (CC0; What's New with the Nutrition Facts Label)

Table 7.4.2: Food Packaging Claims Regarding Sodium[2]

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

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, HCl.

Functions of Chloride

Chloride aids in fluid balance mainly because it follows sodium in order to maintain charge neutrality. Chloride channels also play a role in regulating fluid secretion, such as pancreatic juice into the small intestine and the flow of water into mucus. Fluid secretion

and mucus are important for many of life's processes. Chloride has several other functions in the body, most importantly in acid-base balance. Blood pH is maintained in a narrow range and the number of positively charged substances is equal to the number of negatively charged substances. Proteins, such as albumin, as well as bicarbonate ions and chloride ions, are negatively charged and aid in maintaining blood pH. Hydrochloric acid (a gastric acid composed of chlorine and hydrogen) aids in digestion and also prevents the growth of unwanted microbes in the stomach. Immune-system cells require chloride, and red blood cells use chloride anions to remove carbon dioxide from the body. Chloride 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 7.4.3).[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 7.4.3.

Table 7.4.3: Adequate Intakes for Chloride[3]

Age Group	Adequate Intake (mg/day)
Infants (0–6 months)	180
Infants (7–12 months)	570
Children (1–3 years)	1,500
Children (4–8 years)	1,900
Children (9–13 years)	2,300
Adolescents (14–18 years)	2,300
Adults (19–50 years)	2,300
Adults (51–70 years)	2,000
Adults (> 70 years)	1,800

Sources of Chloride

Most chloride in the diet comes from salt. (Salt is 60% chloride.) 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. Most potassium is lost in the urine (80-90%) and the remainder is via the feces. Ninety percent of potassium exists in intracellular fluid, with about 10 percent in extracellular fluid, and only 1 percent in blood plasma. As with sodium, potassium levels in the blood are strictly regulated. The hormone aldosterone is what primarily controls potassium levels, but other hormones (such as insulin) also play a role. When potassium levels in the blood increase, the adrenal glands release aldosterone. The aldosterone acts on the collecting ducts of kidneys, where it stimulates an increase in the number of sodium-potassium pumps. Sodium is then reabsorbed and more potassium is excreted. Because potassium is required for maintaining sodium levels, and hence fluid balance, only about 200 mg of potassium are lost from the body every day.

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 membrane potential 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. High levels of potassium in the blood, or **hyperkalemia**, is toxic and also affects the heart. It is a silent condition as it often displays no signs or symptoms. Extremely high 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.

Groups at risk of developing hypokalemia are individuals with renal and large intestine issues such as urine and diarrhea losses; people with uncontrolled diabetes which causes diabetic acidosis and urine losses; dehydration; prolonged diarrhea or vomiting; and, certain drugs like diuretics, steroids or laxatives. These deficiencies are due to excessive loss and not a dietary deficiency.

Potassium Recommendations

The National Academies of Sciences, Engineering, and Medicine set Adequate Intake (AI) levels for potassium as outlined in (Table 7.4.4).[1]

Table 7.4.4: Dietary Reference Intakes for Potassium[1]

Age Group	Adequate Intake (mg/day)	Tolerable Upper Intake Level (mg/day)	Chronic Disease Risk Reduction Intake (CDRR)

. ND = not determined

Infants (0–6 months)	400	ND
Infants (7–12 months)	860	ND

. ND = not determined

Children (1–3 years)	2,000	ND	ND
Children (4–8 years)	2,300	ND	ND

. ND = not determined

Children (9–13 years)	2,500 (males), 2,300 (females)	ND	ND
Adolescents (14–18 years)	3,000 (males), 2,300 (females)	ND	ND

. ND = not determined

Adults (>19 years)	3,400 (males), 2,600 (females)	ND

ND = not determined

Sources of Potassium

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

Phosphorus

Phosphorus is the primary negatively-charged ion/electrolyte 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 7.4.5).[4]

Table 7.4.5: Dietary Reference Intakes for Phosphorus[4]

Age Group	Recommended Dietary Allowance (mg/day)	Tolerable Upper Intake Level (g/day)
Infants (0–6 months)	100*	ND
Infants (7–12 months)	275*	ND
Children (1–3 years)	460	3

* denotes Adequate Intake; ND = not determined

Age Group	Recommended Dietary Allowance (mg/day)	Tolerable Upper Intake Level (g/day)
Children (4–8 years)	500	3
Children (9–13 years)	1,250	4
Adolescents (14–18 years)	1,250	4
Adults (19 - 70 years)	700	4
Adults (> 70 years)	700	3
* denotes Adequate Intake; ND = not determined		

Sources of Phosphorus

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

Key Takeaways

- Sodium is the primary positively-charged ion in extracellular fluid.
- Sodium helps regulate fluid balance and plays important roles in nerve transmission, muscle contraction, and nutrient absorption and reabsorption.
- Most sodium in the typical American diet comes from processed and prepared foods.
- Chloride is the primary negatively-charged ion in extracellular fluid.
- Chloride aids in fluid balance by helping to maintain charge neutrality. Chloride channels also play a role in regulating fluid secretion, such as the flow of pancreatic juice into the small intestine and the flow of water into mucus.
- Potassium is the primary positively-charged ion in intracellular fluid.
- Potassium has multiple functions including its role in regulating fluid balance and nerve transmission.
- Fruits, vegetables, and whole grains tend to be good sources of potassium.
- Phosphorus is the primary negatively-charged ion/electrolyte in the intracellular fluid.
- Phosphorus is found in many foods and is found in high amounts in 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.

This page titled 7.4: Electrolytes is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

7.5: 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, low (dark color urine) 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 7.5.1).

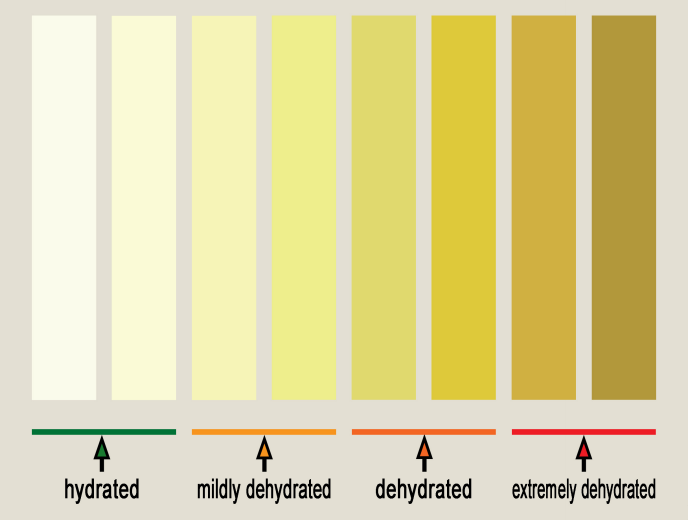


Figure 7.5.1: Urine color chart. (CC BY-SA 4.0; by Petar Milosevic via Wikimedia Commons)

Caffeine and alcohol consumption can increase urinary output. If the output is not matched by input, then the person can become dehydrated.

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

Heat 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. 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. 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.

Key Takeaways

- Overhydration (water intoxication) can occur with excessive water intake or excessive water retention and results in hyponatremia.
- Dehydration decreases blood volume.
- The elderly, infants, and athletes are the most at risk for dehydration.
- Chronic dehydration is linked to higher incidences of some diseases.
- Heat exhaustion is characterized by heavy sweating, dizziness, rapid breathing, and fast pulse.
- Dehydration is a primary cause of heat stroke; symptoms of heat stroke include dry skin (absence of sweating), trouble breathing, rapid pulse, and confusion.

References

1. Exercise and Fluid Replacement. *Medicine & Science in Sports & Exercise.* 2007;39(2):377-390. doi: 10.1249/mss.0b013e31802ca597.

This page titled 7.5: Understanding Dehydration and Heat Illnesses is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

CHAPTER OVERVIEW

8: Nutrients Important for Antioxidant Activity and Vision

8.1: Introduction to Free Radicals and Antioxidants

8.2: Antioxidant Nutrients

8.3: Vitamin A and Vision

8.4: Cancer

Template:HideTOC

This page titled 8: Nutrients Important for Antioxidant Activity and Vision is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

8.1: Introduction to Free Radicals and Antioxidants

Learning Objectives

- Describe free radicals.
- Identify various free radical detoxifying enzymes and antioxidants.
- Explain oxidative stress and identify diseases associated with oxidative stress.

In mainstream advertising you may have heard that antioxidants can extend your life by preventing disease and slowing 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 antioxidants *singularly* provide bodily benefits, but there is evidence that certain benefits are achieved by ingesting antioxidants as part of a balanced, healthy, nutrient-rich diet. This is to say antioxidants may go a long way toward preventing damage, but other nutrients are necessary to repair damage and sustain health. No one nutrient acts alone!

Oxidation

Antioxidants are compounds that protect cells from damage caused by oxidation. But what is oxidation? Oxidation is a chemical reaction in which atoms lose electrons. Atoms have a nucleus (central core) which is positively charged. Orbiting around the nucleus are electrons which are negatively charged. The opposite attraction between the positively charged nucleus and negatively charged electrons keeps an atom stable. However, during metabolic reactions, atoms exchange electrons. Oxidation is the loss of electrons from an atom. Conversely, reduction is the gain of electrons by an atom. Oxidation and reduction usually occur together as an exchange reaction. One way to remember the difference between oxidation and reduction in the exchange reaction is to remember "OIL RIG":

- **OIL** = **O**xidation **I**s **L**oss of electrons
- **RIG** = **R**eduction **I**s **G**aining of electrons

Free Radicals

Oxidation sometimes results in the formation of free radicals. Remember those electrons that are orbiting the nucleus of an atom? Well those electrons contain energy; however, this energy is not always stable. The stability depends on the number of electrons that are within an atom. Atoms are more stable when their electrons orbit in pairs. An atom with an odd number of electrons must have an unpaired electron. When oxygen (a molecule with two atoms) has one unpaired electron it is known as superoxide (Figure 8.1.1). Atoms and molecules such as superoxide that have unpaired electrons are called free radicals (Figure 8.1.2). The unpaired electron in free radicals makes the atom or molecule unstable.



Figure 8.1.1: Superoxide: A molecule with one unpaired electron, which makes it a free radical. (CC BY-SA 3.0; by DoSiDo via Wikimedia Commons)

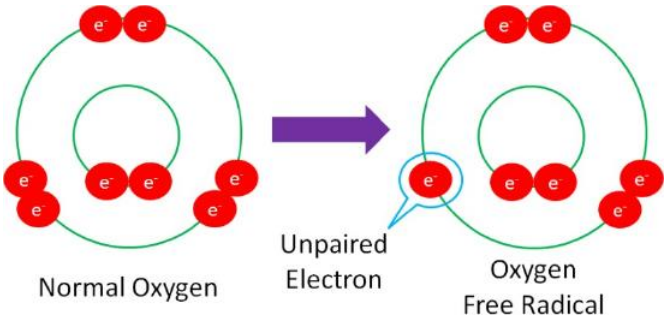


Figure 8.1.2: Normal oxygen is converted to an oxygen free radical by losing one electron in its outer orbital, leaving one unpaired electron. (CC BY 4.0; by Brian Lindshield via LibreTexts)

Electrons in atoms "hate" not existing in pairs. An atom with an unpaired electron (a free radical) wants to become stable again, so it quickly seeks out another electron to "steal" from another atom or molecule. The instability of free radicals is what poses a threat to macromolecules such as DNA, RNA, proteins, and fatty acids. Free radicals can cause chain reactions that ultimately damage cells. For example, a free radical may react with a fatty acid and steal one of its electrons. The fatty acid then becomes a free radical that can react with another fatty acid nearby. As this chain reaction continues, the permeability and fluidity of cell membranes changes, proteins in cell membranes experience decreased activity, and receptor proteins undergo changes in structure that either alter or stop their function. If receptor proteins designed to react to insulin levels undergo a structural change it can negatively effect glucose uptake.

Free radical reactions can continue unchecked unless stopped by a defense mechanism.

The Body's Defense

Free radical development is unavoidable, but human bodies have adapted by setting up and maintaining defense mechanisms that reduce their impact. The body's two major defense systems are free radical detoxifying enzymes and antioxidants. Free radical detoxifying enzyme systems are responsible for protecting the insides of cells from free radical damage. An antioxidant is any molecule that can block free radicals from stealing electrons; antioxidants act both inside and outside of cells.

Free Radical Detoxifying Enzymes

The three major enzyme systems and the chemical reactions they catalyze are:

1. **Superoxide Dismutases (SOD).** These enzymes have either a manganese, copper, or zinc cofactor, which is essential for their free radical detoxifying activity. During SOD-mediated enzymatic catalysis, two superoxides are converted into hydrogen peroxide and oxygen. Hydrogen peroxide (H_2O_2) is still considered a free radical, but it is less reactive than some other free radicals (e.g., superoxide). SOD enzymes are one of the fastest enzymes known, and they are also inducible, meaning that the higher their exposure to superoxides, the greater their number and detoxifying activity.
2. **Catalase.** This enzyme contains iron as a cofactor and converts hydrogen peroxide to water and oxygen, thereby finishing the detoxification reaction started by SOD. In cells, catalase enzymes are found in high numbers and continuously patrol for hydrogen peroxide molecules. Catalase is highly efficient and is capable of destroying millions of hydrogen peroxide molecules per second.
3. **Glutathione Peroxidases.** The majority of enzymes within this family are dependent on the micronutrient selenium. Similar to catalase, these enzymes convert hydrogen peroxide to water and oxygen.

Antioxidants

Antioxidants are compounds that protect cells from damage caused by oxidation. Antioxidants are broadly classified as either hydrophilic (water soluble) or hydrophobic (lipid soluble), and this classification determines where they act in the body. Hydrophilic antioxidants act in the cytosol of cells or in extracellular fluids such as blood; hydrophobic antioxidants are largely responsible for protecting cell membranes from free radical damage. The body can synthesize some antioxidants, but others must be obtained from the diet.

Antioxidants the Body Synthesizes

There are two antioxidants that the body synthesizes. They are:

1. **Glutathione.** This molecule is composed of three amino acids and is found in high concentrations in cells. Glutathione contains a sulfur group that can donate an electron to a free radical, thereby stabilizing it. After glutathione has lost its electron, it is regenerated enzymatically so that it can perform its antioxidant function once again.
2. **Uric Acid.** This molecule is a metabolic intermediate in the breakdown of nucleotides such as adenine, which is found in DNA and RNA, among other macromolecules. It circulates at high concentrations in the blood and disables circulating free radicals. However, too high of a concentration in the blood can cause gout, a painful joint disorder.

Antioxidants Obtained from the Diet

There are many different antioxidants in food (Table 8.1.1). Antioxidant vitamins (e.g., Vitamin E, Vitamin C) donate their electrons to free radicals to stabilize them. Antioxidant phytochemicals (e.g., beta-carotene and other carotenoids) may inhibit the oxidation of lipids or donate electrons. Antioxidant minerals act as cofactors within complex antioxidant enzyme systems (e.g., superoxide dismutases, catalase, glutathione peroxidases described earlier) to convert free radicals to less damaging substances that can be excreted.

Table 8.1.1: Some Antioxidants Obtained from Diet and Their Related Functions

Antioxidant	Functions
Vitamin E	Protects cellular membranes, prevents glutathione depletion
Vitamin C	Protects DNA, RNA, proteins, and lipids, aids in regenerating vitamin E
Carotenoids	Free radical scavengers
Selenium	Cofactor of free radical detoxifying enzymes, maintains glutathione levels, aids in regeneration of vitamins C and E

The Body's Offense

While our bodies have acquired multiple defenses against free radicals, we also use free radicals to support its functions. For example, the immune system uses the cell-damaging properties of free radicals to kill pathogens. First, immune cells engulf an invader (such as a bacterium), then they expose it to free radicals such as hydrogen peroxide, which destroys its membrane. The invader is thus neutralized.

Free radicals are necessary for many other bodily functions as well. The thyroid gland synthesizes its own hydrogen peroxide, which is required for the production of thyroid hormone. Free radicals have been found to interact with proteins in cells to produce signaling molecules. The free radical nitric oxide has been found to help dilate blood vessels and act as a chemical messenger in the brain.

Sources of Free Radicals in the Environment

The body creates free radicals through the normal processes of metabolism (i.e., turning food into usable energy/ATP). When the amount of free radicals exceeds the body's ability to eliminate or neutralize them, an oxidative imbalance results.

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

Oxidative Stress

Oxidative stress occurs when there is an imbalance between free radical production and their detoxification. Sustained oxidative tissue damage that can contribute to disease occurs only when free radical detoxification systems and repair systems are overwhelmed. 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.

Key Takeaways

- Free radicals, unstable molecules with unpaired electrons, are an unavoidable byproduct of cellular metabolism.
- Free radicals can steal electrons from lipids, proteins, RNA, and DNA, causing them damage.
- The body has defenses against free radicals—free radical detoxifying enzymes and antioxidants.
- The body can synthesize some antioxidant molecules, but many are obtained from the diet.
- The body sometimes uses free radicals for beneficial functions such as killing pathogens.
- Oxidative stress is an imbalance between free radical production and detoxification and repair systems. It also plays an integral role in the development of many chronic diseases and in age-related decline of tissues.
- Excessive sunlight, pollution, ozone, smoke, heavy metals, radiation, asbestos, and other toxic chemicals increase the amount of free radicals in the body and can accelerate the progression of diseases in which oxidative stress is a contributing cause.

This page titled 8.1: Introduction to Free Radicals and Antioxidants is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

8.2: Antioxidant Nutrients

Learning Objectives

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

The market is flooded with advertisements for “super antioxidant” supplements that block free radical production, stimulate the immune system, prevent cancer, and reduce the signs of aging. Based on the antioxidant-supplement industry’s success, the general public appears to believe these health claims. However, these claims are not backed by scientific evidence; rather, there is some evidence suggesting supplements can actually cause harm. While scientists have found evidence supporting the consumption of antioxidant-rich foods as a method of reducing the risk of chronic disease, there is no “miracle cure;” no pill or supplement alone can provide the same benefits as a healthy diet. Remember, it is the combination of antioxidants and other nutrients in healthy foods that is beneficial. In this section, we will review how particular antioxidants function in the body, learn how they work together to protect the body against free radicals, and explore nutrient-rich dietary sources of antioxidants.

Vitamin E

Vitamin E is a fat-soluble vitamin. "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 increase vitamin A absorption if vitamin A intake from the diet is low.

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) and anemia.

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 8.2.1. 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 8.2.1: Dietary Reference Intakes for Vitamin E[1]

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	4*	ND

*denotes Adequate Intake; ND=not determined

Age Group	RDA (mg/day)	UL (mg/day)
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 8.2.2 for a list of foods and their vitamin E content.

Table 8.2.2: Vitamin E Content of Various Foods[2]

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

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

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 reduced 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 8.2.3. 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 8.2.3: 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
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 8.2.4. 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 8.2.4: Vitamin C Content of Various Foods[3]

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.

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.[4] 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 8.2.5 for the beta-carotene content of various foods.

Table 8.2.5: Beta-Carotene Content of Various Foods[5]

Food	Serving Size	Beta-carotene (mg)
Sweet potato, baked	1 cup	23
Pumpkin, canned	1 cup	17
Collards (frozen), cooked	1 cup	11.6

Food	Serving Size	Beta-carotene (mg)
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 a critical component of the glutathione peroxidase antioxidant enzyme system. As an integral functioning part of this enzyme system, selenium aids in the regeneration of glutathione and oxidized vitamin C. Selenium, as part of glutathione peroxidase, also protects lipids from free radicals, and, in doing so, spares vitamin E. This is just one example of how antioxidants work together to protect the body against free radical-induced damage. Other functions of selenium-containing proteins include protecting endothelial cells that line tissues, converting inactive thyroid hormone to the active form, 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 glutathione peroxidases found in blood plasma. The RDA for different age groups are listed in Table 8.2.6.

Table 8.2.6: 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 8.2.7 for the selenium content of various foods.

Table 8.2.7: Selenium Content of Various Foods

Food	Selenium (mcg)	% Daily Value
Brazil nuts (1 ounce)	544	989

Food	Selenium (mcg)	% Daily Value
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.

Manganese, Copper, Zinc, and Iron

Manganese, copper, and zinc are part of the superoxide dismutase (SOD) antioxidant enzyme system which converts superoxide free radicals into hydrogen peroxide and oxygen. Iron is part of catalase which converts hydrogen peroxide to water and oxygen, thereby finishing the detoxification reaction started by SOD. In the proper doses they allow for optimal detoxification of free radicals. In excess and when not bound to proteins, manganese, iron, and copper actually accelerate the production of free radicals. This is an attribute of all antioxidants in general, although the effect is greater for certain antioxidants. Antioxidants can become pro-oxidants when the conditions are altered. Recall that oxidative stress results from an imbalance in free radicals with their detoxifying and repair systems. Another factor that can cause oxidative stress is a high level of antioxidants, as some will revert to acting as pro-oxidants.

Key Takeaways

- Consuming antioxidant-rich foods is scientifically supported to reduce the risk of chronic diseases.
- Antioxidants have specific functions and they can act in concert with each other to protect against free radicals.
- Some antioxidants are involved in the regeneration of other antioxidants.
- Many phytochemicals act as antioxidants, but they perform several other functions as well.
- Dietary antioxidants and phytochemicals in the proper doses are beneficial to health but can cause harm in excess.

References

1. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 19, 2025.
2. Vitamin E - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
3. Vitamin C - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
4. Beta-Carotene. Medline Plus. mdlineplus.gov. Accessed May 19, 2025.
5. USDA National Nutrient Database for Standard Reference, Release 28. ods.od.nih.gov. Accessed May 19, 2025.

This page titled 8.2: Antioxidant Nutrients is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

8.3: 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 a generic term for a group of similar compounds called retinoids. Retinol is the form of vitamin A found in animal-derived foods, and it is converted in the body to the biologically active forms of vitamin A: retinal and retinoic acid. About 10% of plant-derived carotenoids, including beta-carotene, can be converted in the body to retinoids and are another source of functional vitamin A. Vitamin A is fat-soluble and is packaged into chylomicrons in small intestine mucosal cells, and then transported to the liver. The liver stores and exports vitamin A as needed; it is released into the blood bound to a retinol-binding protein, which transports it to cells. Although the liver stores about 90% of our vitamin A, some vitamin A is also stored in our adipose (fat) tissue, kidneys, and lungs.

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

Insufficient intake of dietary vitamin A over time can also cause complete vision loss. In fact, vitamin A deficiency is the number one cause of preventable blindness worldwide. Vitamin A not only supports the vision function of eyes but also maintains the coverings and linings of the eyes. Vitamin A deficiency can lead to the dysfunction of the linings and coverings of the eye, 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 twenty-first century, science has demonstrated that vitamin A greatly affects the immune system. What we are still lacking are clinical trials investigating the proper doses of vitamin A required to help ward off infectious disease and how large of an effect vitamin A supplementation has on populations that are not deficient in this vitamin. This brings up one of our common themes in this text—micronutrient deficiencies may contribute to the development, progression, and severity of a disease, but this does not mean that an increased intake of these micronutrients will solely prevent or cure disease. The effect, as usual, is cumulative and depends on the diet as a whole, among other things.

Growth and Development

Vitamin A acts similarly to some hormones in that it is able to change the amount of proteins in cells by interacting with DNA. This is the primary way that vitamin A affects growth and development. Vitamin A deficiency in children is linked to growth

retardation; however, vitamin A deficiency is often accompanied by protein malnutrition and iron deficiency, thereby confounding the investigation of vitamin A's specific effects on growth and development.

Both males and females require vitamin A in the diet to effectively reproduce. In the fetal stages of life, vitamin A is important for limb, heart, eye, and ear development; 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 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.

Vitamin A Recommendations

There is more than one source of vitamin A in the diet. There is preformed vitamin A, which is abundant in many animal-derived foods, and there are carotenoids, which are found in high concentrations in yellow and orange colored fruits and vegetables and some oils.

Some carotenoids are converted to retinol in the body by intestinal cells and liver cells. However, only small amounts of certain carotenoids are converted to retinol, meaning fruits and vegetables are not necessarily good sources of vitamin A. Beta-carotene dissolved in oil is more readily converted to retinol; one-half of a microgram of beta-carotene is converted to retinol. Overall, the carotenoids do not have the same biological potency of preformed vitamin A, but as you will soon find out, they have other attributes that influence health, most notably their antioxidant activity.

The Recommended Dietary Allowances (RDAs) and Tolerable Upper Intake Levels (ULs) for different age groups for vitamin A are provided in Table 8.3.1.The RDA for vitamin A includes all sources of vitamin A. The amount of vitamin A obtained from carotenoids—the retinol activity equivalent (RAE)—can be calculated. For example, 12 micrograms of fruit- or vegetable-based beta-carotene will yield 1 microgram of retinol. The RDA for vitamin A is considered sufficient to support growth and development, reproduction, vision, and immune system function while maintaining adequate stores (good for four months) in the liver.

Table 8.3.1: Dietary Reference Intakes for Vitamin A[2]

Age Group	RDA (mcg/day)	UL (mcg/day)
Infants (0–6 months)	400*	600
Infants (7–12 months)	500*	600
Children (1–3 years)	300	600
Children (4–8 years)	400	900
Children (9–13 years)	600	1,700
Adolescents (14–18 years)	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 8.3.2) for a list of foods and their vitamin A content (given in mcg of Retinol Activity Equivalent).

Table 8.3.2: Vitamin A Content of Various Foods[3]

Food	Vitamin A (mcg RAE)	% Daily Value
Beef liver (3 ounces)	6,582	731
Sweet potato (1 whole)	1,403	156

Food	Vitamin A (mcg RAE)	% Daily Value
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.

Key Takeaways

- Vitamin A is a fat-soluble vitamin that plays a major role in vision.
- Vitamin A can be found in animal foods and plant foods. Preformed vitamin A is abundant in many animal-derived foods. Carotenoids are found in high concentrations in yellow and orange colored fruits and vegetables and some oils.

References

1. Sommer A. Vitamin A Deficiency and Clinical Disease: An Historical Overview. *The Journal of Nutrition. 2008;*138(10):1835–1839.
2. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 19, 2025.
3. Vitamin A - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.

This page titled 8.3: Vitamin A and Vision is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

8.4: Cancer

Learning Objectives

- Describe the development of cancer.
- Identify risk factors for cancer.

Cancer

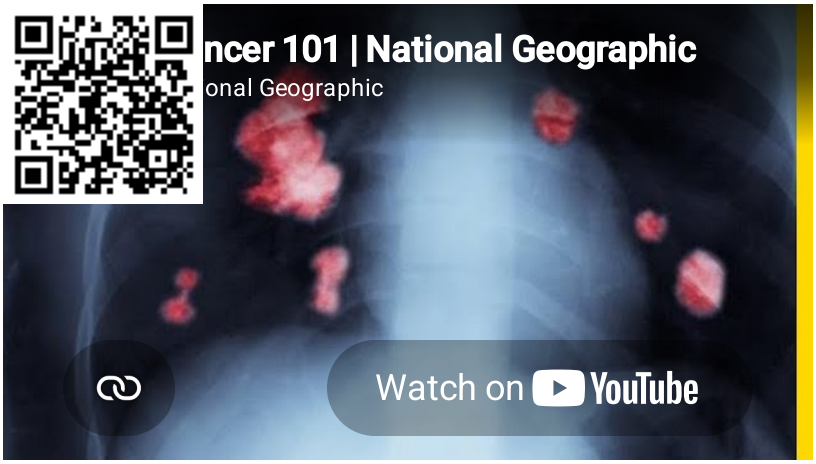
Cancer is a group of diseases characterized by the uncontrolled growth of abnormal cells. Cancer progresses in 3 stages:

- 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:



"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 8.4.1 shows some common risk factors for a number of different types of cancer.

Table 8.4.1: Some Risk Factors for Cancer[1,2,3,4]

Unmodifiable Risk Factors	Modifiable Risk Factors

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:

- be at 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)
- eat a diet rich in whole grains, vegetables, fruit, and beans
- limit consumption of fast foods and other processed foods high in fat, starches or sugars
- limit consumption of red and processed meat
- limit consumption of sugar sweetened drinks
- limit alcohol consumption
- 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

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

Key Takeaways

- Cancer is a group of diseases characterized by the uncontrolled growth of abnormal cells. As these abnormal cells grow, they can form tumors, interfere with the healthy functioning of the body, and spread throughout the body in a process known as metastasis.
- Risk factors for different cancers vary and often include modifiable risk factors that can be managed to reduce risk.
- Recommendations for preventing cancer and staying healthy include being physically active, eating healthy foods, and limiting less healthful choices.

References

1. Risk Factors for Cancer. National Cancer Institute. cancer.gov. Accessed May 19, 2025.
2. American Cancer Society. Cancer Facts & Figures 2025. Atlanta: American Cancer Society; 2025. Accessed May 19, 2025.
3. Interactive Cancer Risk Matrix. wcrf.org. Accessed May 19, 2025.
4. Understanding Family Cancer Syndromes. cancer.org. Accessed May 19, 2025.
5. Evidence for Our Recommendations. wcrf.org. Accessed May 19, 2025.

This page titled 8.4: Cancer is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

CHAPTER OVERVIEW

9: Nutrients Important for Bone Health

9.1: Bone Structure and Function

9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D

9.3: Other Essential Micronutrients for Bone Health

9.4: Osteoporosis

Template:HideTOC

This page titled 9: Nutrients Important for Bone Health is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

9.1: 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 9.1.1 below.

Table 9.1.1: Functions of Bone

Functions Related to Structure and Support	Functions Related to Metabolic Processes
• Bones provide physical support for organs and body segments. • Bones 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. • Bones work with muscles and tendons to allow movement - muscles attach to bones via tendons, and their contraction produces movement at the body's joints.	• Bone tissue acts as a storage reservoir for many minerals, including calcium, phosphorus, and fluoride. The body draws upon such deposits when these minerals are needed for various body processes; however, this can reduce bone mass. • Most blood cells are produced in the bone marrow.

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 spongy (or trabecular) bone and compact (or cortical) bone (Figure 9.1.1).

- 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.

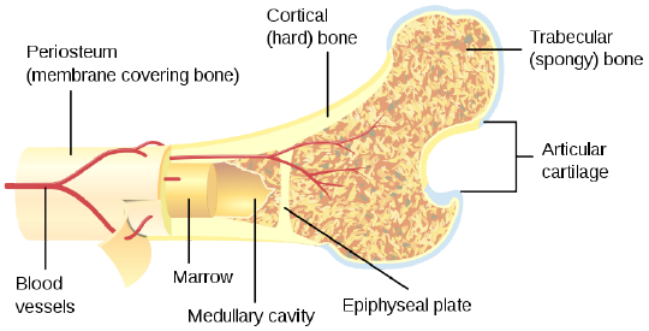


Figure 9.1.1: Cross-section of a bone showing trabecular and cortical bone. (CC BY 3.0; by Pbroks13 via Wikimedia Commons)

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 percent 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 9.1.2)[2]. These cells fuse tightly to the bone and secrete hydrogen ions, which acidify the local environment and dissolve the minerals in the bone tissue matrix. This process is called bone resorption and resembles pit excavation. Our bodies excavate pits in our bone tissue because bones act as storehouses for calcium and other minerals. Bones supply these minerals to other body tissues as the demand arises. Bone tissue also remodels when it breaks so that it can repair itself.

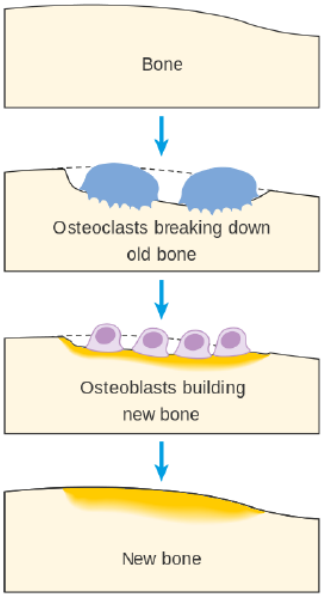


Figure 9.1.2: Bone remodeling requires osteoclast activity to break down old bone and osteoblast activity to build new bone tissue. (CC BY-SA 4.0; by Cancer Research UK via Wikimedia Commons)

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 9.1.2). 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 for more on osteoblasts, osteoclasts, and bone remodeling:



"Osteoblasts and Osteoclasts" by Amgen



"Bone Remodeling and Modeling" by Amgen

Key Takeaways

- The skeletal system aids in movement, provides support for and protects organs, synthesizes platelets and red and white blood cells, and serves as a storage depot for minerals, such as calcium.
- Bones consist of two different tissue types: compact (cortical) bone and trabecular (spongy) bone.
- Bone remodeling is a multifaceted process involving four steps: osteocyte activation, osteoclast-mediated bone resorption, surface preparation, and osteoblast-mediated bone building.
- The bone remodeling process requires certain nutrients such as calcium, phosphorus, magnesium, fluoride, vitamin D, and vitamin K.

This page titled 9.1: Bone Structure and Function is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

9.2: 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 greater 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 it performs the most critical functions. Blood calcium levels are rigorously controlled so that if blood levels drop the body will rapidly respond by stimulating bone resorption, thereby releasing stored calcium into the blood. Thus, bone tissue sacrifices its stored calcium to maintain blood calcium levels. This is why bone health is dependent on the intake of dietary calcium and also why blood levels of calcium do not always correspond to dietary intake.

Functions of Calcium

Calcium plays a role in a number of different functions in the body:

- **Bone and tooth formation.** The most well-known calcium function is to build and strengthen bones and teeth. Recall that when bone tissue first forms during the modeling or remodeling process, it is unhardened, protein-rich osteoid tissue. In the osteoblast-directed process of bone mineralization, calcium phosphates (salts) are deposited on the protein matrix. The calcium salts gradually crystallize into hydroxyapatite, which typically makes up about 65 percent of bone tissue. When your diet is calcium deficient, the mineral content of bone decreases causing it to become brittle and weak. Thus, increased calcium intake helps to increase the mineralized content of bone tissue which leads to greater bone strength.
- **Nerve impulse transmission.** Calcium facilitates electrical impulse transmission from one nerve cell to another. Calcium binds to vesicles that contain neurotransmitters, causing a release into the neural synapses (junction between nerve cells). This allows the flow of ions in and out of nerve cells. If calcium is lacking, nerve-cell function will fail.
- **Muscle contraction.** 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. If calcium levels fall below a crucial range, the muscles can't relax after contracting. The muscles become stiff and involuntary twitching may ensue in 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 hormone produced from vitamin D. Parathyroid hormone and calcitriol act in a concert to increase calcium levels in the blood, while calcitonin does the opposite and decreases blood calcium levels. These hormones maintain calcium levels in the blood in a range between 9 and 11 milligrams per deciliter.

Parathyroid Hormone

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 increases blood calcium levels via three different mechanisms (Figure 9.2.1). First, PTH stimulates the release of calcium stored in the bone. Second, PTH acts on kidney cells to increase calcium reabsorption and decrease its excretion in the urine. Third, PTH stimulates enzymes in the kidney that activate vitamin D to calcitriol which acts on intestinal cells to increase dietary calcium absorption. Thus, 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.

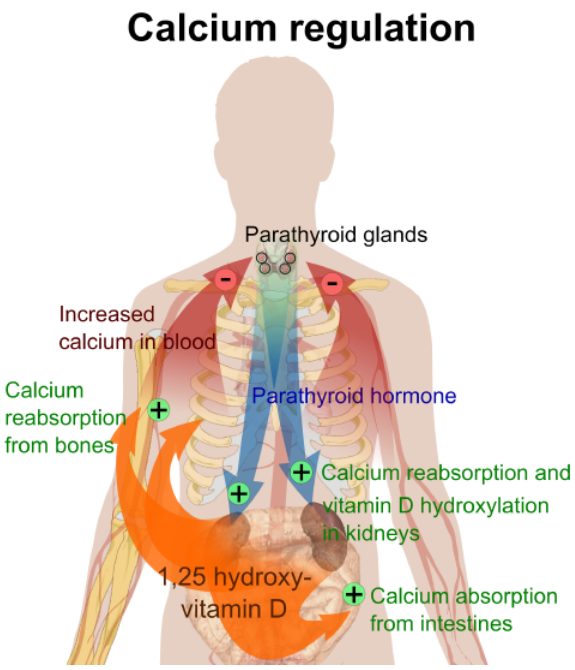


Figure 9.2.1: Overview of calcium regulation. Low calcium levels in the blood stimulate parathyroid hormone (PTH) release. PTH increases the movement of calcium from the bones, kidneys, and intestine to the blood. The now higher calcium levels in the blood shut off further PTH release. (public domain; by Mikael Häggström via Wikimedia Commons)

Calcitriol (1,25-dihydroxyvitamin D_3)

Calcitriol functions as a second hand to PTH. It not only increases calcium release from bone tissue, but also it increases the absorption of calcium in the small intestine and increases calcium reabsorption by the kidneys. Neither hormone will work unless accompanied by the other. Vitamin D regulates PTH secretion and PTH regulates vitamin D activation to calcitriol. Adequate levels of vitamin D allow for a balance of the calcium between what is released by bone tissue and what is incorporated into bone tissue, so that bone health is not compromised. Calcitriol and PTH function together to maintain calcium homeostasis.

Calcitonin

Calcitonin is a hormone secreted by certain 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. This route of feedback inhibition helps prevent calcium's further accumulation in the blood. When needed, calcitonin lowers blood calcium levels by increasing calcium excretion in the urine, preventing further absorption of calcium in the gut and by directly inhibiting bone resorption.

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 9.2.1. 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 9.2.1: 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 9.2.2).

Table 9.2.2: 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 9.2.2). However, this is not the

bioactive 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 percent of their vitamin D_3 comes from the casual exposure to the UVB rays in sunlight. Anything that reduces your exposure to the sun's UVB rays decreases the amount of vitamin D_3 your skin synthesizes. That would include long winters, your home's altitude, whether you are wearing sunscreen, and the color of your skin (including tanned skin). Twenty to thirty minutes of sun exposure 2-3 times per week is thought to provide adequate vitamin D synthesis.

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 9.2.2). 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 (six to twelve 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. The Institute of Medicine states that serum levels above 20 nanograms per milliliter are sufficient to maintain bone health in healthy individuals.[4]

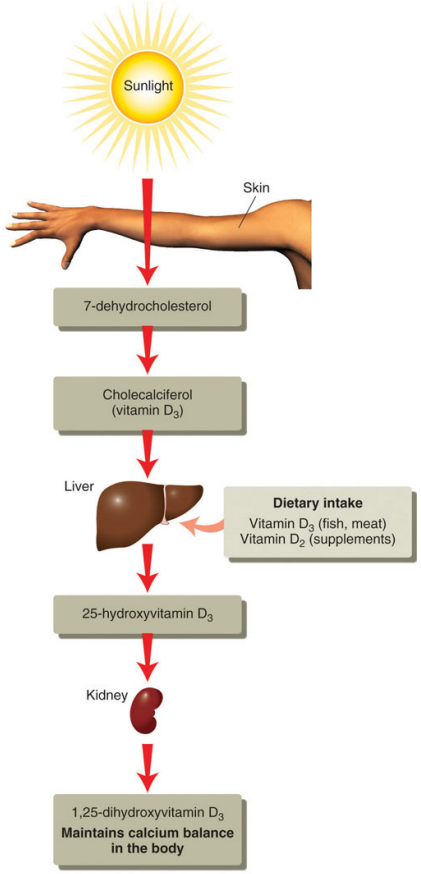


Figure 9.2.2: The Activation of Vitamin D to Calcitriol. © Networkgraphics

Functions of Vitamin D

As previously discussed, activated vitamin D_3 (calcitriol) regulates blood calcium levels in concert 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, 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 9.2.3. For adults, the RDA is 15 micrograms of vitamin D. The National Osteoporosis Foundation recommends slightly higher levels and that adults under age fifty get 400-800 international units (10-20 micrograms) of vitamin D every day, and adults fifty and older get 800-1,000 international units (20-25 micrograms) of vitamin D every day.[5] 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 9.2.3: 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. Oily fish, such as salmon, is one of the best. 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 9.2.4: 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
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.

Key Takeaways

- Calcium is the most abundant mineral in the body and has four primary functions: making bones strong and healthy, facilitating nerve-to-nerve communication, stimulating muscle contraction, and activating blood-clotting factors.

- Blood levels of calcium are controlled by three hormones: parathyroid hormone (PTH), calcitriol, and calcitonin.
- Vitamin D is essential for maintaining calcium levels in the body. Once activated to calcitriol, it acts in concert with PTH to keep blood levels of calcium constant, especially by enhancing its intestinal absorption.

References

1. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 19, 2025.
2. Calcium - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
3. Calcium Content. ods.od.nih.gov. Accessed May 19, 2025.
4. Vitamin D - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
5. Calcium and Vitamin D. nof.org. Accessed May 19, 2025.

This page titled 9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

9.3: 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.

Bone tissue is greater than 70% inorganic material and as such, minerals are important for maintaining skeletal health. In addition to calcium, other minerals critical for bone health include phosphorus, magnesium, fluoride and vitamin K. But that is not all—iron, copper, zinc, and vitamin C are also essential for the synthesis of collagen. Consuming too much or too little vitamin A affects bone health too, as it plays a role in osteoclast and osteoblast activities. 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. In Table 9.3.1, notice the important nutrients for bone health and good food sources for each.

Table 9.3.1: Micronutrients and Bone Health

Micronutrient	Functional Role in Bone Health	Food Sources
Calcium	• Component of mineralized bone • Provides structure and microarchitecture	collards, mustard greens, kale, turnips, broccoli, beans, black molasses, fortified juices, milk
Phosphorus	• Component of mineralized bone • Provides structure and microarchitecture	soy, legumes, whole grains, dairy, nuts, seeds
Magnesium	• Component of mineralized bone • Provides structure and microarchitecture	whole grains, legumes, almonds, cashews, hazelnuts, beets, collards, kelp
Fluoride	• Component of mineralized bone • Provides structure and microarchitecture • Stimulates new bone growth	fluoridated water (tap water), foods prepared in fluoridated water, seafood (because the ocean contains natural sodium fluoride)
Vitamin D	• Critical for maintaining calcium levels • Aids the absorption of calcium, promotes bone health	salmon, rainbow trout, sardines, mushrooms, cod liver oil, egg yolks, fortified milk
Vitamin K	• Stimulates bone remodeling	kale, spinach, turnip, dark leafy vegetables
Boron	• May enhance calcium absorption and estrogen metabolism	avocado, nuts, peanut butter, green and orange vegetables, grapes, raisins
Iron	• Helps enzymes and regulators function properly so the body can form optimal bone structure for bone strength	red meat, egg yolks, dark leafy vegetables, dried fruit, iron-fortified foods, beans, lentils, chick peas, liver, artichoke
Vitamin C	• Helps enzymes and regulators function properly so the body can form optimal bone structure for bone strength	citrus fruits, tomatoes and tomato juice, potatoes, Brussels sprouts, cauliflower, broccoli, strawberries, cabbage, spinach
Zinc	• Helps enzymes and regulators function properly so the body can form optimal bone structure for bone strength	oysters, wheat germ, pumpkin seeds, squash, watermelon seeds, beans, sesame seeds, tahini, beef, lamb

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

Excessive vitamin D supplements can cause high phosphorus levels, muscle spasms, and convulsions. Deficiencies of phosphorus are rare in healthy adults.

Phosphorus Recommendations

The Dietary Reference Intakes (DRIs) for phosphorus are listed in Table 9.3.2.

Table 9.3.2: 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
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. Phosphate is present in many foods popular in the American diet including meat, fish, dairy products, and processed foods. Phosphate 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 per day,[2] well above the RDA of 700 milligrams per day.

Table 9.3.3: Dietary Sources of Phosphorus

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. 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.

In addition to participating in bone maintenance, magnesium has several other functions in the body. Every reaction that involves ATP requires magnesium. More than three hundred enzymatic reactions require magnesium. Magnesium plays a role in the synthesis of DNA and RNA, carbohydrates, and lipids, and is essential for nerve conduction and muscle contraction. Another health benefit of magnesium is that it may decrease blood pressure.

Magnesium Imbalances

Generally, people don't get magnesium toxicity from food. However, magnesium supplements can cause diarrhea, nausea, cramps, and dehydration. Hypermagnesemia can also occur in individuals with impaired kidney function.

Magnesium is found in a variety of foods. Therefore, if you eat an adequate and varied diet you will most likely consume required amounts. Hypomagnesemia can result in low blood calcium and osteoporosis. Hypomagnesemia can be caused by kidney disease, chronic diarrhea, or chronic alcohol intake.

Magnesium Recommendations

The DRIs for magnesium are listed in Table 9.3.4. 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 9.3.4: 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 9.3.5). 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 9.3.5: Dietary Sources of Magnesium[3]

Food	Magnesium (mg)	% Daily Value

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 stained and pitted as shown in Figure 9.3.1. 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.

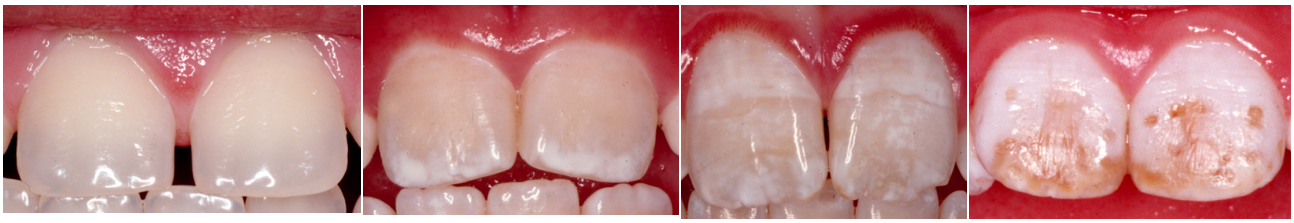


Figure 9.3.1: Fluorosis Progression: normal teeth, mild fluorosis, moderate fluorosis, and severe fluorosis including pitted surfaces.

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 9.3.6). The AIs are based on the doses of fluoride shown to reduce the incidence of tooth decay, but not cause dental fluorosis.

Table 9.3.6: Dietary Reference Intakes for Fluoride[1]

Age Group	AI (mg/day)	UL (mg/day)
Infants (0–6 months)	0.01	0.7
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

Age Group	AI (mg/day)	UL (mg/day)
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 it was grown in soils and water that contained fluoride or cooked with fluoridated water. Canned meats and fish that contain bones do contain some fluoride. In addition, most toothpastes contain fluoride.

Vitamin K

Vitamin K refers to a group of fat-soluble vitamins that are similar in chemical structure.

Functions of Vitamin K

Vitamin K acts as a coenzyme and plays an essential role in blood coagulation. Without vitamin K, blood would not clot. Vitamin K is also required for maintaining bone health; it modifies the protein osteocalcin, which is involved in the bone remodeling process.

Vitamin K Imbalances

Based on current research, there are no known side effects when healthy individuals consume large amounts of vitamin K. Since vitamin K plays a role in blood coagulation, individuals taking blood thinners (e.g., coumadin, warfarin) should avoid large increases or decreases in their vitamin K intake. Sudden changes in vitamin K intake can impact the medicine's effect and lead to dangerous bleeding (if you consume less vitamin K) or blood clots (if you consume more vitamin K).[5]

Vitamin K deficiency is rare in healthy individuals but can lead to reduced blood clotting and excessive bleeding. People suffering with diseases that cause malabsorption of fat, such as celiac, Crohn's, and cystic fibrosis can suffer from a deficiency of vitamin K.

Vitamin K Recommendations

The Institute of Medicine has established Adequate Intakes (AIs) for vitamin K, but has not yet developed RDAs (Table 9.3.7). A Tolerable Upper Intake Level (UL) for vitamin K has not been set.

Table 9.3.7: Dietary Reference Intakes for Vitamin K[1]

Age Group	AI (mcg/day)
Infants (0–6 months)	2.0
Infants (7–12 months)	2.5
Children (1–3 years)	30
Children (4–8 years)	55
Children (9–13 years)	60
Adolescents (14–18 years)	75
Adults (> 19 years)	120 (males), 90 (females)

Sources of Vitamin K

Vitamin K is present in many foods. It is found in highest concentrations in green vegetables such as broccoli, cabbage, kale, parsley, spinach, and lettuce (Table 9.3.8).[5] Additionally, vitamin K can be synthesized via bacteria in the large intestine. The exact amount of vitamin K synthesized by bacteria that is actually absorbed in the lower intestine is not known, but likely contributes less than 10% of the recommended intake. Newborns have low vitamin K stores and it takes time for the sterile newborn gut to acquire the good bacteria it needs to produce vitamin K. So, it has become a routine practice to inject newborns with a single intramuscular dose of vitamin K. This practice has basically eliminated vitamin K-dependent bleeding disorders in babies.

Table 9.3.8: Dietary Sources of Vitamin K[5]

Food	Vitamin K (mcg)	% Daily Value
Natto (3 ounces)	850	708
Collards, boiled (1/2 cup)	530	442
Spinach, raw (1 cup)	145	121
Broccoli, boiled (1/2 cup)	110	92
Soybean oil (1 tablespoon)	25	21
Pumpkin, canned (1/2 cup)	20	17

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

Key Takeaways

- Phosphorous, a primary mineral component of bone, is regulated in parallel with calcium, and in high amounts is detrimental to bone health.
- Magnesium helps keep bones strong. A deficiency in magnesium can compromise bone health.
- Fluoride combats tooth decay and benefits teeth and bones when present in the diet at the recommended intake.
- Vitamin K is a coenzyme that participates in the modification of proteins that act in bone tissues and promotes normal blood clotting.

References

1. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 19, 2025.
2. Phosphorus - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
3. Magnesium - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
4. About Community Water Fluoridation. cdc.gov. Accessed May 19, 2025.
5. Vitamin K - Health Professional Fact Sheet. ods.od.nih.gov. Accessed July 22, 2025.

This page titled 9.3: Other Essential Micronutrients for Bone Health is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

9.4: Osteoporosis

Learning Objectives

- Describe the test used to measure bone density.
- Identify test scores related to normal bone density, low bone density, and very low bone density.
- 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 over time. It 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 seventy.

Measuring Bone Density

Bones grow and mineralize predominately during infancy, childhood, and puberty. During this time, bone growth exceeds bone loss. By age 20, bone growth is fairly complete and only a small amount (about 10%) of bone mass accumulates in the third decade of life. By age 30, bone mass is at its greatest in both men and women and then gradually declines after age 40. 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. 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 degradation exceeds that of the bone building activity of osteoblasts. The increased bone degradation decreases the mineral content of bone tissue leading to a decrease in bone strength and increased fracture risk.

Detection and treatment of osteoporosis, before the occurrence of a fracture, can significantly improve the quality of life. To detect osteopenia (low bone density) or osteoporosis (very low bone density), bone density must be measured. Bone density is a measurement of the amount of calcified tissue in grams per centimeter squared of bone tissue. Bone density can be thought of as the total amount of bone mass in a defined area. When bone density is high, bone strength will be great. Similar to measuring blood pressure to predict the risk of stroke, a bone density measurement can help predict the risk of bone fracture. 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. During the procedure, a person lies on their back and a DEXA scanner passes two low-dose X-ray beams through their body (see Figure 9.4.1). The amount of X-ray energy that passes through the bone is measured for both beams. The total amount of the X-ray energy that passes through a person varies depending on their bone thickness. Using this information and a defined area of bone, the amount of calcified tissue in grams per unit area (cm^2) is calculated. Most often, the DEXA scan focuses on measuring bone density in the hip and the spine. These measurements are then used as indicators of overall bone strength and health.



Figure 9.4.1: DEXA bone density scan. (CC BY-ND 2.0; by ActiveSteve via flickr)

The results of a DEXA scan are most often reported as T-scores. A T-score compares a person's bone density to the average peak bone density of a healthy 30-year-old population of the same sex. The following bone density scores (T-scores) are used when

diagnosing bone density:

- T-score between +1 and -1 indicates normal bone density
- T-score between -1 and -2.5 indicates low bone density (osteopenia) and increased risk for fractures
- T-score more negative than -2.5 indicates osteoporosis (very low bone density)

Osteoporosis

During the course of osteoporosis, bone density decreases and the bone tissue microarchitecture is compromised. Excessive bone resorption in the trabecular tissue increases the size of the holes in the lattice-like structure making it more porous and weaker. 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 (Figure 9.4.2). 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*.

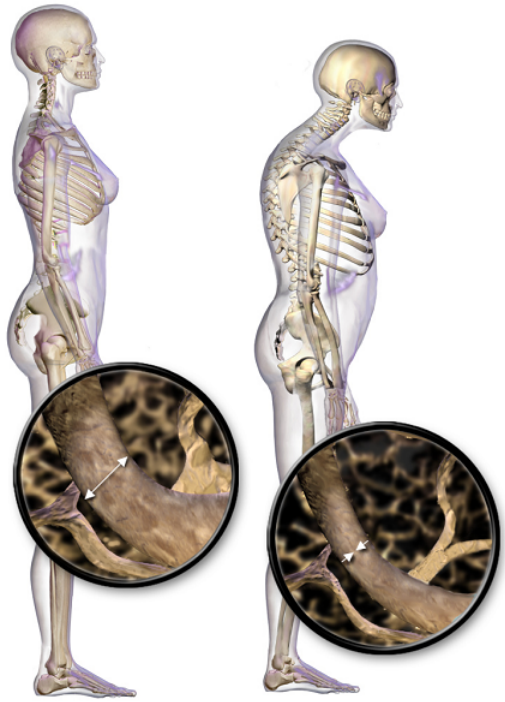


Figure 9.4.2: Osteoporosis is characterized by a gradual weakening of the bones, which leads to poor skeletal formation. (CC BY 3.0; by Blausen.com staff via *WikiJournal of Medicine*. 2014;1(2). ISSN 2002-4436.)

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 9.4.1 reviews the unmodifiable and modifiable risk factors for osteoporosis.

Table 9.4.1: Osteoporosis Risk Factors

Unmodifiable Risk Factors	Modifiable Risk Factors

• **Age.** Risk increases after the age of 40 due to bone breakdown (resorption) exceeding bone building. Age-related hormonal changes influence bone loss. 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 or 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.** Adequate calcium intake enhances bone density. Diets adequate in vitamin D help minimize bone loss. Diets high in fruits and vegetables are associated with improved bone health. • **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 such as strength training with weights, and aerobic weight-bearing activities, such as walking, running, and stair climbing. Certain aerobic exercises such as biking and swimming do not build bones, although they are very good for cardiovascular fitness.

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.

Key Takeaways

- Bone density is an indicator of bone quality and correlates with bone strength.
- Bone density is a measurement of calcified bone tissue and positively correlates with overall bone health. DEXA is a clinical tool used to assess bone density.
- Excessive bone loss can lead to the development of osteopenia and eventually osteoporosis.
- Osteoporosis is influenced by unmodifiable and modifiable risk factors. Unmodifiable risk factors include age, sex, family history and race. Modifiable risk factors include physical inactivity, low calcium and vitamin D intake, cigarette smoking, low body weight and estrogen deficiency.
- Prevention of osteoporosis begins early in life with proper diet and exercise.

This page titled 9.4: Osteoporosis is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

CHAPTER OVERVIEW

10: Nutrients Important for Metabolism and Blood Function

10.1: Overview of Blood and Metabolism

10.2: Vitamins Important for Metabolism and Blood Function

10.3: Minerals Important for Metabolism and Blood Function

Template:HideTOC

This page titled 10: Nutrients Important for Metabolism and Blood Function is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

10.1: 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, transporting nutrients to cells and waste products from cells. It supports cellular metabolism by transporting synthesized macromolecules and waste products. Additionally, it 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 10.1.1).

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) are the most numerous of the components and make up ~45% of total blood. The most vital duty of red blood cells is to transport oxygen from the lungs to all cells in the body so that they can make energy via aerobic metabolism. 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.

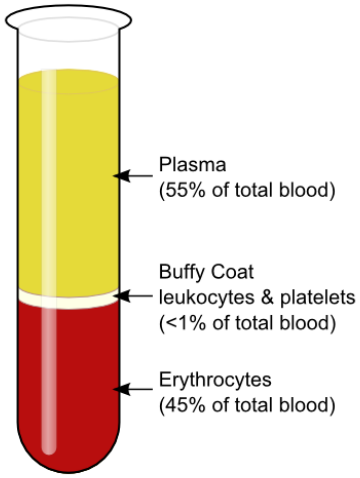


Figure 10.1.1: Components of blood include erythrocytes, leukocytes, platelets, and plasma. (CC BY 3.0; by KnuteKnudsen via Wikimedia Commons)

Once absorbed from the small intestine, all nutrients require transport to cells in need of their support. Additionally, molecules manufactured in other cells sometimes require delivery to other organ systems. Blood transports nutrients and molecules to all cells. Water-soluble molecules, such as some vitamins, minerals, sugars, and many proteins, move independently in blood. Fat-soluble vitamins, triglycerides, cholesterol, and other lipids are packaged into lipoproteins that allow for transport in the watery environment of blood. Many proteins, drugs, and hormones are dependent on transport carriers, primarily albumin. In addition to transporting all of these molecules, blood must transfer the oxygen breathed in by the lungs to all cells in the body. For additional information about the composition of blood and how that composition relates to anemia, watch this video from the Khan Academy:



"What's Inside of Blood?" (CC BY-NC-SA 4.0 by Khan Academy)

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

Microcytic vs. Macrocytic Anemia

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 10.1.2)). Microcytic anemia can develop with iron, copper, or vitamin B_6 deficiencies. When iron, copper, or vitamin B6 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.

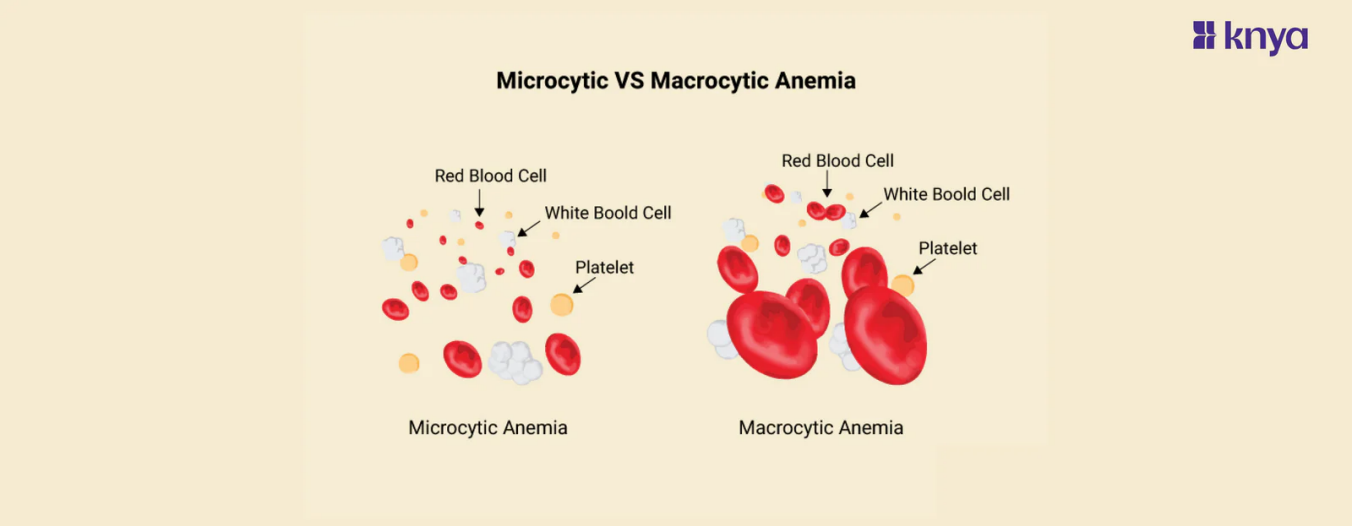


Figure 10.1.2: Comparison of microcytic and macrocytic red blood cells. (by Knya)

Metabolism

Metabolism is defined as the sum of all chemical reactions required to support cellular function. Metabolism is either categorized as catabolism, referring to all metabolic processes involved in molecule breakdown, or anabolism, which includes all metabolic processes involved in building bigger molecules. Generally, catabolic processes release energy and anabolic processes consume energy. The overall goals of metabolism are energy transfer and matter transport. Energy is transformed from food macronutrients

into cellular energy, which is used to perform cellular work. Metabolism transforms the matter of macronutrients into substances a cell can use to grow and reproduce and also into waste products.

In Chapter 6, you learned that enzymes are proteins and that their job 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. A metabolic pathway is a series of enzymatic reactions that transform the starting material (known as a substrate) into intermediates, which are the substrates for the next enzymatic reactions in the pathway, until, finally, an end product is synthesized by the last enzymatic reaction in the pathway.

Food is 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.

Energy metabolism refers more specifically to the metabolic pathways that release or store energy. Some of these are catabolic pathways, like glycolysis (the splitting of glucose), β-oxidation (fatty-acid breakdown), and amino acid catabolism (Table 10.1.1). Others are anabolic pathways, and include those involved in storing excess energy (such as glycogenesis), and synthesizing triglycerides (lipogenesis) (Table 10.1.2). When energy levels are high, cells build molecules; when energy levels are low, catabolic pathways are initiated to make energy.

Table 10.1.1: Catabolic Pathways

Catabolic Pathways	Function
Glycolysis	Glucose breakdown
Glycogenolysis	Glycogen breakdown
β-oxidation	Fatty-acid breakdown
Proteolysis	Protein breakdown to amino acids

Table 10.1.2: Anabolic Pathways

Anabolic Pathways	Function
Gluconeogenesis	Synthesize glucose
Glycogenesis	Synthesize glycogen
Lipogenesis	Synthesize triglycerides
Amino-acid synthesis	Synthesize amino acids

Key Takeaways

- Blood is the fluid in the body that transports absorbed nutrients to cells and waste products from cells.
- The fluid part of blood, plasma, makes up the largest amount of blood volume and contains proteins, ions, glucose, lipids, vitamins, minerals, waste products, gases, enzymes, and hormones.
- The cellular components of blood include red blood cells, white blood cells, and platelets.
- As blood travels through smaller and smaller vessels the rate of blood flow is dramatically reduced, allowing for efficient exchange of nutrients and oxygen for cellular waste products.
- Metabolism is defined as the sum of all chemical reactions required to support cellular function. The overall goals of metabolism are energy transfer and matter transport.
- A metabolic pathway is a series of enzymatic reactions that transforms the starting material (known as a substrate) into intermediates, which are the substrates for the next enzymatic reactions in the pathway, until, finally, an end product is synthesized by the last enzymatic reaction in the pathway.
- Energy metabolism refers more specifically to the metabolic pathways that release or store energy. When energy levels are high cells build molecules, and when energy levels are low catabolic pathways are initiated to make energy.

This page titled 10.1: Overview of Blood and Metabolism is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

10.2: Vitamins Important for Metabolism and Blood Function

Learning Objectives

- Summarize the role of the B vitamins in metabolism.
- Describe the role of the B vitamins in blood function.
- Explain how Vitamin K supports blood function.

While the 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 (vitamins and minerals don't directly provide energy/calories). Vitamins and minerals that make up part of enzymes are referred to as coenzymes and cofactors, respectively. Coenzymes and cofactors are required by enzymes to catalyze a specific reaction. They assist in converting a substrate to an end-product (Figure 10.2.1). Coenzymes and cofactors play many roles in catabolic and anabolic pathways.

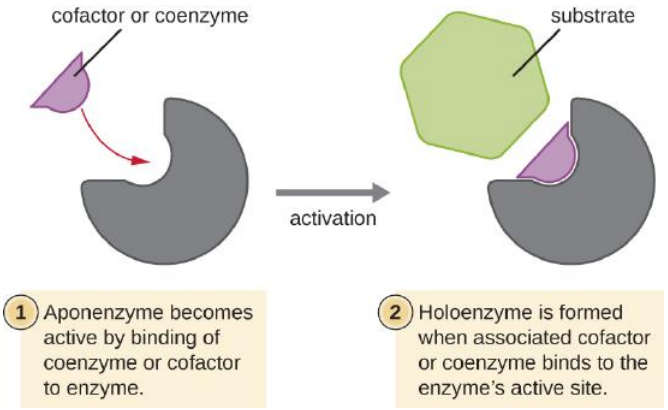


Figure 10.2.1: Coenzymes and cofactors are the particular vitamin or mineral required for enzymes to catalyze a specific reaction. (CC BY 4.0; by OpenStax)

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 wastes. In this section we will focus on the vitamins that take part in metabolism and blood function.

Thiamin (Vitamin B_1)

The water-soluble vitamin, thiamin, is especially important in glucose metabolism. It acts as a coenzyme for enzymes that break down glucose and branched chain amino acids for energy production. Additionally, thiamin plays a role in the synthesis of ribose from glucose and is therefore required for RNA, DNA, and ATP synthesis. The brain and heart are most affected by a deficiency in thiamin. Thiamin deficiency, also known as beriberi, can cause symptoms of fatigue, confusion, muscle wasting, nerve damage, movement impairment, pain in the lower extremities, swelling, and heart failure. The DRIs for thiamin are listed in Table 10.2.1. A Tolerable Upper Intake Level (UL) for thiamin has not been set. Food sources of thiamin include whole grains, meat, fish, and enriched or fortified grains. Other good food sources of thiamin are included in Table 10.2.2.

Table 10.2.1: Dietary Reference Intakes for Thiamin[1]

Age Group	RDA (mg/day)
Infants (0–6 months)	0.2*
Infants (7–12 months)	0.3*
Children (1–3 years)	0.5
Children (4–8 years)	0.6
Children (9–13 years)	0.9

* denotes Adequate Intake

Age Group	RDA (mg/day)
Adolescents (14–18 years)	1.2 (males), 1.0 (females)
Adults (> 19 years)	1.2 (males), 1.1 (females)
* denotes Adequate Intake	

Table 10.2.2: Dietary Sources of Thiamin[2]

Food	Thiamin (mg)	% Daily Value
Rice, white, enriched, cooked (1/2 cup)	1.4	117
Breakfast cereals, fortified (1 serving)	1.2	100
Pork chop (3 ounces)	0.4	33
Black beans, boiled (1/2 cup)	0.4	33

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

Riboflavin (Vitamin B_2)

Riboflavin is a water-soluble vitamin that is an essential component of flavoproteins, which are coenzymes involved in many metabolic pathways of carbohydrate, lipid, and protein metabolism. Furthermore, the functions of other B-vitamin coenzymes, such as vitamin B_6 and folate, are dependent on the actions of flavoproteins. In addition, riboflavin is part of the antioxidant enzyme glutathione peroxidase. The “flavin” portion of riboflavin gives a bright yellow color to riboflavin, an attribute that led to its discovery as a vitamin. Riboflavin is destroyed when exposed to light. Riboflavin deficiency (ariboflavinosis) is rare but when it occurs is often accompanied by other dietary deficiencies (most notably protein) and can be common in people that suffer from alcoholism. Signs and symptoms of riboflavin deficiency include dry, scaly skin, mouth inflammation and sores, sore throat, itchy eyes, fatigue, muscle weakness, and light sensitivity. The DRIs for riboflavin are listed in Table 10.2.3. A Tolerable Upper Intake Level (UL) for riboflavin has not been set. Food sources of riboflavin include eggs, meat, and milk. Other good food sources of riboflavin are included in Table 10.2.4.

Table 10.2.3: Dietary Reference Intakes for Riboflavin[1]

Age Group	RDA (mg/day)
Infants (0–6 months)	0.3*
Infants (7–12 months)	0.4*
Children (1–3 years)	0.5
Children (4–8 years)	0.6
Children (9–13 years)	0.9
Adolescents (14–18 years)	1.3 (males), 1.0 (females)
Adults (> 19 years)	1.3 (males), 1.1 (females)
* denotes Adequate Intake	

Table 10.2.4: Dietary Sources of Riboflavin[3]

Food	Riboflavin (mg)	% Daily Value
Beef liver (3 ounces)	2.9	223

Food	Riboflavin (mg)	% Daily Value
Breakfast cereals, fortified (1 serving)	1.3	100
Yogurt, plain, fat free (1 cup)	0.6	46
Portabella mushrooms (1/2 cup)	0.3	23
Almonds (1 ounce)	0.3	23

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

Niacin (Vitamin B_3)

Niacin is a water-soluble vitamin that is a component of coenzymes involved in the catabolism and/or anabolism of carbohydrates, lipids, and proteins. Niacin deficiency is commonly known as pellagra and is characterized by diarrhea, dermatitis, dementia, and sometimes death. Niacin toxicity may result from taking niacin supplements; symptoms include flushing (burning, tingling, itching, and red skin). The DRIs for niacin are listed in Table 10.2.5. Niacin is present in a wide variety of foods including those listed in Table 10.2.6.

Table 10.2.5: Dietary Reference Intakes for Niacin[1]

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	2*	ND
Infants (7–12 months)	4*	ND
Children (1–3 years)	6	10
Children (4–8 years)	8	15
Children (9–13 years)	12	20
Adolescents (14–18 years)	16 (males), 14 (females)	30
Adults (> 19 years)	16 (males), 14 (females)	35
* denotes Adequate Intake; ND=not determined		

Table 10.2.6: Dietary Sources of Niacin[4]

Food	Niacin (mg)	% Daily Value
Beef liver (3 ounces)	14.9	93
Chicken breast (3 ounces)	10.3	64
Salmon (3 ounces)	8.6	54
Peanuts (1 ounce)	4.2	26
Potato, baked (1 medium)	2.3	14

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

Vitamin B_6

Vitamin B_6 is a water-soluble vitamin and coenzyme involved in nitrogen transfer between amino acids (transamination) and therefore plays a role in non-essential amino acid synthesis and catabolism. Also, it functions to release glucose from glycogen in the catabolic pathway of glycogenolysis and is required by enzymes for the synthesis of multiple neurotransmitters and

hemoglobin. A deficiency in vitamin B_6 can cause signs and symptoms of muscle weakness, dermatitis, mouth sores, fatigue, and confusion. Vitamin B_6 is a required coenzyme for the synthesis of hemoglobin. A deficiency in vitamin B_6 can cause a type of anemia where the red blood cell size is normal or somewhat smaller but the hemoglobin content is lower. This means each red blood cell has less capacity for carrying oxygen, resulting in muscle weakness, fatigue, and shortness of breath. A deficiency of vitamin B_6 is also associated with an increased risk of cardiovascular disease due to elevated homocysteine levels. Vitamin B_6 toxicity may result from supplements and lead to nerve damage. The DRIs for vitamin B_6 are listed in Table 10.2.7. Vitamin B_6 is present in a wide variety of foods including those listed in Table 10.2.8.

Table 10.2.7: Dietary Reference Intakes for Vitamin B_6[1]

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	0.1*	ND
Infants (7–12 months)	0.3*	ND
Children (1–3 years)	0.5	30
Children (4–8 years)	0.6	40
Children (9–13 years)	1.0	60
Adolescents (14–18 years)	1.3 (males), 1.2 (females)	80
Adults (19-50 years)	1.3	100
Adults (> 50 years)	1.7 (males), 1.5 (females)	100
* denotes Adequate Intake; ND=not determined		

Table 10.2.8: Dietary Sources of Vitamin B_6[5]

Food	Vitamin B_6 (mg)	% Daily Value
Chickpeas (1 cup)	1.1	65
Yellowfin tuna (3 ounces)	0.9	53
Chicken breast (3 ounces)	0.5	29
Potatoes, boiled (1 cup)	0.4	25
Banana (1 medium)	0.4	25

Learn even more about this nutrient by reading the Vitamin B_6 Fact Sheet from the National Institutes of Health, Office of Dietary Supplements.

Biotin

Biotin, a water-soluble vitamin, is required as a coenzyme in lipid metabolism. It is also required as an enzyme in the synthesis of glucose and some nonessential amino acids. Biotin is important for gluconeogenesis (the generation of new glucose from amino acids when carbohydrate intake is low). Biotin deficiency is rare, but can be caused by eating large amounts of raw egg whites over an extended period of time. This is because a protein in raw egg whites tightly binds to biotin making it unavailable for absorption. The Adequate Intakes (AIs) for biotin are listed in Table 10.2.9. A Tolerable Upper Intake Level (UL) for biotin has not been set. Food sources of biotin include eggs, meat, and fish (Table 10.2.10).

Table 10.2.9: Dietary Reference Intakes for Biotin[1]

Age Group	AI (mcg/day)
Infants (0–6 months)	5
Infants (7–12 months)	6

Age Group	AI (mcg/day)
Children (1–3 years)	8
Children (4–8 years)	12
Children (9–13 years)	20
Adolescents (14–18 years)	25
Adults (> 19 years)	30

Table 10.2.10: Dietary Sources of Biotin[6]

Food	Biotin (mcg)	% Daily Value
Beef liver (3 ounces)	30.8	103
Egg, whole, cooked (1 large)	10.0	33
Salmon, canned (3 ounces)	5.0	17
Pork chop (3 ounces)	3.8	13
Sunflower seeds (1/4 cup)	2.6	9

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

Folate

Folate, a water-soluble vitamin, is a required coenzyme for the synthesis of the amino acid methionine as well as RNA and DNA synthesis. Therefore, rapidly dividing cells are most affected by folate deficiency. Folate is especially essential for the growth and specialization of cells of the central nervous system. Children whose mothers were folate-deficient during pregnancy have a higher risk of neural-tube birth defects such as spina bifida, a neural-tube defect that occurs when the spine does not completely enclose the spinal cord (Figure 10.2.2). Observational studies show that the prevalence of neural-tube defects in the United States decreased after the fortification of enriched cereal grain products with folate began in 1996 compared to before grain products were fortified with folate.

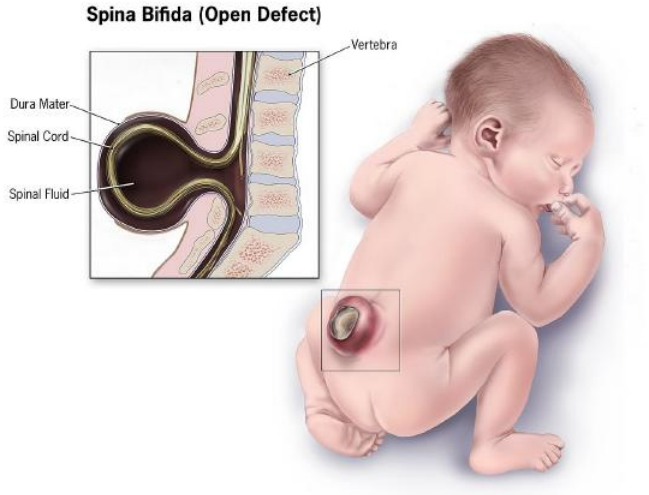


Figure 10.2.2: Spina bifida is a neural-tube defect that can have severe health consequences. (CC0; by Centers for Disease Control and Prevention via Wikimedia Commons)

Folate deficiency can lead to macrocytic (also called megaloblastic) anemia. Macrocytic and megaloblastic mean “big cell,” and anemia refers to fewer red blood cells or red blood cells containing less hemoglobin. Macrocytic anemia is characterized by larger and fewer red blood cells. It is caused by red blood cells being unable to produce DNA and RNA fast enough—cells grow but do not divide, making them large in size. Folate toxicity can occur when taking supplements. Excess folate can mask a vitamin B_{12} deficiency which can lead to nerve damage. The DRIs for folate are listed in Table 10.2.11. Folate is present in a wide variety of foods including those listed in Table 10.2.12. Folate is sensitive to heat and can lost when foods are cooked.

Table 10.2.11: Dietary Reference Intakes for Folate[1]

Age Group	RDA (mcg/day)	UL (mcg/day)
Infants (0–6 months)	65*	ND
Infants (7–12 months)	80*	ND
Children (1–3 years)	150	300
Children (4–8 years)	200	400
Children (9–13 years)	300	600
Adolescents (14–18 years)	400	800
Adults (> 18 years)	400	1,000
* denotes Adequate Intake; ND=not determined		

Table 10.2.12: Dietary Sources of Folate[7]

Food	Folate (mcg)	% Daily Value
Spinach, boiled (1/2 cup)	131	33
Black-eyed pea, boiled (1/2 cup)	105	26
Rice, white, cooked (1/2 cup)	90	22
Asparagus (4 spears)	89	22
Lettuce, romaine (1 cup)	64	16

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

Vitamin B_{12}

Vitamin B_{12} is a water-soluble vitamin and an essential part of coenzymes necessary for fat and protein catabolism, for folate coenzyme function, and for hemoglobin synthesis. In addition, vitamin B_{12} is required for proper nerve functioning. Vitamin B_{12} works with folate to convert homocysteine into methionine; by preventing a build-up of homocysteine these nutrients help reduce cardiovascular disease risk. An enzyme requiring vitamin B_{12} is needed by a folate-dependent enzyme to synthesize DNA. Thus, a deficiency in vitamin B_{12} has similar consequences to health as folate deficiency. In children and adults, vitamin B_{12} deficiency causes macrocytic anemia; in babies born to vitamin B_{12}-deficient mothers there is an increased risk for neural-tube defects.

In order for the human body to absorb vitamin B_{12}, the stomach, pancreas, and small intestine must be functioning properly. Cells in the stomach secrete a protein called intrinsic factor that is necessary for vitamin B_{12} absorption, which occurs in the small intestine. Impairment of secretion of this protein can lead to either atrophic gastritis or pernicious anemia. Atrophic gastritis, a condition where there is chronic inflammation of the stomach (often due to an *H. pylori* infection or an autoimmune disorder), can lead to reduced stomach acid production and then in turn less vitamin B_{12} absorption. Atrophic gastritis becomes more common in people over the age of 50. Pernicious anemia, a type of macrocytic anemia, is treated by large oral doses of vitamin B_{12} or by putting the vitamin under the tongue (sublingual), where it is absorbed into the blood stream without passing through the intestine.

In patients that do not respond to oral or sublingual treatment, vitamin B_{12} is given by injection. 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. There are no known adverse effects related to vitamin B_{12} toxicity.

The DRIs for vitamin B_{12} are listed in Table 10.2.13. A Tolerable Upper Intake Level (UL) for vitamin B_{12} has not been set. Vitamin B_{12} is naturally found in animal products (Table 10.2.14).

Table 10.2.13: Dietary Reference Intakes for Vitamin B_{12}[1]

Age Group	RDA (mcg/day)
Infants (0–6 months)	0.4*
Infants (7–12 months)	0.5*
Children (1–3 years)	0.9
Children (4–8 years)	1.2
Children (9–13 years)	1.8
Adolescents (14–18 years)	2.4
Adults (> 19 years)	2.4
* denotes Adequate Intake	

Table 10.2.14: Dietary Sources of Vitamin B_{12}[8]

Food	Vitamin B_{12} (mcg)	% Daily Value
Rainbow trout, wild (3 ounces)	5.4	225
Salmon (3 ounces)	4.8	200
Tuna, light, canned in water (3 ounces)	2.5	104
Milk, low-fat (1 cup)	1.2	50
Egg (1 large)	0.6	25

Learn even more about this nutrient by reading the Vitamin B_{12} Fact Sheet from the National Institutes of Health, Office of Dietary Supplements.

B Vitamin Summary

B vitamins are water-soluble and are not stored in significant amounts in the body. Therefore, they must be continuously obtained from the diet. B vitamins are naturally present in numerous foods, and many other foods are enriched with them. In the United States, B-vitamin deficiencies are rare. A summary of the prominent functions of the B vitamins in metabolism and blood function, and their deficiency syndromes is given in Table 10.2.15.

Table 10.2.15: B-Vitamin Functions in Metabolism and Blood, and Deficiency Syndromes

B Vitamin	Function	Deficiency: Signs and Symptoms
B_1 (thiamin)	Coenzyme: assists in glucose metabolism, RNA, DNA, and ATP synthesis	Beriberi: fatigue, confusion, movement impairment, swelling, heart failure
B_2 (riboflavin)	Coenzyme: assists in glucose, fat and carbohydrate metabolism, electron carrier, other B vitamins are dependent on	Ariboflavinosis: dry scaly skin, mouth inflammation and sores, sore throat, itchy eyes, light sensitivity
B_3 (niacin)	Coenzyme: assists in glucose, fat, and protein metabolism, electron carrier	Pellagra: diarrhea, dermatitis, dementia, death

B Vitamin	Function	Deficiency: Signs and Symptoms
Vitamin B_6 (pyridoxine)	Coenzyme; assists in amino-acid synthesis, glycogenolysis, neurotransmitter and hemoglobin synthesis	Muscle weakness, dermatitis, mouth sores, fatigue, confusion
Biotin	Coenzyme; assists in glucose, fat, and protein metabolism, amino-acid synthesis	Muscle weakness, dermatitis, fatigue, hair loss
Folate	Coenzyme; amino acid synthesis, RNA, DNA, and red blood cell synthesis	Diarrhea, mouth sores, confusion, anemia, neural-tube defects
B_{12} (cobalamin)	Coenzyme; fat and protein catabolism, folate function, red-blood-cell synthesis	Muscle weakness, sore tongue, anemia, nerve damage, neural-tube defects

Vitamin K

Vitamin K is a fat-soluble vitamin. As discussed in Chapter 9, Vitamin K is required for optimal bone metabolism. Vitamin K is also critical for blood function, as it is a coenzyme for enzymes involved in blood clotting. Blood-clotting proteins are continuously circulating in the blood. Upon injury to a blood vessel, platelets stick to the wound forming a plug. The clotting factors circulating close by respond in a series of protein-protein interactions resulting in the formation of the fibrous protein, fibrin, which reinforces the platelet plug. A deficiency in vitamin K causes bleeding disorders. Signs and symptoms include nosebleeds, easy bruising, broken blood vessels, bleeding gums, and heavy menstrual bleeding in women. The function of the anticoagulant drug warfarin is impaired by excess vitamin K intake from supplements. The Adequate Intakes (AIs) for vitamin K are listed in Table 10.2.16. A Tolerable Upper Intake Level (UL) for vitamin K has not been set. Vitamin K is present in many foods and most highly concentrated in green leafy vegetables. Desirable intestinal bacteria also produce vitamin K in the large intestine. See Table 10.2.17 for a list of dietary sources of vitamin K.

Table 10.2.16: Dietary Reference Intakes for Vitamin K[1]

Age Group	AI (mcg/day)
Infants (0–6 months)	2.0
Infants (7–12 months)	2.5
Children (1–3 years)	30
Children (4–8 years)	55
Children (9–13 years)	60
Adolescents (14–18 years)	75
Adults (> 19 years)	120 (males), 90 (females)

Table 10.2.17: Dietary Sources of Vitamin K[9]

Food	Vitamin K (mcg)	% Daily Value
Natto (3 ounces)	850	708
Collards, frozen, boiled (1/2 cup)	530	442
Spinach, raw (1 cup)	145	121
Broccoli, boiled (1/2 cup)	110	92
Soybeans, roasted (1/2 cup)	43	36
Edamame (1/2 cup)	21	18

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

Key Takeaways

- Vitamins play a different kind of role in energy metabolism; they are required as functional parts of enzymes involved in energy release and storage.
- The water-soluble B vitamins are involved as coenzymes in the breakdown of nutrients and in the building of macromolecules, such as protein, RNA, and DNA.
- B-vitamin deficiencies are relatively rare especially in developed countries; although the health consequences can be severe as with folate deficiency during pregnancy and the increased risk of neural-tube defects in offspring.
- The B vitamins, pyridoxine (B_6), folate, and cobalamin (B_{12}) are needed for blood-cell renewal and/or function.
- Vitamin K is necessary for blood clotting.

References

1. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 19, 2025.
2. Thiamin - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
3. Riboflavin - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
4. Niacin - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
5. Vitamin B_6 - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
6. Biotin - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
7. Folate - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
8. Vitamin B_{12} - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
9. Vitamin K - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.

This page titled 10.2: Vitamins Important for Metabolism and Blood Function is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

10.3: Minerals Important for Metabolism and Blood Function

Learning Objectives

- Identify the primary function of each of the minerals involved in metabolism.
- Summarize the roles of minerals important in blood function.
- Identify iron-deficiency anemia as the most prevalent nutritional deficiency worldwide.

Minerals are cofactors for hundreds of enzymes involved in metabolism. In addition, several minerals are critical for proper blood function. Interestingly, the mineral content of foods is greatly affected by the soil from which it grew, and thus geographic location is the primary determinant of the mineral content of foods. For instance, iodine comes mostly from seawater so the greater the distance from the sea the lesser the iodine content in the soil.

Magnesium

Magnesium is a macromineral (major mineral) that participates as a cofactor in hundreds of metabolic reactions. ATP exists as a complex with magnesium and therefore this mineral is involved in all reactions that synthesize or require ATP including carbohydrate, lipid, protein, RNA, and DNA synthesis. Many Americans do not get the recommended intake of magnesium from their diets. Some observational studies suggest mild magnesium deficiency is linked to increased risk for cardiovascular disease. Signs and symptoms of severe magnesium deficiency may include tremor, muscle spasms, loss of appetite, and nausea. Magnesium is also involved with bone health; the DRIs and good food sources for magnesium can be found in Chapter 9.

Iron

Red blood cells contain the oxygen-carrier protein hemoglobin. It is composed of four globular peptides, each containing a heme complex. Iron (Fe^{2+}) lies in the center of each heme complex (Figure 10.3.1). Iron is a trace mineral and a key component of hundreds of metabolic enzymes. Iron is also involved in numerous metabolic reactions that take place mainly in the liver and detoxify harmful substances. The great majority of iron used in the body is recycled from the continuous breakdown of red blood cells.

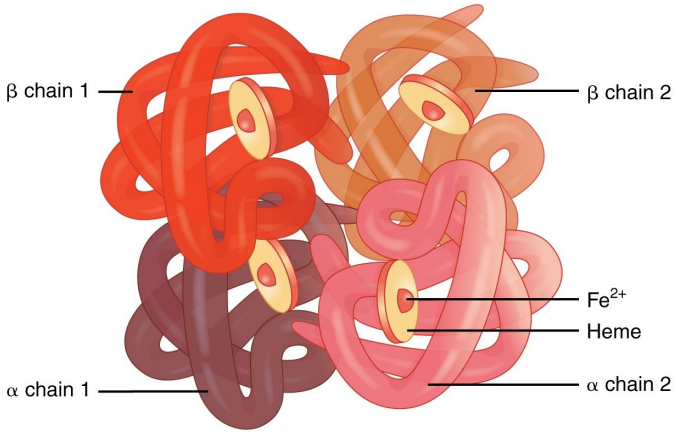


Figure 10.3.1: Hemoglobin is composed of four peptides. Each contains a heme group with iron (Fe^{2+}) in the center. (CC BY 4.0; by OpenStax Anatomy and Physiology)

Oxygen transport is one of the main functions of iron. The iron in hemoglobin binds to oxygen in the capillaries of the lungs and transports it to cells where the oxygen is released. If iron levels are low, hemoglobin is not synthesized in sufficient amounts and the oxygen-carrying capacity of red blood cells is reduced, resulting in anemia. When iron levels are low in the diet the small intestine more efficiently absorbs iron in an attempt to compensate for the low dietary intake, but this process cannot make up for the excessive loss of iron that occurs with chronic blood loss or low intake. When blood cells are decommissioned for use, the body recycles the iron back to the bone marrow where red blood cells are made. The body stores some iron in the bone marrow, liver, spleen, and skeletal muscle. A relatively small amount of iron is excreted when cells lining the small intestine and skin cells die and in blood loss, such as during menstrual bleeding. The lost iron must be replaced from dietary sources.

The bioavailability of iron (ability for your body to absorb and use 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 nonheme iron. In addition, some plants contain chemicals (such as phytates, oxalates, tannins, and polyphenols) that inhibit iron absorption. 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. Iron toxicity can cause symptoms such as nausea, vomiting, diarrhea, dizziness, and confusion. In the United States, iron overdose is the most common cause of poisoning deaths in children younger than 6, so iron supplements should be stored out of children's reach. The DRIs for iron are listed in Table 10.3.1. Good food sources of iron are listed in Table 10.3.2.

Table 10.3.1: Dietary Reference Intakes for Iron[1]

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	0.27*	40
Infants (7–12 months)	11	40
Children (1–3 years)	7	40
Children (4–8 years)	10	40
Children (9–13 years)	8	40
Adolescents (14–18 years)	11 (males), 15 (females)	45
Adults (19-30 years)	8 (males), 18 (females)	45
Adults (31-50 years)	8 (males), 18 (females)	45
Adults (> 50 years)	8	45
* denotes Adequate Intake		

Table 10.3.2: Dietary Sources of Iron[2]

Food	Iron (mg)	% Daily Value
Oysters (3 ounces)	8	44
White beans, canned (1 cup)	8	44
Chocolate, dark, 45-69% cacao (3 ounces)	7	39
Beef liver (3 ounces)	5	28
Spinach, boiled (1/2 cup)	3	17

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

Iron-Deficiency Anemia

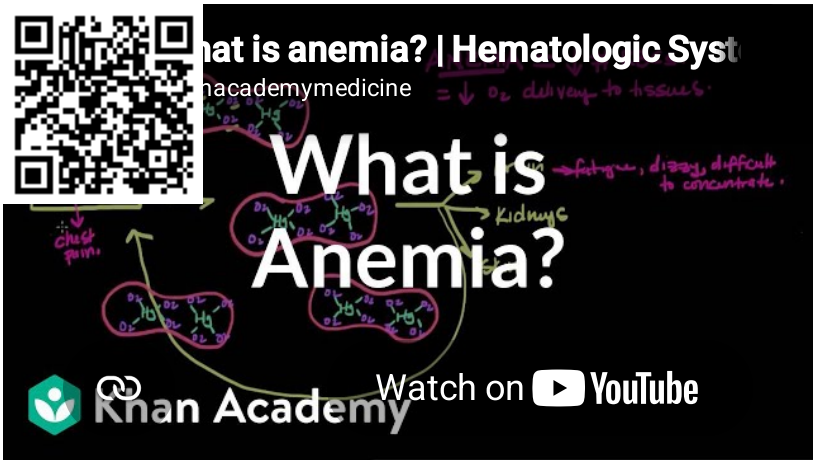
Iron-deficiency anemia is the most common and widespread nutritional disorder in the world.[3] It's a condition that develops from having insufficient iron levels in the body resulting in fewer and smaller red blood cells containing lower amounts of hemoglobin. Iron-deficiency anemia has the following signs and symptoms, which are linked to the essential functions of iron in energy metabolism and blood health:

- Fatigue
- Weakness
- Pale skin
- Shortness of breath

- Dizziness
- Swollen, sore tongue
- Abnormal heart rate

Iron-deficiency anemia is diagnosed from characteristic signs and symptoms and confirmed with simple blood tests that count red blood cells and determine hemoglobin and iron content in blood. Anemia is most often treated with iron supplements and increasing the consumption of foods that are higher in iron.

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. One more high-risk group is the elderly. Both elderly men and women have a high incidence of anemia and the most common causes are dietary iron deficiency and chronic disease such as ulcer, inflammatory diseases, and cancer. Additionally, those who have recently suffered from traumatic blood loss, frequently donate blood, or take excessive antacids for heartburn need more iron in the diet. For more on anemia, watch the following video from the Khan Academy:



"What is Anemia?" (CC BY-NC-SA 4.0 by Nauroz Syed for Khan Academy)

Zinc

Zinc is a trace mineral and a cofactor for over two hundred enzymes in the human body and plays a direct role in RNA, DNA, and protein synthesis. Zinc is a required cofactor for an enzyme that synthesizes the heme portion of hemoglobin and severely deficient zinc diets can result in anemia. Zinc is also a cofactor for enzymes involved in energy metabolism. Zinc also performs structural functions - it helps stabilize the structure of proteins involved in gene expression, vision, antioxidant enzyme systems, and immune function. In addition, zinc regulates gene expression (e.g., activates cells that regulate cell growth during fetal development). As the result of its prominent roles in anabolic and energy metabolism, a zinc deficiency in infants and children limits growth. In adults, severe zinc deficiency can cause hair loss, diarrhea, skin sores, loss of appetite, and weight loss. Toxicity can occur from supplements; symptoms include intestinal pain, headaches, and depressed immune function. The DRIs for zinc are listed in Table 10.3.3. Red meat and poultry provide the majority of zinc in the American diet. Additional good food sources of zinc are listed in Table 10.3.4.

Table 10.3.3: Dietary Reference Intakes for Zinc[1]

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	2*	4
Infants (7–12 months)	3	5
Children (1–3 years)	3	7
Children (4–8 years)	5	12

* denotes Adequate Intake

Age Group	RDA (mg/day)	UL (mg/day)
Children (9–13 years)	8	23
Adolescents (14–18 years)	11 (males), 9 (females)	34
Adults (> 18 years)	11 (males), 8 (females)	40
* denotes Adequate Intake		

Table 10.3.4: Dietary Sources of Zinc[4]

Food	Zinc (mg)	% Daily Value
Beef, chuck roast (3 ounces)	7	64
Alaska king crab (3 ounces)	6.5	59
Pork chop (3 ounces)	2.9	26
Baked beans, canned (1/2 cup)	2.9	26
Chicken, dark meat (3 ounces)	2.4	22
Pumpkin seeds (1 ounce)	2.2	20

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

Iodine

Iodine is a trace element essential for the synthesis of thyroid hormone, which regulates metabolism, growth, and development. Low iodine levels can lead to hypothyroidism which has many signs and symptoms including fatigue, sensitivity to cold, constipation, weight gain, depression, dry, itchy skin and paleness. The development of goiter (Figure 10.3.2) may often be the most visible sign of chronic iodine deficiency, but the consequences of low levels of thyroid hormone can be severe during infancy, childhood, and adolescence as it affects all stages of growth and development. Thyroid hormone plays a major role in brain development and growth. Fetuses and infants with severe iodine deficiency develop a condition known as cretinism, in which physical and neurological impairment can be severe. Too much iodine blocks the synthesis of thyroid hormones and also results in goiter. The DRIs for iodine are listed in Table 10.3.5. Seaweed is one of the best food sources of iodine, but it is highly variable in its content. Seafood and dairy products are good food sources of iodine (Table 10.3.6). For many people worldwide, iodized salt is the only source of iodine.



Figure 10.3.2: Woman with large goiter. (CC BY-SA 3.0; Dr. J.S. Bhandari via Wikimedia Commons)

Table 10.3.5: Dietary Reference Intakes for Iodine[1]

Age Group	RDA (mcg/day)	UL (mcg/day)
Infants (0–6 months)	110*	ND
Infants (7–12 months)	130*	ND
Children (1–3 years)	90	200
Children (4–8 years)	90	300
Children (9–13 years)	120	600
Adolescents (14–18 years)	150	900
Adults (> 18 years)	150	1,100
* denotes Adequate Intake; ND=not determined		

Table 10.3.6: Dietary Sources of Iodine[5,6]

Food	Iodine (mcg)	% Daily Value
Cod, baked (3 ounces)	158	106
Nori, seaweed, dried (2 tablespoons)	116	77
Yogurt, plain, low-fat (3/4 cup)	87	58
Iodized salt (1/4 teaspoon)	76	51
Egg, hard boiled (1 large)	26	17
Shrimp (3 ounces)	13	9

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

Selenium

Selenium is a trace mineral and a cofactor for enzymes that release active thyroid hormone in cells; therefore, low levels can cause similar signs and symptoms as iodine deficiency. Selenium also functions as an antioxidant; the DRIs and good food sources for selenium can be found in Chapter 8. Learn even more about this nutrient by reading the Selenium Fact Sheet from the National Institutes of Health, Office of Dietary Supplements.

Copper

Copper is a trace mineral and cofactor for enzymes essential in iron absorption and transport. The other important function of copper is as an antioxidant, which was also discussed briefly in Chapter 8. Symptoms of mild to moderate copper deficiency are rare. More severe copper deficiency can cause anemia from the lack of iron mobilization in the body for red blood cell synthesis. Other signs and symptoms include growth retardation in children and neurological problems, because copper is a cofactor for an enzyme that synthesizes myelin, which surrounds many nerves. The DRIs for copper are listed in Table 10.3.7. Good food sources of copper are included in (Table 10.3.8).

Table 10.3.7: Dietary Reference Intakes for Copper[1]

Age Group	RDA (mcg/day)	UL (mcg/day)
Infants (0–6 months)	200*	ND
Infants (7–12 months)	220*	ND
* denotes Adequate Intake; ND=not determined		

Age Group	RDA (mcg/day)	UL (mcg/day)
Children (1–3 years)	340	1,000
Children (4–8 years)	440	3,000
Children (9–13 years)	700	5,000
Adolescents (14–18 years)	890	8,000
Adults (> 18 years)	900	10,000
* denotes Adequate Intake; ND=not determined		

Table 10.3.8: Dietary Sources of Copper[7]

Food	Copper (mcg)	% Daily Value
Oysters, wild, cooked (3 ounces)	4,850	539
Baking chocolate, unsweetened (1 ounce)	938	104
Potatoes (1 medium)	675	75
Mushrooms, shitake (1/2 cup)	650	70
Tofu, raw, firm (1/2 cup)	476	53
Pasta, whole wheat, cooked (1 cup)	263	29
Avocado (1/2 cup)	219	24

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

Chromium

The functioning of chromium in the body is less understood than that of most other minerals. Chromium is a trace mineral that enhances the actions of insulin and plays a role in carbohydrate, fat, and protein metabolism. More research is needed to better determine the full range of chromium's roles in the body. The Adequate Intakes (AIs) for chromium are listed in Table 10.3.9. A Tolerable Upper Intake Level (UL) for chromium has not been set. The chromium content of foods cannot be reliably determined, so the values presented in Table 10.3.10 should only be used as a guide.

Table 10.3.9: Dietary Reference Intakes for Chromium[1]

Age Group	AI (mcg/day)
Infants (0–6 months)	0.2
Infants (7–12 months)	5.5
Children (1–3 years)	11
Children (4–8 years)	15
Children (9–13 years)	25 (males), 21 (females)
Adolescents (14–18 years)	35 (males), 24 (females)
Adults (19-50 years)	35 (males), 25 (females)
Adults (> 50 years)	30 (males), 20 (females)

Table 10.3.10: Dietary Sources of Chromium[8]

Food	Chromium (mcg)	% Daily Value
Broccoli (1/2 cup)	11	31
Grape juice (1 cup)	8	23
English muffin, whole wheat (1)	4	11
Potatoes, mashed (1 cup)	3	9

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

Mineral Summary

A summary of the prominent functions of minerals involved in metabolism and blood function as well as their related deficiency syndromes is given in Table 10.3.11.

Table 10.3.11: Mineral Functions in Metabolism and Blood and Deficiency Syndrome

Mineral	Function	Deficiency: Signs and Symptoms
Macro		
Magnesium	ATP synthesis and utilization, carbohydrate, lipid, protein, RNA, and DNA synthesis	Tremor, muscle spasms, loss of appetite, nausea
Trace		
Iron	Assists in energy production, DNA synthesis required for red blood cell function	Anemia: fatigue, paleness, faster heart rate
Zinc	Assists in energy production, protein, RNA and DNA synthesis; required for hemoglobin synthesis	Growth retardation in children, hair loss, diarrhea, skin sores, loss of appetite, weight loss
Iodine	Making thyroid hormone, metabolism, growth and development	Goiter, cretinism, other signs and symptoms include fatigue, depression, weight gain, itchy skin, low heart-rate
Selenium	Essential for thyroid hormone activity	fatigue
Copper	Assists in energy production, iron metabolism	Anemia: fatigue, paleness, faster heart rate
Chromium	Assists insulin in carbohydrate, lipid and protein metabolism	abnormal glucose metabolism

Mineral Bioavailability

Minerals are not as efficiently absorbed as most vitamins and so the bioavailability of minerals (ability for your body to absorb and use minerals) can be very low. Plant-based foods often contain factors, such as oxalates and phytates, that bind to minerals and inhibit their absorption. In general, minerals are better absorbed from animal-based foods. In most cases, if dietary intake of a particular mineral is increased, absorption will decrease. Some minerals influence the absorption of others. For instance, excess zinc in the diet can impair iron and copper absorption. Conversely, certain vitamins enhance mineral absorption. For example, vitamin C boosts iron absorption, and vitamin D boosts calcium and magnesium absorption. As is the case with vitamins, certain gastrointestinal disorders and diseases, such as Crohn's disease and kidney disease, as well as the aging process, impair mineral absorption, putting people with malabsorption conditions and the elderly at higher risk for mineral deficiencies.

Key Takeaways

- Minerals are cofactors for hundreds of enzymes involved in metabolism.
- Iron, copper and zinc are critical for blood function.
- Iron-deficiency anemia is a condition that develops from having insufficient iron levels in the body, resulting in fewer and smaller red blood cells containing lower amounts of hemoglobin. 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 by all causes.
- Minerals are not as efficiently absorbed as most vitamins and bioavailability can be very low.

References

1. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 19, 2025.
2. Iron - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
3. Anaemia. who.int. Accessed May 19, 2025.
4. Zinc - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
5. Iodine - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
6. USDA, FDA and ODS-NIH Database for the Iodine Content of Common Foods Release 2.0 (2022). ars.usda.gov. Accessed May 19, 2025.
7. Copper - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.
8. Chromium - Health Professional Fact Sheet. ods.od.nih.gov. Accessed May 19, 2025.

This page titled 10.3: Minerals Important for Metabolism and Blood Function is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

CHAPTER OVERVIEW

11: Energy Balance

11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution
11.2: Balancing Energy Intake with Energy Output
11.3: Physical Fitness and Physical Activity
11.4: Fuel and Nutrient Needs for Physical Activity
11.5: Health Risks of Overweight and Underweight
11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain

Template:HideTOC

This page titled 11: Energy Balance is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution

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.

Although the terms "overweight" and "obese" are often used interchangeably, they mean different things. Body weight consists of water weight, lean muscle weight, bone weight, and weight from body fat (adipose). "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 excessive body fat and therefore body weight is an indicator of obesity in much of the population. 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 quantify the amount of tissue mass (muscle, fat, and bone) in an individual, and then categorize that person as underweight, normal weight, overweight, or obese based on that value. Commonly accepted BMI categories are included in Table 11.1.1.

Table 11.1.1: 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 11.1.1). Instead, you'd like to be in the middle range of the BMI which is what they use for "normal weight".

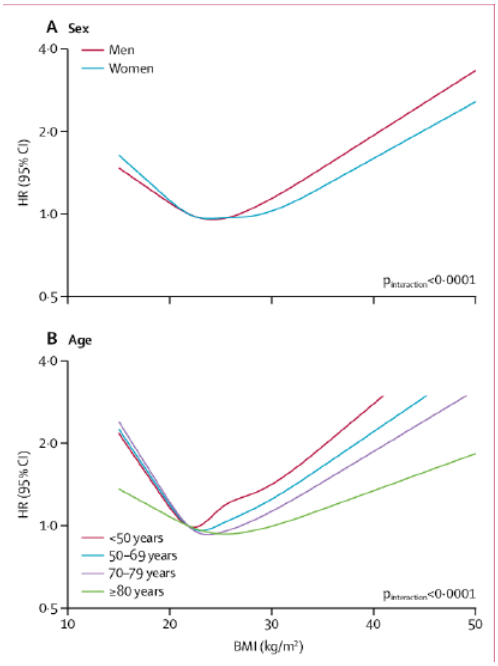


Figure 11.1.1: Mortality risk vs. BMI by sex (A) and age (B). (CC BY 4.0; Bhaskaran K, Silva I, Leon D, Douglas I, and Smeeth L via ResearchGate)

Limitations of BMI

BMI is a fairly simple measurement. 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 overweight or obese people and overestimate it in more muscular people. For instance, a muscular athlete will have more muscle mass (which is heavier than fat mass) than a couch potato of the same height. Based on their BMIs the muscular athlete would be less “ideal” and may be categorized as more overweight or obese than the couch potato; however this is an infrequent problem with BMI calculation. BMI 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. Recently, a new policy of the American Medical Association recognized issues with using 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 doesn't consider a person's gender or ethnicity.[1] BMI also has limitations when used with pregnant and lactating women. Ultimately, BMI is a useful inexpensive tool to categorize people and is highly correlative with disease risk, but other measurements are needed to diagnose obesity and more accurately assess disease risk.

Body Composition

Water, organs, bone tissue, fat, and muscle tissue make up a person’s weight. Having more fat mass may be indicative of disease risk, but fat mass also varies with sex, age, and physical activity level. Females have more fat mass, which is needed for reproduction and, in part, is a consequence of different levels of hormones. The optimal fat content of a female is between 20 and 30% of her total weight and for a male is between 12 and 20%. 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. It is a noninvasive and fairly accurate method of measuring fat mass, but should be done by a trained professional using appropriate calculations based on individual demographics.
- **Underwater weighing.** This technique requires a chamber full of water big enough for the whole body to fit in. First, a person is weighed outside the chamber and then weighed again while immersed in water. Bone and muscle weigh more than water, but fat does not—therefore a person with a higher muscle and bone mass will weigh more when in water than a person with less bone and muscle mass.
- **Bioelectric Impedance Analysis (BIA).** This device is based on the fact that fat slows down the passage of electricity through the body. When a small amount of electricity is passed through the body, the rate at which it travels is used to determine body

composition. These devices are also sold for home use and commonly called body composition scales.

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

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 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. Two measurements are typically used to determine fat distribution:

- **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 greater risk for chronic disease.
- **Waist-to-Hip Ratio.** The waist-to-hip ratio is often considered a better measurement than waist circumference alone in predicting disease risk. To calculate your waist-to-hip ratio, use a measuring tape to measure your waist circumference and then measure your hip circumference at its widest part. Next, divide the waist circumference by the hip circumference to arrive at the waist-to-hip ratio. Observational studies have demonstrated that people with "apple-shaped" bodies, (who carry more weight around the waist/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 above 0.90 for males and above 0.85 for females.[2]

Key Takeaways

- Most people who are overweight also have excessive body fat and therefore body weight is an indicator of obesity in much of the population.
- Body weight can be evaluated using BMI, body composition and/or fat distribution.
- Body weight in relation to height is called BMI and is correlated with disease risk.
- Total body fat mass is another predictor of disease risk and can be measured using a variety of methods including skin-fold tests, underwater weighing, bioelectric impedance analysis, and dual-energy x-ray absorptiometry.
- Fat distribution is measured via waist circumference and/or waist-to-hip ratio.

References

Chapter cover photo "Scale of Justice" by DTR is licensed under CC0.

1. American Medical Association. *AMA: Use of BMI alone is an imperfect clinical measure*. Accessed May 19, 2025.
2. World Health Organization. *Waist circumference and waist–hip ratio: report of a WHO expert consultation*. Geneva, Switzerland: WHO Press; 2011. Accessed May 19, 2025.

This page titled 11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

11.2: 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 output.

Energy Balance

Recall that the macronutrients you consume are either converted to energy, stored, or used to synthesize macromolecules. A nutrient's metabolic path is dependent upon energy balance. When you are in a positive energy balance the excess nutrient energy will be stored or used to grow (e.g., during childhood, pregnancy, and wound healing). When you are in negative energy balance you aren't taking in enough energy to meet your needs, so your body will need to use its stores to provide energy. Energy balance is achieved when intake of energy is equal to energy expended.

Weight can be thought of as a whole body estimate of energy balance. Body weight is maintained when the body is in energy balance. Weight is lost when the body is in negative energy balance. Weight is gained when the body is in positive energy balance. In general, weight is a good predictor of energy balance, but many other factors play a role in energy intake and energy expenditure. Some of these factors are under your control and others are not. Let us begin with the basics of energy intake and energy output. Then we will consider the other factors that play a role in maintaining energy balance and hence, body weight.

Energy Intake

The amount of energy taken in 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 11.2.1).

Basal metabolism refers to those metabolic pathways necessary to support and maintain the body's basic functions (e.g., breathing, heartbeat, liver and kidney function) while at rest. The basal metabolic rate (BMR) is the amount of energy required by the body to conduct its basic functions over a certain time period. The great majority of energy expended (between 60 and 75%) daily is from conducting life's basic processes. BMR is dependent on body size, body composition, sex, age, nutritional status, and genetics (Table 11.2.1). 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 BMRs are generally lower than men's. As we get older, muscle mass declines and thus so does BMR. Nutritional status also affects basal metabolism. Caloric restriction, as occurs while dieting, for example, causes a decline in BMR. This is because the body attempts to maintain homeostasis and will adapt by slowing down its basic functions to offset the decrease in energy intake. Body temperature and thyroid hormone levels are additional determinants of BMR. 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 the 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. The main control a person has over total energy expenditure is to increase physical activity.

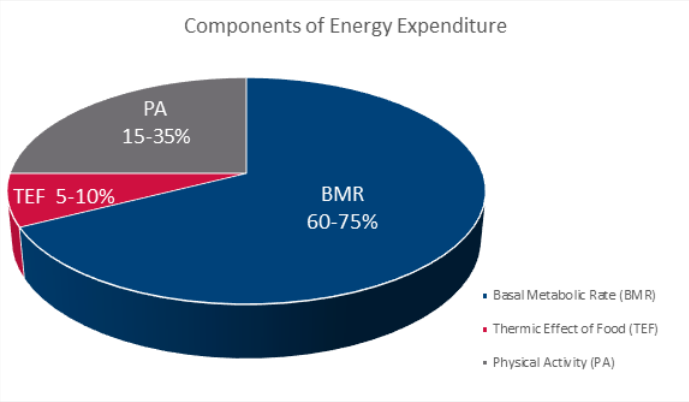


Figure 11.2.1: Energy expenditure is the sum of energy expended at rest (BMR), during digestion (TEF), and during physical activity (PA). ("Components of Energy Expenditure" by Ann Diker is licensed under CC BY 4.0)

Table 11.2.1: 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. It receives hormonal and neural signals, which determine if you feel hungry or full. Hunger is an unpleasant sensation of feeling empty that is communicated to the brain by both mechanical and chemical signals from other parts of the body. Conversely, satiety is the sensation of feeling full and it also is 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.” 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 (peptide YY) and others when it is empty (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 satiety center in 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.



"Hormone Control of Hunger" (CC BY-NC-SA 4.0 by Khan Academy)

Genetic Influences

Genetics certainly play a role in body fatness and weight and also affects food intake. Children who have been adopted typically are similar in weight and body fatness to their biological parents. Moreover, identical twins are twice as likely to be of similar weights as compared to fraternal twins. The scientific search for obesity genes is ongoing and a few have been identified, such as the gene that encodes for leptin. However, overweight and obesity that manifests in millions of people is not likely to be attributed to one or even a few genes, but rather to the interactions of hundreds of genes with the environment.

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 associated with food intake.

Certain behaviors can be predictive of how much a person eats. Some of these are 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 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" works 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 not long 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, increased intake of high fat foods & 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.[1]

- **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.

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 in daily life. 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 of many Americans. Even remote controls contribute to being less active.

Socioeconomic status has been found to be related to weight gain; people of lower economic status have higher rates of obesity and related chronic diseases than people with higher incomes.[2] 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 that at a nearby gas station.

Key Takeaways

- Energy balance is achieved when energy intake is equal to energy expended.
- The amount of energy you expend every day includes not only the calories you burn during physical activity, but also the calories you burn at rest (basal metabolism), and the calories you burn when you digest food.
- Basal metabolic rate (BMR) is dependent on body size, body composition, sex, age, nutritional status, genetics, body temperature, and thyroid hormone levels. The great majority of energy expended (between 60 and 75%) daily comes from conducting life’s basic processes.
- The main control a person has over total energy expenditure is to increase physical activity.
- Energy intake and energy expenditure are regulated by complex physiological responses and are influenced by genetics, behavior, and society.

References

1. Liu BN, Liu XT, Liang ZH, Wang JH. Gut microbiota in obesity. World J Gastroenterol. 2021 Jul 7;27(25):3837-3850. doi: 10.3748/wjg.v27.i25.3837.
2. Pan L, Sherry B, Njai R, Blanck HM. Food insecurity is associated with obesity among US adults in 12 states. *J Acad Nutr Diet*. 2012;112(9):1403-1409. doi:10.1016/j.jand.2012.06.011

This page titled 11.2: Balancing Energy Intake with Energy Output is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

11.3: 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 are important, yet distinct, parts of 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.

Components of 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
- speed

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, and swimming help increase cardiorespiratory endurance. Both the *Physical Activity Guidelines for Americans* and the World Health Organization recommend at least 150 minutes (2 hours and 30 minutes) to 300 minutes (5 hours) a week of moderate-intensity, or 75 minutes (1 hour and 15 minutes) to 150 minutes (2 hours and 30 minutes) a week of vigorous-intensity aerobic physical activity.[1,2] 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.

Musculoskeletal fitness includes both muscle strength and muscle endurance. Musculoskeletal fitness training can involve the use of resistance machines, resistance bands, free weights, or other tools that can be found at a gym or can be homemade. You can also use your own body weight and do push-ups, leg squats, abdominal crunches, and other exercises to build your 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]

Flexibility is the range of motion available to your joints. Yoga, tai chi, pilates, and stretching exercises work to improve this element of fitness. Stretching not only improves your range of motion, it also promotes better posture, and helps you perform activities that can require greater flexibility, such as chores around the house.

Balance is the ability to maintain equilibrium while moving or while stationary.[1] Walking backward, standing on one leg, 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.

Speed refers to the ability to move the body quickly. 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.

Some forms of exercise confer multiple benefits, which can help you to balance the different components of physical fitness. For example, riding a bicycle for thirty 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.

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:

- **Healthier weight.** 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, 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, absorption, and distraction, effectively draining tension from the body.
- **Reduced risk of depression, or limited symptoms of it.** Some people have called exercise "nature's antidepressant," and studies have shown that physical activity reduces the risk of and helps people cope with the symptoms of depression.
- **Cognitive skills retention.** Regular physical activity can help people maintain thinking, learning, and judgment as they age.
- **Better sleep.** A good night's sleep is essential for clear thinking, and regular exercise promotes healthy, sound sleep. It can also help you fall asleep faster and deepen your rest.

Physical activity is recommended for everyone because a physically active lifestyle yields so many health benefits. Even small changes such as taking the stairs instead of the elevator, or parking farther away from a store to add a bit more walking into your day can lead to a more active lifestyle and set you on the road to optimal health. 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 it.

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.

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
- 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.

Key Takeaways

- Physical fitness is an important part of the pursuit of optimal health.
- The components of physical fitness are cardiorespiratory fitness, musculoskeletal fitness, flexibility, balance, and speed.
- Physical activity yields multiple benefits in terms of preventing disease and promoting health.

References

1. U.S. Department of Health and Human Services. *Physical Activity Guidelines for Americans*, 2nd edition. Washington, DC: U.S. Department of Health and Human Services; 2018. Accessed May 19, 2025.
2. Bull FC, Al-Ansari SS, Biddle S, *et al.* World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine* 2020;54:1451-1462.

This page titled 11.3: Physical Fitness and Physical Activity is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

11.4: Fuel and Nutrient Needs for Physical Activity

Learning Objectives

- Describe the various processes used to break down macronutrients into fuels that support physical activity.
- Describe how nutrient needs for energy, macronutrients and micronutrients may change in response to an increase in physical activity.

You learned in earlier chapters that the macronutrients (carbohydrate, fat and protein) are the only nutrients that give us energy in the form of the calorie. The vast majority of the energy for exercise is derived from carbohydrate and fat. If you remember the protein chapter, you will recall that protein is used for many other important roles in the body. In fact it is considered a waste of good protein/amino acids to use it for energy, especially when carbohydrate and fat do this so well!

Next up we discuss how your body actually uses these energy-yielding nutrients. It is important to note, as you move forward, that the direct source of energy for cellular work, including muscle contraction, is a compound called adenosine triphosphate (ATP). Unfortunately very little ATP is stored by the body, so you must continually replenish ATP stores. To do this, we harness the energy from the macronutrients, again mostly carbs and fats, and an additional source known as Creatine Phosphate (CP).

What Fuels Our Activities?

Adenosine triphosphate (ATP; Figure 11.4.1) – the energy carrying molecule in the body - provides the direct source of energy for our activities. ATP includes adenosine and 3 phosphate groups. When a phosphate is broken away/off, energy is released. The body regenerates ATP by adding a phosphate back. ATP must be generated continuously since muscles store only enough ATP for 1 – 3 seconds of activity.

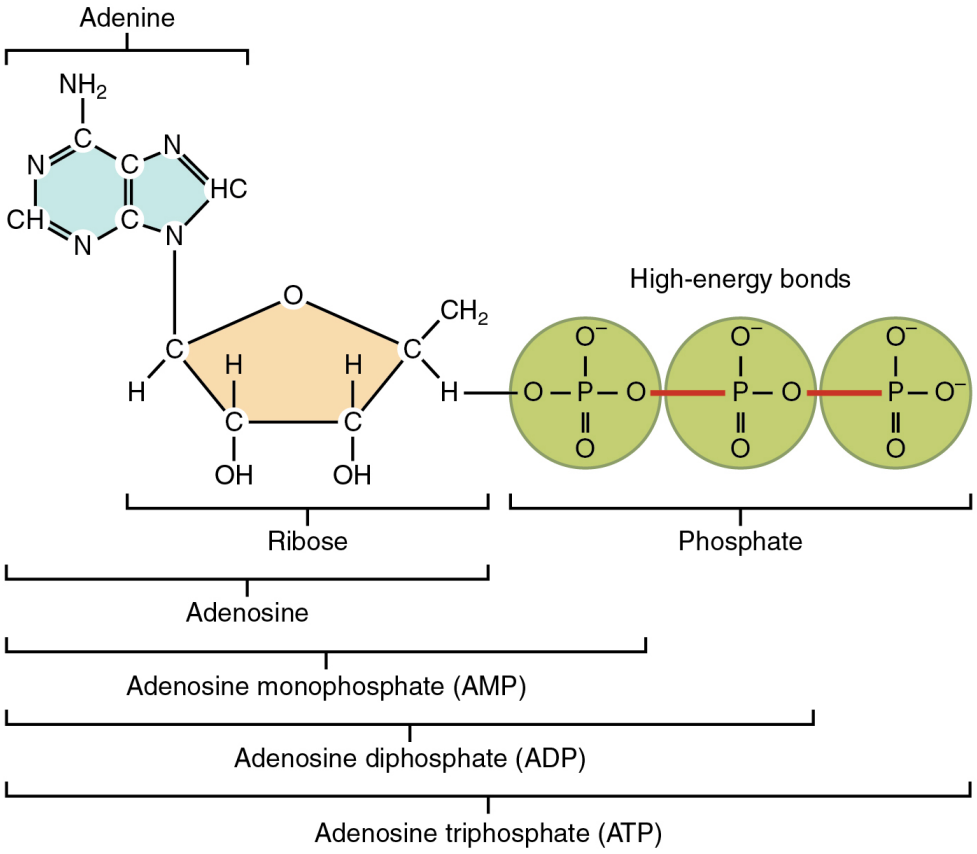


Figure 11.4.1: Structure of adenosine triphosphate (ATP). (CC BY 3.0; OpenStax College via Wikimedia Commons)

After depleting ATP stores, muscles turn to other sources. Initially, creatine phosphate (CP) is used. CP stores some energy that can be used to make ATP. Creatine phosphate stores enough energy for 3 to 15 seconds of maximal physical effort. When CP is broken

down into a molecule of creatine and an independent phosphate molecule, energy is released. This energy, along with the independent phosphate molecule, can then be used to regenerate ATP.

After creatine phosphate, carbohydrates are the next source of energy for the production of ATP as shown in Figure 11.4.2. Glucose is the primary carbohydrate used to generate ATP in a process called glycolysis (breakdown of glucose). For each molecule of glucose, glycolysis yields 2 ATP molecules and 2 molecules of pyruvate. Pyruvate, which is the primary end product of glycolysis, is further metabolized in one of two ways:

- Anaerobic (without oxygen) breakdown of pyruvate yields lactic acid
- Aerobic (with oxygen) breakdown of pyruvate yields 36 – 38 molecules of ATP. Aerobic metabolism supports physical activity that lasts more than 3 minutes.

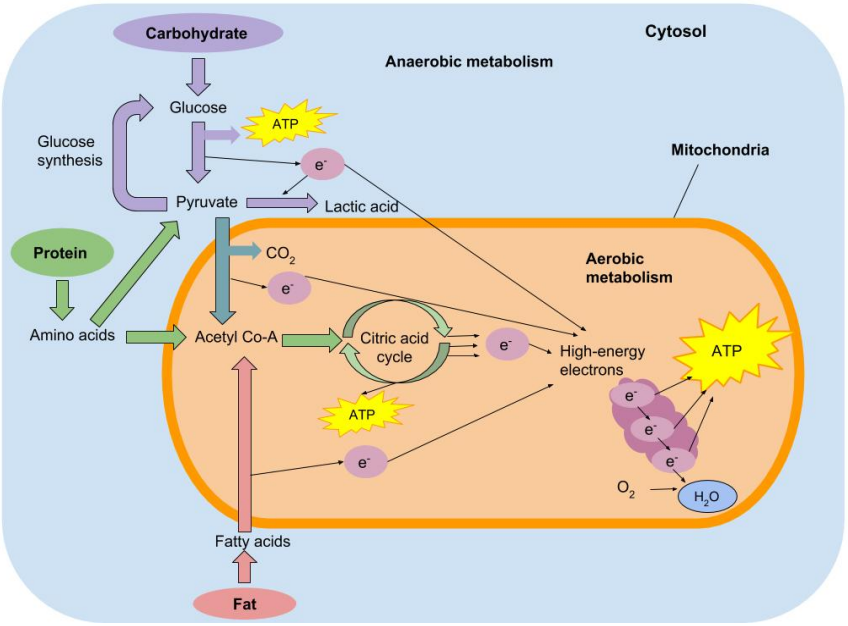


Figure 11.4.2: Anaerobic and aerobic metabolism. (CC BY 4.0; Allison Calabrese via Human Nutrition 2020 Ed [Hawaii])

Triglycerides (fatty acids) can also be metabolized to generate ATP. Triglyceride metabolism for energy is a relatively slow process, but is used for low intensity exercise and exercise of long duration. The amount of energy provided depends on the chain length of the fatty acid.

For most daily activities, including exercise, we use a mixture of carbohydrate and fat for energy (see Figure 11.4.3). At rest and lower exercise intensities, we rely more on fat as a fuel source. As exercise intensity increases, we rely more on carbohydrate for energy. Proteins (amino acids) are used minimally as a fuel source for exercise (about 3-6%, if needed).

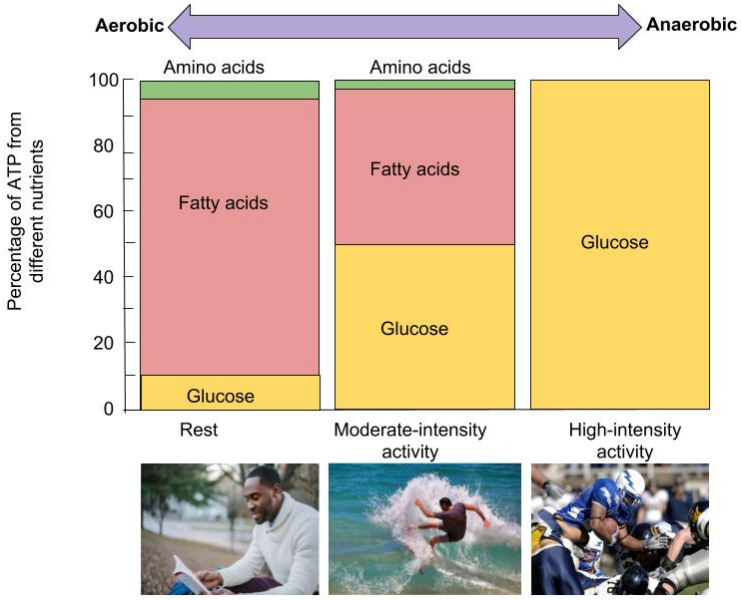
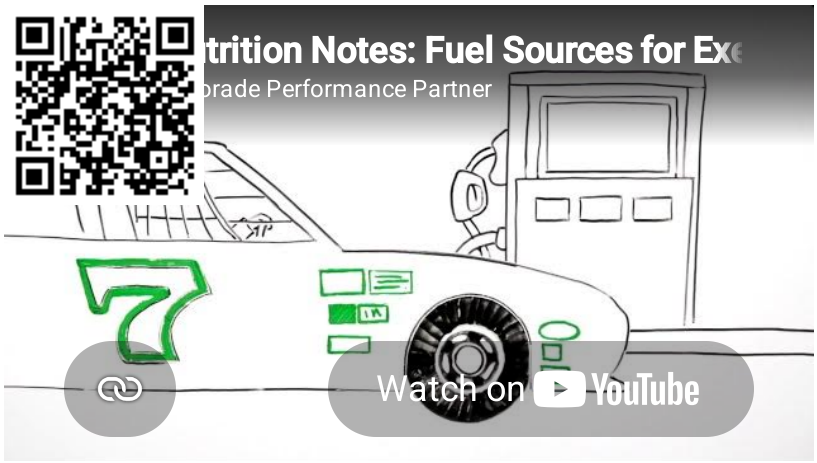


Figure 11.4.3: Fuel Sources Used During Various Exercise Intensities. (CC BY 4.0; Allison Calabrese via Human Nutrition 2020 Ed [Hawaii])

For a review of fuel use during exercise, watch this short video:



"Nutrition Notes: Fuel Sources for Exercise" by Gatorade Sports Science Institute

How Does Physical Activity Affect Nutrient Needs?

Energy needs may be higher for athletes, it depends on body size as well as the type, intensity, and duration of physical activity. The recommended diet includes:

- At least 45% of calories from carbohydrates. To optimize muscle glycogen stores, carbohydrate intake of 6-10 g/kg body weight is often recommended. However, more carbohydrates may be needed to support vigorous exercise. When choosing carbohydrate-rich foods athletes should focus on fiber-rich, less-processed whole grains, fruits, and vegetables. In addition to adequate quantity, timing of carbohydrate intake is key. Athletes should strive to consume carbohydrate-dense foods in the first few hours after finishing exercise to effectively replenish glycogen stores. Carbohydrate/glycogen loading for endurance activities is sometimes pursued and involves altering exercise duration and carb intake so muscle glycogen storage is maximized. 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.
- 10-35% kcal from protein. Protein intakes range from 1.2-2.0 g/kg body weight. The majority of athletes, not to mention Americans, consume enough protein (so protein supplements are usually not necessary).

Regular exercise increases our need for fluids. During exercise, heat is dissipated through sweating. Heat illnesses occur because our muscles and skin compete for blood flow, so maintaining water balance is critical for physically active people. Hydration recommendations include:

- Drink fluids before, during, and after exercise.
- Consume enough water 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 water intake – dehydration is a serious threat.
- Do not rely on thirst as an indicator of hydration status. Clear, light-colored, and odorless urine indicates proper hydration.
- Water is appropriate for most activities less than one hour in duration.
- Sports beverages supply fluid, sodium, and carbohydrates and are indicated when activities last beyond one hour.

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 should 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

Key Takeaways

- Adenosine triphosphate (ATP) provides the direct source of energy for our activities.
- After depleting ATP stores, muscles turn to other sources of energy including creatine phosphate (CP), glucose (carbohydrates), triglycerides, and protein (if needed).
- For most daily activities, including exercise, we use a mixture of carbohydrate and fat for energy. At rest and lower exercise intensities, we rely more on fat as a fuel source. As exercise intensity increases, we rely more on carbohydrate for energy.
- The recommended diet for athletes includes at least 45% of calories from carbohydrates, 20-35% of calories from fat, and 10-35% of calories from protein.
- Maintaining water balance is critical for physically active people.

This page titled 11.4: Fuel and Nutrient Needs for Physical Activity is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

11.5: 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 73% of adults are either overweight or obese.[1] Overweight and obesity raise the risk for certain health problems including[2,3]:

- 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
- Certain cancers (including endometrial cancer, liver cancer, kidney cancer, postmenopausal breast cancer, and colon cancer)
- Osteoarthritis
- Alzheimer's disease

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[4]:

- **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 an unhealthy degree. 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. 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 a 2-hour period), eating fast during binge episodes, and eating alone or in secret to avoid embarrassment.

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 healthy body weight, teach normal eating patterns, and address body image issues.

Key Takeaways

- Overweight and obesity increase the risk for certain health problems including heart disease, Type 2 diabetes, high blood pressure, sleep apnea, certain cancers, and osteoarthritis.
- 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.
- Common eating disorders include anorexia nervosa, bulimia nervosa, and binge-eating disorder. 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 healthy body weight, teach normal eating patterns, and address body image issues.

References

1. Obesity and Overweight. cdc.gov. Accessed May 19, 2025.
2. Health Risks of Overweight & Obesity. niddk.nih.gov. Accessed May 19, 2025.
3. Obesity and Cancer. cancer.gov. Accessed May 19, 2025.
4. Eating Disorders. nimh.nih.gov. Accessed May 19, 2025.

This page titled 11.5: Health Risks of Overweight and Underweight is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

- **11.4: Fuel and Nutrient Needs for Physical Activity** by Ann Diker is licensed CC BY-NC-SA 3.0.

11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain

Learning Objectives

- Identify strategies for safe and effective weight loss and weight gain.

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. 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 lead to reduced energy intake.
- **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 only by changing the diet *and* by increasing physical activity. Doing one without the other limits the amount of weight lost and the length of time that weight loss is sustained.

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, and dried fruit.
- **Eat 500-1,000 calories/day more than needed for weight maintenance.**
- **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 foods 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.

Key Takeaways

- Strategies for safe weight loss include setting realistic goals, making reasonable reductions to energy intake, participating in physical activity, and using behavior modification techniques.
- Strategies for effective weight gain include choosing energy-dense food options, eating more frequently, avoiding tobacco products, and participating in physical activity.

References

1. NWCR Facts. nwcr.ws. Accessed May 19, 2025.

This page titled 11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

- **11.5: Health Risks of Overweight and Underweight** by Ann Diker is licensed CC BY-NC-SA 3.0.

CHAPTER OVERVIEW

12: Lifecycle Nutrition: Pregnancy to the Toddler Years

12.1: Pregnancy and Nutrition

12.2: Infancy and Nutrition

12.3: Nutrition in the Toddler Years

Template:HideTOC

This page titled 12: Lifecycle Nutrition: Pregnancy to the Toddler Years is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

12.1: Pregnancy and Nutrition

Learning Objectives

- Identify weight gain recommendations for pregnancy.
- Discuss nutritional requirements and concerns during pregnancy.
- Explore the relationship between fetal development and nutritional choices.
- Describe various discomforts and complications of pregnancy.

It is crucial to consume healthy foods at every phase of life, beginning in the womb. Good nutrition is vital for any pregnancy and not only helps an expectant 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 during pregnancy.

The Early Days 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. Embryos are extremely vulnerable to teratogens during this time; exposure to teratogens can cause birth defects and/or spontaneous abortion (miscarriage). At week 8 the embryo transitions to being called a fetus. Another 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). Major changes begin to occur in the earliest days, often weeks before a person even knows that they are pregnant. During this period, adequate nutrition supports cell division, tissue differentiation, and organ development. As each week passes, new milestones are reached. Therefore, people who are trying to conceive should make proper dietary choices to ensure the delivery of a healthy baby. All parents-to-be should consider their eating habits; a sedentary lifestyle and a diet low in fresh fruits and vegetables may affect fertility.

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 megaloblastic anemia (the development of abnormal 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 brain, 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. As discussed in Chapter 10, inadequate folate can result in birth defects, such as spina bifida, which is the failure of the spinal column to close. Leafy green vegetables (such as spinach and kale) and legumes (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.

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 12.1.1 for the Institute of Medicine (IOM) recommendations.

Table 12.1.1: Body Mass Index and Pregnancy[1]

Prepregnancy BMI	Weight Category	Recommended Weight Gain
Below 18.5	Underweight	28–40 pounds

Prepregnancy BMI	Weight Category	Recommended Weight Gain
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 12.1.1. Those who are pregnant with more than one fetus are advised to gain even more weight to ensure the health of their unborn babies.

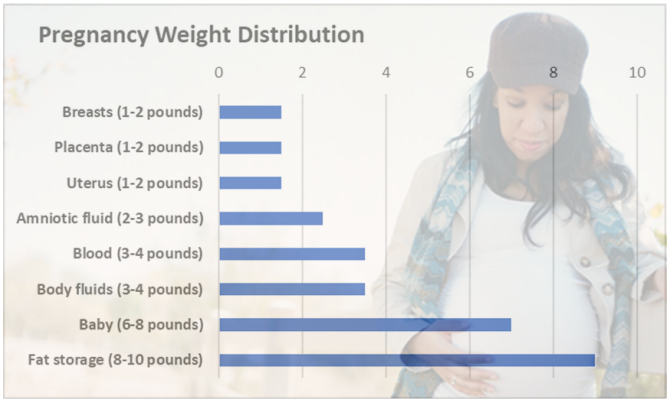


Figure 12.1.1: Pregnancy Weight Distribution (background image: CC BY-NC-ND 2.0; Andreanna Arambula via flickr)

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.

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 North America 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.

Fiber

Ideally, a pregnant person should eat 28 grams of dietary fiber per day. Recall from Chapter 4 that there are two types of fiber. Insoluble fiber acts as a natural laxative, which softens stools and speeds the elimination of waste material through the colon to avoid constipation. Sources of insoluble fiber include whole grains, fruits, vegetables, dried peas, and beans. Soluble fiber has little effect on the intestines, however it helps to lower blood-cholesterol levels and regulate blood glucose. Sources of soluble fiber include fruits, vegetables, and beans, along with oats, barley, and other fiber-filled whole grains.

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 12.1.2 compares the normal levels of required 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 12.1.2: Recommended Nutrient Intakes during Pregnancy[4]

Nutrient	Non-pregnancy Recommendation	Recommendation during Pregnancy
Vitamin A (mcg)	700	770
Vitamin B_6 (mg)	1.3	1.9

Nutrient	Non-pregnancy Recommendation	Recommendation during Pregnancy
Vitamin B_{12} (mcg)	2.4	2.6
Vitamin C (mg)	75	85
Vitamin D (mcg)	15	15
Vitamin E (mg)	15	15
Calcium (mg)	1,000	1,000
Folate (mcg dietary folate equivalents; mcg DFE)	400	600
Iron (mg)	18	27
Magnesium (mg)	320	360
Niacin (B_3) (mg)	14	18
Phosphorus (mg)	700	700
Riboflavin (B_2) (mg)	1.1	1.4
Thiamin (B_1) (mg)	1.1	1.4
Zinc (mg)	8	11

The micronutrients involved with building the skeleton—vitamin D, calcium, phosphorus, and magnesium—are crucial during pregnancy to support fetal bone development. Although the levels are the same (or very similar) during both non-pregnancy and pregnancy, many individuals do not typically consume adequate amounts and should make an extra effort to meet those needs during pregnancy.

There is an increased need for several vitamins and minerals during pregnancy. Adequate vitamin B_6 supports the metabolism of amino acids, while more vitamin B_{12} is needed for the synthesis of red blood cells and DNA. Additional zinc is crucial for cell development and protein synthesis. Extra iron intake is important because of the increase in blood supply during pregnancy and to support the fetus and placenta. In addition, during the 3rd trimester, the fetus stores iron for use during the first few months after birth. Iron is the one micronutrient that is almost impossible to obtain in adequate amounts from food sources only. Therefore, even if a pregnant person consumes a healthy diet, there is still typically a need to take an iron supplement. Also, remember that folate needs increase during pregnancy to 600 micrograms DFE per day to prevent neural tube defects, assist with cell division, and to help produce the extra blood a pregnant body requires.

Those who are pregnant should avoid exceeding any 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

A number of 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 results in a range of abnormalities that fall under the umbrella of fetal alcohol spectrum disorders. They include learning and attention deficits, heart defects, and abnormal facial features. 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 tea, sodas, chocolate, and energy drinks. Current recommendations suggest limiting caffeine to less than 200 milligrams a day (which is the amount in 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 Chapter 14.

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 12.1.2 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.

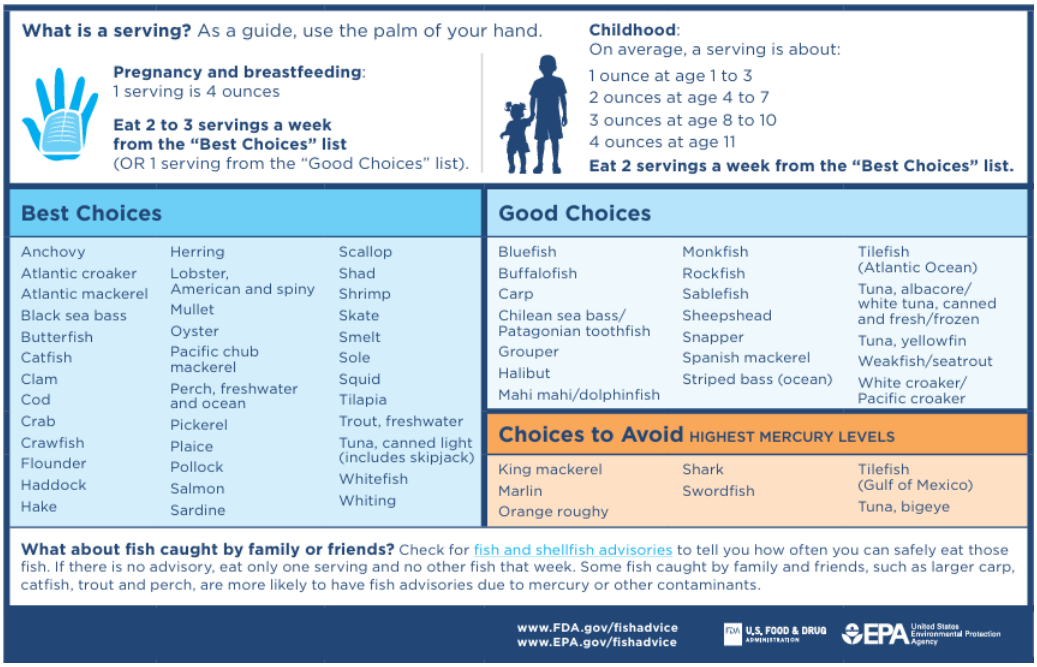


Figure 12.1.2: Best choices, good choices, and choices of fish to avoid during pregnancy.

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 WHO 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

About 4% of pregnant people suffer from a condition known as gestational diabetes, which is abnormal glucose tolerance during pregnancy. The body becomes resistant to the hormone insulin, which enables cells to transport glucose from the blood. Gestational diabetes is usually 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.

Key Takeaways

- Pre-pregnancy BMI determines how much weight a person needs to gain throughout their pregnancy.
- During pregnancy, it is imperative to meet the nutritional needs of both the pregnant person and the unborn child. This includes an increase in certain micronutrients, such as iron and folate.
- Common discomforts that can impact nutritional intake during pregnancy include nausea and vomiting, heartburn, and constipation.
- Gestational hypertension is a condition that results in a rise of blood pressure levels and can lead to preeclampsia during a pregnancy.
- Gestational diabetes is a condition that results in a rise of blood glucose levels and can lead to Type 2 diabetes later in life.

References

Chapter cover photo "Maternity shot with toddler" by Philippe Put is licensed under CC BY 2.0.

1. Institute of Medicine. Weight gain during pregnancy: reexamining the guidelines . Washington, DC: National Academies Press; 2009.
2. Han, Z., Mulla, S., Beyene, J., Liao, G., McDonald, S.D., Knowledge Synthesis Group. Maternal underweight and the risk of preterm birth and low birth weight: a systematic review and meta-analysis. *International Journal of Epidemiology;* 2011;40(1): 65-101.
3. Obesity and Pregnancy. acog.org. Accessed May 19, 2025.
4. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 19, 2025.
5. Foods to avoid or limit during pregnancy. marchofdimes.org. Accessed May 19, 2025.
6. People at Increased Risk for *Listeria* Infection. cdc.gov. Accessed May 19, 2025.

7. U.S. Department of Health and Human Services. *Physical Activity Guidelines for Americans*, 2nd edition. Washington, DC: U.S. Department of Health and Human Services; 2018. Accessed May 19, 2025.
8. World Health Organization. *WHO recommendations for prevention and treatment of pre-eclampsia and eclampsia*. Geneva, Switzerland: WHO Press; 2011. Accessed May 19, 2025.

This page titled 12.1: Pregnancy and Nutrition is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

12.2: Infancy and Nutrition

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for infants.
- Describe the physiologic basis for lactation and the specific components of human milk.
- Discuss the benefits and barriers related to breastfeeding.
- Examine feeding problems that parents and caregivers may face with infants.

Diet and nutrition have a major impact on a child's development from infancy into the adolescent years. A healthy diet not only affects growth, but also immunity, intellectual capabilities, and emotional well-being. 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, height increases by 50%, while weight triples. Physicians and other health professionals can use growth charts to track an infant's development process. Because infants cannot stand, length is used instead of height to determine the rate of a child's growth. Other important developmental measurements include head circumference and weight. All of these must be tracked and compared against standard measurements for an infant's age. Nationally-accepted growth charts are based on data collected by the National Center for Health Statistics. These charts allow for tracking trends over time and comparing with other infants among percentiles within the United States. Growth charts may provide warnings that a child has a medical problem or is malnourished. Insufficient weight or height gain during infancy may indicate a condition known as failure-to-thrive (FTT), which is characterized by poor growth. FTT can happen at any age, but in infancy, it typically occurs after six months. Some causes include poverty, lack of enough food, feeding inappropriate foods, and excessive intake of fruit juice.

Nutritional Requirements

Requirements for macronutrients and micronutrients on a per-kilogram basis are higher during infancy than at any other stage in the human life cycle. These needs are affected by the rapid cell division that occurs during growth, which requires energy and protein, along with the nutrients that are involved in DNA synthesis. During this period, children are entirely dependent on parents and caregivers to meet these needs. For almost all infants six months or younger, human milk is the best source to fulfill nutritional requirements. An infant may require feedings eight to twelve times a day or more in the beginning. Typically, after about six months, infants can gradually begin to consume solid foods to help meet nutrient needs.

Energy

Energy needs relative to size are much greater in an infant than an adult; 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 two weeks and six weeks of age, and again at about three months and six 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 to 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 four to six 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.

Fluids

Infants have a high need for fluids, 1.5 milliliters per kilocalorie consumed compared to 1.0 milliliters per kilocalorie consumed for adults. This is because children have larger body surface area per unit of body weight and a reduced capacity for perspiration. Therefore, they are at greater risk of dehydration. However, parents or other caregivers can meet an infant's fluid needs with human milk or formula. As solid foods are introduced, parents and caregivers must make sure that young children continue to drink fluids throughout the day.

Breastfeeding

The alveoli cells produce milk (Figure 12.2.1). To secrete it, they contract and push milk into the ducts and sinuses, which collects the milk. When a breastfeeding infant's gums press on the areola and nipple, the sinuses squeeze the milk into the baby's mouth.

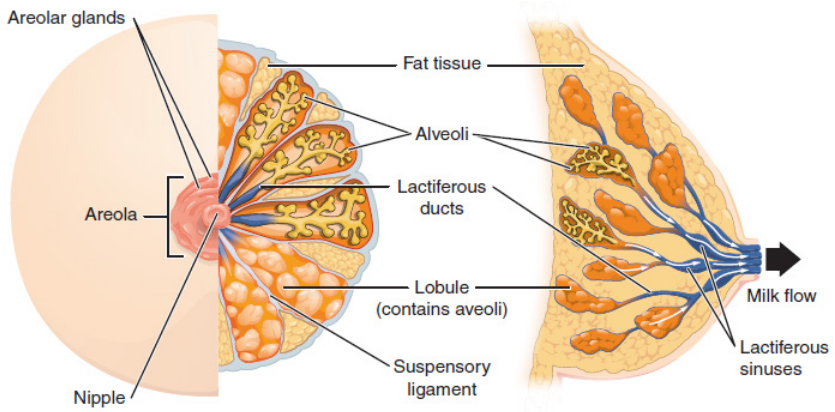


Figure 12.2.1: Anatomy of the breast. (CC BY 4.0; by OpenStax)

After the birth of the baby, nutritional needs must be met to ensure that an infant not only survives, but thrives from infancy into childhood. Breastfeeding provides the fuel a newborn needs for rapid growth and development. As a result, the World Health Organization (WHO) and the American Academy of Pediatrics (AAP) recommend that breastfeeding be done exclusively for the first six 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, which is known as the milk ejection reflex. However, levels of the hormone progesterone need to decrease for successful milk production, because progesterone inhibits milk secretion. Shortly after birth, the expulsion of the placenta triggers progesterone levels to fall, which activates lactation.

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 six 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 six 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 12.2.1 compares the recommended vitamins and minerals during lactation to the levels during non-pregnancy and pregnancy.

Table 12.2.1: 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 not only provides adequate nutrition for infants, 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 produced immediately after birth, prior to the start of milk production, and lasts for several days after the arrival of the baby. Colostrum is thicker than human milk, and is yellowish or creamy in color. This protein-rich liquid fulfills an infant's nutrient needs during those early days. Although low in volume, colostrum is packed with concentrated nutrition for newborns. 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 two to four days after birth, colostrum is replaced by transitional milk. Transitional milk is a creamy liquid that lasts for approximately two weeks and includes high levels of fat, lactose, and water-soluble vitamins. It also contains more calories than colostrum. 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 two 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

Breastfeeding has a number of benefits, several of which are listed in Table 12.2.2. 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. 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 12.2.2: 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 to 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 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 infected 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, which makes 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 make sure not to use contaminated water to mix formula in order to prevent foodborne illnesses. Follow the instructions for powdered and concentrated formula carefully—formula that is over-diluted would not provide adequate calories and protein, while over-concentrated formula provides too much protein and too little water which can impair kidney function.

Introducing Solid Foods

Infants should be breastfed or formula fed exclusively for the first six months of life. Infants should not consume solid foods prior to six months because solid foods do not contain the right nutrient mix that infants need. Also, eating solids 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 is not ready, their 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 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 bought commercially or prepared from regular food using a food processor, blender, food mill, or grinder at home. 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 palmer 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 one, children slowly begin to use utensils to handle their food. Unbreakable dishes and cups are essential, since very young children may play with them or throw them when they become bored with their food.

Feeding Problems during Infancy

Parents and caregivers should be mindful of certain diet-related problems that may arise during infancy. 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 one, 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 one 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 only introduce 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 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

Key Takeaways

- Growth charts are used to track an infant's growth and development over time.
- Dietary recommendations for infants are different from recommendations for adults. For example, about 40-50% of an infant's calorie intake should come from fat.
- The World Health Organization (WHO) and the American Academy of Pediatrics (AAP) recommend that breastfeeding be done exclusively for the first six months of an infant's life.
- Benefits of breastfeeding for an infant include a lower risk of diarrhea, respiratory diseases, gastrointestinal problems, and ear infections. Breastfeeding has several health benefits for the birthing parent as well, such as reducing the risk of breast cancer and ovarian cancer.
- Solid foods should be introduced after six months of age and introduced one at a time to help identify allergic responses or food intolerances.

References

1. National Academies of Sciences, Engineering, and Medicine. 2005. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*. Washington, DC: The National Academies Press.
2. Exclusive breastfeeding for six months best for babies everywhere. who.int. Accessed May 19, 2025.
3. Breastfeeding and the Use of Human Milk. Section on Breastfeeding. *Pediatrics.* 2012;129(3):e827-841. doi.org/10.1542/peds.20.11-3552.
4. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 19, 2025.
5. Breastfeeding Overview. americanpregnancy.org. Accessed May 19, 2025.
6. Alcohol. cdc.gov. Accessed May 19, 2025.
7. Notarbartolo V, Giuffrè M, Montante C, Corsello G, Carta M. Composition of Human Breast Milk Microbiota and Its Role in Children's Health. *Pediatr Gastroenterol Hepatol Nutr*. 2022 May;25(3):194-210. doi: 10.5223/pghn.2022.25.3.194.
8. Breastfeeding Fast Facts. cdc.gov. Accessed May 19, 2025.
9. The Baby-Friendly Hospital Initiative. babyfriendlyusa.org. Accessed May 19, 2025.
10. Infant and young child feeding. who.int. Accessed May 19, 2025.

This page titled 12.2: Infancy and Nutrition is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

12.3: Nutrition in the Toddler Years

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for toddlers.
- Examine feeding problems that parents and caregivers may face with toddlers.

By the age of two, children have advanced from infancy and are on their way to becoming school-aged children. Their physical growth and motor development slows compared to the progress they made as infants. However, toddlers experience enormous intellectual, emotional, and social changes. Of course, food and nutrition continue to play an important role in a toddler's development. During this stage, the diet shifts from breastfeeding or formula feeding to solid foods and healthy beverages. The toddler years pose interesting challenges for parents and caregivers, as children learn how to eat on their own and begin to develop personal preferences.

Nutritional Requirements

A toddler's serving sizes should be approximately one-quarter that of an adult's. One way to estimate serving sizes for young children is one tablespoon for each year of life. For example, a two-year-old child would be served 2 tablespoons of fruits or vegetables at a meal, while a four-year-old would be given 4 tablespoons, or 1/4 cup. Here is an example of a toddler-sized meal:

- 1 ounce of meat or chicken, or 2 to 3 tablespoons of beans
- One-quarter slice of whole-grain bread
- 1 to 2 tablespoons of cooked vegetable
- 1 to 2 tablespoons of fruit

Energy

The energy requirements for per kilogram of weight for toddlers is lower than it is for infants, but the total energy requirements are higher because toddlers are larger and more active than infants. The recommended caloric intake varies with each toddler's level of activity. Because toddlers have small stomachs they require small, frequent, nutritious snacks and meals to satisfy energy requirements.

Macronutrients

The Acceptable Macronutrient Distribution Ranges (AMDRs) for toddlers are listed in Table 12.3.1. Carbohydrate recommendations include eating complex carbohydrates for energy needs. While 100% juice can be a source of nutrients, the American Academy of Pediatrics recommends limiting consumption of fruit juice to 4 ounces (1/4 cup) per day or less.[2] The AMDR for fat for toddlers is 30-40% of total calories including essential fatty acids that are vital for the development of the toddler's nervous system.

Table 12.3.1: Acceptable Macronutrient Distribution Ranges (AMDRs) for Toddlers[1]

Macronutrient	AMDR
Carbohydrate	45-65% of total calories
Protein	5-20% of total calories
Fat	30-40% of total calories

Micronutrients

As a child grows bigger, the demands for micronutrients increase. These needs for vitamins and minerals can be met with a balanced diet, with a few exceptions. Nutrients of concern include:

- **Vitamin D.** Toddlers need 15 micrograms of vitamin D per day. Vitamin D-fortified milk and cereals can help to meet this need. However, toddlers who do not get enough of this micronutrient should receive a supplement. According to the American Academy of Pediatrics, toddlers who are consuming less than 32 ounces per day of vitamin D-fortified milk, should receive a vitamin D supplement of 10 micrograms a day.[3]
- **Calcium.** Calcium is needed for toddlers to build optimal bone mass. Toddlers need 700 mg of calcium per day. Dairy products and calcium-fortified beverages are good sources of calcium. At one year old, whole-fat cow's milk may be given; at two year's

old, milk can be reduced-fat.

- **Iron.** Iron-deficiency anemia is the most common nutrient deficiency in young children. Iron-deficiency anemia causes a number of problems including weakness, pale skin, shortness of breath, and irritability. It can also result in intellectual, behavioral, or motor problems. In infants and toddlers, iron-deficiency anemia can occur as young children are weaned from iron-rich foods, such as breast milk and iron-fortified formula. There are steps that parents and caregivers can take to prevent iron-deficiency anemia, such as adding more iron-rich foods to a child's diet, including lean meats, fish, poultry, eggs, legumes, and iron-enriched whole-grain breads and cereals.

Feeding Problems in the Toddler Years

During the toddler years, parents and caregivers may face a number of problems related to food and nutrition. Possible obstacles include difficulty helping a young child overcome a fear of new foods, or fights over messy habits at the dinner table. Even in the face of problems and confrontations, parents and caregivers must make sure their toddler has nutritious choices at every meal. Toddlers' stomachs are small; providing 3 meals and 2-3 snacks per day is recommended. The gold standard in feeding 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 parent/caregiver and child:

- Parents and caregivers are responsible for *what* toddlers eat, *when* they eat, and *where* they eat.
- Toddlers are responsible for *how much* food they eat and *whether* they eat.

Parents' and caregivers' responsibilities in feeding include:

- selecting and preparing food
- providing regular meals and snacks
- making eating times pleasant
- showing children, by example, how to behave at family mealtime
- being considerate of children's lack of food experience without catering to likes and dislikes
- not letting children have food or beverages (except for water) between meals and snack times
- letting children grow up to get bodies that are right for them[4]

High-Risk Choking Foods

Certain foods (that tend to be small and round) are difficult for toddlers 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

Picky Eaters

Parents and caregivers of toddlers are likely to notice a sharp drop in their child's appetite. This is normal since toddlers' growth rate is slower than it was when they were an infant. Children at this stage are often picky about what they want to eat and they are beginning to develop food preferences. Toddlers may reject new foods, but it's helpful to know that food preferences take time to develop. It can take as many as 10 or more times tasting a food before a toddler's taste buds accept it.

Food Jags

For weeks, toddlers may go on a food jag and eat one or two preferred foods—and nothing else. It is important to understand that preferences will be inconsistent as a toddler develops eating habits. This is one way that young children can assert their individuality and independence. However, parents and caregivers should be concerned if the same food jag persists for several months, instead of several weeks. Options for addressing this problem include rotating acceptable foods while continuing to offer

diverse foods, remaining low-key to avoid exacerbating the problem, and discussing the issue with a pediatrician. Also, children should not be forced to eat foods that they do not want. It is important to remember that food jags do not have a long-term effect on a toddler's health, and are usually temporary situations that will resolve themselves.

Key Takeaways

- Toddlers' physical growth and motor development slows compared to the progress they made as infants.
- Recommendations for fat intake are lower than recommendations for infants, but higher than recommendations for adults.
- Nutrients of concern for toddlers include vitamin D, calcium, and iron.
- The Division of Responsibility is considered the gold standard for feeding children. Parents and caregivers are responsible for *what* toddlers eat, *when* they eat, and *where* they eat; toddlers are responsible for *how much* food they eat and *whether* they eat.
- Some food- and nutrition-related problems that can occur during the toddler years include choking, picky eating, and food jags.

References

1. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 19, 2025.
2. Where We Stand: Fruit Juice for Children. healthychildren.org. Accessed May 19, 2025.
3. Vitamin D for Babies, Children and Adolescents. healthychildren.org. Accessed May 19, 2025.
4. Raise a healthy child who is a joy to feed. ellynsatterinstitute.org. Accessed May 19, 2025.

This page titled 12.3: Nutrition in the Toddler Years is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

CHAPTER OVERVIEW

13: Lifecycle Nutrition: Childhood to Late Adulthood

13.1: Childhood and Nutrition
13.2: Early Adolescence and Nutrition
13.3: Older Adolescence and Nutrition
13.4: Young Adulthood and Nutrition
13.5: Middle Age and Nutrition
13.6: Older Adults and Nutrition

Template:HideTOC

This page titled 13: Lifecycle Nutrition: Childhood to Late Adulthood is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

13.1: Childhood and Nutrition

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for school-aged children.
- Discuss the most important nutrition-related concerns during childhood.

Nutritional needs change as children leave the toddler years. From ages four to eight, school-aged children grow consistently, but at a slower rate than infants and toddlers. They also experience the loss of deciduous, or “baby,” teeth and the arrival of permanent teeth, which typically begins at age six or seven. As new teeth come in, the positioning of the teeth can affect their ability to chew food. Other changes that affect nutrition include the influence of peers on dietary choices and the kinds of foods offered by schools and afterschool programs, which can make up a sizable part of a child’s diet. Food-related problems for young children can include tooth decay, food sensitivities, and malnourishment. Also, excessive weight gain early in life can lead to obesity into adolescence and adulthood. At this life stage, a healthy diet facilitates physical and mental development and helps to maintain health and wellness.

Energy

Children’s energy needs vary, depending on their sex, growth, and level of physical activity. Recommended intakes of macronutrients and most micronutrients are higher relative to body size, compared with nutrient needs during adulthood. Therefore, children should be provided nutrient-dense food at meal- and snack-time. However, it is important not to overfeed children, as this can lead to childhood obesity, which is discussed later in this chapter.

Macronutrients

The Acceptable Macronutrient Distribution Ranges (AMDRs) for children from 4-8 years old are listed in Table 13.1.1. For carbohydrates, the Acceptable Macronutrient Distribution Range (AMDR) is 45–65% of daily calories which is the same AMDR as adults. Carbohydrates high in fiber are important as children should get 25 grams of fiber per day.[1] The AMDR for protein is 10–30% of daily calories. Children have a high need for protein to support muscle growth and development, so it's recommended that children get 0.95 grams protein/kg body weight/day. High levels of essential fatty acids are needed to support growth (although not as high as in infancy and the toddler years). As a result, the AMDR for fat drops to 25–35% of daily calories.

Table 13.1.1: Acceptable Macronutrient Distribution Ranges (AMDRs) for Children Ages 4-8[1]

Macronutrient	AMDR
Carbohydrate	45-65% of total calories
Protein	10-30% of total calories
Fat	25-35% of total calories

Micronutrients

Micronutrient needs should be met with foods first. Parents and caregivers should select a variety of foods from each food group to ensure that nutritional requirements are met. Deficiencies in iron, zinc, protein, and vitamin A can result in stunted growth, illness, and limited development. The most common nutrient deficiency in young children is iron. Because children grow rapidly, they require foods that are high in iron, such as lean meats, legumes, fish, poultry, and iron-enriched cereals. Other important micronutrient requirements during childhood include adequate calcium and vitamin D intake. Both are needed to build dense bones and a strong skeleton. Calcium is necessary to achieve peak bone mass. Dairy products are the most common source of calcium for children. However, "milk displacement" (replacing milk with soda or other sugary drinks) typically leads to low calcium intake. According to the American Academy of Pediatrics, children who are consuming less than 32 ounces per day of vitamin D-fortified milk, should receive a vitamin D supplement of 10 micrograms a day.[2] Table 13.1.2 shows the micronutrient recommendations for children ages 4-8. Note that the recommendations are the same for boys and girls. As we progress through the different stages of the life cycle, there will be some differences between males and females regarding micronutrient needs.

Table 13.1.2: Micronutrient Levels during Childhood[1]

Nutrient	Children, Ages 4–8

Nutrient	Children, Ages 4–8
Vitamin A (mcg)	400
Vitamin B_6 (mg)	0.6
Vitamin B_{12} (mcg)	1.2
Vitamin C (mg)	25
Vitamin D (mcg)	15
Vitamin E (mg)	7
Vitamin K (mcg)	55
Calcium (mg)	1,000
Folate (mcg)	200
Iron (mg)	10
Magnesium (mg)	130
Niacin (B_3) (mg)	8
Phosphorus (mg)	500
Riboflavin (B_2) (mg)	0.6
Selenium (mcg)	30
Thiamin (B_1) (mg)	0.6
Zinc (mg)	5

Factors Influencing Intake

A number of factors can influence children's eating habits and attitudes toward food. Family environment, societal trends, taste preferences, and messages in the media all impact the emotions that children develop in relation to their diet. Therefore, it is critical that parents and caregivers direct children toward healthy choices. One way to encourage children to eat healthy foods is to make meal- and snack-time fun and interesting. Parents should include children in food planning and preparation, for example selecting items while grocery shopping or helping to prepare part of a meal, such as making a salad. At this time, parents can also educate children about kitchen safety.

The National School Lunch Program

Beginning with preschool, children consume at least one of their meals in a school setting. Many children receive both breakfast and lunch outside of the home. Therefore, it is important for schools to provide meals that are nutritionally sound. In the United States, more than 30 million children are provided meals by the National School Lunch Program. Participating schools receive cash subsidies and USDA foods for each reimbursable meal they serve. In exchange, the schools must serve lunches that meet federal meal pattern requirements and offer the lunches at a free or reduced price to eligible children.[3]

Food Allergies and Food Intolerances

The development of food allergies is a concern during the toddler years. This remains an issue for school-aged children. Approximately 8% of children have a food allergy; the most common food allergies in children are to peanuts, milk, and shellfish.[4] 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.[5] 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. Milk, eggs, wheat, soy, fish, shellfish, peanuts, and tree nuts are the most

likely to trigger this type of response. A dose of the drug epinephrine is often administered via a “pen” to treat a person who goes into anaphylactic shock.

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, though rare in very young children, is one example. Children who suffer from this condition experience an adverse reaction to the lactose in milk products. It is a result of the small intestine’s inability to produce enough of the enzyme lactase, which is produced by the small intestine. Symptoms of lactose intolerance usually affect the GI tract and can include bloating, abdominal pain, gas, nausea, and diarrhea. An intolerance is best managed by making dietary changes and avoiding any foods that trigger the reaction.

Lead Toxicity

There is a danger of lead toxicity, or lead poisoning, among school-aged children. Lead is found in plumbing in old homes, in lead-based paint, and occasionally in the soil. Contaminated food and water can increase exposure and result in hazardous lead levels in the blood. Children under age six are especially vulnerable. They may consume items tainted with lead, such as chipped, lead-based paint. 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.

Key Takeaways

- The recommended intakes of macronutrients and micronutrients for children are higher (relative to body size) compared to nutrient needs during adulthood.
- Children’s daily energy needs vary depending on their level of physical activity, growth, and sex.
- Some food- and nutrition-related problems that can affect school-aged children include micronutrient deficiencies, food allergies, food intolerances, and lead toxicity.

References

1. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 20, 2025.
2. Vitamin D for Babies, Children and Adolescents. healthychildren.org. Accessed May 20, 2025.
3. FNS-101: National School Lunch Program. fns.usda.gov. Accessed May 20, 2025.
4. Allergy Statistics. aaaai.org. Accessed May 20, 2025.
5. Common Allergens. foodallergy.org. Accessed May 20, 2025.

This page titled 13.1: Childhood and Nutrition is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

13.2: Early Adolescence and Nutrition

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for adolescents.
- Discuss the most important nutrition-related concerns during early adolescence.
- Discuss the growing rates of childhood obesity and the long-term consequences of it.

Puberty is the beginning of adolescence. The onset of puberty brings a number of changes, including the development of primary and secondary sex characteristics, growth spurts, an increase in body fat, and an increase in bone and muscle development. All of these changes must be supported with adequate intake and healthy food choices.

Energy

The energy requirements for adolescents differ according to sex, growth, and activity level. Physically active adolescents who regularly participate in sports or exercise need to eat a greater number of calories to account for increased energy expenditure.

Macronutrients

The Acceptable Macronutrient Distribution Ranges (AMDRs) for 9-13 year olds are listed in Table 13.2.1. For carbohydrates, the AMDR is 45 to 65% of daily calories which is the same AMDR as adults. Fiber recommendations increase from childhood. The recommendation for 9-13 year old females is 26 grams of fiber per day; the recommendation for males is 31 grams per day. The AMDR for protein is 10-30% of daily calories (0.85 grams of protein/kg body weight/day) and the AMDR for fat is 25-35% of daily calories.

Table 13.2.1: Acceptable Macronutrient Distribution Ranges (AMDRs) for Early Adolescence[1]

Macronutrient	AMDR
Carbohydrate	45-65% of total calories
Protein	10-30% of total calories
Fat	25-35% of total calories

Micronutrients

Key vitamins needed during early adolescence include vitamins A and D. Adequate calcium intake is essential for building bone and preventing osteoporosis later in life. Young females need more iron at the onset of menstruation, while young males need additional iron for the development of lean body mass. Almost all of these needs should be met with dietary choices, not supplements (iron is an exception since it is hard to get enough iron from food during this stage of life). Table 13.2.2 shows the micronutrient recommendations for young adolescents.

Table 13.2.2: Micronutrient Levels during Early Adolescence

Nutrient	Adolescents, Ages 9–13
Vitamin A (mcg)	600
Vitamin B_6 (mg)	1
Vitamin B_{12} (mcg)	1.8
Vitamin C (mg)	45
Vitamin D (mcg)	15
Vitamin E (mg)	11
Vitamin K (mcg)	60
Calcium (mg)	1,300
Folate (mcg)	300

Nutrient	Adolescents, Ages 9–13
Iron (mg)	8
Magnesium (mg)	240
Niacin (B_3) (mg)	12
Phosphorus (mg)	1,250
Riboflavin (B_2) (mg)	0.9
Selenium (mcg)	40
Thiamin (B_1) (mg)	0.9
Zinc (mg)	8

Childhood Obesity

Children need adequate caloric intake for growth, and it is important not to impose very restrictive diets. However, exceeding caloric requirements on a regular basis can lead to childhood obesity, which has become a major problem in North America. According to a national survey, nearly 20% of children ages 2 to 19 are obese.[2]

There are a number of reasons behind the problem of childhood obesity, including:

- larger portion sizes
- increased consumption of sugary beverages
- limited access to nutrient-rich foods
- increased access to fast foods and vending machines
- lack of breastfeeding support
- declining physical education programs in schools
- insufficient physical activity and a sedentary lifestyle
- lack of sleep
- community factors (safe environment for physical activity, affordability of healthy food options)
- media messages encouraging the consumption of unhealthy foods

Children who suffer from obesity are more likely to become overweight or obese adults. Obesity has a profound effect on self-esteem, energy, and activity level. Even more importantly, it is a major risk factor for a number of diseases later in life, including high blood pressure, heart disease, Type 2 diabetes, sleep apnea, joint problems, and certain cancers.[3]

A percentile for body mass index (BMI) specific to age and sex is used to determine if a child is overweight or obese. For example, if BMI is higher than that of 85% of U.S. children of the same age and sex, the child would be classified as overweight. If BMI is higher than that of 95% of U.S. children of the same age and sex, the child would be classified as obese. This is more appropriate than the BMI categories used for adults because the body composition of children varies as they develop, and differs between boys and girls. If a child gains weight inappropriate to growth, parents and caregivers could use strategies such as:

- limiting energy-dense, nutrient-poor snack foods
- 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

Programs to address childhood obesity can include behavior modification, exercise counseling, psychological support or therapy, family counseling, and family meal-planning advice. For most, the goal is not weight loss, but rather allowing height to catch up with weight as the child continues to grow. Rapid weight loss is not recommended for preteens or younger children due to the risk of deficiencies and stunted growth.

Key Takeaways

- The energy requirements for adolescents differ according to sex, growth, and activity level.
- Micronutrients of concern during early adolescence include vitamin A, vitamin D, calcium, and iron.

- One of the primary nutritional concerns for early adolescents is obesity. Adolescents should be encouraged to develop good habits, including consuming a healthy diet and regularly participating in physical activity.

References

1. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 20, 2025.
2. Stierman B, Afful J, Carroll MD, et al. National Health and Nutrition Examination Survey 2017–March 2020 prepandemic data files development of files and prevalence estimates for selected health outcomes. *Natl Health Stat Report*. 2021;158.
3. About Obesity. cdc.gov. Accessed May 20, 2025.

This page titled 13.2: Early Adolescence and Nutrition is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

13.3: Older Adolescence and Nutrition

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for teens.
- Discuss the most important nutrition-related concerns during older adolescence.

In this section, we will discuss the nutritional requirements for young people ages 14-18. Growth and development during adolescence differs between males and females. In teenage girls, fat assumes a larger percentage of body weight, while teenage boys experience greater muscle and bone increases. Skeletal growth ceases once closure of the epiphyseal plate occurs. The motor functions of an older adolescent are comparable to those of an adult. Adequate nutrition and healthy choices support this stage of growth and development.

Energy

Adolescents have increased appetites due to increased nutritional requirements. Nutrient needs are greater in adolescence than at any other time in the life cycle, except during pregnancy. The extra energy required for physical development during the teenage years should be obtained from foods that provide nutrients instead of “empty calories”.

Macronutrients

Older adolescents are more responsible for their dietary choices than younger children, but parents and caregivers must make sure that teens continue to meet their nutrient needs. The Acceptable Macronutrient Distribution Ranges (AMDRs) for 14-18 year olds are listed in Table 13.3.1. For carbohydrates, the AMDR is 45-65% of daily calories. Adolescents require more servings of grains than younger children, and should eat whole grains, such as whole wheat bread, corn tortillas, oats, and brown rice. Whole grain food choices will also help meet the fiber recommendations for this age group which is 26 grams of fiber per day for females and 38 grams per day for males. The Institute of Medicine recommends higher intakes of protein for growth in the adolescent population. The AMDR for protein is 10-30% of daily calories; lean proteins, such as meat, poultry, fish, beans, nuts, and seeds are excellent ways to meet those nutritional needs. The AMDR for fat is 25-35% of daily calories.

Table 13.3.1: Acceptable Macronutrient Distribution Ranges (AMDRs) for Older Adolescence[1]

Macronutrient	AMDR
Carbohydrate	45-65% of total calories
Protein	10-30% of total calories
Fat	25-35% of total calories

Micronutrients

Micronutrient recommendations for older adolescents are mostly the same as for adults, though children this age need more of certain minerals to promote bone growth (e.g., calcium and phosphorus, along with iron and zinc for girls). Again, vitamins and minerals should be obtained from food first, with supplementation for certain micronutrients only (such as iron). The most important micronutrients for adolescents are calcium, vitamin D, vitamin A, and iron. Adequate calcium and vitamin D are essential for building bone mass. The recommendation for calcium is 1,300 milligrams for both boys and girls. Low-fat dairy, green leafy vegetables, and almonds are good sources of calcium. It can also be helpful for adolescents to consume products fortified with calcium, such as breakfast cereals and calcium-fortified orange juice. Iron supports the growth of muscle and lean body mass. Adolescent girls also need to ensure sufficient iron intake as they start to menstruate. Girls ages 14-18 require 15 milligrams of iron per day. Increased amounts of vitamin C from orange juice and other sources can aid in iron absorption. Also, adequate fruit and vegetable intake allows for meeting vitamin A needs. Table 13.3.2 shows the micronutrient recommendations for older adolescents, which differ slightly for males and females, unlike the recommendations for early adolescence.

Table 13.3.2: Micronutrient Levels during Older Adolescence[1]

Nutrient	Males, Ages 14–18	Females, Ages 14–18
Vitamin A (mcg)	900	700

Nutrient	Males, Ages 14–18	Females, Ages 14–18
Vitamin B_6 (mg)	1.3	1.2
Vitamin B_{12} (mcg)	2.4	2.4
Vitamin C (mg)	75	65
Vitamin D (mcg)	15	15
Vitamin E (mg)	15	15
Vitamin K (mcg)	75	75
Calcium (mg)	1,300	1,300
Folate (mcg)	400	400
Iron (mg)	11	15
Magnesium (mg)	410	360
Niacin (B_3) (mg)	16	14
Phosphorus (mg)	1,250	1,250
Riboflavin (B_2) (mg)	1.3	1.0
Selenium (mcg)	55	55
Thiamin (B_1) (mg)	1.2	1.0
Zinc (mg)	11	9

Key Takeaways

- Older adolescents experience numerous physical changes and must increase their energy intake to support these changes and meet nutrient needs.
- Nutrient needs are greater during adolescence than at any other time in the life cycle, except during pregnancy.
- The most important micronutrients for adolescents are calcium, vitamin D, vitamin A, and iron.

References

1. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 20, 2025.

This page titled 13.3: Older Adolescence and Nutrition is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

13.4: Young Adulthood and Nutrition

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for young adults.
- Discuss the most important nutrition-related concerns during young adulthood.
- Explain how nutritional and lifestyle choices can affect current and future health.

With the onset of adulthood, good nutrition can help young adults enjoy an active lifestyle. For most people, young adulthood (ages 19-30) is the time when their bodies are in the best condition. The body of an adult does not need to devote its energy and resources to support the rapid growth and development that characterizes youth. However, the choices made during those formative years can have a lasting impact. Eating habits and preferences developed during childhood and adolescence influence health and fitness into adulthood. Adults must monitor their dietary decisions and make sure their caloric intake provides the energy that they require, without going into excess.

During this stage, growth is completed and people reach their physical peak. Major organs and body systems have fully matured by this stage of the life cycle. In order to maintain health and fitness at this age, it is important to continue to practice good nutrition. Healthy eating habits promote metabolic functioning, assist repair and regeneration, and prevent the development of chronic conditions.

Energy

Young men typically have higher nutrient needs than young women. For ages 19-30, typical energy requirements for women are 1,800-2,400 calories, and 2,400-3,000 calories for men, depending on activity level. These estimates do not include women who are pregnant or breastfeeding, who require a higher energy intake.

Macronutrients

The Acceptable Macronutrient Distribution Ranges (AMDRs) for 19-30 year olds are listed in Table 13.4.1. For carbohydrates, the AMDR is 45-65% of daily calories. All adults, young and old, should eat fewer energy-dense carbohydrates, especially refined, sugar-dense sources, particularly for those who lead a more sedentary lifestyle. The AMDR for fiber is 25 grams per day for women and 38 grams per day for men. Soluble fiber may help improve cholesterol and blood sugar levels, while insoluble fiber can help prevent constipation. The AMDR for protein is 10-35% of total daily calories, and should include a variety of lean meat and poultry, eggs, beans, peas, nuts, and seeds. It is also important to replace proteins that are high in saturated fat with ones that are lower in solid fats and calories. All adults should limit total fat to 20-35% of their daily calories and keep saturated fatty acids to less than 10% of total calories by replacing them with monounsaturated and polyunsaturated fatty acids.

Table 13.4.1: Acceptable Macronutrient Distribution Ranges (AMDRs) for Younger Adults[1]

Macronutrient	AMDR
Carbohydrate	45-65% of total calories
Protein	10-35% of total calories
Fat	20-35% of total calories

Micronutrients

Micronutrient needs in adults differ slightly according to sex. Males require more of vitamins C and K, along with thiamin, riboflavin, and niacin. Females require extra iron due to menstruation. Table 13.4.2 shows the micronutrient recommendations for young adult men and women.

Table 13.4.2: Micronutrient Levels during Young Adulthood[1]

Nutrient	Young Adult Males	Young Adult Females
Vitamin A (mcg)	900	700
Vitamin B_6 (mg)	1.3	1.3

Nutrient	Young Adult Males	Young Adult Females
Vitamin B_{12} (mcg)	2.4	2.4
Vitamin C (mg)	90	75
Vitamin D (mcg)	15	15
Vitamin E (mg)	15	15
Vitamin K (mcg)	120	90
Calcium (mg)	1,000	1,000
Folate (mcg)	400	400
Iron (mg)	8	18
Magnesium (mg)	400	310
Niacin (B_3) (mg)	16	14
Phosphorus (mg)	700	700
Riboflavin (B_2) (mg)	1.3	1.1
Selenium (mcg)	55	55
Thiamin (B_1) (mg)	1.2	1.1
Zinc (mg)	11	8

Nutritional Concerns in Young Adulthood

There are a number of intake recommendations for young adults. According to the IOM, an Adequate Intake (AI) of fluids for men is 3.7 liters per day, from both food and liquids. The AI for women is 2.7 liters per day, from food and liquids.[1] It is best when fluid intake is from water, instead of sugary beverages, such as soda. Fresh fruits and vegetables, including watermelon and cucumbers, are excellent food sources of fluid. In addition, young adults should avoid consuming excessive amounts of sodium. The health consequences of high sodium intake include high blood pressure and its complications. Therefore, it is best to limit sodium to less than 1,500 milligrams per day.[1]

Gastrointestinal Integrity

Good nutrition during the young adult years can help to support gastrointestinal integrity and prevent digestive disorders, such as constipation and diarrhea. Dietary fiber helps bind indigestible food together and normalize bowel movements. It also holds more water in the stool to make it softer for those who suffer from constipation. Excellent sources of fiber include oats, barley, rye, wheat, brown rice, celery, carrots, nuts, seeds, dried beans, oranges, and apples. In addition, healthy intestinal microflora can be supported by prebiotics, which stimulate the growth of beneficial bacteria already in the colon and are found in fruits and vegetables, and probiotics, which change or improve the bacterial balance in the gut and are found in fermented foods such as yogurt, kimchi, kombucha, miso, and sauerkraut. Learn even more about probiotics by reading the Probiotics Fact Sheet from the National Institutes of Health, Office of Dietary Supplements.

Obesity during Adulthood

Obesity remains a major concern into young adulthood. For adults, a BMI above 25 is considered overweight, and a BMI of 30 or higher is obese. By that measurement, more than 73% of all adults in the United States are overweight or obese, with over 40% considered to be obese.[2] As during childhood and adolescence, physical inactivity and poor dietary choices are major contributors to obesity in adulthood. Young adults should participate in regular physical activity and limit intake of high-fat, high-sugar foods and beverages to maintain a healthy weight.

Key Takeaways

- Young adults typically have reached their physical peak and can support health and wellness with adequate nutrition and exercise.
- Nutritional concerns for young adults include adequate energy and fluid intake, sodium intake, and the consumption of fiber.
- Young adults should participate in regular physical activity and limit intake of high-fat, high-sugar foods and beverages to maintain a healthy weight.

References

1. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 20, 2025.
2. Obesity and Overweight. cdc.gov. Accessed May 20, 2025.

This page titled 13.4: Young Adulthood and Nutrition is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

13.5: Middle Age and Nutrition

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for middle-aged adults.
- Discuss the most important nutrition-related concerns during middle age.
- Define and give examples of “preventive nutrition”.

During middle age (ages 31-50), adults begin to experience the first outward signs of aging. Wrinkles begin to appear, joints ache after a highly active day, and body fat accumulates. There is also a loss of muscle tone and elasticity in the connective tissue. Many people in their late thirties and in their forties notice a decline in endurance, the onset of wear-and-tear injuries (such as osteoarthritis), and changes in the digestive system. Wounds and other injuries also take longer to heal. Throughout the aging process, good nutrition can help middle-aged adults maintain their health and recover from any medical problems or issues they may experience. To maintain health and wellness during the middle-aged years and beyond, it is important to:

- maintain a healthy body weight
- consume nutrient-dense foods
- drink alcohol moderately or not at all
- be a nonsmoker
- engage in moderate physical activity at least 150 minutes per week[1]
- engage in muscle-strengthening activities at least 2 days per week[1]

Energy

The energy requirements for ages 31-50 typically range from 1,800-2,200 calories for women and 2,200-3,000 calories for men, depending on activity level. These estimates do not include women who are pregnant or breastfeeding. Middle-aged adults must rely on healthy food sources to meet these needs. Following the dietary guidelines in the middle-aged years provides adequate but not excessive energy, macronutrients, vitamins, and minerals.

Macronutrients

The Acceptable Macronutrient Distribution Ranges (AMDRs) for 31-50 year olds are listed in Table 13.5.1. The AMDRs for carbohydrates, protein, and fat remain the same from young adulthood into middle age. It is important to avoid putting on excess pounds and limiting intake of saturated fats and added sugars to help avoid cardiovascular disease, diabetes, and other chronic conditions.

Table 13.5.1: Acceptable Macronutrient Distribution Ranges (AMDRs) for Middle-Aged Adults[2]

Macronutrient	AMDR
Carbohydrate	45-65% of total calories
Protein	10-35% of total calories
Fat	20-35% of total calories

Micronutrients

Many micronutrient recommendations remain the same or very similar from young adulthood into middle age; recommendations for middle-aged adults can be seen in Table 13.5.2. Some key vitamins needed during the middle-aged years include folate and vitamins B_6 and B_{12} to prevent elevation of homocysteine, a byproduct of metabolism that can damage arterial walls and lead to atherosclerosis, a cardiovascular condition.

Table 13.5.2: Micronutrient Recommendations for Middle-Aged Adults[2]

Nutrient	Middle-Aged Adult Males	Middle-Aged Adult Females
Vitamin A (mcg)	900	700
Vitamin B_6 (mg)	1.3	1.3

Nutrient	Middle-Aged Adult Males	Middle-Aged Adult Females
Vitamin B_{12} (mcg)	2.4	2.4
Vitamin C (mg)	90	75
Vitamin D (mcg)	15	15
Vitamin E (mg)	15	15
Vitamin K (mcg)	120	90
Calcium (mg)	1,000	1,000
Folate (mcg)	400	400
Iron (mg)	8	18
Magnesium (mg)	420	320
Niacin (B_3) (mg)	16	14
Phosphorus (mg)	700	700
Riboflavin (B_2) (mg)	1.3	1.1
Selenium (mcg)	55	55
Thiamin (B_1) (mg)	1.2	1.1
Zinc (mg)	11	8

Preventive/Defensive Nutrition

During the middle-aged years, preventive nutrition can promote wellness and help organ systems to function optimally. Preventive nutrition is defined as dietary practices directed toward reducing disease and promoting health and well-being. Healthy eating in general—such as eating unrefined carbohydrates instead of refined carbohydrates and avoiding saturated fats—helps to promote wellness. However, there are also some things that people can do to target specific concerns. One example is consuming foods high in antioxidants, such as strawberries, blueberries, and other colorful fruits and vegetables, to reduce the risk of cancer.

Phytochemicals are "plant chemicals" found in fruits and vegetables that act as defense systems for plants. Phytochemicals may beneficially affect human health. There are several different phytochemicals that are being studied including carotenoids, flavonoids, garlic, phytosterols, and soy isoflavones. For example, results of observational studies suggest that diets high in carotenoid-rich fruit and vegetables (such as carrots, cantaloupes, sweet potatoes, and butternut squash) are associated with reduced risks of cardiovascular disease and some cancers.[3] For more information, visit the Phytochemicals page of the Linus Pauling Institute at Oregon State University.

Omega-3 fatty acids can help to prevent coronary artery disease. These crucial nutrients are found in oily fish, including salmon, mackerel, tuna, herring, cod, and halibut. Other beneficial fats that are vital for healthy functioning include monounsaturated fats, which are found in plant oils, avocados, peanuts, and pecans.

Key Takeaways

- Middle-aged adults begin to experience signs of aging and must continue to support their health and wellness with nutrition and physical activity.
- Nutritional concerns for middle-aged adults relate to the prevention of chronic disease.
- Preventive nutrition for middle-aged adults includes consumption of foods high in antioxidants, phytochemicals, or omega-3 fatty acids.

References

1. U.S. Department of Health and Human Services. *Physical Activity Guidelines for Americans*, 2nd edition. Washington, DC: U.S. Department of Health and Human Services; 2018. Accessed May 20, 2025.
2. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 20, 2025.

3. Carotenoids. lpi.oregonstate.edu. Accessed May 20, 2025.

This page titled 13.5: Middle Age and Nutrition is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

13.6: Older Adults and Nutrition

Learning Objectives

- Summarize nutritional requirements and dietary recommendations for older adults.
- Discuss the most important nutrition-related concerns for older adults.
- Discuss the influence of diet on health and wellness for older adults.

Beginning at age 51, requirements change once again and relate to the nutritional issues and health challenges that older people face. 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 underhydration; 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 sixty, primarily due to reduced intake or malabsorption. The loss of mobility among frail, homebound elderly adults also impacts their access to healthy, diverse foods.

Energy

Due to reductions in lean body mass and metabolic rate, older adults require less energy than younger adults. The decrease in physical activity that is typical of older adults also influences nutritional requirements.

Macronutrients

The AMDRs for carbohydrates, protein, and fat remain the same from middle age into old age (Table 13.6.1). Older adults should try to include unrefined carbohydrates, such as whole grains and brown rice, as fiber is especially important in preventing constipation and diverticulitis, and may also reduce the risk of colon cancer. Protein should be lean, and healthy fats, such as unsaturated and omega-3 fatty acids, are part of any good diet.

Table 13.6.1: Acceptable Macronutrient Distribution Ranges (AMDRs) for Older Adults[1]

Macronutrient	AMDR
Carbohydrate	45-65% of total calories
Protein	10-35% of total calories
Fat	20-35% of total calories

Micronutrients

An increase in certain micronutrients can help maintain health during this life stage. The recommendations for calcium increase to 1,200 milligrams per day for men over the age of 70 and all older adult women to slow bone loss. Also to help protect bones, vitamin D recommendations increase to 20 micrograms per day for men and women over the age of 70. Vitamin B_6 recommendations rise to 1.7 milligrams per day for older men and 1.5 milligrams per day for older women to help lower levels of homocysteine and protect against cardiovascular disease. As adults age, the production of stomach acid can decrease; stomach acid is critical for the absorption of vitamin B_{12}; therefore, a decrease in stomach acid can lead to a vitamin B_{12} deficiency. Because 10-30% of older people may have difficulty absorbing vitamin B_{12} from food (because of low stomach acid production), it is advisable for those older than 50 years to meet their vitamin B_{12} recommended intake mainly by consuming foods fortified with vitamin B_{12} or a supplement containing vitamin B_{12}.[1] For older adult women, higher iron levels are no longer needed postmenopause and recommendations decrease to 8 milligrams per day.

Table 13.6.2: Micronutrient Recommendations for Older Adults

Nutrient	Older Adult Males	Older Adult Females

Vitamin A (mcg)	900	700
Vitamin B_6 (mg)	1.7	1.5
Vitamin B_{12} (mcg)	2.4	2.4
Vitamin C (mg)	90	75
Vitamin D (mcg)	15 (51-70 years old); 20 (over 70 years old)	15 (51-70 years old); 20 (over 70 years old)
Vitamin E (mg)	15	15
Vitamin K (mcg)	120	90
Calcium (mg)	1,000 (51-70 years old); 1,200 (over 70 years old)	1,200
Folate (mcg)	400	400
Iron (mg)	8	8
Magnesium (mg)	420	320
Niacin (B_3) (mg)	16	14
Phosphorus (mg)	700	700
Riboflavin (B_2) (mg)	1.3	1.1
Selenium (mcg)	55	55
Thiamin (B_1) (mg)	1.2	1.1
Zinc (mg)	11	8

Nutritional Concerns for Older Adults

Dietary choices can help improve health during this life stage and address some of the nutritional concerns that many older adults face. In addition, there are specific concerns related to nutrition that affect adults in their later years. They include medical problems, such as disability and disease, which can impact diet and activity level. For example, dental problems can lead to difficulties with chewing and swallowing, which in turn can make it hard to maintain a healthy diet. The use of dentures or the preparation of pureed or chopped foods can help solve this problem. There also is a decreased thirst response in the elderly, and the kidneys have a decreased ability to concentrate urine, both of which can lead to dehydration.

Sensory Issues

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 the appetite. An intake of foods high in sugar and sodium can increase due to an inability to discern those tastes. The sense of smell also decreases, which impacts attitudes toward food. Sensory issues may also affect digestion because the taste and smell of food stimulates the secretion of digestive enzymes in the mouth, stomach, and pancreas.

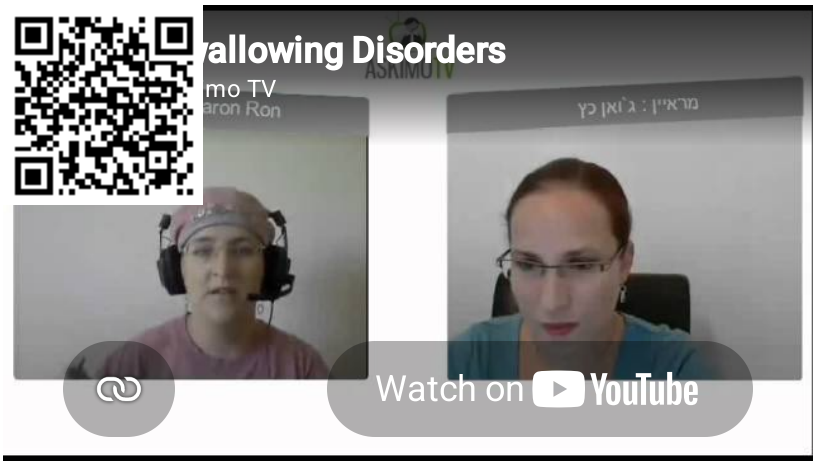
Gastrointestinal Problems

A number of gastrointestinal issues can affect food intake and digestion among 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, and can also be tied to low fluid intake, decreased physical activity, and a diet low in fiber, fruits, and vegetables.

Dysphagia

Some older adults have difficulty getting adequate nutrition because of the disorder dysphagia, which impairs the ability to swallow. Any damage to the parts of the brain that control swallowing can result in dysphagia. Therefore, stroke and dementia are two common causes. 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 dysphagia patients.

Watch this video to learn more about the symptoms and complications of dysphagia.



"Swallowing Disorders" by Knowledge On Line Ltd.

Obesity in Old Age

Similar to other life stages, obesity is a concern for older adults. Adults over age 60 are more likely to be obese than young or middle-aged adults. As explained throughout this chapter, excess body weight has severe consequences. Being overweight or obese increases the risk for potentially fatal conditions that can afflict the elderly. They include cardiovascular disease, which is the leading cause of death in the United States, and Type 2 diabetes, which causes over 100,000 deaths in the United States annually.[2] Obesity is also a contributing factor for a number of other conditions, including arthritis.

For older adults who are overweight or obese, dietary changes to promote weight loss should be combined with an exercise program to protect muscle mass. This is because dieting reduces muscle as well as fat, which can exacerbate the loss of muscle mass due to aging. Although weight loss among the elderly can be beneficial, it is best to be cautious and consult with a health-care professional before beginning a weight-loss program.

The Anorexia of Aging

In addition to concerns about obesity among senior citizens, being underweight can be a major problem. A condition known as the anorexia of aging is characterized by poor food intake, which results in dangerous weight loss. This major health problem among the elderly leads to a higher risk for immune deficiency, frequent falls, muscle loss, and cognitive deficits. Reduced muscle mass and physical activity mean that older adults need fewer calories per day to maintain a normal weight. It is important for health care providers to examine the causes for anorexia of aging among their patients, which can vary from one individual to another. Understanding why some elderly people eat less as they age can help health-care professionals assess the risk factors associated with this condition. Decreased intake may be due to disability or the lack of a motivation to eat. Also, many older adults skip at least one meal each day. As a result, some elderly people are unable to meet even reduced energy needs.

Nutritional interventions should focus primarily on a healthy diet. Remedies can include increasing the frequency of meals and adding healthy, high-calorie foods (such as nuts and dried fruits) to the diet. Liquid supplements between meals may help to improve caloric intake. Health care professionals should consider a patient's habits and preferences when developing a nutritional treatment plan. After a plan is in place, patients should be weighed on a weekly basis until they show improvement.

Vision Problems

Many older people suffer from vision problems and a loss of vision. Age-related macular degeneration is 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 in Americans over age 50.[3] This disorder can make food planning and preparation extremely difficult and people who suffer from it often must depend on caregivers for their meals. Self-feeding also may be difficult if an 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 to prevent macular degeneration. Consuming colorful fruits and vegetables increases the intake of lutein and zeaxanthin. Several studies have shown that these antioxidants provide protection for the eyes.[4] Lutein and zeaxanthin are found in green, leafy vegetables such as spinach, kale, and collard greens.

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.

Longevity and Nutrition

The foods you consume in your younger years influence your health as you age. Good nutrition and regular physical activity can help you live longer and healthier. Conversely, poor nutrition and a lack of exercise can shorten your life and lead to medical problems. The right foods provide numerous benefits at every stage of life. They help an infant grow, an adolescent develop mentally and physically, a young adult achieve his or her physical peak, and an older adult cope with aging. Nutritious foods form the foundation of a healthy life at every age.

Key Takeaways

- As adults age, physical changes impact nutrient needs and can result in deficiencies.
- Older adults are more susceptible to medical problems, such as disability and disease, which can impact appetite, the ability to plan and prepare food, chewing and swallowing, self-feeding, and general nutrient intake.
- A nutrient-dense diet can help prevent or support the healing of a number of disorders that impact older adults.

References

1. Summary Report of the Dietary Reference Intakes. nationalacademies.org. Accessed May 20, 2025.
2. Deaths and Mortality. cdc.gov. Accessed May 20, 2025.
3. Age-Related Macular Degeneration (AMD). nei.nih.gov. Accessed May 20, 2025.
4. Carotenoids. lpi.oregonstate.edu. Accessed May 20, 2025.
5. Alzheimer's Disease Fact Sheet. nia.nih.gov. Accessed May 20, 2025.

This page titled 13.6: Older Adults and Nutrition is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

CHAPTER OVERVIEW

14: Food Safety, Technology, Security, and Sustainability

14.1: Foodborne Illness and Food Safety

14.2: Food Technology

14.3: Food Security

14.4: Food Sustainability

Template:HideTOC

This page titled 14: Food Safety, Technology, Security, and Sustainability is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

14.1: 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 from consuming contaminated food. But, whether you become seriously ill depends on the microorganism, the amount you have consumed, and your overall health. In addition, some groups have a higher risk than others for developing severe complications to foodborne 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

According to the CDC, more than 250 different foodborne diseases have been identified; most are food infections caused by bacteria, viruses, and parasites.[1] The infection then grows inside the body and becomes the source of symptoms. Food infections can be sporadic and often are not reported to physicians. However, occasional outbreaks occur that put communities at risk.

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. In order to reproduce within food, microorganisms require the following conditions:

- **Temperature.** Between 40°F and 140°F, which is called the danger zone, microorganisms multiply more rapidly.
- **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 botulism toxin which 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.

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 14.1.1 lists the symptoms, when symptoms begin, and common food sources for several bacteria that cause foodborne illness.

Table 14.1.1: Bacteria that Cause Foodborne Illness[2]

Bacteria	Timeframe for onset of symptoms	Symptoms	Common food sources
Salmonella	6 hours - 6 days	diarrhea, fever, stomach cramps, vomiting	raw or undercooked chicken or turkey; eggs; unpasteurized milk or juice
Clostridium perfringens	6 - 24 hours	diarrhea, stomach cramps	beef or poultry; gravies; dried foods
Campylobacter	2-5 days	bloody diarrhea, stomach cramps, fever	raw or undercooked poultry, raw milk, contaminated water
Staphylococcus aureus (Staph)	30 minutes - 6 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)
Listeria monocytogenes	1-4 weeks	fever, muscle aches, headache, stiff neck, confusion	soft cheeses, raw sprouts, melons, hot dogs, deli meats, smoked seafood, unpasteurized milk

Bacteria	Timeframe for onset of symptoms	Symptoms	Common food sources
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
Clostridium botulinum	18-36 hours	blurred vision, slurred speech, difficulty swallowing or breathing, muscle weakness and paralysis	improperly canned or fermented food, honey
Vibrio	1-4 days	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.[3]

Hepatitis A is one of the more well-known food-contaminating viruses. Sources include raw shellfish from polluted water, and food handled by an infected person. This virus can go undetected for weeks and, on average, symptoms do not appear until about one month after exposure. At first, symptoms include loss of appetite, nausea, vomiting, and fever. Three to ten days later, additional symptoms can manifest, including jaundice and darkened urine. Severe cases of a hepatitis A can result in liver damage and death.

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 (for example, 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 (for example, *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 and can be transported by air, water, or insects. Spores also enable mold to reproduce. Additionally, molds have root-like threads that may grow deep into food and be difficult to see. The threads are very deep when a food shows heavy mold growth. Foods that contain mold may also have bacteria growing alongside it.

Some molds, like the kind found in blue cheese, are desirable in foods, while other molds can be dangerous. The spores of some molds can cause allergic reactions and respiratory problems. In the right conditions, a few molds produce mycotoxins, which are natural, poisonous substances that can make you sick if they are consumed. Mycotoxins are contained in and around mold threads, and in some cases, may have spread throughout the food.

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:[4]

- **Clean.** Wash hands thoroughly with warm, soapy water for at least twenty 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^{o}F or above) after it has been cooked.
- **Chill.** Refrigerate any leftovers within two hours. Make sure your refrigerator is set to 40^{o}F or below and your freezer is set to 0^{o}F or below. Never thaw or marinate food on the counter; it's best to thaw or marinate foods 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.

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.

Key Takeaways

- Groups at risk for foodborne illness include young children, elderly people, pregnant women, and people with compromised immune systems.
- Foodborne illnesses are classified as either food infections or food intoxications.
- Causes of food contamination include bacteria, viruses, parasites, and mold toxins.
- Consumers can take steps to prevent foodborne illness. The four most important steps for handling, preparing, and serving food are clean, separate, cook, and chill.
- Food regulatory agencies such as the FDA, USDA, and EPA work to protect the consumer and ensure the safety of our food.

References

1. Foodborne Disease Outbreak Surveillance System. cdc.gov. Accessed May 20, 2025.
2. Symptoms of Food Poisoning. cdc.gov. Accessed May 20, 2025.
3. About Norovirus. cdc.gov. Accessed May 20, 2025.
4. 4 Steps to Food Safety. foodsafety.gov. Accessed May 20, 2025.

This page titled 14.1: Foodborne Illness and Food Safety is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

14.2: 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 the selection, preservation, processing, packaging, distribution, and use of safe food.[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 14.2.1).



Figure 14.2.1: 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 14.2.1 lists some common food additives and their uses.

Table 14.2.1: 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

Additive	Uses
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

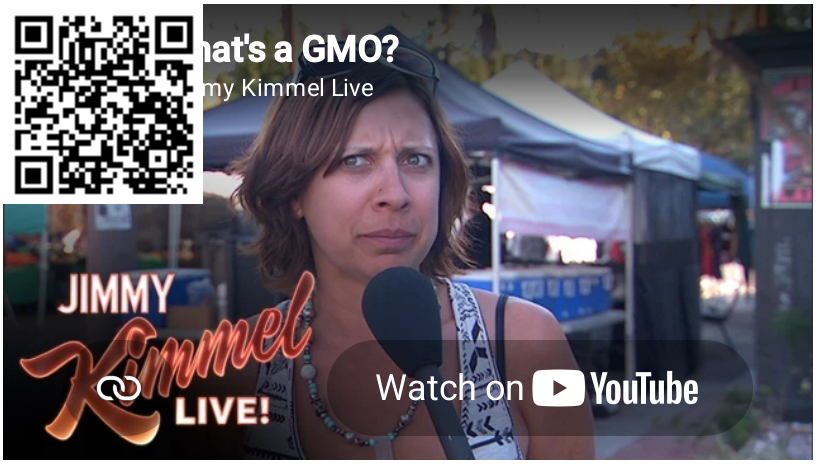
The FDA works to protect the public from potentially dangerous additives. Passed in 1958, the Food Additives Amendment states that a manufacturer is responsible for demonstrating the safety of an additive before it can be approved. The Delaney Clause that was added to this legislation prohibits the approval of any additive found to cause cancer in animals or humans. However, most additives are considered to be “Generally Recognized as Safe” (GRAS), a status that is determined by the FDA.

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.

Genetic Modification

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 end 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] To find out what some people think "GMO" means, watch this Jimmy Kimmel segment:



"What's a GMO?" by Jimmy Kimmel Live

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 14.2.2).
- **Made with organic ingredients.** Products that contain at least 70% organic ingredients; these products *cannot* display the organic seal.



Figure 14.2.2: USDA Organic Seal (CC0; by United States Department of Agriculture via Wikimedia Commons)

Key Takeaways

- Food preservation includes the handling or treating of food to prevent or slow down spoilage; preservation methods include curing, smoking, pickling, fermenting, canning, pasteurization, and irradiation.

- Food additives are natural or synthetic substances 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.
- Genetic modification is the process of changing an organism (plant or animal) by manipulating its genetic material. Although genetic modification has improved productivity for farmers, it has also stirred up debate about consumer safety and environmental protection.
- Food residues are chemicals that remain on foods after cleaning and processing; persistent organic pollutants and pesticides are two examples of food residues.
- Some consumers choose to reduce their exposure to pesticides by purchasing organic produce. Foods labeled as "organic" or "made with organic ingredients" must meet the respective definition developed by the USDA.

References

1. About Food Science and Technology. ift.org. Accessed May 20, 2025.
2. CSPI's Food Additive Safety Ratings. cspinet.org. Accessed May 20, 2025.
3. Overview of Food Ingredients, Additives & Colors. fda.gov. Accessed May 20, 2025.
4. GMO Crops, Animal Food, and Beyond. fda.gov. Accessed May 20, 2025.
5. Food, genetically modified. who.int. Accessed May 20, 2025.
6. EWG's Shopper's Guide to Pesticides in Produce. ewg.org. Accessed May 20, 2025.

This page titled 14.2: Food Technology is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

14.3: 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 14.3.1 shows the food security status of U.S. households during 2023, including:

- **Food secure households.** These households had access, at all times, to enough food for an active, healthy life for all household members. Throughout 2023, 86.5% 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 2023, 13.5% 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 2023, 8.4% 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% of U.S. households had very low food security at some time during 2023.

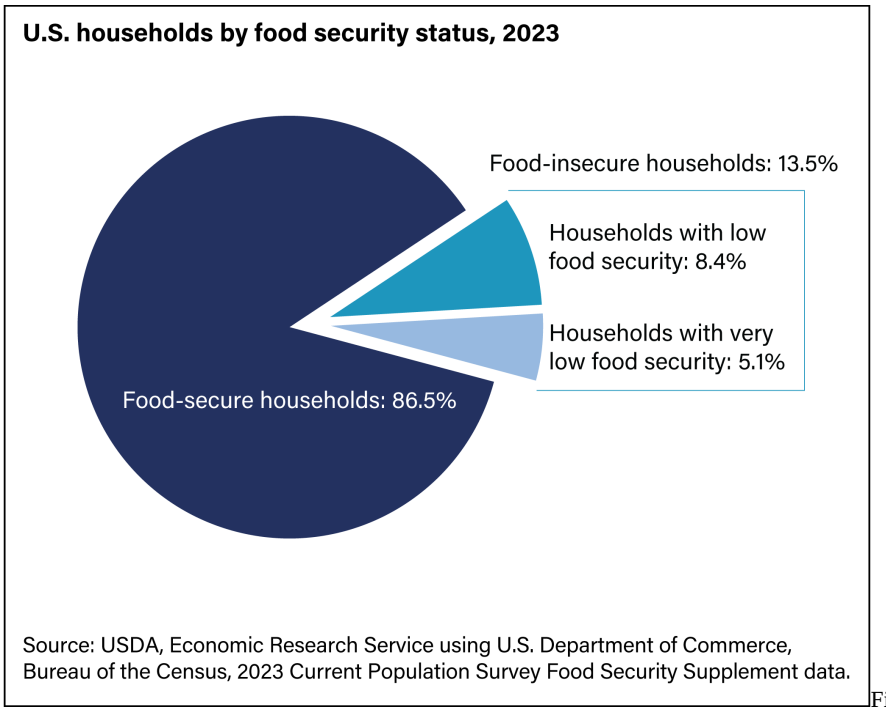


Figure 14.3.1: Food security status of U.S. households. (CC0; by United States Department of Agriculture, Economic Research Service)

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 $32,150 for a family of four in 2025)[1]

Food Assistance Programs

The federal government has established a number of programs that work to alleviate hunger and ensure that many low-income families receive the nutrition they require to live a healthy life. Programs include:

- **The Supplemental Nutrition Assistance Program.** Formerly known as the Food Stamp Program, the Supplemental Nutrition Assistance Program (SNAP) provides monthly benefits for low-income households to purchase approved food items at authorized stores. Clients qualify for the program based on available household income, assets, and certain basic expenses. 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.
- **The Special Supplemental Nutrition Program for Women, Infants, and Children.** The Special Supplemental Nutrition Program for Women, Infants and Children (WIC) provides food packages to pregnant and breastfeeding women, as well as to infants and children up to age five, to promote adequate intake for healthy growth and development. Most state WIC programs provide vouchers that participants use to acquire supplemental packages at authorized stores.
- **The National School Lunch Program.** The National School Lunch Program (NSLP) and School Breakfast Program (SBP) provide nutritionally balanced, low-cost or free breakfasts and/or lunches to children each school day.
- **The Child and Adult Care Food Program.** The Child and Adult Care Food Program (CACFP) offers meals and snacks at child-care centers, daycare homes, and after-school programs.
- **The Summer Food Service Program.** The Summer Food Service Program provides meals to children during summer break. Sponsors include day camps and other recreation programs where at least half of the attendees live in households with incomes below the federal poverty level.

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.

Key Takeaways

- 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.
- There are a number of groups at risk for hunger, including households with children, black households, Hispanic households, and low-income households.
- The United States has a number of federal and state programs, as well as local charities, which provide assistance and education for people who fall into the category of food insecurity.

References

1. Poverty Guidelines. U.S. Department of Health and Human Services. Accessed May 20, 2025.

This page titled 14.3: Food Security is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

14.4: 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. In recent years, consumers have become more conscientious about the decisions they make in the supermarket, especially as they relate to sustainability.

Sustainable Eating

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 in a way that is more sustainable can follow 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.
- **Buy organic foods.** Organic farms don’t use chemicals that require large amounts of energy to produce, pollute soil and water, and present human health impacts.
- **Buy locally grown foods.** Transportation accounts for approximately 14% of the total energy used in the US food system. Eating local, and consolidating shopping trips can reduce this impact.
- **Participate in community supported agriculture (CSA).** CSA 'shares' are sold to the public; 'shares' typically consist of a box of produce from the farm on a regular basis. Learn more about community supported agriculture (CSA) at Local Harvest.
- **Participate in the slow food movement.** The slow food movement advocates for nutritious, fresh food produced in ways that preserve biodiversity, sustain the environment, ensure animal welfare, and respects the dignity of all food laborers.

Concerns exist about harmful toxins in our food supply, and the sustainability of our oceans. The Monterey Bay Aquarium's video below includes information about seafood selection to avoid contaminants and to eat "sustainably."



"Make Better Seafood Choices" by Seafood Watch

Key Takeaways

- Sustainability is the ability to meet basic needs (now and in the future) without undermining natural resources and environmental quality.
- Food-related practices that positively impact food system sustainability include eating less meat, reducing waste, buying organic foods, buying locally grown foods, participating in community supported agriculture, and participating in the slow food movement.

References

1. U.S. Food System Factsheet. Center for Sustainable Systems. css.umich.edu. Accessed May 20, 2025.

This page titled 14.4: Food Sustainability is shared under a CC BY-NC-SA 3.0 license and was authored, remixed, and/or curated by Ann Diker.

Index

A

absorption
3: Digestion
4: Carbohydrates
4.3: Digestion and Absorption of Carbohydrates
5: Lipids
5.2: Digestion and Absorption of Lipids
6: Proteins
6.2: Digestion and Absorption of Proteins

acceptable macronutrient distribution ranges
2.4: Understanding Dietary Reference Intakes (DRIs)

accessible education
InfoPage

active lifestyle
13.4: Young Adulthood and Nutrition

adaptive homework
InfoPage

adenosine triphosphate
11.4: Fuel and Nutrient Needs for Physical Activity

adequate intake
2.4: Understanding Dietary Reference Intakes (DRIs)
4.5: Carbohydrate Recommendations

adipose tissue
5.2: Digestion and Absorption of Lipids

adolescence
13.3: Older Adolescence and Nutrition

adolescents
13.2: Early Adolescence and Nutrition

aging
13.5: Middle Age and Nutrition
13.6: Older Adults and Nutrition

agricultural practices
14.4: Food Sustainability

alcohol
2: Achieving a Healthy Diet
2.8: Is Alcohol Part of a Healthy Diet?

alcoholism
2.8: Is Alcohol Part of a Healthy Diet?

allergens
2.6: Understanding Food Labels

amino acids
6.1: Introduction to Proteins
6.2: Digestion and Absorption of Proteins
6.3: Functions of Protein

anabolism
10.1: Overview of Blood and Metabolism

anorexia
13.6: Older Adults and Nutrition

anorexia nervosa
11.5: Health Risks of Overweight and Underweight

antioxidant nutrients
8: Nutrients Important for Antioxidant Activity and Vision

antioxidants
8: Nutrients Important for Antioxidant Activity and Vision
8.1: Introduction to Free Radicals and Antioxidants
8.2: Antioxidant Nutrients

appetite
3: Digestion
3.2: Hunger vs. Appetite

artificial sweeteners
4.7: Sugar Substitutes

aspartame
4.7: Sugar Substitutes

atherosclerosis
5.5: Understanding Blood Cholesterol and Heart Disease

athletic performance
4.4: Functions of Carbohydrates

ATP
11.4: Fuel and Nutrient Needs for Physical Activity

B

balance
11.3: Physical Fitness and Physical Activity

balanced diet
2.1: What is a Healthy Diet?
6.6: Vegetarian and Vegan Diets

basal metabolism
11.2: Balancing Energy Intake with Energy Output

behavior modification
11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain

benefits
2.8: Is Alcohol Part of a Healthy Diet?

benefits of physical activity
11.3: Physical Fitness and Physical Activity

bile
5.2: Digestion and Absorption of Lipids

biological processes
3.1: Human Body Organization

blood
10: Nutrients Important for Metabolism and Blood Function
10.1: Overview of Blood and Metabolism

blood calcium levels
9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D

blood cholesterol
5: Lipids

blood function
10: Nutrients Important for Metabolism and Blood Function
10.2: Vitamins Important for Metabolism and Blood Function

blood glucose
4.3: Digestion and Absorption of Carbohydrates
4.6: Looking Closely at Diabetes

blood glucose control
4.2: Benefits of Fiber

blood lipid profile
5.5: Understanding Blood Cholesterol and Heart Disease

BMI
11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution

body composition
11: Energy Balance
11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution

body fluid
7.1: Overview of Fluid and Electrolyte Balance

body mass index
11: Energy Balance
11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution

body tissues
6.3: Functions of Protein

body weight
11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution
13.5: Middle Age and Nutrition

bone anatomy
9.1: Bone Structure and Function

bone density
9.4: Osteoporosis

bone function
9: Nutrients Important for Bone Health

bone health
9: Nutrients Important for Bone Health
9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D
9.3: Other Essential Micronutrients for Bone Health
9.4: Osteoporosis

bone remodeling
9.1: Bone Structure and Function

bone structure
9: Nutrients Important for Bone Health

bone tissue
9.1: Bone Structure and Function

breastfeeding
2.8: Is Alcohol Part of a Healthy Diet?

breastfeeding benefits
12.2: Infancy and Nutrition

bulimia nervosa
11.5: Health Risks of Overweight and Underweight

C

calcium
9: Nutrients Important for Bone Health
9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D
9.3: Other Essential Micronutrients for Bone Health
13.2: Early Adolescence and Nutrition

calcium functions
9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D

caloric intake
12.2: Infancy and Nutrition

calorie intake
2.7: Understanding Portion Sizes

calories
1: Foundational Concepts

cancer
8: Nutrients Important for Antioxidant Activity and Vision
8.4: Cancer

cancer stages
8.4: Cancer

carbohydrate
11.4: Fuel and Nutrient Needs for Physical Activity

carbohydrates
1.2: Overview of Nutrients and Calories
4: Carbohydrates
4.1: Introduction to Carbohydrates
4.3: Digestion and Absorption of Carbohydrates
4.4: Functions of Carbohydrates
4.5: Carbohydrate Recommendations

carcinogens
8.4: Cancer
cardiorespiratory fitness
11.3: Physical Fitness and Physical Activity
cardiovascular disease
4.2: Benefits of Fiber
caregivers
12.3: Nutrition in the Toddler Years
cartilage
9.1: Bone Structure and Function
catabolism
10.1: Overview of Blood and Metabolism
catalase
8.1: Introduction to Free Radicals and Antioxidants
CCK
3.2: Hunger vs. Appetite
cell
3.1: Human Body Organization
cell membrane
7.1: Overview of Fluid and Electrolyte Balance
cell theory
3.1: Human Body Organization
cells
Glossary
cellular respiration
Glossary
central nervous system
Glossary
chemical breakdown
3.3: Digestion and Absorption
chemical digestion
6.2: Digestion and Absorption of Proteins
chemical energy
Glossary
chemical reactions
7.2: Functions of Water
childhood
12: Lifecycle Nutrition: Pregnancy to the Toddler Years
13: Lifecycle Nutrition: Childhood to Late Adulthood
childhood nutrition
13.1: Childhood and Nutrition
childhood obesity
13.1: Childhood and Nutrition
13.2: Early Adolescence and Nutrition
chloride
7.4: Electrolytes
cholesterol
5.1: Introduction to Lipids
5.5: Understanding Blood Cholesterol and Heart Disease
chronic disease
2.2: Understanding the Dietary Guidelines
4.7: Sugar Substitutes
6.5: Diseases Involving Proteins
8.2: Antioxidant Nutrients
11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution
chronic disease risk reduction intake
2.4: Understanding Dietary Reference Intakes (DRIs)
chronic diseases
1.1: Defining Nutrition, Health, and Disease
4.5: Carbohydrate Recommendations
11.5: Health Risks of Overweight and Underweight
chylomicrons
5.2: Digestion and Absorption of Lipids
5.5: Understanding Blood Cholesterol and Heart Disease
circulatory system
Glossary
clinical trials
1.3: The Broad Role of Nutritional Science
coenzymes
10.2: Vitamins Important for Metabolism and Blood Function
cognitive deficits
13.6: Older Adults and Nutrition
collaborative platform
InfoPage
community supported agriculture
14.4: Food Sustainability
complete proteins
6.4: Protein Recommendations
complex carbohydrates
4.1: Introduction to Carbohydrates
complications of pregnancy
12.1: Pregnancy and Nutrition
components of fitness
11.3: Physical Fitness and Physical Activity
connective tissues
9.1: Bone Structure and Function
consumer safety
2.5: Dietary Supplements
14.2: Food Technology
consumption
2.8: Is Alcohol Part of a Healthy Diet?
curriculum development
InfoPage
customizable textbooks
InfoPage

D

daily intake
13.3: Older Adolescence and Nutrition
dairy
2.3: Tools to Help Design a Healthy Diet
deficiency
10.2: Vitamins Important for Metabolism and Blood Function
dehydration
7: Nutrients Important for Fluid and Electrolyte Balance
7.3: Regulation of Water Balance
7.5: Understanding Dehydration and Heat Illnesses
detoxifying enzymes
8.1: Introduction to Free Radicals and Antioxidants
DEXA
9.4: Osteoporosis
diabetes
1.1: Defining Nutrition, Health, and Disease
4: Carbohydrates
4.2: Benefits of Fiber
4.6: Looking Closely at Diabetes
diet
1: Foundational Concepts
1.2: Overview of Nutrients and Calories
4.2: Benefits of Fiber
6: Proteins
6.6: Vegetarian and Vegan Diets
12: Lifecycle Nutrition: Pregnancy to the Toddler Years
13.6: Older Adults and Nutrition
dietary
10: Nutrients Important for Metabolism and Blood Function
dietary allowance
4.5: Carbohydrate Recommendations
dietary choices
12.1: Pregnancy and Nutrition
dietary decisions
8.1: Introduction to Free Radicals and Antioxidants
dietary fat
5: Lipids
dietary fiber
4.1: Introduction to Carbohydrates
Glossary
dietary guidelines
1.1: Defining Nutrition, Health, and Disease
1.3: The Broad Role of Nutritional Science
1.4: Nutrition and the Media
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
4: Carbohydrates
5.1: Introduction to Lipids
5.4: Lipid/Fat Recommendations
12.2: Infancy and Nutrition
13.5: Middle Age and Nutrition
dietary habits
11.2: Balancing Energy Intake with Energy Output
dietary protein
6.5: Diseases Involving Proteins
dietary proteins
6.3: Functions of Protein
dietary recommendations
2.2: Understanding the Dietary Guidelines
4: Carbohydrates
7.4: Electrolytes
8.3: Vitamin A and Vision
9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D
12.2: Infancy and Nutrition
12.3: Nutrition in the Toddler Years
13.1: Childhood and Nutrition
13.2: Early Adolescence and Nutrition
13.3: Older Adolescence and Nutrition
13.4: Young Adulthood and Nutrition
13.5: Middle Age and Nutrition
dietary reference intakes
2: Achieving a Healthy Diet
2.4: Understanding Dietary Reference Intakes (DRIs)
4.5: Carbohydrate Recommendations
10.2: Vitamins Important for Metabolism and Blood Function
10.3: Minerals Important for Metabolism and Blood Function
dietary requirements
6.1: Introduction to Proteins
dietary supplements
2: Achieving a Healthy Diet
2.5: Dietary Supplements
8.2: Antioxidant Nutrients

digestion
3: Digestion
3.4: Disorders That Can Compromise Health
4: Carbohydrates
4.3: Digestion and Absorption of Carbohydrates
5: Lipids
6: Proteins
digestion process
3.3: Digestion and Absorption
digestive enzymes
5.2: Digestion and Absorption of Lipids
digestive organs
3.3: Digestion and Absorption
digestive system
3.3: Digestion and Absorption
6.2: Digestion and Absorption of Proteins
disease
1: Foundational Concepts
disease prevention
1.1: Defining Nutrition, Health, and Disease
1.3: The Broad Role of Nutritional Science
diseases
3.4: Disorders That Can Compromise Health
6: Proteins
disorders
3: Digestion
3.4: Disorders That Can Compromise Health
DRIs
2: Achieving a Healthy Diet

E

early childhood nutrition
12: Lifecycle Nutrition: Pregnancy to the Toddler Years
early development
12: Lifecycle Nutrition: Pregnancy to the Toddler Years
earlyadolescence
13: Lifecycle Nutrition: Childhood to Late Adulthood
eating disorders
11.5: Health Risks of Overweight and Underweight
effective weight gain
11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain
elderly
13.6: Older Adults and Nutrition
electrolyte balance
7: Nutrients Important for Fluid and Electrolyte Balance
7.4: Electrolytes
electrolyte composition
7.1: Overview of Fluid and Electrolyte Balance
electrolyte imbalance
7.5: Understanding Dehydration and Heat Illnesses
electrolytes
7.4: Electrolytes
emulsification
5.2: Digestion and Absorption of Lipids
energy
1.2: Overview of Nutrients and Calories
11.4: Fuel and Nutrient Needs for Physical Activity
energy balance
11.2: Balancing Energy Intake with Energy Output
energy expenditure
11.2: Balancing Energy Intake with Energy Output
energy intake
11: Energy Balance
11.2: Balancing Energy Intake with Energy Output
11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain
13.3: Older Adolescence and Nutrition
energy metabolism
10.2: Vitamins Important for Metabolism and Blood Function
10.3: Minerals Important for Metabolism and Blood Function
Glossary
energy needs
13.1: Childhood and Nutrition
energy output
11: Energy Balance
11.2: Balancing Energy Intake with Energy Output
energy production
4.4: Functions of Carbohydrates
energy requirements
12.3: Nutrition in the Toddler Years
13.2: Early Adolescence and Nutrition
13.4: Young Adulthood and Nutrition
energy storage
4.4: Functions of Carbohydrates
5.3: Functions of Lipids
enrichment
2.6: Understanding Food Labels
environmental quality
14.4: Food Sustainability
enzymes
3.3: Digestion and Absorption
6.2: Digestion and Absorption of Proteins
6.3: Functions of Protein
10.1: Overview of Blood and Metabolism
Glossary
epidemiological studies
1.3: The Broad Role of Nutritional Science
erythrocytes
10.1: Overview of Blood and Metabolism
essential amino acids
Glossary
essential fatty acids
5.1: Introduction to Lipids
5.3: Functions of Lipids
5.4: Lipid/Fat Recommendations
essential nutrients
2.1: What is a Healthy Diet?
9: Nutrients Important for Bone Health
estimated average requirement
2.4: Understanding Dietary Reference Intakes (DRIs)
estimated energy requirement
2.4: Understanding Dietary Reference Intakes (DRIs)
estimating portion size
2.7: Understanding Portion Sizes
exercise
4.4: Functions of Carbohydrates
7.5: Understanding Dehydration and Heat Illnesses
9.4: Osteoporosis
11.3: Physical Fitness and Physical Activity
extracellular fluid
7.1: Overview of Fluid and Electrolyte Balance

F

factors affecting BMR
11.2: Balancing Energy Intake with Energy Output
fat
11.4: Fuel and Nutrient Needs for Physical Activity
fat distribution
11: Energy Balance
fat intake
5.4: Lipid/Fat Recommendations
fats
5.4: Lipid/Fat Recommendations
fatty acids
5.1: Introduction to Lipids
FDA approval
4.7: Sugar Substitutes
feeding problems
12.3: Nutrition in the Toddler Years
fetal development
12.1: Pregnancy and Nutrition
fiber
4: Carbohydrates
4.2: Benefits of Fiber
flexibility
11.3: Physical Fitness and Physical Activity
fluid balance
7: Nutrients Important for Fluid and Electrolyte Balance
7.1: Overview of Fluid and Electrolyte Balance
7.4: Electrolytes
fluid imbalance
7.5: Understanding Dehydration and Heat Illnesses
fluid intake
7.3: Regulation of Water Balance
fluid replacement
7.5: Understanding Dehydration and Heat Illnesses
food additives
4.7: Sugar Substitutes
14: Food Safety, Technology, Security, and Sustainability
14.2: Food Technology
food allergies
13.1: Childhood and Nutrition
food assistance programs
14.3: Food Security
food choices
1.1: Defining Nutrition, Health, and Disease
food contamination
14.1: Foodborne Illness and Food Safety
food digestion
3.3: Digestion and Absorption
food groups
2.1: What is a Healthy Diet?
food handling
14.1: Foodborne Illness and Food Safety
food insecurity
14.3: Food Security
food label
2.7: Understanding Portion Sizes
food labels
2: Achieving a Healthy Diet
2.6: Understanding Food Labels
food packaging
14.2: Food Technology
food patterns
2.3: Tools to Help Design a Healthy Diet
food poisoning
14.1: Foodborne Illness and Food Safety

food portion sizes
2.7: Understanding Portion Sizes
food preparation
14.1: Foodborne Illness and Food Safety
food preservation
14: Food Safety, Technology, Security, and Sustainability
14.2: Food Technology
food processing
14.2: Food Technology
food residues
14: Food Safety, Technology, Security, and Sustainability
food safety
1.4: Nutrition and the Media
2.5: Dietary Supplements
14: Food Safety, Technology, Security, and Sustainability
14.1: Foodborne Illness and Food Safety
14.2: Food Technology
food science
14: Food Safety, Technology, Security, and Sustainability
food security
14: Food Safety, Technology, Security, and Sustainability
14.3: Food Security
food storage
14.1: Foodborne Illness and Food Safety
food sustainability
14: Food Safety, Technology, Security, and Sustainability
food system
14.4: Food Sustainability
food technology
14: Food Safety, Technology, Security, and Sustainability
14.2: Food Technology
foodborne diseases
14.1: Foodborne Illness and Food Safety
foodborne illness
14: Food Safety, Technology, Security, and Sustainability
14.1: Foodborne Illness and Food Safety
foodborne illnesses
14.2: Food Technology
fortification
2.6: Understanding Food Labels
free radicals
8: Nutrients Important for Antioxidant Activity and Vision
8.1: Introduction to Free Radicals and Antioxidants
8.2: Antioxidant Nutrients
fruits
2.2: Understanding the Dietary Guidelines
2.3: Tools to Help Design a Healthy Diet
4.2: Benefits of Fiber
functions
5: Lipids
6: Proteins
functions of lipids
5.3: Functions of Lipids
functions of protein
6.3: Functions of Protein
functions of water
7.2: Functions of Water

G

gastrointestinal
3.4: Disorders That Can Compromise Health
gastrointestinal tract
6.2: Digestion and Absorption of Proteins
gastrointestinal upset
4.7: Sugar Substitutes
genetic modification
14: Food Safety, Technology, Security, and Sustainability
14.2: Food Technology
gestational diabetes
4.6: Looking Closely at Diabetes
12.1: Pregnancy and Nutrition
ghrelin
3.2: Hunger vs. Appetite
glucagon
3.2: Hunger vs. Appetite
4.3: Digestion and Absorption of Carbohydrates
glucose
4.1: Introduction to Carbohydrates
4.4: Functions of Carbohydrates
glutathione peroxidase
8.1: Introduction to Free Radicals and Antioxidants
glycogen
4.1: Introduction to Carbohydrates
4.3: Digestion and Absorption of Carbohydrates
4.4: Functions of Carbohydrates
growth charts
12.2: Infancy and Nutrition

H

HDL
5.5: Understanding Blood Cholesterol and Heart Disease
health
1: Foundational Concepts
1.1: Defining Nutrition, Health, and Disease
2.2: Understanding the Dietary Guidelines
2.4: Understanding Dietary Reference Intakes (DRIs)
2.5: Dietary Supplements
2.8: Is Alcohol Part of a Healthy Diet?
3: Digestion
3.4: Disorders That Can Compromise Health
4: Carbohydrates
5: Lipids
7: Nutrients Important for Fluid and Electrolyte Balance
10: Nutrients Important for Metabolism and Blood Function
10.2: Vitamins Important for Metabolism and Blood Function
10.3: Minerals Important for Metabolism and Blood Function
12: Lifecycle Nutrition: Pregnancy to the Toddler Years
13.4: Young Adulthood and Nutrition
13.6: Older Adults and Nutrition
health and wellness
13.5: Middle Age and Nutrition
health benefits
2.1: What is a Healthy Diet?
4.1: Introduction to Carbohydrates
4.2: Benefits of Fiber
4.7: Sugar Substitutes
5.3: Functions of Lipids
6.4: Protein Recommendations
6.6: Vegetarian and Vegan Diets
health claims
2.5: Dietary Supplements
2.6: Understanding Food Labels
8.2: Antioxidant Nutrients
health consequences
4.6: Looking Closely at Diabetes
health optimization
8.1: Introduction to Free Radicals and Antioxidants
health promotion
1.1: Defining Nutrition, Health, and Disease
1.4: Nutrition and the Media
health recommendations
4.5: Carbohydrate Recommendations
7.4: Electrolytes
health risk
11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution
health risks
1.3: The Broad Role of Nutritional Science
6.5: Diseases Involving Proteins
11: Energy Balance
11.5: Health Risks of Overweight and Underweight
14.2: Food Technology
healthful eating
2.7: Understanding Portion Sizes
healthy diet
2: Achieving a Healthy Diet
2.1: What is a Healthy Diet?
2.3: Tools to Help Design a Healthy Diet
6.4: Protein Recommendations
6.5: Diseases Involving Proteins
13.1: Childhood and Nutrition
healthy eating
11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain
healthy fats
2.2: Understanding the Dietary Guidelines
2.3: Tools to Help Design a Healthy Diet
healthy foods
12.1: Pregnancy and Nutrition
heart disease
5: Lipids
5.5: Understanding Blood Cholesterol and Heart Disease
heart health
5.1: Introduction to Lipids
5.5: Understanding Blood Cholesterol and Heart Disease
heat cramps
7.5: Understanding Dehydration and Heat Illnesses
heat exhaustion
7.5: Understanding Dehydration and Heat Illnesses
heat illnesses
7: Nutrients Important for Fluid and Electrolyte Balance
7.5: Understanding Dehydration and Heat Illnesses
Heat Stroke
7.5: Understanding Dehydration and Heat Illnesses
homeostasis
7.1: Overview of Fluid and Electrolyte Balance
hormonal responses
7.3: Regulation of Water Balance
hormones
6.3: Functions of Protein
human anatomy
7.1: Overview of Fluid and Electrolyte Balance

human body
3.1: Human Body Organization
4.4: Functions of Carbohydrates
7.2: Functions of Water
human body organization
3: Digestion
human proteins
6.1: Introduction to Proteins
human skeleton
9.1: Bone Structure and Function
hunger
3: Digestion
3.2: Hunger vs. Appetite
14.3: Food Security
hydration
7: Nutrients Important for Fluid and Electrolyte Balance
hyponatremia
7.5: Understanding Dehydration and Heat Illnesses
hypothalamus
3.2: Hunger vs. Appetite
hypothesis
1.3: The Broad Role of Nutritional Science

I

immune system
8.1: Introduction to Free Radicals and Antioxidants
8.2: Antioxidant Nutrients
8.3: Vitamin A and Vision
Glossary
indicators of health
11: Energy Balance
infancy
12: Lifecycle Nutrition: Pregnancy to the Toddler Years
infant nutrition
12.2: Infancy and Nutrition
initiation
8.4: Cancer
insulating
5.3: Functions of Lipids
insulin
3.2: Hunger vs. Appetite
4.3: Digestion and Absorption of Carbohydrates
4.6: Looking Closely at Diabetes
interactive textbooks
InfoPage
intracellular fluid
7.1: Overview of Fluid and Electrolyte Balance
iron
9.3: Other Essential Micronutrients for Bone Health
iron deficiency anemia
10.3: Minerals Important for Metabolism and Blood Function

K

kidney disease
6.5: Diseases Involving Proteins
kidneys
7.3: Regulation of Water Balance
Kwashiorkor
6.5: Diseases Involving Proteins

L

lactose intolerance
4.3: Digestion and Absorption of Carbohydrates
large intestine
3.3: Digestion and Absorption
LDL
5.5: Understanding Blood Cholesterol and Heart Disease
learning objectives
2.7: Understanding Portion Sizes
4.2: Benefits of Fiber
4.5: Carbohydrate Recommendations
6.1: Introduction to Proteins
9.1: Bone Structure and Function
10.3: Minerals Important for Metabolism and Blood Function
11.3: Physical Fitness and Physical Activity
11.4: Fuel and Nutrient Needs for Physical Activity
11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain
12.1: Pregnancy and Nutrition
12.2: Infancy and Nutrition
13.4: Young Adulthood and Nutrition
leptin
3.2: Hunger vs. Appetite
leukocytes
10.1: Overview of Blood and Metabolism
LibreTexts
InfoPage
lifestyle
4.6: Looking Closely at Diabetes
ligaments
9.1: Bone Structure and Function
lipid digestion
5.2: Digestion and Absorption of Lipids
lipids
1.2: Overview of Nutrients and Calories
5: Lipids
5.1: Introduction to Lipids
5.3: Functions of Lipids
5.4: Lipid/Fat Recommendations
lipoproteins
5.2: Digestion and Absorption of Lipids
5.5: Understanding Blood Cholesterol and Heart Disease
local foods
14.4: Food Sustainability
lubricant
7.2: Functions of Water

M

macromolecules
3.1: Human Body Organization
6.1: Introduction to Proteins
macronutrient distribution range
4.5: Carbohydrate Recommendations
macronutrients
1.2: Overview of Nutrients and Calories
6.4: Protein Recommendations
11.4: Fuel and Nutrient Needs for Physical Activity
12.2: Infancy and Nutrition
13.1: Childhood and Nutrition
13.2: Early Adolescence and Nutrition
13.3: Older Adolescence and Nutrition
13.4: Young Adulthood and Nutrition
magnesium
9.3: Other Essential Micronutrients for Bone Health
malabsorption
3.4: Disorders That Can Compromise Health
managing portion sizes
2.7: Understanding Portion Sizes
maternal nutrition
12: Lifecycle Nutrition: Pregnancy to the Toddler Years
measurable goals
11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain
mechanical breakdown
3.3: Digestion and Absorption
mechanical digestion
6.2: Digestion and Absorption of Proteins
metabolism
1: Foundational Concepts
2.8: Is Alcohol Part of a Healthy Diet?
4.3: Digestion and Absorption of Carbohydrates
4.4: Functions of Carbohydrates
10: Nutrients Important for Metabolism and Blood Function
10.1: Overview of Blood and Metabolism
10.2: Vitamins Important for Metabolism and Blood Function
10.3: Minerals Important for Metabolism and Blood Function
11.2: Balancing Energy Intake with Energy Output
metastasis
8.4: Cancer
micronutrients
1.2: Overview of Nutrients and Calories
9: Nutrients Important for Bone Health
13.1: Childhood and Nutrition
13.2: Early Adolescence and Nutrition
13.3: Older Adolescence and Nutrition
middleage
13: Lifecycle Nutrition: Childhood to Late Adulthood
mineral
2.5: Dietary Supplements
minerals
1.2: Overview of Nutrients and Calories
6.6: Vegetarian and Vegan Diets
9.3: Other Essential Micronutrients for Bone Health
10: Nutrients Important for Metabolism and Blood Function
10.3: Minerals Important for Metabolism and Blood Function
13.3: Older Adolescence and Nutrition
moderation
2.1: What is a Healthy Diet?
2.8: Is Alcohol Part of a Healthy Diet?
moderation strategies
2.7: Understanding Portion Sizes
muscle building
6.3: Functions of Protein
muscle contraction
9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D
muscle loss
13.6: Older Adults and Nutrition
muscle wasting
6.5: Diseases Involving Proteins
musculoskeletal fitness
11.3: Physical Fitness and Physical Activity

N

National School Lunch Program
14.3: Food Security
night blindness
8.3: Vitamin A and Vision

nitrogen balance
6.4: Protein Recommendations
nutrient absorption
3.3: Digestion and Absorption
9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D
nutrient content claims
2.6: Understanding Food Labels
nutrient deficiencies
2.5: Dietary Supplements
nutrient needs
11.4: Fuel and Nutrient Needs for Physical Activity
13.6: Older Adults and Nutrition
nutrient recommendations
2.4: Understanding Dietary Reference Intakes (DRIs)
nutrient transport
6.3: Functions of Protein
7.4: Electrolytes
nutrients
1: Foundational Concepts
1.2: Overview of Nutrients and Calories
9.3: Other Essential Micronutrients for Bone Health
10.1: Overview of Blood and Metabolism
nutrition
1: Foundational Concepts
1.1: Defining Nutrition, Health, and Disease
2: Achieving a Healthy Diet
2.1: What is a Healthy Diet?
2.2: Understanding the Dietary Guidelines
2.5: Dietary Supplements
2.6: Understanding Food Labels
3.1: Human Body Organization
3.4: Disorders That Can Compromise Health
4: Carbohydrates
4.1: Introduction to Carbohydrates
4.3: Digestion and Absorption of Carbohydrates
4.4: Functions of Carbohydrates
4.6: Looking Closely at Diabetes
5: Lipids
6.4: Protein Recommendations
6.5: Diseases Involving Proteins
6.6: Vegetarian and Vegan Diets
8.2: Antioxidant Nutrients
9.4: Osteoporosis
10: Nutrients Important for Metabolism and Blood Function
10.2: Vitamins Important for Metabolism and Blood Function
12: Lifecycle Nutrition: Pregnancy to the Toddler Years
13: Lifecycle Nutrition: Childhood to Late Adulthood
13.6: Older Adults and Nutrition
14.3: Food Security
nutrition concerns
13.2: Early Adolescence and Nutrition
13.4: Young Adulthood and Nutrition
nutrition education
1.4: Nutrition and the Media
Nutrition Facts
2.6: Understanding Food Labels
nutrition guidelines
4.5: Carbohydrate Recommendations
nutrition research
1.4: Nutrition and the Media
nutritional choices
13.4: Young Adulthood and Nutrition
nutritional deficiencies
11.5: Health Risks of Overweight and Underweight
nutritional deficiency
10.3: Minerals Important for Metabolism and Blood Function
nutritional needs
13.1: Childhood and Nutrition
nutritional requirements
12.1: Pregnancy and Nutrition
12.2: Infancy and Nutrition
12.3: Nutrition in the Toddler Years
13.2: Early Adolescence and Nutrition
13.3: Older Adolescence and Nutrition
13.4: Young Adulthood and Nutrition
13.5: Middle Age and Nutrition
nutritional science
1: Foundational Concepts

O

obesity
1.1: Defining Nutrition, Health, and Disease
3.2: Hunger vs. Appetite
3.4: Disorders That Can Compromise Health
11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution
11.2: Balancing Energy Intake with Energy Output
11.5: Health Risks of Overweight and Underweight
OER
InfoPage
olderadolescence
13: Lifecycle Nutrition: Childhood to Late Adulthood
olderadults
13: Lifecycle Nutrition: Childhood to Late Adulthood
oral health
4.7: Sugar Substitutes
organ systems
3.1: Human Body Organization
organic foods
14.4: Food Sustainability
organism
3.1: Human Body Organization
organs
3.1: Human Body Organization
osmosis
7.1: Overview of Fluid and Electrolyte Balance
osteoporosis
9: Nutrients Important for Bone Health
9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D
9.3: Other Essential Micronutrients for Bone Health
9.4: Osteoporosis
overview
10: Nutrients Important for Metabolism and Blood Function
overweight
11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution
11.5: Health Risks of Overweight and Underweight
oxidative stress
8.1: Introduction to Free Radicals and Antioxidants

P

parents
12.3: Nutrition in the Toddler Years
pediatric nutrition
12.2: Infancy and Nutrition
peptide bonds
6.1: Introduction to Proteins
phospholipids
5.1: Introduction to Lipids
5.2: Digestion and Absorption of Lipids
phosphorus
7.4: Electrolytes
9.3: Other Essential Micronutrients for Bone Health
physical activity
2.7: Understanding Portion Sizes
11: Energy Balance
11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution
11.3: Physical Fitness and Physical Activity
11.4: Fuel and Nutrient Needs for Physical Activity
11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain
physical fitness
11: Energy Balance
11.3: Physical Fitness and Physical Activity
physiological control
7.3: Regulation of Water Balance
physiology
7: Nutrients Important for Fluid and Electrolyte Balance
picky eaters
12.3: Nutrition in the Toddler Years
plasma
10.1: Overview of Blood and Metabolism
platelets
10.1: Overview of Blood and Metabolism
portion sizes
2: Achieving a Healthy Diet
potassium
7.4: Electrolytes
pregnancy
2.8: Is Alcohol Part of a Healthy Diet?
12: Lifecycle Nutrition: Pregnancy to the Toddler Years
pregnancy nutrition
12.1: Pregnancy and Nutrition
prenatal supplements
12.1: Pregnancy and Nutrition
prevention
9.4: Osteoporosis
prevention steps
14.1: Foodborne Illness and Food Safety
preventive nutrition
13.5: Middle Age and Nutrition
progression
8.4: Cancer
promotion
8.4: Cancer
protecting
5.3: Functions of Lipids
protein
2.3: Tools to Help Design a Healthy Diet
6.3: Functions of Protein
6.4: Protein Recommendations
6.6: Vegetarian and Vegan Diets
11.4: Fuel and Nutrient Needs for Physical Activity
protein deficiency
6.5: Diseases Involving Proteins
protein digestion
6.2: Digestion and Absorption of Proteins
protein foods
2.2: Understanding the Dietary Guidelines
protein intake
6.5: Diseases Involving Proteins

protein quality
6.4: Protein Recommendations
protein structure
6.1: Introduction to Proteins
protein synthesis
6.1: Introduction to Proteins
6.3: Functions of Protein
proteins
1.2: Overview of Nutrients and Calories
6: Proteins
public health
1.1: Defining Nutrition, Health, and Disease
1.3: The Broad Role of Nutritional Science
14.1: Foodborne Illness and Food Safety

R

RDA
6.4: Protein Recommendations
recommendations
5: Lipids
6: Proteins
recommended dietary allowance
2.4: Understanding Dietary Reference Intakes (DRIs)
recommended intake
4.5: Carbohydrate Recommendations
reduce waste
14.4: Food Sustainability
regulating hormones
5.3: Functions of Lipids
regulation of water
7: Nutrients Important for Fluid and Electrolyte Balance
reliable information
1.4: Nutrition and the Media
retinal
8.3: Vitamin A and Vision
retinoids
8.3: Vitamin A and Vision
retinol
8.3: Vitamin A and Vision
risk factors
8.4: Cancer
9.4: Osteoporosis
risks
2.8: Is Alcohol Part of a Healthy Diet?

S

saccharin
4.7: Sugar Substitutes
safe weight loss
11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain
satiety
3.2: Hunger vs. Appetite
saturated fat
5.4: Lipid/Fat Recommendations
saturated fats
5.1: Introduction to Lipids
scientific evidence
1.4: Nutrition and the Media
scientific method
1.3: The Broad Role of Nutritional Science
scientific studies
1.3: The Broad Role of Nutritional Science
serving size
2.6: Understanding Food Labels
serving sizes
2.7: Understanding Portion Sizes
shock absorber
7.2: Functions of Water
signaling
5.3: Functions of Lipids
signs and symptoms
8.4: Cancer
simple carbohydrates
4.1: Introduction to Carbohydrates
skeletal system
9.1: Bone Structure and Function
slow food movement
14.4: Food Sustainability
small intestine
3.3: Digestion and Absorption
6.2: Digestion and Absorption of Proteins
SNAP
14.3: Food Security
sodium
7.4: Electrolytes
solid foods
12.3: Nutrition in the Toddler Years
starch
4.1: Introduction to Carbohydrates
stomach
6.2: Digestion and Absorption of Proteins
sugar substitutes
4: Carbohydrates
4.7: Sugar Substitutes
superoxide dismutase
8.1: Introduction to Free Radicals and Antioxidants
sustainability
14.4: Food Sustainability
sustainable eating
14.4: Food Sustainability
symptoms
3.4: Disorders That Can Compromise Health
10.3: Minerals Important for Metabolism and Blood Function

T

teens
13.3: Older Adolescence and Nutrition
temperature regulation
7.2: Functions of Water
tendons
9.1: Bone Structure and Function
thermoregulation
7.2: Functions of Water
thirst mechanism
7.3: Regulation of Water Balance
tissue
3.1: Human Body Organization
toddler
12: Lifecycle Nutrition: Pregnancy to the Toddler Years
toddler nutrition
12.3: Nutrition in the Toddler Years
toddlers
12.3: Nutrition in the Toddler Years
tolerable upper intake level
2.4: Understanding Dietary Reference Intakes (DRIs)
trans fat
5.4: Lipid/Fat Recommendations
transcription
6.1: Introduction to Proteins
translation
6.1: Introduction to Proteins
transportation vehicle
7.2: Functions of Water
transporting nutrients
5.3: Functions of Lipids
treatment
3.4: Disorders That Can Compromise Health
4.6: Looking Closely at Diabetes
9.4: Osteoporosis
treatment plans
11.5: Health Risks of Overweight and Underweight
triacylglycerols
5.1: Introduction to Lipids
5.2: Digestion and Absorption of Lipids
5.5: Understanding Blood Cholesterol and Heart Disease
tumor
8.4: Cancer
Type 1 diabetes
4.6: Looking Closely at Diabetes
Type 2 diabetes
4.6: Looking Closely at Diabetes

U

universal solvent
7.2: Functions of Water
unsaturated fat
5.4: Lipid/Fat Recommendations
unsaturated fats
5.1: Introduction to Lipids

V

variety
2.1: What is a Healthy Diet?
vegan
6: Proteins
6.6: Vegetarian and Vegan Diets
vegetables
2.2: Understanding the Dietary Guidelines
2.3: Tools to Help Design a Healthy Diet
4.2: Benefits of Fiber
vegetarian
6: Proteins
6.6: Vegetarian and Vegan Diets
vision
8: Nutrients Important for Antioxidant Activity and Vision
8.3: Vitamin A and Vision
vision problems
13.6: Older Adults and Nutrition
vitamin
2.5: Dietary Supplements
10.2: Vitamins Important for Metabolism and Blood Function
vitamin A
8: Nutrients Important for Antioxidant Activity and Vision
8.3: Vitamin A and Vision

vitamin C
8.2: Antioxidant Nutrients
vitamin D
9: Nutrients Important for Bone Health
9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D
vitamin E
8.2: Antioxidant Nutrients
vitamin K
9.3: Other Essential Micronutrients for Bone Health
vitamins
1: Foundational Concepts
1.2: Overview of Nutrients and Calories
6.6: Vegetarian and Vegan Diets
10: Nutrients Important for Metabolism and Blood Function
13.2: Early Adolescence and Nutrition
13.3: Older Adolescence and Nutrition

W

water
7.2: Functions of Water
water balance
7.3: Regulation of Water Balance
water functions
7: Nutrients Important for Fluid and Electrolyte Balance
water intake
7.3: Regulation of Water Balance
water movement
7.1: Overview of Fluid and Electrolyte Balance
water output
7.3: Regulation of Water Balance
weight gain
11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain
12.1: Pregnancy and Nutrition
weight loss
11: Energy Balance
11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain
weight management
11.2: Balancing Energy Intake with Energy Output
weight status
11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution
wellness
1: Foundational Concepts
2.5: Dietary Supplements
7: Nutrients Important for Fluid and Electrolyte Balance
10: Nutrients Important for Metabolism and Blood Function
whole foods
2.1: What is a Healthy Diet?
whole grains
2.2: Understanding the Dietary Guidelines
2.3: Tools to Help Design a Healthy Diet
4.2: Benefits of Fiber
WIC
14.3: Food Security

Y

young adults
13.4: Young Adulthood and Nutrition
youngadulthood
13: Lifecycle Nutrition: Childhood to Late Adulthood

Z

zinc
9.3: Other Essential Micronutrients for Bone Health

Glossary

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.

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.

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.

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.

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.

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 offspring.

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.

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.

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.

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.

jaundice | A condition characterized by yellow discoloration of the skin or whites of the eyes.

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.

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.

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.

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.

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).

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 molecules through a semipermeable membrane from an area where it is highly concentrated to an area where it is less concentrated.

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.

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.

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.

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.

solutes | Any dissolved substances 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-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.

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.

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.

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.

Detailed Licensing

Overview

Title: Introduction to Nutrition (1e)

Webpages: 93

Applicable Restrictions: Noncommercial

All licenses found:

- CC BY-NC-SA 3.0: 80.6% (75 pages)
- CC BY-NC-SA 4.0: 18.3% (17 pages)
- Undeclared: 1.1% (1 page)

By Page

- Introduction to Nutrition (1e) - *CC BY-NC-SA 4.0*
  - Front Matter - *CC BY-NC-SA 4.0*
    - TitlePage - *CC BY-NC-SA 4.0*
    - InfoPage - *CC BY-NC-SA 4.0*
    - Table of Contents - *Undeclared*
    - Licensing - *CC BY-NC-SA 4.0*
  - 1: Foundational Concepts - *CC BY-NC-SA 4.0*
    - 1.1: Defining Nutrition, Health, and Disease - *CC BY-NC-SA 3.0*
    - 1.2: Overview of Nutrients and Calories - *CC BY-NC-SA 3.0*
    - 1.3: The Broad Role of Nutritional Science - *CC BY-NC-SA 3.0*
    - 1.4: Nutrition and the Media - *CC BY-NC-SA 3.0*
  - 2: Achieving a Healthy Diet - *CC BY-NC-SA 4.0*
    - 2.1: What is a Healthy Diet? - *CC BY-NC-SA 3.0*
    - 2.2: Understanding the Dietary Guidelines - *CC BY-NC-SA 3.0*
    - 2.3: Tools to Help Design a Healthy Diet - *CC BY-NC-SA 3.0*
    - 2.4: Understanding Dietary Reference Intakes (DRIs) - *CC BY-NC-SA 3.0*
    - 2.5: Dietary Supplements - *CC BY-NC-SA 3.0*
    - 2.6: Understanding Food Labels - *CC BY-NC-SA 3.0*
    - 2.7: Understanding Portion Sizes - *CC BY-NC-SA 3.0*
    - 2.8: Is Alcohol Part of a Healthy Diet? - *CC BY-NC-SA 3.0*
  - 3: Digestion - *CC BY-NC-SA 4.0*
    - 3.1: Human Body Organization - *CC BY-NC-SA 4.0*
    - 3.2: Hunger vs. Appetite - *CC BY-NC-SA 4.0*
    - 3.3: Digestion and Absorption - *CC BY-NC-SA 4.0*
    - 3.4: Disorders That Can Compromise Health - *CC BY-NC-SA 4.0*
  - 4: Carbohydrates - *CC BY-NC-SA 3.0*
    - 4.1: Introduction to Carbohydrates - *CC BY-NC-SA 3.0*
    - 4.2: Benefits of Fiber - *CC BY-NC-SA 3.0*
    - 4.3: Digestion and Absorption of Carbohydrates - *CC BY-NC-SA 3.0*
    - 4.4: Functions of Carbohydrates - *CC BY-NC-SA 3.0*
    - 4.5: Carbohydrate Recommendations - *CC BY-NC-SA 3.0*
    - 4.6: Looking Closely at Diabetes - *CC BY-NC-SA 3.0*
    - 4.7: Sugar Substitutes - *CC BY-NC-SA 3.0*
  - 5: Lipids - *CC BY-NC-SA 3.0*
    - 5.1: Introduction to Lipids - *CC BY-NC-SA 3.0*
    - 5.2: Digestion and Absorption of Lipids - *CC BY-NC-SA 3.0*
    - 5.3: Functions of Lipids - *CC BY-NC-SA 3.0*
    - 5.4: Lipid/Fat Recommendations - *CC BY-NC-SA 3.0*
    - 5.5: Understanding Blood Cholesterol and Heart Disease - *CC BY-NC-SA 3.0*
  - 6: Proteins - *CC BY-NC-SA 3.0*
    - 6.1: Introduction to Proteins - *CC BY-NC-SA 3.0*
    - 6.2: Digestion and Absorption of Proteins - *CC BY-NC-SA 3.0*
    - 6.5: Diseases Involving Proteins - *CC BY-NC-SA 3.0*
    - 6.3: Functions of Protein - *CC BY-NC-SA 3.0*
    - 6.6: Vegetarian and Vegan Diets - *CC BY-NC-SA 4.0*
    - 6.4: Protein Recommendations - *CC BY-NC-SA 3.0*
  - 7: Nutrients Important for Fluid and Electrolyte Balance - *CC BY-NC-SA 3.0*
    - 7.1: Overview of Fluid and Electrolyte Balance - *CC BY-NC-SA 3.0*
    - 7.2: Functions of Water - *CC BY-NC-SA 3.0*
    - 7.3: Regulation of Water Balance - *CC BY-NC-SA 3.0*
    - 7.4: Electrolytes - *CC BY-NC-SA 3.0*
    - 7.5: Understanding Dehydration and Heat Illnesses - *CC BY-NC-SA 3.0*

- 8: Nutrients Important for Antioxidant Activity and Vision - *CC BY-NC-SA 3.0*
  - 8.1: Introduction to Free Radicals and Antioxidants - *CC BY-NC-SA 3.0*
  - 8.2: Antioxidant Nutrients - *CC BY-NC-SA 3.0*
  - 8.3: Vitamin A and Vision - *CC BY-NC-SA 3.0*
  - 8.4: Cancer - *CC BY-NC-SA 3.0*
- 9: Nutrients Important for Bone Health - *CC BY-NC-SA 3.0*
  - 9.1: Bone Structure and Function - *CC BY-NC-SA 3.0*
  - 9.2: Micronutrients Essential for Bone Health - Calcium and Vitamin D - *CC BY-NC-SA 3.0*
  - 9.3: Other Essential Micronutrients for Bone Health - *CC BY-NC-SA 3.0*
  - 9.4: Osteoporosis - *CC BY-NC-SA 3.0*
- 10: Nutrients Important for Metabolism and Blood Function - *CC BY-NC-SA 3.0*
  - 10.1: Overview of Blood and Metabolism - *CC BY-NC-SA 3.0*
  - 10.2: Vitamins Important for Metabolism and Blood Function - *CC BY-NC-SA 3.0*
  - 10.3: Minerals Important for Metabolism and Blood Function - *CC BY-NC-SA 3.0*
- 11: Energy Balance - *CC BY-NC-SA 3.0*
  - 11.1: Indicators of Health: Body Mass Index, Body Composition, and Fat Distribution - *CC BY-NC-SA 3.0*
  - 11.3: Physical Fitness and Physical Activity - *CC BY-NC-SA 3.0*
  - 11.2: Balancing Energy Intake with Energy Output - *CC BY-NC-SA 3.0*
  - 11.4: Fuel and Nutrient Needs for Physical Activity - *CC BY-NC-SA 3.0*
  - 11.5: Health Risks of Overweight and Underweight - *CC BY-NC-SA 3.0*
  - 11.6: Recommendations for Safe and Effective Weight Loss and Weight Gain - *CC BY-NC-SA 3.0*
- 12: Lifecycle Nutrition: Pregnancy to the Toddler Years - *CC BY-NC-SA 3.0*
  - 12.1: Pregnancy and Nutrition - *CC BY-NC-SA 3.0*
  - 12.2: Infancy and Nutrition - *CC BY-NC-SA 3.0*
  - 12.3: Nutrition in the Toddler Years - *CC BY-NC-SA 3.0*
- 13: Lifecycle Nutrition: Childhood to Late Adulthood - *CC BY-NC-SA 3.0*
  - 13.1: Childhood and Nutrition - *CC BY-NC-SA 3.0*
  - 13.2: Early Adolescence and Nutrition - *CC BY-NC-SA 3.0*
  - 13.3: Older Adolescence and Nutrition - *CC BY-NC-SA 3.0*
  - 13.4: Young Adulthood and Nutrition - *CC BY-NC-SA 3.0*
  - 13.5: Middle Age and Nutrition - *CC BY-NC-SA 3.0*
  - 13.6: Older Adults and Nutrition - *CC BY-NC-SA 3.0*
- 14: Food Safety, Technology, Security, and Sustainability - *CC BY-NC-SA 3.0*
  - 14.1: Foodborne Illness and Food Safety - *CC BY-NC-SA 3.0*
  - 14.2: Food Technology - *CC BY-NC-SA 3.0*
  - 14.3: Food Security - *CC BY-NC-SA 3.0*
  - 14.4: Food Sustainability - *CC BY-NC-SA 3.0*
- Back Matter - *CC BY-NC-SA 4.0*
  - Index - *CC BY-NC-SA 4.0*
  - Glossary - *CC BY-NC-SA 4.0*
  - Detailed Licensing - *CC BY-NC-SA 4.0*